Microbial Fermentation: Optimizing Plant Ingredients for Aquafeeds

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ABSTRACT

Plant-based ingredients, whether terrestrial or aquatic, have been recognized as promising alternatives to conventional animal-derived ingredients in aquafeeds. However, many plant-based feedstuffs are low in protein, deficient in essential fatty acids (EFAs) and essential amino acids (EAAs), and contain antinutritional factors (ANFs) that reduce nutrient availability, digestibility, and feed palatability. Microbial fermentation, a cost-effective and biologically driven processing technique, has emerged as a promising solution to enhance the nutritional value of plant-based ingredients while facilitating the utilization of non-conventional resources, thereby reducing reliance on conventional feed sources. Fermentation has been shown to improve nutrient availability and bioavailability, increase palatability and digestibility, and degrade ANFs, ultimately enhancing fish growth and health performance. By integrating fermentation into aquafeed production, sustainable and cost-effective aquaculture can be achieved, ensuring improved feed efficiency and reduced environmental impact.

INTRODUCTION

Aquaculture is one of the fastest-growing food production sectors globally, driven by the increasing demand for fish as a high-quality protein source. The growth of aquaculture goes hand in hand with advancements in the feed industry. Modern aquaculture has shifted from natural-based farming to feed-based farming, even for low-trophic species like carp. As aquaculture practices move toward high stocking density, the demand for formulated feed will continue to rise. However, the heavy reliance on conventional ingredients (fishmeal, Soyabean meal, rice bran, etc) which are also widely used in terrestrial animal farming, has led to competition, price fluctuations, and supply constraints (Giri, 2024). To mitigate this dependency, it is essential to explore alternative ingredients, including both conventional and non-conventional plant-based sources, as viable replacements in aquafeeds.

Conventional agro-industrial byproducts such as soybean meal, rice bran, and wheat bran, along with non-conventional plant ingredients like sweet potato leaves, guar meal, rubber seed, copra meal, etc., offer promising alternatives, but they come with certain limitations. Many plant-based ingredients contain ANFs, which reduce feed palatability, hinder nutrient digestion and absorption, and often exhibit high fiber content, and an unbalanced amino acid profile negatively impacts fish physiology and growth (Aragão *et al.*, 2022). These challenges highlight the need for processing techniques that enhance the nutritional quality and digestibility of plant ingredients for their full inclusion in aquafeed formulation.

Microorganisms have the ability to degrade ANF and complex compounds in a plant-based substrate that release bound nutrients, thereby enhancing nutrient availability. Microbial fermentation has emerged as a cost-effective controllable microbial processing techniques for enhancing the nutritional quality of plant-based ingredients. It has been shown to increase nutrient bioavailability, complete reduction of ANFs, increase EAA, improve digestibility and increase feed overall nutritional content of plant-derived ingredients.

Problem with plant-based ingredient

Agri-industries byproducts, both conventional and non-conventional, along with leaf meal, are nutrient-rich, abundant, widely available, and cheap, making them sustainable alternative to conventional feed ingredients. However, several challenges limit their complete inclusion in aquafeed formulations. Despite having high protein content, many plant proteins have an imbalance EAA like lysine and methionine. Additionally, the presence of ANFs such as such as saponins, tannins, phytate, polyphenolic compounds, enzyme inhibitors, and non-starch polysaccharides can negatively impact feed palatability due to undesirable flavours, reducing feed intake and also hinder nutrient digestion and absorption (Aragão *et al.*, 2022). Furthermore, high fiber content and complex carbohydrates like NSPs can interfere with nutrient absorption and increase gut viscosity, further reducing digestibility (Glencross *et al.*, 2024). Conventional processing techniques, such as heat or chemical treatments used to mitigate ANFs, may degrade essential nutrients, highlighting the need for alternative processing methods to enhance the nutritional quality of plant-based ingredients.

Microbial Fermentation

Fermentation is a biologically driven process in which microorganisms convert complex organic compounds into simpler, more

bioavailable forms. It is a cost-effective method, as it does not require sophisticated instruments, high-cost infrastructure, or extensive operational expenses. Different types of microorganisms involved in the fermentation process *Lactobacillus*, *Bacillus*, *Enterococcus*, *Aspergillus*, *Rhizopus*, *Saccharomyces*, etc, contribute specific biochemical transformations. Through enzymatic activity, fermentation enhances the biochemical composition of the substrate by improving protein quality, increasing essential amino acids and mineral content, and breaking down complex compounds, including certain anti-nutritional factors. This process not only enhances nutrient availability but also contributes to improved digestibility and overall nutritional value of the fermented product (Siddik *et al*., 2024). Additionally, fermentation promotes environmental sustainability by reducing the need for chemical treatments, minimizing waste generation, and supporting the efficient utilization of resources. By applying the fermentation process to plant ingredients, they can be transformed into highly digestible, nutrient-rich sources, making them a sustainable and effective alternative to conventional sources for feed formulation (Dawood and Koshio, 2020).

