Revolutionizing Aquaculture with Paste Technology: A New Frontier in Sustainable Aqua feed and Health Management

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Abstract- Aquaculture has emerged as a critical contributor to global food security, supplying over half of the world's seafood and supporting economic development. However, traditional feeding methods and disease management strategies often face challenges related to sustainability, feed efficiency, environmental impact, and effective therapeutic delivery. Conventional pellet feeds can lead to nutrient loss, poor bioavailability of functional ingredients, and increased organic waste, which negatively affect water quality and fish health.

Paste technology is gaining recognition as an innovative solution to these limitations. It involves the use of semi-moist, moldable feed matrices designed to deliver nutrients, probiotics, medications, and other bioactive in a controlled and efficient manner. Unlike heat-processed feeds, paste formulations preserve heat-sensitive compounds, offering improved functionality and palatability. They can be customized to meet the nutritional and behavioral needs of specific species and life stages, making them especially useful in larval and juvenile rearing, as well as in medicated feeding applications.

This review explores the principles, applications, and benefits of paste technology in aquaculture, with a focus on its role in enhancing animal health, feed utilization, and environmental sustainability. With growing interest in precision aquaculture and sustainable practices, paste technology represents a promising tool for the future of the industry.

Keywords: Aquaculture, Paste Technology, Medicated Feed, Functional Feed, Sustainable Aqua feed, Controlled Release, Fish Health, Larval Nutrition

I. INTRODUCTION

With the global population continuing to rise, the demand for sustainable protein sources has intensified, positioning aquaculture as a key contributor to food security. Today, aquaculture provides over 50% of the global fish supply, supporting both nutrition and economic development. However, the industry is increasingly challenged by issues such as inefficient feed utilization, disease outbreaks, environmental degradation, and overreliance on unsustainable inputs like fishmeal and fish oil. These challenges not only raise concerns about ecological impact but also threaten the long-term viability of aquaculture systems[3].

Paste technology has emerged as a promising innovation to address these limitations. This approach involves the use of a semi-solid, pliable matrix capable of delivering nutrients, medications, probiotics, and other functional compounds directly to aquatic animals. Unlike traditional pelleted or extruded feeds, paste feeds can be formulated without high-temperature processing, preserving heat-sensitive bioactive and enhancing palatability. Their customizable nature allows precise dosing, improved digestibility, and reduced feed waste. Furthermore, paste formulations can be tailored to meet the specific needs of various species and life stages, including larvae and juveniles. By merging advances in feed formulation, drug delivery, and bio encapsulation, paste technology represents a versatile tool for

improving efficiency, animal health, and sustainability in modern aquaculture [10].

II. PASTE TECHNOLOGY IN AQUACULTURE: COMPOSITION AND FUNCTIONAL DESIGN

Paste technology (Precision Aquatic Semi-solid Targeted Emulsion) refers to the development of semi-moist feed or delivery systems specifically designed to meet the nutritional, physiological, and therapeutic needs of aquatic animals. These paste formulations consist of a soft, pliable matrix made primarily from water, binders, proteins, lipids, and various active ingredients. Common binders used include natural hydrocolloids such as alginate, carrageenan, and gelatin, which provide structural integrity and water stability to the paste. The matrix may also incorporate bioactive compounds such as probiotics, vitamins, minerals, enzymes, antibiotics, or immunostimulants, depending on the intended application [6].

One of the key advantages of paste feeds is their versatility. They can be molded into different shapes and sizes or applied directly to tank surfaces, enabling targeted and species-specific feeding strategies. The formulation can be tailored to suit a wide range of aquatic species both finfish and shellfish across various developmental stages, from larvae to adults. Pastes are especially useful in larviculture and juvenile rearing, where high palatability, digestibility, and nutrient availability are critical.

Another important feature of paste technology is its ability to support controlled or slow release of nutrients and bioactive. This ensures sustained intake over time, enhances nutrient uptake, and reduces leaching into the water, thereby improving feed efficiency and minimizing environmental pollution.

Moreover, paste feeds are typically produced at low temperatures, preserving the biological activity of heat-sensitive compounds that would be degraded in conventional pelleting or extrusion processes. This makes them ideal for delivering sensitive therapeutic agents or live microbial additives.

