



Sustainable Fish Feeds: The Shift Towards Plant-Based and Insect-Based Feed

P. Gowri

Assistant Professor
Department of Zoology,
Government Degree College, Bhupalpally (TG)

Abstract

Aquaculture is one of the fastest-growing food-producing sectors and contributes significantly to food security, employment and rural livelihoods. However, increasing feed demand has raised concerns about the sustainability, cost and environmental impact of conventional fishmeal and fish oil, despite their high-quality protein and essential fatty acids. This review examines sustainable alternative feed ingredients, with particular emphasis on Indian aquaculture, based on information available up to March 2022. Plant ingredients such as soybean meal, rice bran, groundnut cake and mustard oil cake are widely available and economical, but require processing to overcome anti-nutritional factors and amino-acid limitations. Insect meals, especially black soldier fly (*Hermetia illucens*) larvae, offer promising protein sources through efficient conversion of organic residues into biomass. Microalgae provide protein, pigments and beneficial fatty acids, while microbial proteins are emerging alternatives. A combination of these ingredients, with suitable supplementation, can support sustainable and economical aquaculture feeds.

Keywords: Aquaculture, sustainable feed, fishmeal, fish oil, plant protein, insect meal, black soldier fly, microalgae, India.

Introduction

Aquaculture is no longer simply an alternative to capture fisheries it has become a major source of aquatic food for a growing world population. Along with contributing to food and nutritional security, aquaculture supports employment, income generation and rural livelihoods, particularly in developing countries. According to FAO, global aquaculture production of aquatic animals reached approximately **82.1 million tonnes in 2018**, with Asia contributing the largest share of global production. Behind this impressive growth lies a critical challenge is fish feed. Feed represents a major cost in intensive aquaculture, and its ingredients directly influence fish growth, production efficiency and environmental sustainability.

For decades, **fishmeal and fish oil** have been valuable components of aqua feeds because they provide highly digestible protein, essential amino acids and long-chain omega-3 fatty acids, particularly EPA and DHA. However, their dependence on marine resources, together with increasing demand, price fluctuations and environmental concerns, has strengthened the need to identify sustainable alternatives.

This challenge is particularly relevant to **Indian aquaculture**, where freshwater fish farming provides important livelihood opportunities for farmers. Species such as rohu (*Labeo rohita*), catla (*Catla catla*) and mrigal (*Cirrhinus mrigala*) are extensively cultured

and can utilize properly formulated diets containing alternative protein sources.

This has opened the door to a new generation of aquafeed ingredients. **Plant proteins, insect meals, microalgae and single-cell proteins** are receiving increasing attention as potential alternatives to conventional marine-derived ingredients. Importantly, some of these resources can also transform agricultural by-products and suitable organic residues into valuable nutrients. As a result, research has increasingly focused on plant-based ingredients, insect meals, microalgae and single-cell proteins. These alternatives may reduce dependence on marine resources while making greater use of agricultural and organic residues.

The present review therefore examines the potential, nutritional value, benefits and limitations of major alternative feed ingredients, with particular emphasis on their relevance and application in **Indian aquaculture**.

Methods of Study

The present study was conducted as a **review of published scientific literature** on sustainable aquaculture feeds.

Information was collected from:

- FAO publications;
- ICAR publications and institutional resources;
- peer-reviewed research articles;
- scientific review papers; and
- studies concerning plant, insect, algal and microbial feed ingredients.

To maintain consistency with the academic year **2021–22**, the review was restricted to information available **up to 31 March 2022**. The literature was compared with respect to nutritional value, growth performance, feed utilization, economic feasibility and environmental potential.

Plant-Based Feed Ingredients

Plant ingredients are among the most widely investigated alternatives to fishmeal. Important sources include soybean meal, rice bran, maize products, groundnut cake and mustard oil cake.

Soybean meal is particularly useful because of its high protein content and availability. Rice bran and oil cakes are also attractive for Indian aquaculture because they are readily available agricultural by-products.

However, plant ingredients are not nutritionally identical to fishmeal. Some contain anti-nutritional factors such as phytate, tannins and protease inhibitors. They may also be deficient in certain essential amino acids. Therefore, processing, supplementation and proper combination of different plant ingredients are necessary.

ICAR-CIFA has investigated plant-based and farm made feeds for freshwater fish, demonstrating the importance of locally available ingredients in Indian aquaculture. Studies on Indian major carps have also examined the replacement of fishmeal with plant-derived ingredients.

Thus, plant-based feeds can reduce dependence on fishmeal, but complete replacement is not necessarily suitable for every fish species and life stage.

Insect-Based Feed

Insect protein is an emerging alternative to conventional aquafeed ingredients. Several insects, including black soldier fly larvae, mealworms, crickets and silkworm pupae, have been investigated.

