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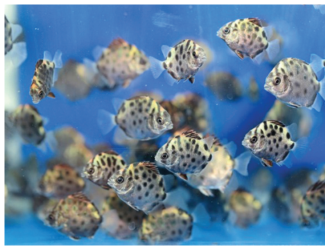

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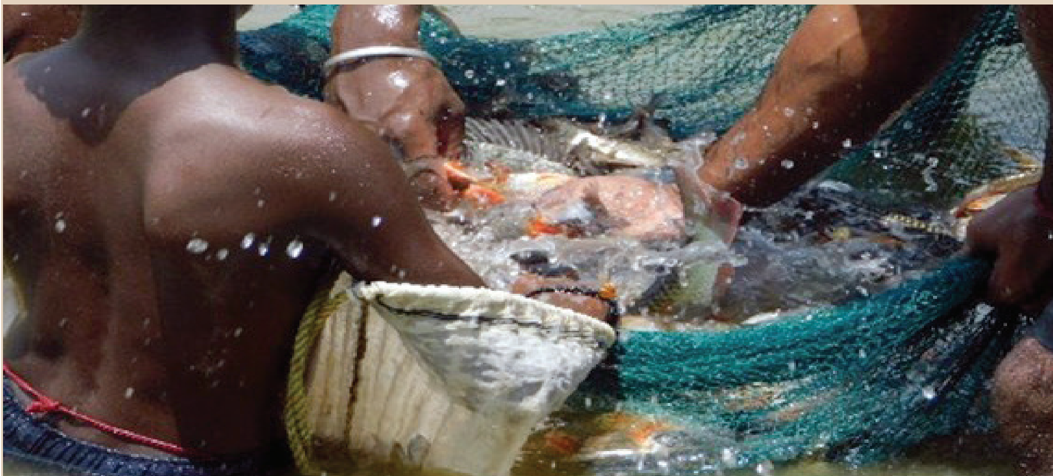

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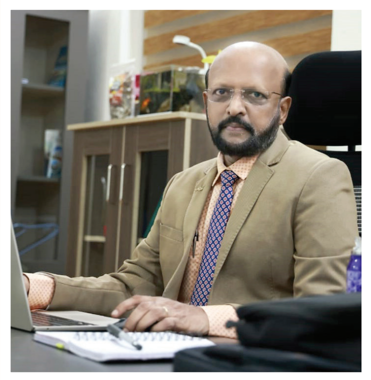
Editor,
Fish Tech Digest

From the Chief Editor's Desk...



Dear esteemed Authors and Readers,

Greetings from the DIFST

It is with great pride that we present the third issue of Fish Tech Digest (FTD), a beacon of knowledge and innovation in the field of fisheries and aquaculture. At the College of Fisheries Science, St. Devasahayam Institute of Fisheries Science & Technology (DIFST), we remain steadfast in our commitment to fostering scientific inquiry and technological advancements that drive sustainable development in the fisheries sector.

This edition showcases groundbreaking research and expert perspectives on diverse and pressing topics, including: Seaweed integration in shrimp farming for eco-friendly aquaculture, transformative potential of fish hydrolysate in agriculture, ecotoxicological impacts of microplastics, revolutionary role of drones in modern fishing technology, and microfinance interventions for rural poverty alleviation.

These contributions not only highlight the interdisciplinary nature of fisheries science but also underscore the importance of collaborative efforts in addressing global challenges. By bridging research with practical applications, this issue aims to inform policies, inspire innovation, and empower stakeholders across the fisheries value chain.

We extend our deepest gratitude to the authors, reviewers, and editorial team for their dedication and scholarly excellence. Their efforts have made this issue a valuable resource for academics, practitioners, and policymakers alike.

As we look ahead, we invite faculty, scientists, and researchers from fisheries colleges and institutes to contribute their insights to future editions. Together, let us continue to advance the frontiers of fisheries science and technology for a sustainable and prosperous future.

Best regards,

Prof. S. Felix
Chief Editor
Fish Tech Digest

Date : 07.07.2025

CONTENT

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Seaweed Integration in Shrimp Farming: A Pathway to Eco-Friendly and Efficient Aquaculture

G. Harini and Madhuri S. Pathak

ICAR- Central Institute of Fisheries Education, Versova, Andheri West, Mumbai

Abstract

Shrimp farming, especially of white-leg shrimp (*Penaeus vannamei*), is a major contributor to global aquaculture and exports from India. To meet high demand, many farms have adopted intensive systems, but these pose risks such as disease outbreaks, environmental degradation, and socio-economic instability. While India's Coastal Aquaculture Authority (CAA) mandates Effluent Treatment Ponds (ETPs), their implementation remains limited. Additionally, there is a lack of alternative, eco-friendly guidelines. Seaweeds offer a sustainable solution, acting as natural biofilters that absorb excess nitrogen and phosphorus, and contribute to carbon sequestration. Integrating seaweed into shrimp farming not only improves water quality but also supports the health and productivity of both organisms, offering a promising path toward environmentally responsible and economically viable aquaculture practices.

Introduction

Aquaculture has grown tremendously during the last two decades, producing 53% of the world's food fish with an annual growth rate of 5.2% (FAO, 2024). By supplying food and a sustainable means of subsistence for millions of people, aquaculture appears to be the most promising industry among the various food-producing sectors globally. Shrimp farming is a rapidly booming sector of aquaculture. Globally, the dominant species produced in 2022 was the white-leg shrimp (*Penaeus vannamei*), with a production volume of 6.8 million tonnes. India ranks among the top shrimp-producing nations, recording a production of 11.84 lakh tonnes in the year 2022–23. Owing to the high global demand for shrimp, many farms are shifting toward intensive farming systems that aim to maximize yield in limited space. However, this shift brings significant challenges, including the frequent outbreak of diseases, environmental degradation, and socio-economic issues like price fluctuations, which together raise concerns about the long-term sustainability of the industry. Although India's Coastal Aquaculture Authority (CAA) mandates that shrimp farms should establish Effluent Treatment Ponds (ETPs) to manage wastewater and reduce environmental impact, these are still largely lacking in most farms across the country. Furthermore, existing regulations do not suggest any other eco-friendly or sustainable alternatives to address ecological concerns. Seaweeds are efficient and cost-effective biofilter which has a high capacity for absorbing N and P compounds. Seaweed farming is a sector with little input that lessens the adverse effects of climate change by absorbing carbon, lowering greenhouse gas emissions. This article explores the sustainable incorporation of seaweeds into shrimp aquaculture systems, emphasizing the synergistic interactions that enhance environmental quality and promote the health and productivity of both species.

Effects of Intensification of Aquaculture

Increased feeding rates and stocking densities put shrimp aquaculture in India at serious risk by threatening its sustainability regarding disease pathogen susceptibility and wastewater treatment. The increased inputs per unit area (e.g., per m^2 or hectare) are one constant feature of intensification. Due to the shortage of resources, innovative high-intensive production such as biofloc-based zero water exchange systems, three-phase shrimp culture systems, Raceways, and RAS have been developed, which paved the way for the discharge of high-nutrient effluent to the adjacent water bodies. Super-intensive systems require greater amounts of feed, energy for water flow and aeration, supplements (such as additives for feed, water nutrients, sanitary products, etc.), and labour than conventional extensive or semi-intensive systems. Farming systems that are much more sensitive both biologically and economically are produced by super-intensive systems, which emphasise the importance of interactions between these inputs and operating parameters. As a result, these farming systems demand higher levels of system management skills. If the nitrogen and phosphorus that make up the majority of shrimp effluent are left untreated, it would contribute to the eutrophication of the environment and result in economic losses.

Potential of seaweed and shrimp farming

Asia ranks first for seaweed aquaculture and consumption. China contributes the largest share to the total production of seaweeds and is ranked first in the production list. The production in the Americas and Europe is dominated by wild collection, and the production in Asia, Africa, and Oceania is dominated by cultivation. Globally, there are around 10,000 seaweed species, with Rhodophyta making up 66%, Phaeophyta 19%, and Chlorophyta 15%. Of these, 221 species are commercially harvested—101 for food and 145 for hydrocolloid extraction. Seaweed, often referred to as a "millennium food," is valued for its high nutritional content and environmental benefits, finding applications in food, cosmetics, pharmaceuticals, and the production of industrial chemicals like agar and alginates. Despite its potential, India's seaweed production stood at only 34,000 tonnes in 2021, representing just 0.01% of global output (FAO, 2021). A total of 23,970 hectares along the Indian coastline have been identified as potential areas for seaweed cultivation, with the majority located in Tamil Nadu, particularly in the Gulf of Mannar and Palk Bay regions. However, these sites remain largely underutilized due to several challenges, including limited awareness among farmers about government schemes, unfavorable monsoons, seed shortages, lack of naturally protected bays, lack of suitable locations and competition from other users for those locations, the need for production setups that can withstand adverse conditions offshore, and the failure to fully realize the industry's economic potential. To address this, the Indian government, under the Pradhan Mantri Matsya Sampada Yojana (PMMSY), has allocated ₹640 crores to promote seaweed cultivation, aiming for 1.12 million metric tonnes by 2025.

Simultaneously, India holds vast potential for shrimp farming, with 11.91 lakh hectares of brackish water available, though only 1.28 lakh hectares are currently utilized; 1.08 lakh for *Litopenaeus vannamei* and 0.58 lakh for *Penaeus monodon* (MPEDA, 2020).

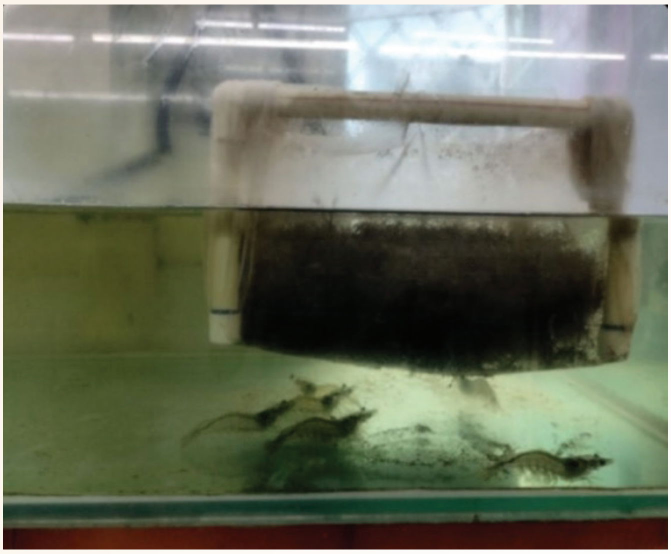
Benefits of the Co-culture of Seaweed with Aquatic Animals

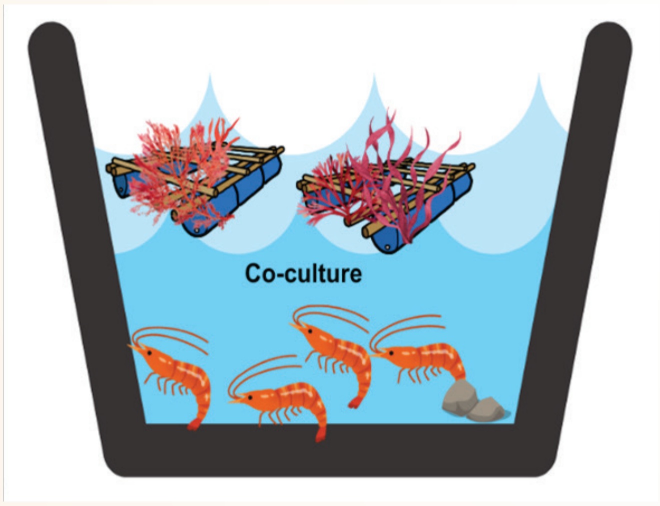
Integrating seaweed into existing shrimp farms offers a practical and sustainable solution to address challenges like limited suitable site availability and monsoon disruptions, while creating a nutrient-rich environment for seaweed cultivation. This approach not only enhances seaweed production and provides an additional income source for farmers but also improves water quality through the absorption of excess nutrients. In shrimp seaweed co-culture systems, seaweeds utilize dissolved nitrogen and phosphorus from uneaten feed and shrimp waste, enhancing their elemental profile and contributing to bioremediation. Improved water quality benefits shrimp by promoting growth, immunity, and overall health (Troell *et al*., 2009). The system represents a mutually beneficial relationship between the two species (Anh *et al*., 2021; Sarkar *et al*., 2021; Omont *et al*., 2022).