Overall, paste technology offers a highly adaptable and efficient platform for advancing nutrition, health, and environmental sustainability in aquaculture, particularly in specialized or intensive production systems.

III. PASTE TECHNOLOGY IS A GAME-CHANGER IN AQUACULTURE

In the evolving world of aquaculture, feeding strategies are undergoing a transformation. Among the most promising innovations is a method that is changing the way aquatic species are nourished at different stages of their life cycle. From precision nutrition to environmental benefits, paste feeds offer a range of advantages that position them as a game-changing solution for modern aquaculture [2].

a. Precision Nutrition

One of the most significant advantages of paste feeds is their ability to deliver customized, species-specific nutrition. Unlike conventional pellet or crumble feeds that are often generalized across multiple species, paste feeds can be finely tuned to meet the exact nutritional needs of different aquatic organisms at various life stages. For example, carnivorous fish require high protein, whereas herbivorous species benefit more from plant-based components. Paste feeds can be easily formulated to reflect these specific dietary profiles. This nutritional precision promotes optimal growth, enhanced immunity, and better reproductive performance, ultimately improving both survival rates and farm productivity.

b. Improved Larval Survival

Larval stages are among the most delicate phases in the life cycle of aquatic species. Fish and shrimp larvae require soft, highly digestible feeds that are rich in essential nutrients, such as amino acids, fatty acids, vitamins, and enzymes. Paste technology makes it possible to incorporate live feed components, microalgae, probiotics, and immunostimulants into a homogenous, soft-textured paste that larvae can easily consume. This leads to improved gut development, immune response, and survival rates. The ability to provide such tailored early nutrition is crucial in hatcheries, where high mortality is often a major challenge.

c. Eco-Friendly Feeding

Environmental sustainability is a core concern in modern aquaculture. One of the issues with dry feeds is nutrient leaching the process where feed breaks apart in water before being consumed, leading to pollution and reduced feed efficiency. Paste feeds, with their sticky and cohesive nature, minimize disintegration in water. This ensures that more feed is consumed and less is wasted, significantly reducing

organic load and improving water quality. Better feed conversion ratios also lower the environmental footprint of farming operations, supporting eco-friendly and responsible aquaculture practices.

d. Ideal for Special Species

Not all aquatic species feed in the same way. Some, like abalone, sea cucumbers, and ornamental fish, have unique feeding behaviors that are poorly served by conventional pellets or floating feeds. Paste feeds can be smeared on tank walls, rocks, or artificial substrates, mimicking the natural feeding surfaces of these bottom dwellers or grazers. This allows such species to feed comfortably and efficiently, leading to improved intake, reduced stress, and better health outcomes.

e. Carrier for Functional Additives

Another major strength of paste feeds is their ability to serve as a delivery system for functional ingredients. Whether it's antibiotics, vitamins, hormones, or probiotics, paste formulations allow for easy incorporation and uniform distribution of these additives. This makes them ideal for targeted treatments or nutritional enhancements during specific production stages, such as breeding, stress periods, or disease outbreaks.

IV. APPLICATIONS OF PASTE TECHNOLOGY IN AQUACULTURE

Paste technology has introduced a new level of precision and adaptability to feeding strategies in aquaculture. Its soft, moldable consistency allows for the inclusion of a wide range of nutritional and therapeutic components, making it an ideal choice for various stages of aquatic animal development and for different species with diverse feeding behaviors. Below are three major application areas of paste feeds in aquaculture:

1. Functional and Medicated Feeds

One of the most promising applications of paste technology is in the development of functional and medicated feeds. Because paste feeds are not subjected to high-temperature processing unlike pelleted feeds that go through extrusion—they retain the biological activity of heat-sensitive compounds. This makes pastes ideal for incorporating:

- Probiotics and immunostimulants to support gut health and enhance immune response.
- Antibiotics and antiparasitics for the treatment and prevention of bacterial or parasitic infections.
- Vitamins, minerals, and hormones to support growth, reproduction, and stress resistance.

By delivering these additives through paste, farmers can ensure effective dosing and targeted delivery, especially during disease outbreaks or critical developmental stages. This application is particularly valuable in hatcheries, quarantine systems, and during broodstock conditioning, where maintaining the health of the stock is essential [11].

