



Utilizing Plant-Based Protein Sources from Agricultural By-Products: Addressing Challenges for Aquaculture Sustainability

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Abstract

Aquaculture is the fastest-growing global food production sector and is vital for food and nutritional security. With output reaching approximately 87.5 million tonnes, over 70% of production relies on formulated feeds. Fish meal (FM) has traditionally been the primary protein source due to its amino acid profile, digestibility, and palatability. However, its limited supply from capture fisheries and rising demand have caused price volatility and supply concerns, making sustainable FM alternatives an urgent priority. Plant-based proteins are promising substitutes due to their abundance, lower cost, renewability, and reduced environmental impact. Ingredients such as soybean meal, *Moringa oleifera* leaf and seed meal, canola meal, sunflower meal, and cottonseed meal are already used in commercial aquafeeds. Yet, antinutritional factors (ANFs) including phytate, tannins, saponins, protease inhibitors, and non-starch polysaccharides limit their inclusion by reducing nutrient bioavailability and impairing fish growth and health. Feed additives such as exogenous enzymes, probiotics, prebiotics, antioxidants, organic acids, and functional nanoparticles can mitigate ANF effects, improve digestibility, and enhance fish health, allowing higher plant protein incorporation. Nevertheless, further research is needed on the long-term physiological, economic, and environmental impacts of large-scale FM substitution. Species-specific formulations, life-cycle assessments, and cost-benefit analyses remain critical. Developing eco-efficient, nutritionally complete, and cost-effective aquafeeds is essential for sustainable aquaculture growth and global food security.

Keywords: Aquaculture, plant by-products, replacement, feed formulation, cost effective, environment friendly