Types of Fermentation Processes

Fermentation in aquafeed processing can be carried out using different methods, based on the liquid content each offering unique benefits. Dry solid plant materials can be fermented using select microbes with limited moisture that break down crude fiber and antinutritional compounds to generate fermented dry substances in a process called solid state fermentation. Plant materials were submerged in a liquid medium where microbes grow and ferment the substrate in a process called Submerged Fermentation. This method promotes the production of beneficial metabolites such as organic acids, enzymes, and probiotics, improving protein digestibility and overall feed quality (Dawood and Koshio, 2020).

Benefits of Fermentation in Fish Nutrition

Fermentation technology offers multiple benefits when applied to plant-ingredient, significantly improving its nutritional quality, digestibility, palatability and overall impact on fish health. Below are the key advantages:

- **Improved Nutrient Availability:** Fermentation breaks down proteins, complex carbohydrates, fiber, and mineral complex (Phytate, oxalate, etc.) in plant substrate into simpler, more bioavailable forms, enhancing nutrient absorption and feed efficiency. Microbial enzymes (e.g., proteases, amylases, cellulases, etc) facilitate the release of essential nutrients, improving protein digestibility and amino acid balance. Additionally, fermentation increases the bioavailability of micro-nutrient nutrients such as phosphorus, iron, calcium, vitamins, etc. supporting fish growth and metabolism. Complex carbohydrates and fiber serve as a source of energy for microorganisms during the fermentation, leading to a reduced level of these components in the final product, thereby enhancing nutrient digestibility, absorption and availability for fish (Dawood and Koshio, 2020).

- **Reduction of Antinutritional Factors (ANFs):** Many plant ingredients naturally contain ANFs like phytic acid, oxalates, tannins, trypsin inhibitors, etc., which interfere with palatability, digestion and nutrient utilization. Microbial fermentation effectively degrades these compounds, enhancing the nutritional quality of plant-based feeds. It breaks down phytic acid, increasing phosphorus bioavailability; reduces the astringent properties of tannins and saponins that impair palatability and protein utilization; and eliminates enzyme inhibitors,

improving protein digestion and nutrient absorption (Siddik *et al*., 2024).

- **Increase in Essential Nutrients and Bioactive Compounds:** Fermentation enhances the nutritional composition of plant ingredients by increasing essential nutrients and bioactive compounds. It boosts the levels of key amino acids such as lysine and methionine, which are often deficient in plant proteins and also other amino acids. The process also enriches the feed with vitamins (e.g., B12, B2, K, etc.) to support fish metabolism and growth. Additionally, some fermentation processes improve the fatty acid profile by increasing beneficial short-chain fatty acids, contributing to better energy utilization. Bioactive peptides and organic acids produced during fermentation further enhance digestion and overall feed efficiency. It also enhances the protein and mineral contents, further enriching the nutritional profile of plant-based ingredients (Siddik *et al*., 2024).

- **Better Feed Palatability and Utilization:** Fermentation enhances the taste and aroma of plant-based feed, making it more appealing to fish. Many plant ingredients contain compounds such as saponins, tannins, and alkaloids, which impart a bitter or astringent taste, reducing feed intake. Fermentation helps break down these compounds, improving the sensory properties of the feed. Additionally, the breakdown of fiber and starch results in a softer, more digestible feed texture, leading to higher feed intake. This ultimately supports better growth rates and feed utilization efficiency (Glencross *et al*., 2024).

- **Environmental Benefits:** Fermentation promotes sustainable food production by repurposing agri-industrial byproducts and utilizing locally available non-conventional resources, thereby reducing waste and minimizing environmental impact. Enhanced nutrient absorption lowers nitrogen and phosphorus excretion, mitigating water pollution and eutrophication risks. Additionally, reducing dependence on imported ingredients lowers the carbon footprint associated with the transportation, fishing and processing of fish for fishmeal, and promotes the sustainable use of locally available resources, contributing to environmentally responsible feed production in aquaculture.

CONCLUSION

Fermentation technology is a game-changing approach in aquafeed formulation, addressing the limitations of plant-based ingredients by enhancing their nutrient profile, reducing antinutritional factors, and improving digestibility. By using fermentation, plant ingredients that were once considered unsuitable for fish feed are transformed into high-quality, digestible, and nutritionally enhanced feed components. Additionally, microbial biomass contributes to the overall nutritional profile of the fermented plant ingredients. As the aquaculture industry moves towards more sustainable feeding practices, fermented plant-based feeds have the potential to reduce dependence on imported ingredients especially fishmeal and its total replacement for growth out culture without the need for any additives supplementation while ensuring optimal fish growth and health. Continued research and refinement in fermentation technology will further enhance the utilization of plant-based ingredient in aquafeed production.

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