2. Larval and Juvenile Feeding

Feeding during the larval and early juvenile stages is one of the most delicate operations in aquaculture. During this time, aquatic animals have underdeveloped digestive systems and require feeds that are highly digestible, nutritionally dense, and of an appropriate particle size. Paste feeds meet all these criteria.

Pastes can be enriched with live feed organisms such as *Artemia* (brine shrimp) and rotifers, offering a natural transition from live feeding to formulated diets. This enrichment not only enhances palatability but also boosts nutrient intake during a critical growth phase. Additionally, the small particle size and soft texture of pastes make them easy for larvae to consume, reducing feed rejection and mortality.

By supporting a smoother transition from live to formulated feeds, paste technology helps reduce weaning stress and improves both survival and growth rates in young aquatic organisms [11].

3. Species-Specific Formulation

Different aquatic species have distinct feeding behaviors and habitat preferences, which traditional pellet feeds often fail to accommodate. Paste feeds, on the other hand, offer exceptional versatility:

- For benthic or bottom-dwelling species like abalone and sea cucumbers, paste can be spread directly onto tank floors or rocks, encouraging natural grazing behavior.
- For filter feeders, the paste can be suspended in the water column to simulate planktonic food sources.
- In systems with ornamental or selective feeders, pastes can be hand-fed or dispensed using

automated systems to ensure precise portioning and minimize stress.

This level of customization enhances feeding efficiency, reduces waste, and helps maintain better water quality by preventing uneaten feed from accumulating and decomposing [11].

V. BENEFITS OF PASTE TECHNOLOGY OVER TRADITIONAL FEED SYSTEMS IN AQUACULTURE

In the pursuit of sustainable and efficient aquaculture, feeding strategies play a critical role in determining the health, growth, and overall productivity of aquatic species. Traditional feed systems primarily in the form of dry pellets, crumbles, or flakes have long dominated the industry. While effective to a degree, these feeds often fall short when it comes to species-specific nutrition, precision feeding, and environmental sustainability. Paste feed technology, with its adaptable and nutrient-rich formulation, offers several advantages that are transforming the way aquaculture systems operate.

1. Superior Nutrient Preservation

Traditional pelleted feeds are typically produced through high-temperature extrusion, a process that can degrade heat-sensitive nutrients such as vitamins, enzymes, probiotics, and certain medications. In contrast, paste feeds are usually prepared without applying extreme heat, thereby preserving the full nutritional and functional integrity of their ingredients. This allows for the effective delivery of biologically active compounds that are critical for enhancing immune function, digestion, and growth particularly in early-stage aquatic animals or during stress and disease outbreaks [3].

2. Enhanced Customization and Flexibility

Paste feeds offer a high degree of customization, which is difficult to achieve with standard dry pellets. Farmers can formulate pastes to suit the specific dietary requirements of different species, life stages (larval, juvenile, adult), or production goals (growth, reproduction, health management). Ingredients can be easily adjusted, and pastes can be enriched with probiotics, antibiotics, hormones, or live feeds such as rotifers and *Artemia*. This level of flexibility is especially valuable in hatcheries, research settings, and specialty aquaculture such as ornamental fish farming [3].

3. Improved Feed Intake and Palatability

Paste feeds generally have a soft, moist texture that is more appealing and easier to ingest especially for larvae, juveniles, and selective feeders. The consistency of pastes closely resembles the natural diet of many aquatic organisms, promoting better acceptance and feeding behavior. This leads to higher feed intake, improved nutrient absorption, and better growth performance. It also helps during transitions, such as from live feed to formulated diets, by reducing stress and feed refusal [3].

4. Reduced Feed Waste and Environmental Impact

One of the major drawbacks of traditional feed systems is feed wastage, which contributes to water pollution and poor feed conversion ratios (FCRs). Pellets often disintegrate before being consumed, especially if uneaten feed accumulates on the tank bottom. Paste feeds, on the other hand, are more stable in water and can be adhered to surfaces for benthic or grazing species. This targeted delivery reduces leaching and ensures that a larger proportion of the feed is consumed. The result is lower nutrient runoff, improved water quality, and a more sustainable farming environment [3].