The shrimp seaweed co-culture system has been identified as a **bioremediating strategy** for,

- Improving the efficiency of nutrient use,
- Maintaining good water quality,
- Overcoming environmental damage,
- Additional production of a marketable product for little additional input cost
- Ensuring the system's sustainability

There are many research studies regarding shrimp-seaweed co-culture and its practical demonstration in parts of India and abroad (Harini *et al*., 2025; Kang *et al*., 2021; Anh *et al*., 2021; Sarkar *et al*., 2021). The co-culture system shows bioremediation efficiency of 98% TAN uptake and 86% phosphorus (Harini *et al*., 2025). Seaweed readily absorbs NH_3 and NH_4, which can be directly incorporated into proteins, amino acids, and pigments. Red algae have a high capacity to store nutrient reserves, thus making them figured to be efficient nutrient absorbers. Turbidity was mainly observed to be very high in shrimp monoculture due to phytoplankton and bacterial growth, and in co-culture, seaweed uptakes dissolved nutrients, which prevents the growth of microalgae and bacteria and acts as a substrate for the suspended matters to settle. Several studies have shown that the presence of seaweeds in shrimp culture units maintains good water quality and enhances shrimp growth and survival in the integration system (Al-Hafedh *et al*., 2012). Seaweed growth improved as the nutrients from the wastewater were taken up and stored in the thalli, which increased their growth. It also improves the nutritional, pigments and elemental profile of seaweed as it dwells in nutrient-rich water (Omont *et al*., 2022). Water quality is one of the most critical factors in shrimp farming. Seaweed plays a beneficial role by improving water quality, thereby reducing stress on the shrimp and supporting better physiological health. Sometimes grazing of seaweeds in pond was observed which could have been influenced by whiteleg shrimp's omnivorous feeding behavior, with their natural foods including plant materials. So proper structure to hold seaweeds in pond, culture method, aeration and flowrate has to be standardized. This will revolutionize the shrimp industry towards sustainable and eco-friendly aquaculture production.





Conclusion

Seaweed will act as a better nutrient scrapper in shrimp farming, resulting in the abatement of eutrophication and pollution of the natural ecosystem. Farmers have warmly welcomed this bioremediation method, as it increases shrimp growth and disease resistance. Hence it can be successfully implemented in most shrimp farms. Given its effectiveness, this method could be considered for inclusion in shrimp farming guidelines to promote better pond management and environmental safety.

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Fish Hydrolysate / Fish Amino Acid Fertilizer: A Natural Boost for Indian and Asian Agriculture

S. Thamizhanthi and S. Felix

College of Fisheries Science, St. Devasahayam Institute of Fisheries Science and Technology, Amanattantheri, Kanniyakumari – 629 153

Abstract

Fish Hydrolysate or Fish Amino Acid (FAA) is an eco-friendly liquid fertilizer derived from fermented fish waste using jaggery and papaya. Rich in amino acids, enzymes, and nutrients, FAA enhances plant growth, improves soil fertility, and promotes microbial activity. It supports sustainable agriculture by increasing nutrient uptake, stimulating chlorophyll production, and boosting crop resilience. FAA is applied through foliar sprays, soil drenching, or seed treatment and is effective across a wide range of crops including rice, vegetables, fruits, spices, and plantation crops. Widely adopted in organic farming in India and Asia, FAA offers a cost-effective, environmentally friendly alternative to chemical fertilizers, contributing to improved yield, soil health, and crop quality while reducing agricultural pollution and chemical dependency.

Introduction

Fish is a highly perishable and popular staple food item that is essential to the nutritional needs and balanced diet of people in developing nations. Due to its high quantity of vital dietary components including fatty acids, amino acids, and other minerals that are necessary to maintain human health, the choice of eating fish products is significantly growing. FAO (2022) reports that the production of fisheries and aquaculture worldwide jumped to 223.2 million tonnes in 2022, a 4.4 percent rise over 2020. There were 185.4 million tons of aquatic animals generated. Many fish species with lower economic values or damaged portions that cannot be sold on a big scale are considered fish waste. Fish processing wastes include a variety of fish body parts, including the skin, head, fins, viscera, and scales. Fish wastes account for more than 25% of the world's yearly marine harvest, which is estimated to be over 20 million tons. The fish processing business frequently releases a significant amount of trash in the form of wastewater and solid debris. Products such as Fish Hydrolysate and Fish Amino Acid (FAA) fertilizers are gaining attention in an effort to address the rising problem of fish waste and advance environmentally friendly agriculture. These are made by using enzymatic or microbiological techniques to break down fish waste, producing nutrient-rich solutions that are simple for plants to absorb. They are perfect for sustainable agriculture in India and other Asian nations because to their affordability and suitability for organic farming.

Fish Processing waste

Fish carcasses, viscera, skins, and heads are among the solid and liquid waste products produced throughout the fish processing industry. Discards from fish processing make up between 70 and 85 % of the entire catch and are commonly dumped into the ocean or left on land. Enzymes and proteins are present in these wastes. The great majority of byproducts are discarded, even though some are used, which raises concerns about pollution and disposal. Fish waste has up until now been utilized as a raw material for direct aquaculture feeding or to produce inexpensive fishmeal, fertilizer, and fish oil. Approximately 2 million metric tons of fish waste are produced annually in India. Because each species has a unique composition, size, shape, and inherent chemistry, over 70% of all fish caught undergo additional processing before being put on the market, producing significant amounts of fish waste (between 20% and 80%), depending on the level of processing (such as gutting, scaling, and filleting). Muscle trimmings (15–20%), skin and fins (1–3%), bones (9–15%), heads (9–12%), viscera (12–18%), and scales (5%), in that order, are the principal waste products of these processes. Fish processing is essential for large seafood companies because it lowers transportation costs for inedible parts of the fish and improves product stability and quality by eliminating parts like the viscera that could harbor bacteria and enzymes that pose a risk to the fish's processing and storage.

Fish Byproducts as Source of High Added-Value Compounds

Fish emulsions have been shown to encourage soil microbial activity, fruiting, and seedling growth. Fish waste by-products (bones, skull, skin, and other tankage pieces) or fresh fish are fermented with brown sugar to create one such emulsion, known as fish amino acid (FAA). FAA provides just enough nitrogen to the plant for optimal uptake and the creation of chlorophyll to sustain plant health. It is administered as a light foliar mist or a soil drench in combination with other Natural Farming inputs to promote uptake and reduce runoff or leaching. Protein is necessary for the proper growth and development of plants.

Fish Amino Acid / Fish Hydrolysate

A liquid fertilizer known as fish hydrolysate or fish amino acid is created from fish waste (heads, bones, offal, or entire small fish) that has been fermented with the aid of helpful microorganisms and simple sugars such as molasses or jaggery. It is abundant in vitamins, minerals, peptides, enzymes, and amino acids—all of which are necessary for plant growth. Fish hydrolysate is natural, eco-friendly, and increases soil biological activity in contrast to chemical fertilizers. Liquid fish amino acids aid plants in controlling phototropism and photosynthesis, promoting the metabolism of carbon and nitrogen, improving nutrient availability in plant growth substrates, and boosting nutrient uptake and efficiency. Enhancing the nutritional value and yield of fruits, vegetables, and crops is possible with the aid of fish amino acid solutions. The most natural method of supplying green manure is through fish extract. In Korea, Japan, and other countries, organic farmers utilize this extensively.

Preparation of fish amino acid

Materials required

1. Fish waste – 1 kg
2. Country jaggery - 1 kg
3. Well repined Papaya - 1 kg

Procedure 1

Collect fish waste from the harbor or landing center, including the head, bones, skin, fins and viscera.

↓

Weigh 1 kg of fish waste

↓

Procure 1 kg of pure country jaggery from a local source or manufacturer, ensuring it is free from any added substances

↓

Obtain 1 kg of fully ripened papaya.

↓

Choose a plastic jar suitable for fermentation and securely close it with its lid.

↓

Add a layer of fish waste at the base of the container, followed by a layer of powdered country jaggery and papaya

↓

Stir the mixture thoroughly to ensure even blending.

↓

Seal the container with its lid and keep it in a cool, airy place away from direct sunlight and protected from animals.

↓

Within about 3 to 5 days, the fish waste starts to decompose and turn into liquid due to the fermentation process and the osmotic pressure created by the brown sugar added.

↓

The entire process typically requires 2 to 6 months to finish, resulting in fully matured FAA that is ready for application.

↓

Once fully fermented, FAA emits a mildly sweet aroma with a slight hint of fishiness.

Procedure 2

Cut or grind the 1 kg of fish waste into smaller fragments.

↓

Combine the fish waste and jaggery/molasses in equal amounts and mix them well.

↓

Transfer the mixture into a plastic drum.

↓

Cover the container with a breathable lid or cloth, and if sealed airtight, make sure to release the gas daily.

↓

Mix the contents every 2 to 3 days to avoid spoilage.

↓

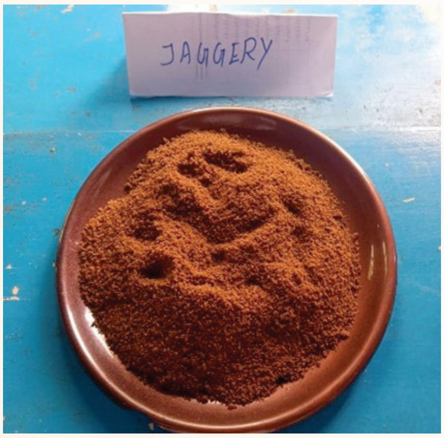
Let the mixture ferment for 20 to 30 days, with the duration varying based on temperature (fermentation occurs more quickly in warmer conditions).

Once fermentation is complete, strain the liquid and keep it stored in a cool, dark location.

If stored correctly, the finished fish hydrolysate can be preserved for up to six months.

Mix 5 ml of this solution with one liter of water to use as a spray for plants.

Fermentation process



Papaya

Jaggery

Fish Waste

Fish Amino Acids as a Bioactive Fertilizer Enhancing Crop Growth and Soil Health

Fish amino acids (FAA) are a natural and efficient source of nutrients that are essential for boosting plant growth by increasing protein synthesis and strengthening crop health in general. Using nitrogen from the soil, hydrogen from water, and carbon and oxygen from the atmosphere, plants use photosynthesis to create amino acids. As a result of these activities, L-amino acids—the sole type actively involved in plant metabolic functions—are formed, aided by collateral metabolic pathways. Threonine, aspartic acid, serine, glutamic acid, valine, lysine, and many other essential amino acids that are needed for protein synthesis and plant physiological control are especially abundant in fish-derived amino acids. FAA works best as a fertilizer in warm, humid environments with active soil microbes. This makes it perfect for foliar sprays, direct soil application, and hydroponic systems, particularly when paired with Effective Microorganisms (EM). Numerous crops, such as vegetables, rice, bananas, cocoa, sugarcane, and flowers, have been shown to benefit from it. Together with amino acids, FAA supports the resilience and vitality of plants by supplying important macro and micronutrients such calcium, magnesium, phosphorus, potassium, nitrogen, zinc, and iron. A sustainable input for contemporary agriculture, fish amino acids naturally increase microbial activity and nutrient availability.

