Journal of Agricultural Education Teachers Association of Nigeria
Vol. 10 Number 1, March 2026

PROCESSING METHODS OF REDUCING AND DETOXIFYING OF ANTI-NUTRIENTS IN FEED INGREDIENTS FOR SUSTAINABLE FISH PRODUCTION: A REVIEW

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Abstract
The presence of anti-nutrients such as phytates, tannins, trypsin inhibitors, lectins, and glucosinolates in seeds, particularly legumes and cereals, poses challenges to their nutritional value in food and feed applications. Various processing techniques have been explored to mitigate these compounds. Fermentation, leveraging phytases from yeast or lactic acid bacteria, significantly reduces phytate content, with studies reporting a 17.7% decrease in fermented locust bean seeds. Soaking, boiling, and autoclaving further diminish anti-nutrients, with autoclaving at 105°C for over 60 minutes eliminating 95-100% of trypsin inhibitors in soybeans, though it requires specialized equipment. Boiling effectively reduces tannins and lectins, with Parkia and Mucuna seeds showing substantial declines. Milling removes phytate-rich outer seed layers, while extrusion at high temperatures enhances carbohydrate digestibility by breaking down cell walls. Aqueous treatments, such as soaking Leucaena in water or ferrous sulphate, degrade mimosine, and water extraction removes saponins and glucosinolates. However, excessive heat treatments risk denaturing proteins, reducing amino acid availability, and compromising nutritional quality. Careful regulation of processing conditions is essential to balance anti-nutrient reduction with the preservation of nutritional integrity. Techniques like de-hulling and supplementation with tannin-complexing agents, such as polyethylene glycol, further mitigate anti-nutrient effects. These methods collectively enhance the nutritional value of seeds for human and animal consumption, fish inclusive.

Keywords: Anti-nutrients, feed, ingredients, processing methods, Sustainable Fish Production.

Introduction

The aquaculture industry has shifted towards plant-based feed ingredients to reduce reliance on fishmeal, but anti-nutritional factors (ANFs) such as phytic acid, tannins, and protease inhibitors in these ingredients impair nutrient bioavailability and fish health (Krogdahl *et al.*, 2022; Siddi*k et al.*, 2024). The rapid growth of aquaculture to meet global seafood demand has underscored the need for sustainable fish production practices, particularly in the optimization of feed ingredients. Anti-nutrients, naturally occurring compounds in plant-based feed ingredients, such as phytic acid, tannins, and protease inhibitors, can impair nutrient absorption, reduce feed efficiency, and negatively affect fish health and growth (Francis *et al.*, 2001). These compounds pose a significant challenge in formulating cost-effective and nutritionally balanced feeds, especially as the industry shifts toward plant-based alternatives to replace expensive and unsustainable fishmeal. Effective processing methods to reduce or detoxify anti-nutrients are critical for enhancing the nutritional quality of feed and ensuring the sustainability of aquaculture systems. This introduction explores the importance of processing methods in mitigating the adverse effects of anti-nutrients in feed ingredients for sustainable fish production.

Anti-nutrients in feed ingredients, such as soybeans, cassava, and other plant-based materials, interfere with digestion and nutrient bioavailability, leading to reduced growth rates and feed conversion efficiency in fish. For instance, phytic acid binds essential minerals like phosphorus, rendering them unavailable, while tannins and saponins can disrupt digestive enzyme

activity (Krogdahl *et al.,* 2010). These effects are particularly pronounced in carnivorous fish species, which have limited ability to tolerate high levels of plant-based feeds. As global aquaculture increasingly relies on plant-derived feed to reduce dependency on marine resources, addressing anti-nutrient challenges through processing techniques like soaking, fermentation, heat treatment, and enzymatic supplementation becomes essential. These methods can degrade or inactivate anti-nutrients, improving feed digestibility and supporting fish health (Gatlin *et al.*, 2007).

Processing methods such as heat treatment and fermentation have proven effective in reducing anti-nutrient levels in feed ingredients. Heat processing, including extrusion and cooking, can denature protease inhibitors and lectins, while fermentation leverages microbial activity to break down compounds like phytic acid and tannins (Refstie *et al.*, 2005). For example, fermentation of soybean meal with specific microbial strains can reduce phytic acid content by up to 90%, significantly enhancing phosphorus availability (Baruah *et al.*, 2007). These techniques not only improve the nutritional value of feed but also minimize the environmental impact of aquaculture by reducing nutrient waste in effluents. By optimizing feed quality, processing methods contribute to sustainable production systems that balance economic viability with environmental stewardship.

The adoption of anti-nutrient reduction techniques also supports the economic and ecological sustainability of aquaculture. Unprocessed plant-based feeds often lead to poor feed conversion ratios, increasing production costs and environmental pollution due to undigested nutrients.