5. Versatility for Diverse Species and Systems

Unlike standard feeds that are designed for general use, paste feeds can be tailored for diverse aquatic species including filter feeders, bottom dwellers, and ornamental species with specialized diets. They can also be administered via manual or automated methods, making them suitable for small-scale farms as well as intensive recirculating aquaculture systems (RAS).

Feature	Traditional Pellet Feed	Paste Feed Technology
Thermal Processing	High temperature	Low temperature (nutrient-friendly)
Palatability	Moderate	High (customizable flavor, texture)
Medication Delivery	Inefficient	Targeted, controlled release
Nutrient Leaching	High in water	Low (good water stability)
Waste Generation	Higher	Significantly lower

Cost-effectiveness	Lower upfront, higher long-term	Medium upfront, better ROI via health gains

VI. ENVIRONMENTAL AND SUSTAINABILITY ASPECTS OF PASTE FEED TECHNOLOGY IN AQUACULTURE

As global aquaculture expands to meet the growing demand for seafood, sustainability has become a key priority. Traditional aquafeeds, especially those heavily reliant on fishmeal and fish oil, contribute to overfishing and place strain on marine ecosystems. In response, paste feed technology has emerged as a more environmentally responsible alternative that aligns with the goals of sustainable aquaculture [3].

One of the most promising features of paste feeds is their ability to incorporate alternative protein sources. Instead of relying solely on fishmeal, paste formulations can include insect meal, microbial protein (such as single-cell protein), algae-based ingredients, and agricultural by-products. These ingredients are not only renewable and readily available but also reduce dependency on wild-caught fish, helping conserve marine biodiversity. The inclusion of such sustainable protein sources makes paste feeds a forward-thinking choice for environmentally conscious aquaculture operations [4].

In addition to ingredient flexibility, paste feeds also contribute to better environmental management within the aquaculture system. Their cohesive and stable consistency minimizes nutrient leaching into the water. Unlike traditional pellet feeds that may break down quickly and release nutrients before being consumed, paste feeds stay intact longer and are more likely to be fully ingested. This results in:

- Lower biological oxygen demand (BOD), as less organic material is left to decompose in the water.
- Reduced risk of eutrophication, which occurs when excessive nutrients cause algal blooms that can deplete oxygen and harm aquatic life.
- Less frequent water exchange requirements, which saves water and energy—especially important in water-sensitive farming systems.

These advantages make paste feeds particularly well-suited for recirculating aquaculture systems (RAS) and biofloc systems, where water quality and nutrient balance are tightly controlled. In such systems, maintaining low waste output is essential to ensure system stability and fish health. Paste technology aligns well with these needs, helping farmers reduce environmental footprints while maintaining high production efficiency.

Moreover, the ability to tailor paste feeds for specific species and feeding behaviors leads to less feed waste overall, further supporting clean and sustainable operations.

VII. CHALLENGES TO OVERCOME IN PASTE TECHNOLOGY FOR AQUACULTURE

While paste feed technology offers numerous advantages in aquaculture—such as precise nutrition delivery, adaptability to different species, and suitability for medicated or enriched feeding it is not without its limitations. For widespread adoption and effective implementation, several practical and economic challenges need to be addressed. Below are the key obstacles associated with paste technology in aquaculture and considerations for overcoming them:

1. Limited Shelf Life and Storage Requirements

One of the most significant challenges with paste feeds is their short shelf life. Unlike pelleted or extruded feeds that are dry and shelf-stable, paste feeds contain higher moisture content, making them prone to microbial spoilage if not stored properly. To maintain freshness and safety, paste feeds often require refrigeration or freezing, which increases logistical complexity, particularly in remote or resource-limited aquaculture operations [5].

In large-scale commercial farms, maintaining cold chain storage systems can add to operational costs and energy use. For small or rural farmers without access to reliable refrigeration, the risk of spoilage or feed degradation can lead to waste and financial loss.

Solutions may involve developing preservative-stabilized paste formulations, improving packaging technology, or investing in cold-chain infrastructure where economically feasible. Research into shelf-

stable, semi-moist alternatives could also help extend the usability of paste feeds without sacrificing nutritional quality.