Application of Fish Hydrolysate

1. Foliar Spray

- Mix 5 ml of fish hydrolysate with 1 liter of water.
- Apply the solution to plant leaves every 15 days, preferably in the early morning or late evening.

2. Soil Drenching

- Mix 10–20 ml with each liter of water.
- Use the solution near the root zone or via drip irrigation every 20 to 30 days.

3. Seed Treatment

- Before planting, soak the seeds in a 1% solution (10 ml per liter of water) for 8 to 12 hours.

Benefits of Fish Amino Acids

1. Enhanced Plant Growth and Development

FAAs provide vital nutrients in an easily accessible form, which supports strong plant growth. The peptides and amino acids found in FAAs operate as building blocks for hormone modulation, enzyme activation, and protein synthesis, promoting the best possible plant development from seedling to maturity.

2. Improved Nutrient Uptake and Efficiency

The increased nutrient uptake and usage by plants due to the bioavailability of the nutrients in FAAs results in increased nutrient efficiency and decreased nutrient waste. This is especially helpful in soils that are low in nutrients or in stressful environments where plants could find it difficult to properly absorb vital nutrients.

3. Soil Amendment and Fertilization

FAA improve soil fertility and encourage microbial activity by acting as natural fertilizers and soil conditioners. FAAs promote beneficial microbial populations, enhance nutrient availability, and improve soil structure when applied to the soil, all of which result in healthier soils and higher crop productivity.

4. Foliar Spray and Root Drench

FAAs are frequently used to directly supply nutrients to plant tissues as root drenches or foliar sprays. While root drenching guarantees systemic uptake and distribution of nutrients throughout the plant, fostering uniform growth and development, foliar spray enables quick nutrient absorption through leaf stomata.

5. Seed Treatment and Plant Health

FAA treatment improves early root formation, seedling vigor, and germination, providing plants with a head start on their life cycle. Regular FAA application during the growing season also improves crop quality and production, preserves plant health, and improves blooming and fruit set.

Benefits of FAA for Different Crops

Sl. No.	Crop Type	Benefits
1	Rice & Cereals	Improves tillering, grain filling, and yield
2	Vegetables	Enhances growth, flowering, and fruit setting
3	Fruits (Mango, Banana, Citrus)	Increases size, sweetness, and shelf-life
4	Spices (Chillies, Turmeric, etc.)	Boosts oil content and aroma
5	Flowers (Rose, Marigold)	Promotes bigger blooms and vibrant colors
6	Plantation Crops (Coconut, Arecanut)	Improves nut set and overall vigor

Current Usage and Growth in India and Asia

- Organic farmers in regions such as Kerala, Tamil Nadu, Andhra Pradesh, Sikkim, and the Northeast are increasingly adopting fish amino acids.
- Natural farming initiatives, including Zero Budget Natural Farming (ZBNF) in Andhra Pradesh, emphasize fish hydrolysates as an essential input.
- In countries like Vietnam, Thailand, Indonesia, and the Philippines, small-scale farmers commonly use fish hydrolysates in rice paddies and vegetable cultivation.
- Indian startups and cooperatives are beginning to establish small-scale units for the commercial production of fish amino acid products.

Advantages over Chemical Fertilizers

- It is environmentally friendly, as it prevents chemical runoff and does not harm soil quality, aligning with sustainable farming practices.
- Made from fish waste and locally sourced materials, it is cost-effective and easily accessible, especially for farmers in rural areas.
- When applied to the soil, it encourages the proliferation of beneficial microbes, boosting soil fertility and enhancing its structure.
- Consistent use strengthens plants' natural resistance, enabling them to better withstand pests, drought, and diseases without synthetic inputs.
- Crops cultivated with this method often exhibit improved growth, higher yields, and enhanced nutritional content, leading to better-tasting produce that fetches premium prices.

Conclusion

A sustainable and successful strategy for boosting plant nutrition, encouraging soil health, and raising agricultural output is the use of fish amino acids. They are useful supplements for the growth and development of plants because of their rich content of vital amino acids, peptides, vitamins, and minerals. Growers may improve plant resilience, optimize nutrient management techniques, and attain sustained agricultural success by utilizing the science behind fish amino acids. Furthermore, fish amino acids promote root growth, boost chlorophyll synthesis, and quicken crop blossoming and fruiting. Their natural source lessens the impact on the environment by reducing reliance on artificial pesticides and fertilizers. Fish amino acids are useful components in integrated nutrient management systems since they can also be combined with other organic inputs. The usage of fish amino acids is becoming more and more common among environmentally concerned farmers globally as awareness of organic and regenerative agriculture rises.

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Impact of Sub-Optimal Temperature on Fish Physiology

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Abstract

Winter imposes substantial ecological and physiological challenges on fish, particularly in temperate and subtropical regions. As poikilothermic organisms, fishes experience reduced metabolic rates, feed intake, growth, and immune functions during cold periods. Key alterations include weakened immunity due to the accumulation of toxic metabolites, compromised digestive efficiency, and suppressed enzymatic activities. The winter season also sees a decline in primary productivity, leading to oxygen depletion and further stressing aquatic life. In aquaculture systems, especially in northern India, winter rearing is severely constrained due to reduced feeding behavior and metabolic depression in species such as carps and salmonids. Physiological stress responses, including neuroendocrine and cellular mechanisms, are activated to cope with cold, but prolonged exposure can lead to growth retardation and increased disease susceptibility. Adaptations such as modulation of membrane fatty acid composition and dormancy behaviors are observed in several species. This article underscores the need for targeted nutritional strategies and winter-specific feeding trials using sustainable, plant-based feed ingredients to mitigate cold-induced stress. Enhancing winter aquaculture resilience could improve farmer livelihoods and contribute to national fish production and economic growth.

Introduction

Winter represents a very interesting and challenging time of the year that exerts a strong selective pressure on individual survival, community structure and year class strength of fishes. Ecological, behavioural and physiological alterations experienced by fishes during pre- and winter season (Suski and Ridgway, 2009). During winter conditions, the animal mostly remains at the bottom, so there is much possibility of accumulation of toxic gases into the fish body that make the immune system become weak and expected to cause diseases thereby affecting its growth and reproduction (Afzal Khan *et al.*, 2004). Fishes are poikilothermic, where feed intake, growth rate, metabolic rate, energy expenditure, feed conversion efficiency (FCE) and stomach evacuation rate (SER) were significantly influenced by temperature (Afzal Khan *et al.*, 2004). The optimum temperature for the growth of Atlantic salmon post-smolts is ranged from 12.8 °C for 70–150 g to 14.0 °C for 150–300 g (Azevedo *et al.*, 1998). A decrease in appetite in brown trout has been observed when temperature exceeds 18 °C (Brett and Groves, 1979). Salmonids showed that SER increased exponentially as temperature increases and that SER depends primarily on water temperature with their consumed food (Azevedo *et al.*, 1998).

Reduction in ambient water temperature, which affects almost all levels of the biological, includes molecular diffusion rate, membrane structure, and cellular function and respiration rates (Gates, 1963). A decline in the diversity of primary producers such as emergent macrophytes, submergent macrophytes, phytoplankton, and epilithic algae were noticed during winter season (Miranda and Pugh, 1997 and Harrision and Hildrew, 1998). This seasonal decline in primary producers might be associated with lower water temperature and light intensity (Welch and Kalff, 1974). Depletion of dissolved oxygen might be related to decline in primary production and oxygen consumption through benthic decomposition (Danylchuk and Tonn, 2003). Due to low temperature, several changes were noticed in fish physiological activities such as lower standard metabolic rate, activity of enzymes, ion pumps, ion channels, and alteration in cell membrane fluidity (Molnar and Tolg, 1962; Fange and Grove, 1979). As results, the feeding and growth will be lowered or ceased at low temperature (Hoxmeier *et al.*, 2001; Richard *et al.*, 2016).

Issues of Winter Rearing

During winter especially November, December and January reduced feed intake and growth of fishes. These three months of fish rearing is challenged for all farmers especially in north India, where water temperature remain less than 16°C and in certain reservoirs it is reported to be ranged between 12-14°C, the fishes almost stop feeding at this temperature (Saxena and Saksena, 2012). Robinson *et al.* (2001) reported that feeding activities during winter months is related to water temperature. Author described that fish do not accept feed if water temperature is less than 10 °C, therefore no feeding is required; feed once a week at 0.25–0.50 % body weight when water temperatures is ranged between 10–15.6 °C; feed alternate day at 0.5–1.0% of body weight when the water temperature is ranged between 15.7–21.1°C. Although deaths are usually associated with exposure to low temperatures and induce fasting, the etiology of winter syndrome appears to be multifactorial (Tort *et al.*, 1998a). Fish exposed to 8 °C had distended liquid-filled Gastrointestinal Tract with fibro-mucous material inside. Low serum albumin and globulins contents are related to low water temperature during the winter season in tench (Collazos *et al.*, 1993) and in different carp species (Wu *et al.*, 1995).

Effect of Low Temperature on physiology of fishes

Physiological performances are significantly depressed in warm water fish with declining temperature (Fontaine *et al.*, 2007). Stress as a physiological positive response of the animal attempting to re-establish homeostasis in the response of the adverse environmental effect (Schreck *et al.*, 2001). Stress is deleterious event and animal undergo 3 regulatory system such as neural, endocrine and immune which finally leads to chronical elevation of cortisol levels, which have immunosuppressive and catabolic actions (Tort *et al.*, 2011). Cold stress initiates a neuroendocrine response at the central nervous system (CNS) and result of it, the primary stress response activates a release of corticosteroid and catecholamine hormones. Secondary responses include metabolic, haematological and osmoregulatory changes. Cellular responses, including expression of heat shock proteins (HSPs), are grouped with the secondary response. Tertiary responses refer to stress on individuals as a whole e.g., changes in growth and development rates, disease resistance and modifications (Barton, 2002). Signs of physiological adaptation to cold in gilthead seabream, such as an increase in mitochondria density and membranes home viscous adaptation (Ibarz *et al.*, 2005). In case of rats, interaction between low temperature and pituitary inter-renal axis show rapid, but transient release of cortisol and adrenocorticotropic hormone (ACTH) (Rotlant *et al.*, 2000). Similarly, the serum lysozyme and myeloperoxidase activities were lower in *L. rohita* during winter (Swain *et al.*, 2004).

Acute temperature changes show amplified endocrine responses (Sumpter *et al.*, 1986). Slow the activity of enzymes, ion pumps, ion channels and alter the phase state, rate of motion and packing arrangement of cellular membranes. Nile tilapia, *Oreochromis niloticus* can tolerate exposure of cold stress if it is acclimatized to low temperature (Charo-Karisa, 2006). Physiological performances are significantly depressed in warm water fish with declining temperature (Fontaine *et al.*, 2007). Fish being a poikilothermic reduce activity levels during winter conditions due to the chemical activity which controls muscular activity occurs more slowly when their body temperature is lowered (Davenport and Sayer, 1993). This slowdown metabolic rate and decrease their activity level, appearing to become fish more lethargic or sluggish to conserve their energy stores. Because they become less active, fish can survive longer with the reduced amounts of food and oxygen in the water under ice and snow (Davenport and Sayer, 1993). Fish can alter the fatty acid composition of cell membrane by reducing the proportion of saturated fatty acid (SFA) and increasing the proportion of poly unsaturated fatty acids (PUFA) to maintain the membrane fluidity at lower temperature (Farkas *et al.*, 2001 and Tocher and Glencross, 2015). Other adaptive strategies for survival over this period are winter dormancy such as reduced opercular activity in fish, reduced gill permeability or ion pump proliferation (Davenport and Sayer, 1993). The stress of cold temperatures may activate the neuroendocrine pathway, including the hypothalamic–pituitary–interrenal axis, the hypothalamic–pituitary–thyroid axis, or the hypothalamus–autonomic nerves–chromaffin axis to cause the release of cortisol, thyroid hormone or catecholamines in vertebrates respectively (Reid *et al.*, 1998; Stouthart *et al.*, 1998). Reduced total protein mostly albumin as well as a1-, a2-, b1- and c-globulin, which cease the regulation mechanisms observed during the wintering period of tench or carp (Wu *et al.*, 1995; Sala-Rabanal *et al.*, 2003).