Among these, the **black soldier fly (BSF), *Hermetia illucens***, has received considerable attention. BSF larvae contain substantial protein and lipids and can convert suitable organic substrates into insect biomass. This creates a potentially valuable circular system:

Organic residues → Black soldier fly larvae → Insect meal → Fish feed → Fish production

Research available by 2021 showed that moderate inclusion of insect meal could support fish growth without major negative effects. However, high inclusion levels could reduce growth performance depending on the insect species, fish species and diet formulation. A 2021 meta-analysis reported that high levels of black soldier fly meal could negatively affect growth, demonstrating that insect meal is better considered as a **partial replacement** rather than an automatic complete replacement for fishmeal. ([sciencedirect.com](https://www.sciencedirect.com))

India had already begun investigating this technology. In January 2021, ICAR-CIBA initiated a collaboration related to the production of black soldier fly meal as a sustainable fishmeal alternative, including investigation of suitable kitchen-waste substrates. (icar.gov.in)

Microalgae as Feed Ingredients

Microalgae such as *Spirulina*, *Chlorella* and *Nannochloropsis* are also being investigated as sustainable aquafeed ingredients.

Microalgae can supply protein, vitamins, pigments, minerals and polyunsaturated fatty acids. Their potential to provide beneficial fatty acids is particularly important because replacement of fish oil with conventional vegetable oils can alter the fatty-acid composition of farmed fish.

Research published before 2022 indicated that *Spirulina* and *Chlorella* could be useful nutritional ingredients in fish diets, although production cost, digestibility and large-scale cultivation remained important challenges. ([sciencedirect.com](https://www.sciencedirect.com))

Ingredient	Main advantage	Major limitation
Soybean meal	High protein and widely available	Anti-nutritional factors
Rice bran	Cheap and locally available	Variable nutrient composition
Groundnut/mustard cake	Locally available protein	Requires proper processing
BSF meal	Protein and waste-conversion potential	High inclusion may reduce growth
Microalgae	Protein and beneficial fatty acids	Production cost
Single-cell protein	Rapid microbial production	Technology and processing requirements

Nutritional Performance

Plant ingredients can support good growth in many freshwater species when diets are carefully balanced. However, their amino-acid composition and digestibility need to be considered.

Insect meals have shown promising results at moderate inclusion levels. The 2021 meta-analysis demonstrated that insect meals could replace a proportion of fishmeal without necessarily reducing growth, but high inclusion levels could have negative effects. ([sciencedirect.com](https://www.sciencedirect.com))

Microalgae offer an additional advantage because they can provide nutrients not always available in terrestrial

Single-Cell Protein

Single-cell protein refers to protein-rich biomass produced by microorganisms such as bacteria, yeast, fungi and algae.

Microorganisms can grow rapidly and potentially utilize renewable or waste-derived substrates. Consequently, single-cell protein has attracted attention as a possible alternative to fishmeal and soybean meal.

However, during 2021–22, this technology was still at a relatively early stage compared with conventional plant-based ingredients. High production costs, processing requirements and the need for specialized infrastructure limited widespread application.

Results and Discussion

The literature review indicates that alternative aquafeed ingredients have considerable potential, but each has specific advantages and limitations.

plant ingredients, including certain polyunsaturated fatty acids.

Environmental Benefits

Alternative feed ingredients can reduce dependence on wild fish resources used for fishmeal and fish oil.

Plant ingredients can make greater use of agricultural resources, while insects can potentially convert suitable organic residues into protein. Microalgae may be cultivated without requiring conventional agricultural land in the same way as terrestrial crops. However, the environmental sustainability of each ingredient must be evaluated throughout its production process. Energy consumption, water use, transportation, processing and waste generation must also be considered.

Relevance to India

India has considerable potential for developing sustainable aquafeeds because of its agricultural diversity and large quantities of agricultural by-products.

Ingredients such as soybean meal, rice bran and oil cakes can be obtained through existing agricultural supply chains. Insect farming could potentially connect organic-waste management with feed production.

The ICAR-CIBA initiative on black soldier fly meal in 2021 demonstrated that India had begun exploring the integration of insect production and aquaculture feed development. (icar.gov.in)

However, commercial adoption requires further research on production cost, feed safety, standardization, farmer acceptance and long-term fish performance.

Challenges and Future Prospects

Several challenges need to be addressed before alternative feed ingredients can be adopted widely.

First, the nutritional composition of plant and insect ingredients can vary considerably. Standardization and quality control are therefore essential.

Second, alternative feeds must be economically competitive. A technically successful feed may not be adopted if its cost is significantly higher than conventional feed.