2. Labor-Intensive Application

Another challenge of paste feed technology is the manual labor required for feeding. Unlike pellet feeds that can be easily broadcast or dispensed using automated systems, paste feeds typically need to be applied by hand smeared on surfaces for benthic species, or strategically placed in tanks and ponds. This process is time-consuming and may not be practical in large-scale or high-density aquaculture operations.

Additionally, paste feeding requires a level of technical skill and observation. Over- or under-feeding can lead to water quality issues or nutritional deficiencies, while inconsistent application may result in uneven growth rates among the stock[7].

To address this, the development and use of automated or semi-automated paste feed dispensers is essential. Innovations in feed delivery systems such as robotic arms, pump-based applicators, or programmable nozzles could significantly reduce labor demands and increase precision in feed application, particularly in hatcheries or recirculating aquaculture systems (RAS).

3. Higher Production Costs

Paste feeds can also be more expensive to produce than traditional feeds. The cost arises from several factors: high-quality ingredients, moisture control, specialized mixing equipment, cold storage, and limited scalability. Furthermore, the inclusion of functional additives like probiotics, enzymes, or hormones while beneficial adds to the formulation cost.

This makes paste technology less accessible to small-scale farmers or regions where economic constraints are a concern. In cost-sensitive markets, the higher price of paste feeds may limit adoption unless there is a clear return on investment through improved survival, growth, or disease resistance.

To make paste feeds more economically viable, efforts should focus on optimizing formulations, using locally sourced raw materials, and improving manufacturing efficiency. Cost-sharing initiatives, cooperative feed centers, or government subsidies might also support wider implementation, especially in developing aquaculture sectors[3].

VIII. FUTURE PERSPECTIVES OF PASTE FEED TECHNOLOGY IN AQUACULTURE

Paste feed technology holds immense potential to transform aquaculture into a more sustainable, efficient, and health-focused industry. As innovations continue to reshape the landscape of fish farming, integrating paste feeds with emerging technologies will be essential for unlocking their full potential[1].

One promising direction is the integration of nanotechnology into paste formulations. Nanoparticles can improve the bioavailability of nutrients and active compounds, allowing for better absorption and enhanced health benefits in aquatic species. This can lead to more effective delivery of vitamins, minerals, and therapeutic agents, even at lower doses[12].

Additionally, the application of artificial intelligence (AI) and sensor technologies can revolutionize paste feed usage by enabling precision feeding. Smart sensors can monitor water quality, feeding behavior, and biomass in real time, while AI algorithms can optimize the timing, quantity, and composition of paste feed delivery. This reduces feed waste and improves both growth performance and environmental outcome [13]s.

Another key opportunity lies in the development of modular, on-site paste production units. These compact systems would allow farms especially small- and medium-scale operations to prepare customized paste feeds using locally available ingredients. This could reduce feed costs, improve freshness, and support region-specific sustainability goals.

Paste feeds may also serve as a promising platform for oral delivery of vaccines and next-generation therapeutics, such as RNA-based disease treatments. Delivering health products through feed can reduce the need for stressful injections and enhance disease prevention in large-scale aquaculture systems[7].

To fully realize these advancements, collaboration among researchers, feed manufacturers, technology developers, and farmers will be essential. Joint efforts will drive innovation, improve cost-efficiency, and

promote adoption of paste technology across various aquaculture sectors.

IX. CONCLUSION

Paste technology is emerging as a highly versatile and innovative solution in aquaculture, offering significant advantages in nutrition, health management, and sustainability. Its unique ability to deliver targeted nutrients, functional additives, and medications in a customizable, soft feed format makes it especially valuable for species with specialized dietary needs and sensitive life stages. By minimizing feed waste and preserving water quality, paste feeds also support environmentally friendly farming practices. As the aquaculture industry shifts toward greater efficiency and precision, paste technology aligns well with these goals, particularly in recirculating systems, hatcheries, and species-specific farming. Furthermore, its potential integration with advanced technologies such as nanotechnology, AI, and bio-therapeutics points to an exciting future of smarter, more sustainable fish farming. With ongoing innovation and collaboration among stakeholders, paste feed systems are well-positioned to become a core component of precision aquaculture and the next generation of sustainable aquatic food production.

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