Plasma indices are useful for detect impact of chronic stress (Barton, 2002). Plasma IGF-1 is a diagnostic index to assess the physiological impact of different feeding of food during winter (Schmidt-Nielson, 1972). In sea bream, the function between low temperatures and the pituitary-inter-renal axis, exhibit a rapid, but temporary release of cortisol and ACTH after reduced from 18 to 9 ºC (Rotllant *et al.*, 2000). In gilthead seabream slow metabolic rate coupled with lower oxygen utilization (Richard *et al.*, 2016). When water temperatures fall from 18 to 9 °C in 24 h in sea bream, it causes higher levels of cortisol and glucose, but lactate does not show that much difference in value (Rotllant *et al.*, 2000). Ibarz *et al.* (2010) reported that the upregulation of proteases for re-establishing cells in gilthead sea bream when exposed to 8 °C. Greater cortisol and glucose when water temperatures become 18 to 9 °C in 24 h in sea bream (Rotllant *et al.*, 2000).

Conclusion

Based on above statements feeding trial need to be conducted to improve the feeding rate, metabolism and absorption rate through locally available plant ingredients and sustainable feed ingredients as well as need to perform on nutrient's requirements study. With this support during winter periods, fish farmers income will increase and ultimately will improve the fish production which will contribute the high GDP to our country.

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Ecotoxicological Impact of Microplastics in Aquaculture System

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Abstract

Microplastics, tiny plastic particles under 5 mm, have become widespread pollutants in aquaculture systems. They enter through water, feed, and equipment, posing risks to aquatic species and human health. Ingested microplastics cause physical harm, reduce growth, and act as carriers of toxic chemicals and pathogens. Their accumulation in farmed species threatens seafood safety and public health. This review highlights the sources, impacts, and health risks of microplastics in aquaculture and outlines strategies for mitigation, including waste management, biodegradable alternatives, and policy interventions to ensure sustainable aquaculture practices.

Introduction

Microplastics, characterized as plastic fragments under 5 mm in size, have become one of the most widespread and enduring environmental contaminants of the 21st century. These minuscule particles come from multiple sources, such as the breakdown of bigger plastic debris, microbeads found in personal care items, and synthetic fibers (Thompson *et al.*, 2004). Microplastics have been found in some of the most isolated areas on earth, ranging from the depths of the Mariana Trench to the heights of the Pyrenees Mountains, illustrating their widespread presence (Chiba *et al.*, 2018; Allen *et al.*, 2019). In contrast to organic substances, plastics do not decompose biologically; rather, they fragment into smaller pieces via physical, chemical, and biological mechanisms, ultimately resulting in microplastics or even nanoplastics (particles less than 1 mm) (Gigault *et al.*, 2018). This fragmentation process is intensified by environmental factors like UV radiation, wave action, and temperature changes, resulting in the ongoing buildup of microplastics in ecosystems (Andrady, 2017). Consequently, microplastics have established themselves as a lasting presence in the environment, with estimates indicating that more than 8 million metric tons of plastic enter the oceans each year, a large portion of which ultimately breaks down into microplastics (Jambeck *et al.*, 2015).

Because of their small dimensions, marine organisms frequently confuse microplastics with food, resulting in physical obstructions, internal damage, and decreased feeding efficacy (Cole *et al.*, 2013). Besides causing physical damage, microplastics may serve as transporters for dangerous chemicals, including persistent organic pollutants (POPs) and heavy metals, which adhere to their surfaces (Rochman *et al.*, 2013). Once consumed, these substances may seep into the tissues of living beings, possibly leading to harmful effects and accumulating in the food web (Bakir *et al.*, 2016). This has sparked worries regarding the possible effects of microplastics on wildlife and human health, especially through the ingestion of contaminated seafood (Smith *et al.*, 2018).As aquaculture expands to satisfy the rising need for seafood, the existence of microplastics in these settings poses significant worries regarding the industry's safety, sustainability, and future. If no measures are taken, microplastics will keep endangering aquatic ecosystems, food safety, and public health.

VERSATILE SOURCES OF MICROPLASTIC

Microplastic contamination is widespread in the global aquaculture industry, affecting both aquatic ecosystems and aquaculture products. Microplastics are of two kinds, viz. primary microplastics, which are intentionally manufactured small plastic particles like microbeads for cosmetics or industrial abrasives, and secondary Microplastics, which are produced from the breakdown of larger plastic debris due to environmental factors like sunlight, waves, and microbial activity.

The sources of microplastics in aquaculture can be divided into two main categories:

1. **External Sources:** Microplastics enter aquaculture environments from rivers, oceans, land-based pollution, and the atmosphere.
2. **Industry-Related Sources:** Microplastics are introduced through aquaculture activities, such as the breakdown of plastic fishing gear, the packaging and handling of feed, and the deterioration of other plastic equipment used in farming.

FLOW OF MICROPLASTICS INTO AQUACULTURE

a. Water Sources

Aquaculture facilities rely on different sources of water, such as rivers, lakes, coastal areas, and groundwater, a significant number of which are already polluted with microplastics. Urban and industrial runoff, along with wastewater discharge and atmospheric deposition, plays a major role in microplastics pollution in these water bodies (Lebel *et al.*, 2019). Research has indicated elevated Microplastics levels in water sources used for aquaculture, such as fish ponds, mariculture regions, and coastal farming locations. For example, studies in Marunda and Muara Kamal, Indonesia, identified microplastic concentrations reaching up to 103.8 ± 20.7 particles/L as a result of being near contaminated river mouths (Priscilla & Patria, 2019). Likewise, in the Great Lakes region of the United States, MP levels peaked at 43,000 particles per km^2 at more than 95% of the examined locations, underscoring the extensive pollution of freshwater resources (Eriksen *et al.*, 2013).The discharge of household wastewater intensifies Microplastics pollution in water bodies, with laundry wastewater contributing more than 1,900 fiber particles for each wash cycle (van der Hal *et al.*, 2017). Moreover, precipitation and wind carry microplastics from land-based ecosystems into aquaculture systems, resulting in their buildup in confined and semi-confined farming environments (Ma *et al.*, 2021). When found in these water bodies, microplastics are moved to aquaculture farms, where they can be consumed by aquatic species, impacting fish health and possibly entering the human food supply (Lusher *et al.*, 2017). The existence of microplastics in aquaculture settings not only endangers cultivated species but also endangers the health of the entire aquatic ecosystem.

b. Feed

Aquafeeds serve as a direct pathway for microplastics to infiltrate aquaculture systems.

Components found in commercial fish feed, including fishmeal and plant-derived proteins, might already have microplastics present prior to processing (Van Cauwenberghe *et al*., 2015). Contamination may occur additionally during production, processing, packaging, and storage. Research conducted in Malaysia found kinds of microplastics particles in three brands of commercial fishmeal, with more than 50% recognized as plastic polymers (Karbalaei *et al*., 2020). The intricacy of sourcing ingredients, along with transportation and storage, heightens the susceptibility of aquafeeds to microplastic contamination (Wang *et al*., 2020b). Additionally, microplastics can infiltrate feeds via additives like colorants, preservatives, and stabilizers employed in aquafeed manufacturing. Certain components, like fishmeal and fish oil, originate from marine sources that are already polluted with microplastics, worsening the issue (Barreto *et al*., 2019). The processes of grinding and pelletizing can also lead to the presence of plastic residues if the equipment and storage facilities are not adequately maintained. As a result, fish that eat these feeds gather microplastics in their bodies, presenting dangers to aquatic health and human eaters through seafood intake (Van Cauwenberghe *et al*., 2015).

c. Equipment

Aquaculture setups make use of different plastic-based farming equipment such as nets, cages, buoys, pipes, and containers, which deteriorate over time and emit microplastics into the ecosystem (Huang *et al*., 2020). Mechanical wear, UV degradation, and biofouling enhance the breakdown of these materials, raising the MP burden in aquaculture settings (Santillo *et al*., 2019). Studies indicate that aquaculture equipment plays a major role in microplastic pollution, especially in intensive farming practices where plastic gear is often utilized and changed (Xiong *et al*., 2023).Another significant contributor to Microplastic pollution is lost or discarded fishing equipment. Equipment made of plastic, including bait machines, aerators, and pumps, can also emit microplastics during use, worsening pollution in both marine and freshwater aquaculture environments (Mohapatra *et al*., 2011). The application of plastic-derived animal health products, such as antibiotics and disinfectants, adds to microplastic pollution since these compounds attach to microplastics and remain in the environment for long durations (Li *et al*., 2018b). The ongoing introduction of microplastics from aquaculture gear presents enduring threats to aquatic organisms, food safety, and the health of ecosystems.

EFFECTS ON AQUATIC SPECIES

Microplastics pose significant risks to aquatic organisms, particularly those cultivated in aquaculture systems:

a. Ingestion and Bioaccumulation

One of the key dangers that microplastics present to aquatic creatures is their consumption and the resulting bioaccumulation. Numerous species of fish and shellfish confuse microplastics for food because of their tiny size and frequent resemblance to plankton or other natural prey. After being consumed, microplastics may build up in the digestive systems of these organisms, resulting in various negative impacts. Lusher *et al*. (2013) and Van Cauwenberghe and Janssen (2014) discovered fish contained microplastics, in their stomachs and intestines. The buildup of MPs in the digestive systems of aquatic species can lead to multiple adverse effects. Initially, it may diminish feeding efficiency, since non-nutritive particles can create a misleading impression of fullness. Consequently, this may lead to decreased food consumption and hindered growth. Secondly, the build-up of microplastics can cause physical obstructions in the digestive system, worsening the adverse effects on feeding and growth. As time goes on, the bioaccumulation of microplastics may result in these particles being passed up the food chain, possibly impacting higher trophic levels, such as humans who eat contaminated seafood. Microplastics show great resilience in aquaculture settings because they are resistant to breaking down. Their extensive specific surface area and hydrophobic characteristics allow them to absorb detrimental organic pollutants like polycyclic aromatic hydrocarbons (PAHs), organochlorine pesticides, and polychlorinated biphenyls (PCBs) (Cai *et al*., 2017). This adsorption boosts their longevity in aquatic systems, raising the probability of bioaccumulation in aquaculture organisms. Additionally, Microplastics act as vectors for microorganisms, promoting the development of biofilms on their surfaces. The creation of this biofilm can increase the discharge of HOCs into aquatic ecosystems, further polluting aquaculture systems. Studies have indicated that Microplastics can build up in different aquaculture species, posing threats to seafood safety. Research has identified Microplastic contamination in fish, crustaceans, and molluscs from both marine and freshwater aquaculture environments.

