Microbial fermentation–based biotransformation of fish discards into aquafeed ingredients

N. Lalitha*, Oimps Lunghar and K. Ambasankar
ICAR-Central Institute of Brackishwater Aquaculture, Chennai-600028
Corresponding Author: lalithaciba@gmail.com

Introduction

Fish discards represent a major environmental and economic challenge for the global fisheries and aquaculture sector. Fish discards (FD) are generated during operations such as deheading, gutting, filleting, descaling, and trimming, and typically accounts for 30–70% of the total biomass of harvested fish. Major components include heads, viscera, frames, skin, scales, and fins. These discards are rich in nutrients like proteins, lipids, minerals, and bioactive compounds, making them suitable raw materials for value-added products when properly processed. In India, a substantial proportion of fish waste is still disposed of untreated, resulting in economic losses and environmental degradation. Microbial fermentation has emerged as a sustainable and low-cost biotransformation strategy to convert fish waste into nutritionally valuable aquafeed ingredients. The advantages of microbial fermentation is that it is a commonly employed fermentation methods, and have practical feed applications in aquaculture. Fermented fish silage–based farm-made feeds for tilapia, highlights the potential of fermentation-driven circular bioeconomy approaches for improving feed efficiency, fish health, and farm profitability. The biochemical composition of fish processing waste varies with species, size, season, and processing method, but generally contains about 40–60% crude protein (dry weight basis) and appreciable levels of essential amino acids and long-chain beneficial polyunsaturated fatty acids. Such nutritional richness underlines the potential of fish processing waste as a feed resource.

Risks Associated with Fish Processing Waste

Untreated fish byproducts pose significant environmental and public health hazards. Rapid microbial decomposition leads to foul odors, oxygen depletion in receiving waters, and the release of ammonia, hydrogen sulfide, and other toxic metabolites. Fish processing waste (FPW) also serves as a potential reservoir for pathogenic microorganisms, including *Salmonella*, *Vibrio*, and *Clostridium* species, which may threaten human and animal health. From a biosecurity perspective, direct incorporation of raw fish waste into feeds is unsafe due to the risk of disease transmission and spoilage. Additionally, lipid oxidation and protein degradation during uncontrolled storage reduce nutritional quality and palatability. These risks necessitate effective stabilization and processing techniques prior to utilization in aquafeeds.

Fermented fish silage

Fermented fish silage is produced by the controlled fermentation of minced fish discards in the presence of fermentable carbohydrates and selected starter microbial cultures, typically lactic acid producing bacteria. The process results in rapid acidification, preservation, and partial hydrolysis of proteins into peptides and free amino acids. Compared to conventional fishmeal production, fermented fish silage (FFS) requires minimal energy input, does not rely on high-temperature processing, and can be implemented at small or farm scale. Studies on fermented fish silage–based diets, is genetically improved farmed tilapia (*Oreochromis niloticus*), have demonstrated improved growth performance, feed conversion ratio, digestive enzyme activity, and economic efficiency, particularly at optimized inclusion levels (e.g., 60% FFS-based formulations).

Advantages of Microbial Fermentation

Microbial fermentation offers multiple advantages for the valorisation of fish processing discard by simultaneously improving safety, nutritional quality, and sustainability. Rapid acidification during fermentation stabilizes the substrate by inhibiting spoilage and pathogenic microorganisms. Enzymatic hydrolysis of proteins enhances digestibility and increases the bioavailability of amino acids, while fermentation by lactic acid bacteria contributes functional benefits, including improved gut health and enhanced immune responses in cultured fish. In addition, the use of locally available discards and low-cost infrastructure makes fermentation an economically viable approach for feed production. From an environmental perspective, fermentation supports circular economy principles by recycling nutrients, minimizing waste disposal, and reducing the environmental burden associated with fish processing discards. Collectively, these makes microbial fermentation as a superior alternative to conventional waste disposal practices or the direct use of unprocessed fish waste in aquafeeds.

Methods of Fermentation

Several fermentation methods are employed for producing fermented fish silage:

(i) Lactic Acid Fermentation: Lactic acid fermentation is the most widely employed method for fish processing waste

valorization, utilizing lactic acid bacteria (LAB) such as *Lactiplantibacillus plantarum*. Here, supplementation with molasses or other carbohydrate sources enhances lactic acid production, resulting in rapid acidification to a pH level below 4.5, thereby ensuring microbial stability. Briefly, fish discard was chopped into 1–2 cm pieces and minced into a uniform paste using a fish mincer. Fermented fish silage was prepared by mixing minced FD with 15% molasses, 5% *Lactiplantibacillus plantarum* with 0.4% papain, and 0.043% potassium sorbate. The mixture was stored in 25 L airtight containers at ambient temperature (28–30 °C) for 7 days, stirred twice daily, and the pH was monitored regularly using a digital pH meter.

(ii) Autofermentation

Autofermentation relies on endogenous enzymes and naturally occurring microorganisms present in fish waste. In this method, fish byproducts are minced and fermented with the addition of 50% molasses. Although the process is simple and cost-effective, it provides limited control over fermentation dynamics and final product quality, and the fermentation duration is comparatively longer than that of controlled lactic acid fermentation.

(iii) Enzyme-Assisted Fermentation

The incorporation of commercial proteolytic enzymes like papain accelerates protein hydrolysis and enhances the uniformity of fermented fish silage, although it results in higher production costs. Key process parameters, including temperature, moisture content, inoculum level, and fermentation duration, critically influence the quality of the final product. In enzyme-assisted fermentation, papain can be added at 0.4% along with 15% molasses, 5% *Lactiplantibacillus plantarum*, and 0.043% potassium sorbate to promote efficient acidification and protein breakdown.

Fermented Fish Silage as a fishmeal ingredient

Fermented fish silage has been successfully incorporated into diets for a wide range of aquaculture species, including tilapia, carps, catfish, and shrimp. As a partial or complete replacement for fishmeal, FFS contributes to satisfactory growth, improved feed utilization, and enhanced health status when properly balanced with plant-based ingredients such as rice bran and oil cakes. Farm-made feeds containing fermented fish silage are particularly beneficial for small-scale farmers, as they reduce dependence on expensive commercial feeds and promote the use of locally available resources. Long-term feeding trials have demonstrated that optimized FFS-based diets can reduce feed costs without compromising fish performance, thereby improving overall farm profitability.

Conclusion and Future Perspectives

Microbial fermentation–based biotransformation of fish discards into aquafeed ingredients represents a practical and sustainable solution to waste management challenges in fisheries and aquaculture. Fermented fish silage offers nutritional, functional, economic, and environmental benefits, especially for resource-limited farming systems. Future research should focus on standardizing fermentation protocols, evaluating long-term health and product quality effects, and scaling up production within circular bioeconomy frameworks.

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