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Copepods in Aquaculture: Nutritional Drivers of Sustainable and Next-Generation Feed Development

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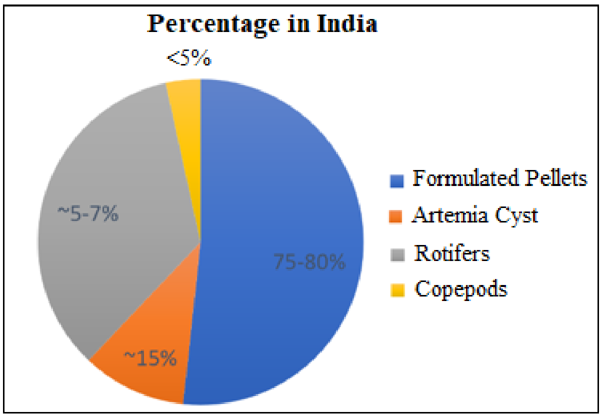
Abstract: ***Aquaculture has emerged as the fastest-growing food sector globally, surpassing capture fisheries in 2022, and is increasingly vital for food security. Yet, sustainability challenges persist due to reliance on fishmeal, synthetic additives, and nutritionally limited live feeds such as Artemia and rotifers. Copepods, the most abundant marine zooplankton, are increasingly recognized as next-generation live feed owing to their superior biochemical composition, including high levels of docosahexaenoic acid (DHA), eicosapentaenoic acid (EPA), balanced amino acids, carotenoids, and bioactive compounds. Their natural role as prey for fish larvae ensures ecological relevance and nutritional adequacy, driving enhanced larval survival, pigmentation, immunity, and stress resilience. Comparative evidence consistently demonstrates that copepods outperform conventional feeds, often without the need for enrichment. Advances in mass culture techniques, microalgal integration, and biotechnological innovations are steadily transforming copepod production from experimental practice to scalable application. Beyond aquaculture, copepod-derived bioactives hold translational potential for nutraceutical and therapeutic industries, reinforcing their role in the circular bioeconomy. However, commercialisation bottlenecks persist, particularly in India, where copepod culture remains at the research stage. The ornamental fish industry, valued at over USD 15 billion, further underscores the indispensability of nutritionally rich live feeds.***

Keywords: Copepods, Live Feed, Sustainable Feed, Aquaculture, Larval development

1. Introduction

Aquaculture has emerged as one of the fastest-growing food production sectors worldwide, surpassing capture fisheries and playing a pivotal role in global food security. Yet, its sustainability is constrained by dependence on conventional live feeds such as Artemia and rotifers, which often fail to meet the complete nutritional requirements of marine fish larvae. Copepods, the most abundant zooplankton in marine ecosystems, have gained increasing attention as a promising alternative due to their superior biochemical composition, including high levels of highly unsaturated fatty acids (HUFA: DHA and EPA), balanced amino acids, carotenoids, and bioactive compounds. Their natural role as prey for fish larvae underscores both ecological relevance and nutritional adequacy, making them ideal candidates for hatchery applications (Marcus, 2005). Recent advances in copepod mass culture techniques and biotechnological innovations further strengthen their potential integration into sustainable aquaculture practices. This review critically evaluates the nutritional drivers of copepods, their role in larval development and immune modulation, and their prospects in next-generation feed development, positioning them as a cornerstone in the transition toward resilient and eco-friendly aquaculture systems.

In India, aquaculture feed use is dominated by formulated pellets, which account for approximately 75–80% of total consumption, particularly in shrimp and finfish grow-out systems. Live feeds collectively contribute 20–25%, but their role is concentrated in hatcheries and larval rearing where nutritional adequacy is critical. Among live feeds, Artemia cysts contribute ~15% and remain the most widely used, though India depends heavily on imports. Rotifers represent 5–7%, valued for ease of culture but nutritionally limited without enrichment. Copepods, despite their superior biochemical profile, currently account for less than 5% due to commercialization bottlenecks and high production costs. This distribution highlights both the dominance of formulated feeds and the indispensable role of live feeds in early larval development.



This review synthesizes literature published between 2010 and 2025, highlighting copepods' nutritional and functional advantages over conventional feeds. Copepods are naturally rich in HUFA (EPA, DHA), carotenoids such as astaxanthin, and vitamins, which collectively enhance larval growth, pigmentation, immunity, and survival. Their ideal size, motility, and digestibility stimulate feeding behaviour and efficient nutrient assimilation. Comparative evidence consistently shows that copepods outperform rotifers and Artemia in survival rates and pigmentation outcomes, with enrichment often optional rather than essential.

Challenges with traditional feeds

- **Nutritional inconsistency:** Fishmeal often show batch-to-batch variation in protein, HUFA, and micronutrient content
- **Overreliance on fishmeal:** Fishmeal is sourced from wild-caught fish, contributing to overfishing and ecosystem stress. Prices fluctuate due to climate events and declining marine stocks.
- **Digestibility and ingestion:** Formulated feeds are often poorly digested by larvae due to underdeveloped gut enzymes.
- **Environmental impact:** Uneaten feed and faecal waste contribute to eutrophication and water quality degradation. Fishmeal production has a high carbon footprint and contributes to marine biodiversity loss.
- **Cost and scalability:** High-quality fishmeal and enrichment products are expensive. Live feed culture (especially enriched Artemia) is labour-intensive and difficult to scale in small hatcheries.
- **Limited functional benefits:** Traditional feeds may lack natural antioxidants, immunostimulants, and pigments, affecting larval stress tolerance and market traits like colouration

Despite these benefits, bottlenecks such as limited commercialization, irregular supply, reliance on skilled labour, and high production costs hinder widespread adoption. Policy support through initiatives like PMMSY aims to strengthen domestic live feed production and reduce dependence on imported Artemia. Integrating copepod culture with microalgal enrichment further enhances nutritional quality. Beyond aquaculture, copepod-derived bioactives hold translational potential for nutraceutical and therapeutic applications, positioning them as pivotal contributors to sustainable aquaculture, food security, and bioeconomy innovation.