b. Toxicity

Along with the physical presence of microplastics in aquatic organisms, these particles can serve as carriers for harmful chemicals, creating substantial toxicological hazards. Microplastics possess a large surface area-to-volume ratio, enabling them to efficiently adsorb and concentrate persistent organic pollutants (POPs) and heavy metals from the surrounding water. When consumed by aquatic creatures, these substances can seep into their bodies, causing various harmful effects. POPs, including PCBs and PAHs, are extremely harmful and can lead to various negative health impacts in aquatic life, such as hormonal disruption, reproductive issues, and greater vulnerability to illnesses. Toxic to aquatic organisms, heavy metals like lead, cadmium, and mercury inflict harm on the nervous system, kidneys, and various other organs. The harmfulness of MPs is intensified by their durability in the environment, resulting in prolonged exposure for aquatic species. Rochman *et al*. (2013) showed that fish subjected to MPs tainted with POPs had greater concentrations of these substances in their tissues than fish exposed to uncontaminated MPs. This underscores the possibility for MPs to serve as a major source of toxic chemical exposure within aquatic ecosystems. MPs along with their related additives can disturb the ecological equilibrium of aquaculture settings. Some types of plastics, including polyvinyl chloride (PVC), emit hydrochloric acid (HCl) when undergoing photocatalytic breakdown, causing the water environment to acidify (Gewert *et al*., 2015). Moreover, microplastics can adversely affect microalgae populations, which serve as the base of aquatic food chains. A reduction in microalgae caused by microplastic toxicity may result in cascading ecological effects, influencing nutrient cycles and the overall productivity of aquaculture. Moreover, Microplastics play a role in the increase of antibiotic resistance within aquaculture settings. Certain plastics have antibacterial substances that gradually leach into the water, fostering the growth of antibiotic-resistant bacteria (Sui *et al*., 2020). The existence of Microplastics has been associated with a higher prevalence of antibiotic resistance genes, potentially diminishing the effectiveness of antibiotics utilized in aquaculture. This occurrence presents a significant threat to the health of aquatic animals and human consumers.

c. Physical Damage

In addition to chemical hazards, microplastics can also inflict physical harm on aquatic life. Numerous Microplastics possess pointed edges or uneven forms, potentially leading to internal harm if swallowed. Such injuries may result in inflammation, damage to tissues, and potentially perforation of the digestive system. In extreme situations, the physical harm inflicted by Microplastics can be lethal. Apart from causing direct physical harm, Microplastics can lead to obstructions in the digestive systems of aquatic creatures. These obstructions can hinder the regular flow of food, resulting in decreased feeding efficiency, stunted growth, and, in certain instances, starvation. The actual presence of Microplastics in the digestive system can also disrupt nutrient absorption, worsening the adverse effects on growth and health. The physical harm inflicted by Microplastics extends beyond the digestive system. Microplastics may also become trapped in different body regions, like the gills, leading to irritation and hindering respiratory ability. This may result in decreased oxygen absorption and heightened vulnerability to illness, which is especially troubling for aquaculture species since it can cause diminished productivity and financial losses for fish farmers. Aside from chemical toxicity, Microplastics can inflict physical harm on aquatic organisms. Because of their tiny size and fibrous characteristics, Microplastics can be unintentionally swallowed, causing obstructions in the digestive systems of fish and shellfish. This may lead to malnutrition, slower growth rates, and higher mortality (Wright et al., 2013). The consumption of MPs has likewise been linked to tissue inflammation and cellular harm in different aquaculture species. Moreover, MPs can disrupt fish gill function by getting trapped in respiratory structures, which decreases oxygen exchange and results in hypoxia. The existence of MPs in aquaculture sediments can change substrate composition, impacting benthic organisms and disturbing natural sediment processes.

IMPLICATIONS FOR HUMAN HEALTH

Microplastics can transfer through trophic levels, moving from primary consumers to higher-level predators, leading to their accumulation and magnification throughout the food web (Tang et al., 2021). A significant issue related to microplastics is their occurrence in seafood from aquaculture, which serves as a key source of dietary exposure for people. Studies show that close to 80% of the main commercial fish species have microplastics (Walkinshaw et al., 2020). Additionally, various research efforts have verified that the intake of aquaculture products results in microplastic consumption in humans (S. Liu et al., 2021). Research on seafood contamination demonstrated that the health risk evaluation of Microplastics in commercially important species from Fuzhou and Xiamen surpassed hazard level IV, according to the hazard scores of plastic polymers and their chemical characteristics (Fang et al., 2019). Moreover, risk evaluations utilizing the Polymer Hazard Index (PHI) showed that Microplastics present in bivalves from Daya Bay carried risks categorized between levels II and III (R. Li et al., 2022). The continued presence of MPs in the human body poses serious health risks. These particles exhibit strong resistance to chemical degradation and are challenging to remove via mechanical methods.

Two main mechanisms were recognized:

(i) MPs create large aggregates with lipids because of their hydrophobic characteristics, which decreases lipid bioavailability

(ii) MPs disrupt lipase function by changing its secondary structure, preventing its open conformation.Additionally, Peyer's patches, found in the ileum of the small intestine, act as important locations for the uptake and translocation of particles (Powell et al., 2016).

Microplastics are also capable of infiltrating mammalian tissues. Particles as small as 130 µm have been noted entering blood vessels and lymphatic tissues, causing inflammatory reactions (Wright & Kelly, 2017). Moreover, Microplastics trigger hemolysis upon their entry into the bloodstream, with research indicating that polystyrene MPs (≤5 µm) resulted in about 4% hemolysis when compared to control samples (Hwang et al., 2020). After entering circulation, Microplastics can travel via the blood and lymphatic systems, reaching different organs. Research shows that Microplastics measuring between 2.15 µm and 103.27 µm have been found in various bodily fluids, such as whole blood and cerebrospinal fluid (Guan et al., 2023).

Some chemical additives found in MPs present significant health hazards. For example, substances such as di(2-ethylhexyl) phthalate (DEHP) and bisphenol A (BPA) show reproductive toxicity, whereas vinyl chloride and butadiene are recognized as carcinogens. Other substances, like benzene and phenol, exhibit mutagenic characteristics (Powell et al., 2010).

STRATEGIES TO MITIGATE MICROPLASTIC POLLUTION IN AQUACULTURE

Effective Waste Management Proper waste disposal is crucial in reducing microplastic pollution. Initiatives like the Clean Kerala Initiative highlight the role of recycling, waste segregation, and public awareness in minimizing plastic waste (Kerala State Pollution Control Board, 2017

- Recycling and reusing plastic-based equipment (nets, cages, packaging).
- Implementing waste collection systems to prevent plastic debris.
- Educating stakeholders on proper disposal practices

Development of Biodegradable

Alternatives Replacing conventional plastics with biodegradable materials like polylactic acid (PLA) and polyhydroxyalkanoates (PHAs) can reduce microplastic pollution (Narancic et al., 2018).

- Using biodegradable nets, ropes, and floats.
- Switching to sustainable packaging for aquafeeds.

- Investing in research to develop eco-friendly aquaculture materials.

Regular Monitoring and Standardized Protocols

Standardized monitoring of microplastics is essential for effective mitigation.

- Consistent sampling methods for water, sediment, and biota.
- Advanced detection tools like FTIR and Raman spectroscopy.
- Uniform data reporting to enhance policy decisions (Li et al., 2021).

Enhancing Feed

Quality Aquafeeds can introduce microplastics into farmed species. To minimize this risk: Implement stringent quality checks on raw materials and feed. Improve processing techniques to reduce contamination. Source sustainable ingredients with minimal plastic exposure.

Technological Innovations in Microplastic Detection

Advanced methods like FTIR and Raman spectroscopy analyze microplastic composition, while microscopy aids in size and shape characterization (Shim et al., 2018). These technologies enhance detection accuracy, enabling targeted mitigation strategies.

Machine Learning: Artificial intelligence and machine learning identify microplastic hotspots and enhance cleanup efforts by examining satellite and environmental information. This allows for focused actions such as initiating cleanup activities in areas at high risk (Garcia-Garin et al., 2020).

Filtering Systems: Biofilters and membrane filtration eliminate microplastics from aquaculture water, safeguarding farmed species and avoiding environmental pollution.

Policy and Regulation: Rules restrict the manufacturing, application, and disposal of plastics.

Banning Microbeads: Nations such as the US, Canada, and the UK have prohibited microbeads in cosmetic items, thereby decreasing primary microplastic contamination (Napper et al., 2015).

Regulating Plastic Waste: Initiatives such as the EU's Single-Use Plastics Directive seek to reduce the production of secondary microplastics by implementing bans and promoting sustainable options.

Collaborative Efforts: Programs such as the Global Partnership on Marine Litter bring together industries, researchers, and policymakers to address plastic waste.

Future Prospects: An active strategy concentrating on research, education, and sustainability is crucial.

Research and Development: Investigations into the toxicity of microplastics, their chemical interactions, and ecological effects are required.

Worldwide Awareness Initiatives: Instructing stakeholders encourages behavioral shifts and sustainable actions.

Sustainable Approaches: Environmentally conscious methods in feed procurement and waste handling aid in minimizing aquaculture's ecological impact.

Conclusion

Microplastic pollution poses a significant challenge to the aquaculture industry, threatening not only the health of aquatic organisms but also the safety of seafood consumers and the sustainability of farming systems. Addressing this issue requires collective action, from local interventions to global regulations. By adopting innovative technologies and sustainable practices, we can safeguard aquaculture's future and ensure a healthier planet for generations to come.

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The Emerging Role of Drones in Fishing Technology

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Abstract

The global fisheries sector, vital for food security and economic development, faces significant challenges due to overfishing, climate change, and habitat degradation. Traditional fish detection technologies, such as active sonar, though widely used, pose ecological risks especially to marine mammals and fish that rely on natural acoustic cues. As an eco-friendly alternative, Unmanned Aerial Vehicles (UAVs), or drones, are emerging as transformative tools in capture fisheries. This paper explores the integration of UAVs into fisheries operations, highlighting their potential to enhance fish detection, monitor fishing zones, and support regulatory enforcement with minimal environmental impact. Equipped with thermal imaging cameras, GPS modules, and RF communication systems, drones provide real-time aerial surveillance, enabling precise fish school identification and habitat monitoring. They also contribute to combating illegal, unreported, and unregulated (IUU) fishing. Despite current limitations in endurance and energy efficiency, advancements in battery technology and solar-powered systems are steadily enhancing UAV capabilities. Overall, UAVs represent a sustainable, cost-effective, and innovative solution for modernizing global fisheries management.

Introduction

Fishing is one of the most vital industries for global food production, and its demand continues to grow steadily. However in recent years, the global fisheries sector has faced growing challenges from overfishing, climate change, habitat loss, and increasing seafood demand. In response, technological advancements are providing new ways to support sustainability and boost productivity. With the increasing number of commercial fishing vessels, there is a rising dependence on sophisticated electronic devices such as sensors, depth sounders, and SONAR systems. Most modern fishing fleets rely heavily on acoustic sonar and echo sounder technologies to determine water depth, seabed contours, and bottom composition. However, studies have shown that the use of active sonar can negatively impact marine life, particularly marine mammals. Species such as whales and dolphins, which rely on echolocation (biological sonar) for navigation, hunting, and communication, may become disoriented or stressed by artificial sonar signals. This interference can disrupt essential behaviours like feeding and mating. Additionally, high-intensity sonar pulses have been found to cause temporary shifts in the hearing thresholds of some fish species. Given these concerns, there is a pressing need to explore alternative, eco-friendly technologies. One promising solution is the use of Unmanned Aerial Vehicles (UAVs) or drones. Instead of relying on invasive sonar systems, drones can provide fishermen with a bird's-eye view of the ocean surface, allowing them to spot fish schools through indirect signs such as the presence of predatory birds, shadows, or surface disturbances well beyond what is visible from a boat.