Advanced processing methods, such as enzymatic treatments, can target specific anti-nutrients, improving feed efficiency and reducing the ecological footprint of fish farming (Drew *et al.,* 2007). Moreover, these methods enable the use of locally available, cost-effective feed ingredients, reducing reliance on imported fishmeal and promoting regional aquaculture development. By enhancing feed quality and minimizing waste, processing methods align with the principles of sustainable intensification in aquaculture.

Processing Methods

Fermentation

Fermentation has been shown to reduce the phytate content of seeds because of the action of phytases produced by yeast or lactic acid bacteria (Duffus and Duffus, 1991). Abu (2005) reported the reduction in phytate contents of fermented locust bean seed(*Parkia filicoidea*) by 17.7%.

Cooking

Kumar *et al*. (1978) reported that cooking decreased both water and acid extractable phytate phosphorus in legumes. Vidavel and Pungalenthi 22(2007) indicated that cooking and autoclaving substantially reduced the level of phytate in Muncuna seed meal.

Soaking

D'Mello *et al*. (1978) suggested the improvement of the nutritional value of Leucaena by soaking it in ferrous sulphate solution for one week prior to usage in feed formulation. Pascal and Penaflorida (1979) indicated that the nutritive value of Leucena leucocephala leaf meal can be improved if the mimosine present in it is degraded by soaking in water for 36hours. Wee and Wang (1987) also suggested the use of soaking as an

efficient method in removal of mimosine from *Leucaena leucocephala* leaf meal.

Makkar and Becker (1997) indicated that glycosinolates could be extracted with water from full-fat and fat-free *Moringa oleifera* kernels. Based on the high solubility of most saponins in water, aqueous extraction (soaking) have been recommended for removal of saponins provided it does not otherwise affect the nutritional quality of the material (Francis *et al.*, 2001a).

Tamburawa (2010) indicated that soaking locust seed meal for 3days considerably reduced the levels of anti-nutrients particularly tannins and phytates (1.08% in the raw to 0.17%; 0.71% to 0.27% respectively) Fermentation is a widely studied method for reducing ANFs. Siddik *et al.* (2024) found that fermenting soybean meal with *Saccharomyces cerevisiae* decreased phytic acid and trypsin inhibitors by up to 70%, improving nutrient digestibility in tilapia. Similarly, Sharawy *et al.* (2024) reported that lactic acid bacteria fermentation of maize flour reduced tannins and phytates by 84%, enhancing protein absorption and reducing feed costs in shrimp aquaculture. Nisar *et al.* (2022) highlighted biofloc technology, a fermentation-based approach, which recycled nutrients in rice bran, reducing ANFs and increasing profitability by 40% in tilapia-shrimp polyculture systems.

Milling

Due to the concentration of phytate in the outer endosperm of seeds particularly cereals, milling has been employed to remove the outer layers of seeds in order to reduce the phytate content to considerable levels.

Heat treatment

Liener (1980) reported that the extent of trypsin inhibitor destruction

in soyabean by heat is a function of temperature, duration of heating, particle size and moisture content of the ingredients. The report further asserted that even though heat treatment effectively eliminated most of the anti-nutrients, careful control of processing conditions was required to prevent functional and nutritional alteration of the protein resulting as a result of denaturation associated with excessive heat treatment.

Heat treatment (Autoclaving)

Heat treatment (autoclaving) was also found to reduce phytic acid in linseed and sesame meals by up to 72% and 74% respectively (Hossain and Jauncey, 1990). Rumsey *et al.* (1993) identified toasting and de-fatting as processing methods that could be used for removal of antinutrients of some leguminous and cereal ingredients for fish feeds. Bangoula *et al.* (1993) indicated the extrusion at high temperature has the potential to improve the carbohydrate digestibility of legume seeds because of a higher break up of cell walls.

Hydrothermal treatment

Viola (1983) reported that hydrothermal treatment of raw full-fat soyabean cooked for 1hour destroyed 80% of trypsin inhibitor. Autoclaving at 105^{C} for more than 60 minutes was observed to be more effective than the boiling procedure because 95-100% of the trypsin inhibitor was removed. Due to the special apparatus required for autoclaving it is unaffordable to most fish farmers.

Moist heat treatment

Norton (1991) indicated that moist heat treatment (and autoclaving for 15 – 30 minutes) is recommended as means of reducing the amount of trypsin inhibitors (TI) below the critical levels. However (Norton, 1991) indicated that the use of heating process should be carefully regulated to minimize the loss of nutritional

quality of feed material, such as the loss of available amino acids like lysine and decrease in protein degradability due to excess heat denaturation.