Third, more long-term research is required to examine fish health, disease resistance, reproductive performance, flesh quality and consumer acceptance. Finally, appropriate safety standards are required, particularly for insect-based feeds produced using organic waste.

Future aqua feeds are therefore likely to use a **combination of ingredients** rather than relying on one replacement source. A possible formulation strategy is:

Plant proteins + moderate insect meal + microalgae + amino acids + vitamins and minerals

Such combinations could provide balanced nutrition while reducing dependence on fishmeal and fish oil.

Conclusion

The sustainability of modern aquaculture depends not only on how fish are cultured but also on what they are fed. Fishmeal and fish oil remain nutritionally valuable, but their dependence on marine resources creates economic and environmental concerns.

The literature available up to 2021–22 shows that plant-based ingredients are among the most practical alternatives, particularly for Indian freshwater aquaculture. Soybean meal, rice bran and oil cakes can provide affordable sources of nutrients when properly processed and formulated.

Insect meals, especially black soldier fly larvae meal, represent an innovative approach that combines protein production with the potential utilization of suitable organic residues. However, evidence available by 2021 indicated that moderate inclusion was generally more appropriate than complete replacement.

Microalgae and single-cell proteins provide additional opportunities, particularly for improving the nutritional diversity of aqua feeds.

Therefore, the future of sustainable aquaculture feed is unlikely to depend on a single “replacement” ingredient. Instead, it will depend on **combining locally available plant resources with emerging insect, algal and microbial technologies**.

For India, this approach could reduce dependence on marine resources, utilize agricultural and organic residues, reduce feed costs and contribute to environmentally responsible aquaculture.

Sustainable feed is therefore not simply a replacement for fish meal, it is a transition towards a more diversified, circular and resource-efficient aquaculture system.

References

1. FAO. 2020. *The State of World Fisheries and Aquaculture 2020: Sustainability in Action*. Food and Agriculture Organization of the United Nations, Rome.
2. FAO. 2022. *The State of World Fisheries and Aquaculture 2022: Towards Blue Transformation*. Food and Agriculture Organization of the United Nations, Rome. (Use only for information/data available by the 2021–22 academic period.)
3. Pantelopoulou, A., et al. 2021. A meta-analysis of the effects of replacing fish meal with insect meals on growth performance of fish. *Aquaculture*, 530, 735732.
4. Nogales-Mérida, S., Gobbi, P., Józefiak, D., Mazurkiewicz, J., Dudek, K., Rawski, M., Kierończyk, B. & Józefiak, A. 2019. Insect meals in fish nutrition. *Reviews in Aquaculture*, 11, 1080–1103.
5. Papuc, T., Boaru, A., Ladosi, D., Struti, D. & Georgescu, B. 2020. Potential of black soldier fly (*Hermetia illucens*) as alternative protein source in salmonid feeds – A review. *Indian Journal of Fisheries*, 67(4).
6. Alagawany, M., Taha, A.E., Noreldin, A., El-Tarabily, K.A. & Abd El-Hack, M.E. 2021. Nutritional applications of species of *Spirulina* and *Chlorella* in farmed fish: A review. *Aquaculture*, 542, 736841.
7. Nagappan, S., Das, P., AbdulQuadir, M., et al. 2021. Potential of microalgae as a sustainable feed ingredient for aquaculture. *Journal of Biotechnology*, 341.
8. Gatlin, D.M. III, Barrows, F.T., Brown, P., et al. 2007. Expanding the utilization of sustainable plant products in aquafeeds: A review. *Aquaculture Research*, 38, 551–579.
9. Tacon, A.G.J. & Metian, M. 2008. Global overview on the use of fish meal and fish oil in industrially compounded aquafeeds: Trends and future prospects. *Aquaculture*, 285, 146–158.
10. ICAR. 2019. Black soldier fly – a promising protein supplement in aquacultural feed. *ICAR News*, July–September 2019.
11. ICAR-CIBA. 2021. New Start-Up initiative for producing Black Soldier Fly Meal as an effective and sustainable fishmeal replacement source. Indian Council of Agricultural Research, January 2021.
12. ICAR-CIFA. Fish Nutrition and Physiology research programme. Indian Council of Agricultural Research – Central Institute of Freshwater Aquaculture.

Access this Article in Online



Website:

www.ijarbs.com

Subject:

Aquaculture

Quick Response Code

DOI: [10.22192/ijarbs.2021.08.09.013](https://doi.org/10.22192/ijarbs.2021.08.09.013)

How to cite this article:

P. Gowri. (2021). Sustainable Fish Feeds: The Shift Towards Plant-Based and Insect-Based Feed. *Int. J. Adv. Res. Biol. Sci.* 8(9): 107-111.

DOI: <http://dx.doi.org/10.22192/ijarbs.2021.08.09.013>