Drones are flying machines or robots that are either controlled remotely or operate using special software to collect information from a specific area over time. This is made possible by sending commands through a ground control station, where the operator can view live camera footage and flight data from the drone (Abrahamsen, 2015; Hodgson *et al*., 2013). In recent years, drone technology has improved a lot. Different types of drones, especially those with cameras and stabilizing propellers, can now capture and show visual data clearly while flying steadily. Their integration into the fisheries sector is revolutionizing traditional practices by offering cost-effective, efficient, and precise solutions to longstanding challenges in fish detection, monitoring, and management. With capabilities in aerial surveillance, data collection, and real-time imaging, drones are enhancing the sustainability and productivity of both capture and aquaculture fisheries.

In marine and inland fishing, drones are employed for scouting fish-rich zones, observing fishing operations, and monitoring illegal, unreported, and unregulated (IUU) fishing activities. Their aerial perspective provides high-resolution images and videos, which are valuable for identifying fish schools, assessing water quality parameters, and mapping habitats such as coral reefs or mangrove ecosystems. In aquaculture, drones are used for pond surveillance, feeding assessment, and health monitoring of cultured species. Furthermore, drones integrated with thermal imaging, GPS, and artificial intelligence are contributing to improved decision-making, resource conservation, and efficient management of fishing activities. As drone technology continues to advance, its role in modernizing and optimizing fishing practices will only become more significant, making it an essential component of future fisheries management strategies.

Many studies have highlighted how new technologies especially drones and their applications can help improve sustainable fishing practices. These tools can be useful for monitoring fish stocks, tracking catches, and managing fisheries. They also offer ways to address growing concerns about declining fish populations, particularly in tropical regions where most small-scale fishers live. (Lukambagire, 2022). Because of their impressive capabilities, drones are being used more and more in many fields with great success. These include precision farming, disaster management, search and rescue, eco-friendly transport, exploration, population monitoring in cities and villages, patrolling, and security work. This also includes types like unmanned aerial vehicles (UAVs) and very small flying devices called nano air vehicles (NAVs). Artisanal fishers, who are becoming more familiar with technology, have found that basic drones are useful for monitoring their boats, fishing areas along the coast, and locating important fish species. This helps reduce the effort and cost of fishing. In countries like Australia, the USA, Japan, China, Belize, Jamaica, Costa Rica, and Brazil, fisheries managers are increasingly using drones and mapping tools for monitoring, control, and surveillance (MCS). These tools help reduce bycatch and protect sensitive areas such as breeding grounds and marine protected areas (MPAs), ultimately lowering the environmental impact of fishing. In Norway, fishermen have welcomed the use of drones for monitoring fisheries (Lukambagire *et al*., 2024). These drones have helped enhance safety at sea, reduce the environmental impact of fishing, and improve the accuracy of fisheries data. Similarly, in Spain, drones have become valuable tools for managing and monitoring marine protected areas (MPAs) used by local fisherfolk.

Working Mechanism of UAVs

The Unmanned Aerial Vehicle (UAV) designed for fisheries applications will be equipped with the following components:

1. **Location Transmitter:** This component enables the UAV to transmit its GPS coordinates at regular intervals. The onboard surveillance systems will relay real-time data and GPS location to a receiver on the fishing vessel using radio frequency (RF) signals. This setup allows fishermen to identify the location of fish schools accurately. Additionally, the GPS data collected can be used for further analysis and mapping of fish movement patterns.
2. **RF Signal Generator:** The RF signal generator, a key part of the UAV's control chipset, produces continuous wave signals that can be tuned across a range of frequencies. This component is central to the UAV's communication and operational control. It offers a simple yet highly efficient alternative to traditional SONAR systems, effectively eliminating the need for acoustically invasive fish detection methods.
3. **Thermal Imaging Camera:** The UAV is also equipped with a high-resolution thermal camera capable of capturing detailed images with high pixel density (PPI). It supports night vision and is effective even in low-visibility conditions such as fog or mist. The camera's data is transmitted back to the vessel, assisting fishermen in spotting fish schools based on thermal contrasts and surface activity.
4. **Endurance and Flight Efficiency:** To maximize the UAV's surveillance range, it is designed to operate at its optimal lift-to-drag ratio, allowing for efficient gliding and extended flight time. By allocating approximately 60% of the UAV's total weight to the battery, its flight radius and loitering capability are significantly enhanced. This improves the probability of detecting fish schools and extends the operational time of the emergency

beacon—an essential feature for ensuring the survival of the operator in case of emergency at sea.

5. **Power Source:** The UAV is powered by a battery, which serves as the primary energy source for all onboard systems, including propulsion, communication, and surveillance equipment. (Ahilan *et al.*, 2015)

Efficient Utilization of UAVs in Fishing Operations

The UAV (Unmanned Aerial Vehicle) designed for this application is a customized and augmented system, specifically engineered to assist fishermen in enhancing operational efficiency and safety. This UAV is both hand-launched and autonomous, requiring minimal intervention from the operator.

Once activated, the UAV autonomously performs a surveillance flight, circling the fishing vessel, fishing zones approximately 30–90 miles for close-range UAVs (Inman *et al.*, 2021). Throughout the mission, it continuously transmits real-time data and imagery back to a receiving unit onboard the fishing vessel, where flight data and captured images are logged and analysed.

The UAV is pre-programmed for autonomous operation, eliminating the need for manual control. Fishermen are only required to switch on the UAV and launch it. In the event of an emergency, an override function can be activated, switching the UAV into emergency mode. In this mode, the UAV will either seek the nearest vessel or head toward the coastline while broadcasting emergency messages containing the boat's GPS location to facilitate rescue operations. To enhance its endurance and operational range, the UAV is powered by a rechargeable lithium-polymer battery supplemented by a solar panel, which continuously charges the battery during daylight hours. This dual power system enables long-duration flights and makes the UAV highly suitable for extended surveillance missions.

Figure 1: Drones used to find the potential fishing zone (PFZ) (Image created by AI)

Operational Role

The UAV functions as an aerial patrol system, scanning the surrounding ocean surface for schools of fish using a high-resolution thermal imaging camera. The camera provides excellent visibility, even under low light or foggy conditions. Once a potential fish school is detected, the captured image is processed onboard and sent to the RF (Radio Frequency) signal generator. Within the UAV, a GPS module records the coordinates of the sighting. The RF generator then converts both the thermal image and the GPS data into radio signals, which are transmitted to the fishing vessel. The boat is equipped with a compatible receiver and display system, allowing the crew to visualize fish locations and make informed navigation decisions.

Emergency Functionality

For enhanced safety at sea, the UAV is equipped with an emergency beacon designed for search and rescue scenarios. If a fisherman activates the UAV's emergency system, it will begin emitting SOS signals containing the vessel's GPS coordinates. The UAV also listens for nearby UAVs or vessels and attempts to establish a connection for rapid assistance. If no nearby UAVs or vessels are detected, the UAV will autonomously fly toward the nearest shoreline while transmitting SOS messages to the closest coastal ground station (Ahilan *et al.*, 2015). In the event of critically low battery levels, the UAV will descend to the water's surface, power down non-essential systems, and conserve energy solely for emergency signalling until help arrives.

Applications of Drones in fisheries

1. Fish School Detection and Monitoring

Drones equipped with high-resolution cameras and thermal sensors can detect fish schools near the water surface. By flying over coastal and nearshore waters, these drones provide real-time data to fishing vessels, enhancing the accuracy of fish location and reducing unnecessary fuel consumption and search time.

2. Surveillance and Anti-Poaching Efforts

Illegal, unreported, and unregulated (IUU) fishing remains a critical threat to global fish stocks. Drones are now being used by coastal authorities and community fisheries to monitor restricted zones, record suspicious activities, and assist in enforcement through geotagged imagery and videos.

3. Environmental and Habitat Assessment

Monitoring sensitive ecosystems such as coral reefs, mangroves, and estuarine habitats is essential for sustainable fisheries. Drones allow scientists to conduct aerial surveys without disturbing marine life, offering insights into habitat changes, erosion, pollution, and biodiversity trends

Operational Advantages of UAV Deployment in Fisheries and Maritime Surveillance

- UAVs can cover a wider area compared to sonar.
- They offer a cheaper alternative that does not require constant maintenance or the technical skills needed to operate sonar equipment.
- Unlike sonar, UAVs can be used even on smaller ships.
- UAVs can alert nearby vessels with important information such as location, presence of fish, and potential threats.
- They can act as emergency beacons, helping to save lives quickly.
- Advances in lithium polymer battery technology are improving UAV endurance by increasing capacity and reducing recharge time.
- Solar-powered UAVs can recharge during daylight, extending flight time and increasing their operational range.
- Integrating UAVs with cloud computing allows for live fish monitoring, which can help assess environmental impacts and

improve understanding of fish migration patterns.

Limitations in Endurance and Energy Efficiency of UAVs in Marine Applications

UAVs currently have limited endurance (flight time). However, this limitation is expected to improve with ongoing advances in battery technology and solar power.

Conclusion

Drones or Unmanned Aerial Vehicles (UAVs) are rapidly transforming the fisheries sector by offering innovative, cost-effective, and eco-friendly solutions to many longstanding challenges. Their ability to cover wide areas, provide real-time data through advanced imaging and sensors, and assist in monitoring fish stocks, illegal fishing, and sensitive marine habitats makes them invaluable tools for sustainable fisheries management. Moreover, their role in aquaculture enhances operational efficiency through surveillance, feeding monitoring, and water quality assessment. While current limitations such as flight endurance exist, ongoing technological advancements in battery and solar power systems promise to overcome these challenges soon. Overall, integrating UAV technology into fisheries and aquaculture not only improves productivity and safety but also supports conservation efforts, paving the way for a more sustainable and responsible future in global seafood production.

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Microfinance Interventions in Rural Poverty Alleviation

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Abstract

In many developing countries, rural poverty arises due to mutually reinforcing constraints that inhibit asset accumulation, productive investment, and access to formal financial services—conditions that are collectively conceptualized as poverty traps. These traps are sustained by low incomes, poor health, limited education, and lack of credit, reinforcing one another over time. Microfinance has emerged as a targeted development intervention to break these cycles by providing small-scale financial services to the rural poor, especially those excluded from formal banking systems. This article examines the theoretical underpinnings of poverty traps and the mechanisms through which microfinance can disrupt these self-perpetuating cycles. Microfinance has shown potential in enabling rural households to invest in livelihoods and smooth consumption. Success of microfinance is often contingent on complementary interventions such as skills training, market access, and institutional support. Microfinance, when embedded in a broader rural development strategy, can be a valuable tool for unlocking economic potential and fostering inclusive growth.

Introduction

Poverty traps are self-perpetuating systems that lead to the continuation of poverty across generations. In rural regions, these traps are intensified by a combination of factors, including low agricultural productivity, inadequate market access, poor infrastructure, and limited availability of formal financial services. Addressing rural poverty has long been a central focus of national policy and planning efforts. However, conventional development strategies have frequently fallen short in overcoming these structural barriers. One critical shortcoming has been the inability of formal financial institutions to effectively meet the credit needs of the rural poor. This gap has catalyzed the rise of microfinance as an alternative approach.

Microfinance refers to a range of financial services—including credit, savings, and insurance—specifically designed for low-income and financially underserved populations. Its primary objective is to enhance income-generating capacity and support livelihood improvement, thereby contributing to an overall rise in living standards. In the Indian context, microfinance has played a pivotal role in promoting rural development. It functions as a strategic tool to mitigate poverty by enabling marginalized communities to build assets, improve household income stability, and participate more actively in local economies. Importantly, it has also emerged as a means of economic empowerment, particularly for women in rural areas.