Aqueous heat treatment

Grant (1991) indicated that lectins can be removed by aqueous heat treatments by using boiling water at 100□C for 10minutes. Lectin content of Jantropha seed meal has been reduced from 102 to 1.17 heamagglutination units by moist heating at 100C for 10minutes (Aregheore *et al.,* 1998). Heat treatment has been reported to be effective in reduction of glucosinolate contents of rape seed meal from 40 to 26□ mol/g after wet pressure cooking (Burel *et al.*, 2000a).

Boiling

The reduction of tannins to tolerable levels by boiling was earlier reported by previous workers including Dakare (2005) for Parkia seeds. Due to the presence of high levels of tannin in the seed coats of many seeds, the boiling processing technique has been reported to reduce tannin to tolerable levels. Previous workers, Dakare (2005); Vidavel and Pungalenthi (2007); Tamburawa (2010) who worked on parkia seed, mucuna and parkia respectively indicated that a considerable level of tannins and other anti-nutrient contens of seeds evaluated were reduced when subjected to boiling.

De-hulling

Griffiths (1991) recommended the removal of condensed tannins by de-hulling the seed to remove the tannin-rich outer layer. Makkar *et al.* (1995b) and Makkar and Becker (1996) also indicated that treatment of tannin-containing feeds with oxidizing agents and supplementation with a tannin complexing agent, polyethylene glycol could mitigate their negative effect on animals. A reduction in

tannin content of sesame seed meal from 20 to 2410g/kg after fermentation with lactic acid has been observed (Mukhopadhyay and Ray, 1999a).

Enzymatic treatments target specific ANFs effectively. Hundal *et al.* (2021) demonstrated that phytase and xylanase supplementation in tilapia diets increased apparent digestibility coefficients for energy and minerals, reducing nitrogen and phosphorus excretion by 17.51 g kg^{-1} and 10.09 g kg^{-1} of body weight gain, respectively. This minimizes environmental pollution from aquaculture waste. Ferreira *et al.* (2025) noted that enzymatic preprocessing of microalgal biomass (*Tetraselmis* sp.) improved protein digestibility in gilthead seabream, despite high phytic acid levels, supporting sustainable feed formulations.

High-pressure homogenization (HPH) is an emerging eco-friendly technique. Ferreira et al. (2025) applied HPH to tomato peels, enhancing lycopene bioavailability and feed palatability for fish while using water as a processing medium to reduce environmental impact. Hassoun *et al.* (2024) explored HPH and ultrasound-assisted extraction for valorizing seafood by-products, finding that these methods reduced chitin in shrimp waste, improving nutrient availability. However, high energy costs limit scalability (Hassoun *et al., 2*024).

Solid-state fermentation (SSF) with ANF-degrading microbes also shows promise. Mandal and Ghosh (2019) reported that SSF of linseed oil cake reduced phytic acid and tannins, increasing amino acid bioavailability for fish feed. Although published slightly before 2021, its relevance to recent SSF advancements is noted in

Nisar et al. (2022), who emphasized SSF's role in nutrient recycling within biofloc systems, enhancing sustainability.

Conclusion

The importance of processing methods for reducing and detoxifying anti-nutrients in feed ingredients cannot be overstated in the context of sustainable fish production. These techniques address the nutritional limitations of plant-based feeds, improve fish growth and health, and reduce the environmental impact of aquaculture operations. As the industry continues to grow, ongoing research and innovation in processing technologies will be vital to optimize feed formulations and ensure the long-term sustainability of global aquaculture. By integrating effective anti-nutrient reduction strategies, aquaculture can meet the increasing demand for fish protein while maintaining ecological balance and economic feasibility. The reduction of anti-nutritional factors (ANFs) in plant-based feed ingredients is crucial for enhancing nutrient bioavailability and promoting fish health in aquaculture. Various processing methods, including fermentation, enzymatic treatments, and high-pressure homogenization, have shown significant potential in mitigating the adverse effects of ANFs such as phytic acid, tannins, and protease inhibitors. Fermentation, in particular, has emerged as a highly effective technique, with studies demonstrating substantial reductions in ANFs and improvements in nutrient digestibility. This not only benefits fish health but also contributes to the economic viability of aquaculture operations by lowering feed costs and increasing profitability.

Moreover, the integration of innovative techniques like enzymatic

treatments and high-pressure homogenization offers promising avenues for further enhancing feed formulations. These methods not only target specific ANFs but also improve the overall nutritional profile of feed ingredients, thereby minimizing environmental impacts associated with aquaculture waste. As the industry continues to seek sustainable alternatives to fishmeal, the ongoing research and development of these processing methods will play a pivotal role in shaping the future of aquaculture, ensuring that it remains both economically and environmentally sustainable. The collective findings underscore the importance of continued exploration and application of these techniques to optimize feed efficiency and support the growth of a resilient aquaculture sector.

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