Understanding Poverty Traps

Poverty traps can be conceptualized within several economic frameworks. These mechanisms interact in complex ways, reinforcing each other and impeding upward mobility.

i) **Asset-based traps,** where households lack the capital to invest in productive activities.

ii) **Nutritional traps,** where low caloric intake leads to poor health and reduced labor productivity.

iii) **Behavioral and informational traps,** involving cognitive burdens, lack of knowledge, and poor decision-making capacity.

iv) **Market failure traps,** such as absence of credit or insurance markets and insecure property rights.

Microfinance as an Anti-Poverty Tool: Microfinance typically includes services such as:

1) **Microcredit:** Small loans without collateral to start or expand businesses.

2) **Microsavings:** Secure savings facilities with no minimum balance for poor households.

3) **Microinsurance:** Low-cost insurance products to protect against health, crop, or climate risks.

Microfinance in India

The concept of microfinance began to take shape during the 1970s, through initiatives like the Grameen Bank in Bangladesh, established under the leadership of Muhammad Yunus, who is widely regarded as a pioneer in the field. These early efforts laid the foundation for what would become the modern microfinance movement. In India, similar developments took place around the same time. A significant milestone was the establishment of the Shri Mahila SEWA Sahakari Bank by the Self-Employed Women's Association (SEWA) in Gujarat. This urban cooperative bank was created with the aim of delivering financial services to economically disadvantaged women, marking one of the earliest examples of organized microfinance initiatives in the country.

Microfinance and Poverty Reduction for Rural Development in India

A significant portion of India's population continues to live below the poverty line. According to World Bank estimates, between 260 and 290 million individuals in India are classified as poor. This figure rises to approximately 390 million when applying the international poverty threshold of living on less than one US dollar per day. Poverty in India is heavily concentrated in rural areas, with nearly 75% of the poor residing in the countryside. States such as Uttar Pradesh, Bihar, and Madhya Pradesh account for nearly half of the country's impoverished population. This rural concentration of poverty is further intensified by the widening economic gap between urban and rural regions.

The Indian government's strategy for poverty alleviation includes a multi-pronged focus on infrastructure development, improvements in health and education, and the enhancement of rural livelihoods. It is within this third pillar—rural livelihood development—that microfinance institutions (MFIs) play a central role. Many low-income households, despite limited formal support, engage in informal income-generating activities and gradually build their homes and small enterprises over time. Access to appropriate financial services can significantly enhance their ability to grow income, accumulate assets, and improve economic resilience.

However, conventional financial institutions have largely excluded poor and rural households, especially those headed by women, from their lending operations. This exclusion arises partly due to unstable income flows among self-employed households and the high transaction costs associated with administering small, numerous loans. Additionally, formal lenders often require collateral, which many low-income families are unable to provide. Hence, poor individuals rely on informal credit markets, often at exploitative interest rates.

In recent decades, the emergence of microfinance has demonstrated that low-income entrepreneurs, when provided with timely and appropriately structured financial services, are capable of repaying loans and using the proceeds to improve their livelihoods. Microfinance has evolved as a reliable and scalable poverty alleviation tool, as evidenced by the success of community-based organizations, NGOs, and self-help groups in extending microcredit. These models have shown that lending to the poor can be both socially impactful and financially sustainable, making microfinance a key driver in the broader agenda of rural development and poverty reduction in India.

Top 10 Microfinance institutions in India

1) State Bank of India
2) Ujjivan Financial Services
3) Equitas Small Finance Bank Ltd.
4) M&M Financial Services
5) Sundaram Finance Ltd
6) Bandhan Financial Services
7) Bharat Financial Inclusion Ltd
8) Muthoot Microfin Ltd
9) Janalakshmi Financial Services
10) MUDRA Bank

Role of microfinance in overcoming poverty traps

- Enable investment in income-generating activities.
- Smooth consumption and reduce vulnerability to shocks.
- Build social capital and collective action through group lending models.
- Enhance women's agency and household-level decision-making.

Limitations and Critiques of Microfinance

- Debt overhang and repayment stress among borrowers.
- Inadequate targeting of the poorest households who may be risk-averse.
- Commercialization of MFIs, leading to mission drift.
- Lack of impact on household consumption or employment in some contexts.
- There is also a need to differentiate between short-term income support and long-term poverty alleviation.

Microfinance into Broader Rural Development Strategy: Microfinance can be more effective when combined with:

- Skills training and business development services.
- Access to infrastructure and markets.
- Social safety nets and health programs.
- Digital finance innovations to enhance outreach and reduce transaction costs.

Conclusion

Microfinance institutions have played a pivotal role in extending the reach of formal financial services to marginalized populations, particularly women, thereby enhancing their access to credit and contributing to poverty alleviation. Despite its transformative potential, the sector has witnessed uneven growth across regions and varying interest rate structures, raising concerns about equity and affordability. Beyond providing capital for income-generating activities, microfinance can also support improvements in housing and urban services, aligning with broader poverty reduction strategies. However, the effectiveness of microfinance depends on designing flexible credit instruments that address the diverse and evolving needs of low-income borrowers, particularly during the interim phase between initiating new ventures and realizing returns. While microfinance offers significant promise as a tool for rural poverty reduction, it should not be viewed as a standalone solution. Its success in breaking poverty traps is contingent upon the local context, thoughtful program design, and integration with complementary interventions such as livelihood training, health services, and infrastructure development. To maximize its long-term impact, future microfinance initiatives must prioritize scalability, client protection, and the provision of bundled services, supported by robust monitoring and rigorous impact evaluations to inform policy and practice.

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Operational Challenges of Fish Hatcheries in Thanjavur, Tamil Nadu

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Abstract

Tamil Nadu's extensive inland water resources play an important role in supporting aquaculture in the state, among which Thanjavur is emerging as a major fish seed hub due to its vast and strong irrigation infrastructure and private hatchery network. However, despite their potential in recent days, these fish seed hatcheries in this region face significant constraints, particularly due to the non-availability of labor, seasonal and climatic changes, temperature fluctuations, poor availability of market, limited credit access, high cost of feed, irregular technical and extension support, which affects their production as well as the quality and availability of fish seeds which in turn affects the sustainability of the aquaculture in the key aquaculture hub of the state. To overcome these issues, strategic interventions such as skill development programs, climate-resilient hatchery infrastructure, market linkages, improved financial accessibility, and strengthened extension services are necessary, producing high-quality feed production through subsidies and further in-field research initiatives can further enhance productivity and sustain their production. Implementing these solutions will improve hatchery efficiency and ensure a steady fish seed supply, and resilient hatchery sector in Thanjavur, which ensures the sustainability of the aquaculture in the entire state.

Keywords: Fish seed, Hatchery, Thanjavur, Constraints, Fish hatcheries, Hatchery constraints

Introduction

Tamil Nadu possesses a vast network of inland water resources covering over 3.83 lakh hectares which includes various reservoirs, irrigation tanks, ponds, rivers, backwaters, and other water bodies. This extensive system plays a major role in improving the economic growth of the aquaculture sector and the creation of job opportunities (Krishnamoorthy *et al.,* 2020). Among all the districts in the state, Thanjavur, often referred to as the "Rice Bowl of Tamil Nadu," has experienced significant growth in inland fisheries, particularly in terms of aquaculture, due to its well-developed river systems, irrigation infrastructure, and groundwater resources (Kumar *et al.,* 2021).

Fig 1: Fish Seed farm in Thanjavur

To foster sustainable aquaculture development, a constant and consistent supply of high-quality fish seeds is essential. To maintain this constant supply, hatcheries play a crucial role by serving as the primary source of fish seed production. To maintain the constant supply, by understanding the need, Tamil Nadu has established a comprehensive network of hatcheries, by establishing 13 government fish hatcheries, one operated by the Tamil Nadu Fisheries Development Corporation (TNFDC), and 37 privately owned hatcheries all across the state and within this ecosystem, Thanjavur stands out as a significant contributor by having highest number of private hatcheries in the state, with over 8 private seed farms and one government seed farm. However, hatchery operators in Thanjavur face various challenges that affect their efficiency and growth. This article aims to highlight the major constraints encountered by fish seed farms in this region and also offers potential recommendations and policy implications to ensure the sustainability of the aquaculture sector in the district.

Key Challenges Faced by Fish Hatcheries

Constraint in a fish hatchery is usually known as the factor that affects and limits the efficiency, productivity, or profitability of an operation which can be economical, environmental, technical, or infrastructural (Narayanakumar *et al.*, 2022).

1. Labour constraints

The foremost challenge in most fish hatcheries is the unavailability of skilled laborers, as most of these farms require round-the-clock monitoring, particularly during peak breeding months and larval rearing stages. Several factors such as migration to better job opportunities in urban areas and declining interest among younger generations to consider this as a potential business option have led to labor gaps in the sector which affects the overall hatchery efficiency and productivity (Patil & Krishnan, 2021). In addition to that, low salaries and improper incentives to the existing laborers also discourage workers from staying in the sector.

2. Climate change constraints

Fig 2: Algal affected fish pond

Environmental changes, such as varying temperatures and erratic rainfall patterns, affect the district's fish seed production and sustainability. Due to these severe environmental changes, there are issues such as changes in metabolic rates, rising algal bloom issues, and dissolved oxygen depletion which lead to poor survival rates and stress-related mortality, thus directly affecting the sustainability of the sector. (Kumar *et al.*, 2020).

3. Marketing Constraints

Hatcheries in Thanjavur are also affected by several marketing issues, such as limited access, inadequate market infrastructure, fluctuating prices, poor demand-supply alignment and the absence of organized marketing channels forces them to entirely rely on intermediaries who take the majority of their profits from them. (Sharma & Gupta, 2019). In addition to this, the lack of proper certifications and digital presence reduces consumers' and other fish farm owners' confidence in availing of these locally produced fish seeds and they started to procure seeds from other states, such as Andhra Pradesh, which have these kinds of certifications supported by strong digital presence.

4. Non-Availability of Credit

Most of the hatcheries in the district face challenges in expanding their operations due to lack and limited access to financial aid and credit options. This lack of credit availability is also associated with high interest rates, and quick payback periods, and requires more copious documentation. Hatchery owners are also don't have that much amount to invest in cutting-edge technology, improved infrastructure, or high-quality feed which forces them to rely on these lending agencies who lend loans at high rates of interest (Rao *et al.*, 2018). These issues are further made worse by frequent delays in availing of government subsidies and a lack of knowledge about financial assistance programs offered by the government.

5. Constraints Related to Extension Services

Hatchery owners often lack adequate technical knowledge and training in advanced management techniques. Extension services play a critical role in bridging this knowledge gap. However, limited outreach programs and inadequate dissemination of scientific advancements prevent farmers from adopting modern technologies, which indirectly affects their production efficiency (Das *et al.*, 2017). Hatchery owners often lack adequate technical knowledge and training in advanced management techniques. Extension services play a critical role in bridging this knowledge gap. However, limited outreach programs and inadequate dissemination of scientific advancements prevent farmers from adopting modern technologies, which indirectly affects their production efficiency (Rajendran *et al.*, 2022).

6. High Cost of Feed

Hatchery is completely dependent on feed right from seed production to feeding the brodders it plays a major role but due to the rising cost of premium larval feed and prepared diets the production of fish seeds is becoming less viable. Fish seed health and survival rates suffer because many producers turn to cheaper, inferior feed (Singh & Verma, 2021) which in turn affects or reduces the confidence of consumers who are procuring their seeds and not getting proper yield. Feed costs are the most significant financial burden for most hatchery operators, as they account for more than 40 – 45% of overall operating costs in fish seed hatcheries in Tamil Nadu (Muralidharan *et al.*, 2022).

Recommendations and Policy Implications

1. The government should introduce structured training programs to create a skilled workforce for hatchery operations. Additionally, incentives such as ensuring fair wages, providing insurance and better working conditions can be done to retain the existing workers (Krishnamoorthy & Rajendran, 2023). Vocational training programs can be conducted targeting rural

youth which could help in addressing the labor shortage issue in the long run.

Fig 3: Selection of Brooders for seed production

2. Investment in climate-resilient hatchery infrastructure, such as temperature-controlled breeding systems and efficient water recycling methods, can help mitigate climate-related changes. Government subsidies should be there to support the hatchery owners in adopting such technologies (Venkatesh *et al.*, 2022).
3. Establishing farmer cooperatives, fish farmer producer organizations and digital marketing platforms will help hatchery operators overcome intermediaries and gain better prices for their fish seed by fixing the fair price on their own for their seed. Government intervention can be made in setting up transport facilities which ensures seed viability during distribution and increases the survival rate (Chandrasekhar & Anand, 2021).
4. Financial institutions can develop hatchery-specific loans with relaxed collateral requirements and lower interest rates and the timely disbursement of government subsidies without any frequent delays can be made to support farmers (Raghavan & Menon, 2022). Microfinance initiatives tailored to the seasonal needs of hatchery operations could provide timely financial support during critical production phases in the hatchery.
5. The knowledge gap can be closed by setting up specialized fisheries extension centers in each district and using digital platforms to provide real-time advising services. Productivity will be further increased by routine training in sophisticated hatchery practices (Rahaman & Kar, 2023). The reach of extension services could be greatly increased by mobile applications that offer hatchery management advice particular to a certain region.
6. The government should use industrial partnerships and subsidy schemes to promote local production of high-quality, reasonably priced fish feed. Costs can be further decreased by providing incentives for research and development of substitute feed ingredients (Marimuthu & Sukumaran, 2022). Promoting feed produced on farms with materials found on farms could lessen reliance on commercial feeds and save operating expenses.

Conclusion

Fish seed hatcheries in Thanjavur are crucial for sustaining the growing aquaculture industry. However, their effectiveness is hampered by a lack of workers, climate variability, market limitations, restricted access to credit, and deficiencies in technical understanding. Strengthening the sector requires targeted measures like financial reforms, improved market access, talent development programs, and the adoption of cutting-edge technologies. Hatchery farmers can increase resilience and productivity with deliberate interventions and more significant institutional assistance. In addition to supporting fisheries, a healthy supply of fish seeds would give rural populations in Tamil Nadu long-term food security and economic stability.

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Jeppiaar Fishing Harbour: Fostering Social Connections and Opportunities

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Abstract

Jeppiaar Fishing Harbour in Muttom, Kanniyakumari, is a strong example of how private investment can positively impact fishing communities. Since its inauguration in 2015, the harbour has introduced modern infrastructure, improved fish storage facilities, and created increased employment opportunities for the local population. Thousands of families now benefit from safer and more efficient fishing operations, leading to higher incomes. The harbour also emphasizes environmental sustainability and community development. With future plans to evolve into a hub for marine research, Jeppiaar Fishing Harbour not only supports present-day livelihoods but also paves the way for long-term growth and innovation in the sector.

Introduction

Jeppiaar Fishing Harbour Muttom Private Limited (JFHMPL) is a good example of how private investment can help coastal areas in India. The harbour was registered in 2008 and started working in January 2015. It was started by the late Col. Dr. Jeppiaar and his family, and now, Dr. Mariazeena Johnson and Dr. Marie Johnson manage it. The harbour is located at Muttom, Tamil Nadu, near Vellimalai, Kanniyakumari. It is very important for the local fishing community, helps people earn a living, and brings new ideas and progress to the region. This article explains how the harbour was developed, what facilities it has, how it helps the local people, and what the future may hold.

Fig 1. JPR harbour

Vision and Background of Fishing Harbour's Development

The main goal behind building Jeppiaar Fishing Harbour was to help fishermen and people working in related fields. The founders wanted to make fishing safer and more productive. They also wanted to create more jobs for local people. The harbour gives jobs directly to about 155 people and 120 daily wage workers. Besides this, nearly 5,000 families in nearby villages also benefit from the harbour. The focus has always been on safety, efficiency, and making sure the community grows in a healthy way.

Infrastructure and Support Facilities

One big reason for JFHMPL's success is its modern and well-planned infrastructure. The harbour has a large auction hall, 250 meters long, where fish are sold quickly and fairly. There is a boat yard where boats can be built and repaired, which helps fishermen keep their boats in good shape. The workshops and lathe center help fix and make fishing tools, so fishermen do not lose time waiting for repairs.

The harbour also has fuel stations with fuel from Indian Oil and Bharat Petroleum, so boats can always get the fuel they need. There is a huge ice plant that can store 250 tons of ice, and there are cold storage rooms to keep the fish fresh. This reduces waste and helps fishermen get better prices for their catch. Clean drinking water and water for cooking and bathing are also available, making life better for workers and their families.

Fig 2. Ice Plant at the JPR Fishing harbour

For convenience, there are shops selling groceries, vegetables, nets, ropes, and other fishing tools. LPG cylinders for boats are supplied by Indian Oil. There are also bakeries, tea stalls, hotels, and modern restrooms for everyone at the harbour. To protect the environment, the harbour has effluent and sewage treatment plants that keep the water clean and safe. There is a plenty of parking, and the harbour has a 1,500-meter berthing area where up to 250 boats can dock, with special areas for tagging and single-tag berthing.

Comparison of Infrastructure of JFHMPL with Government Runs Harbours

The table 1 provides a side-by-side comparison of key infrastructure components between JPR Harbour and traditional government-run harbours.

Table 1: Comparison Infrastructure between JPR Harbour and Government-Run Harbours

Feature	JPR Harbour (Private)	Government-Run Harbours
Investment Flexibility	Dynamic, market-driven reinvestment strategies	Budget-dependent, incremental modernization
Technological Adoption	Rapid incorporation of advanced technologies	Standardized, with periodic upgrades
Facility Design	Customizable layouts for diverse vessel sizes	Uniform design based on national standards
Maintenance Cycle	Frequent, proactive maintenance regimes	Scheduled, often delayed by bureaucratic processes
Capacity for Innovation	Highly responsive to market trends and technological change	Moderate—governed by policy and long-term planning

This systematic comparison reveals that while JPR Harbour benefits significantly from its agile, private investment model, government-run harbours prioritize stability and adherence to standardized practices invariably affecting their operational adaptability and modernization pace.

Daily Operations and Fish Transport Efficiency

Fig 3. Large auction hall at the JPR harbour

Every day, about 25 boats come in and out of the harbour. The system for moving fish is quick and smooth. Once the fish are caught, they are brought to the harbour, auctioned, and then sent to cold storage or processing units. The availability of enough ice, cold storage, and good transport facilities, helps the fisher to keep the fish fresh, without any microbial activity. This leads the fish to fetch higher price at the local and international markets as it meets the consumer preferences, also the loss due to spoilage is very minimal.

Operational Practices

Table 2 shows the difference between private and government harbours. Private harbours like JPR are flexible and quick to respond, while government ones have to follow strict rules and regulation. This affects how fast work gets done, customer satisfaction, and overall efficiency. Private harbours tend to be faster and more adaptable, while government ones while are more stable but less flexible.

Table 2: Operational Practices Comparison

Operational Factor	JPR Harbour (Private)	Government-Run Harbours
Management Approach	Lean, agile, decentralized	Bureaucratic, centralized
Decision-Making Process	Data-driven, flexible	Policy-driven, compliance-focused
Customer Interaction	High responsiveness	Regulated through formal channels
Technological Integration	Rapid adoption, innovative	Gradual integration
Overall Efficiency	High, adaptable	Stable, structured

Socio-Economic Impact: Transforming Lives with Modern Infrastructure

Fig 4. Landing at JPR Fishing Harbour

A survey of fishermen who use the harbour shows how much things have improved. About 30.9% of the fishermen are between 36 and 45 years old, which means many are experienced workers. Most of them 87.3% are married, showing that fishing is important for families.

Many fishermen have little formal education; 36.4% cannot read or write, and only 3.5% have postgraduate degrees. This means there is a need for more training and education so fishermen can learn new skills. Before the harbour was built, 76.4% of fishermen relied mainly on fishing for their income. After the harbour opened, this number went up to 87.3%, showing that the harbour made fishing a more stable job.

Also, 45.5% of the fishermen have more than ten years of experience. Large number of fishermen are now using motorized boats. Before the establishment of harbour, 25.5% of fisher used motorized, but at present 50.9% of them use motorized boats. This shows that technology is helping them work better. The survey also found that before the harbour, 92.7% of fishermen faced a lot of competition from other sellers. Now, problems like payment delays and fish spoilage are less common, making it easier for fishermen to earn a living.

Efficient Fish Supply Chain and Social connection

The way fish are moved and sold at JFHMPL is simple and effective. Fish are brought to the harbour, sold quickly in auctions, and then sent to cold storage or processing centers. Because there is enough ice and good transport, the fish stay fresh and fishermen earn more money. This also means less fish is wasted.

The harbour is more than just a place to work; it is also a place where people meet and support each other. The auction hall, workshops, and places to stay help fishermen and their families connect and work together. This sense of community is important for everyone's well-being. The harbour also helps keep local fishing traditions alive, while bringing in new technology and better ways of working.

Environmental Responsibility and Sustainable Practices

JFHMPL cares about the environment. The effluent and sewage treatment plants help keep the water clean and protect the local sea life. By managing waste properly, the harbour makes sure the area stays healthy for future generations. These efforts help make fishing more sustainable and responsible.

Future Directions: Innovation, Research, and Sustainable Growth

There are plans to make JFHMPL a center for scientific research. Because it is close to the Bay of Bengal, Arabian Sea, and Indian Ocean, it is a good place to study the sea, fish, and climate. Research vessels will be able to dock at the harbour, making it easier for scientists to study things like seaweed farming, ocean microbes, and how weather affects fishing.

Fig 5. Ice loading at JPR harbour

Some research has already started, such as studying how seaweed grows and how to prevent biofouling. In the future, more projects will look at ocean data and climate patterns. These activities could bring new ideas, funding, and technology to help local fishermen.

Supporting Livelihoods and Economic Development

The harbour helps many people earn a living. It gives direct jobs to 155 people and 120 daily wage workers, and helps about 5,000 families indirectly. The boat yard, workshops, and ice plant create many different jobs, from skilled work to simple labor. The auction hall and shops also help local businesses grow.

This approach helps reduce poverty and supports the local economy. By building good infrastructure, the harbour helps people live better lives and encourages growth in the region.

Overcoming Challenges and Seizing Opportunities

Even though JFHMPL has done well, there are still some issues. Fishermen largely are in need of more training and education to learn new skills. Market problems like payment delays and fish spoilage still happen and need to be fixed. Environmental threats, such as climate change, are also a concern.

However, these challenges also create chances to improve. Making the harbour a research center could bring in new ideas and money. This could help fishermen use better methods, manage resources wisely, and keep the local economy strong.

Conclusion

Jeppiaar Fishing Harbour Muttom Private Limited shows how private investment can change a traditional industry for the better. With modern facilities, a focus on helping people, and care for the environment, JFHMPL has improved the lives of many fishermen and their families. Its plans for future research and innovation, in this way the harbour will keep growing and supporting the community for many years to come.

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