2. Objectives

- To evaluate nutritional profile and compare copepods with other traditional live feeds.
- To analyse survey findings of copepods and other live feeds in Indian aquaculture.
- Identify commercialization bottlenecks including supply gaps, labour dependence, and production costs.
- Propose sustainable strategies for next-generation feed development integrating copepods into resilient aquaculture systems

3. Methods

The literature review includes articles published between 2010 and 2025, retrieved from ScienceDirect, PubMed, FAO, CMFRI and the Department of Fisheries. Selection criteria included peer-reviewed studies on copepod nutrition, enrichment approaches, larval performance outcomes and commercial-scale production. Comparative evidence against rotifers and artemia was drawn from experimental trials, while policy documents such as PMMSY guidelines were referred to contextualise Indian practices.

4. Results and Discussion

The copepod culture sector offers superior nutritional and functional advantages. They are rich in Highly Unsaturated Fatty Acids (EPA and DHA), carotenoids (astaxanthin) and vitamins, which make them particularly valuable in aquaculture. Their ideal size, natural motility and high digestibility promote efficient nutrient assimilation and stimulate optimal feeding behaviour in larvae.

Nutritional profile of copepods

Copepods possess a unique and highly favorable nutritional composition that distinguishes them from conventional live feeds such as Artemia and rotifers. Their lipid fraction is particularly rich in long-chain polyunsaturated fatty acids (pufas), including docosahexaenoic acid (DHA) and eicosapentaenoic acid (EPA), which are essential for neural development, membrane fluidity, and stress resilience in fish larvae. Unlike Artemia, which often requires enrichment to achieve adequate HUFA levels, copepods naturally provide these compounds in bioavailable forms, thereby reducing the need for costly supplementation. In addition to lipids, copepods contain a balanced amino acid profile that supports protein synthesis and somatic growth, with notable levels of lysine, methionine, and arginine that are often limiting in other live feeds. Their nutritional superiority extends to pigments and micronutrients; copepods are abundant in carotenoids such as astaxanthin and canthaxanthin, which enhance pigmentation, act as antioxidants, and contribute to immune modulation. Trace minerals and vitamins further complement their biochemical profile, ensuring comprehensive nutritional support during critical larval stages (Fernández-Díaz and Yúfera 1997; Cahu and Zambonino-Infante 2001). Beyond classical nutrients, copepods also harbor bioactive compounds, including antimicrobial peptides and immunostimulants, which have been shown to improve disease resistance and gut health. Collectively, this multifaceted nutritional portfolio positions copepods not only as a natural prey item but also as a functional feed source capable of driving enhanced survival, growth, and overall performance in aquaculture species.

Role in larval development and health

The inclusion of copepods in aquaculture diets has demonstrated profound impacts on larval development, survival, and overall health, positioning them as a superior alternative to conventional live feeds. Their naturally high levels of DHA and EPA contribute to enhanced neural development, visual acuity, and membrane stability, which are critical during the early ontogenetic stages of marine fish. Larvae fed copepods consistently exhibit higher growth rates, improved metamorphosis success, and reduced deformities compared to those reared on Artemia or rotifers. Beyond growth performance, copepods play a pivotal role in gut maturation by stimulating digestive enzyme activity and supporting the establishment of a diverse and functional microbiota, thereby improving nutrient assimilation and resilience against opportunistic pathogens. Immunologically, copepod-derived bioactive compounds, including carotenoids and antimicrobial peptides, have been shown to modulate innate immune responses, enhance phagocytic activity, and increase resistance to bacterial and viral infections. These benefits extend to stress tolerance, with copepod-fed larvae

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displaying greater resilience under suboptimal environmental conditions such as temperature fluctuations and salinity stress. Case studies in species such as groupers (*Epinephelus spp.*), European seabass (*Dicentrarchus labrax*) and ornamental fish have consistently reported superior larval performance when copepods are incorporated into hatchery protocols (Gatten et al. 1983; Watanabe et al. 1983; Witt et al.1984; Sargent and Henderson 1986; Fraser and Sargent 1989; Klungsøyr et al. 1989; Olsen et al.1991; Van der Meeren et al. 1993; Norsker and Støttrup 1994; Evjemo and Olsen 1997; Evjemo et al.2003; Morehead et al. 2005). Collectively, these findings underscore the multifaceted role of copepods not only as a nutritional resource but also as a functional feed that supports robust larval development, immune competence, and long-term aquaculture productivity.

Advances in copepod mass culture

The successful integration of copepods into aquaculture systems depends largely on the development of reliable and scalable mass culture techniques. Traditional extensive methods, which rely on open ponds or natural seawater systems, have provided valuable insights but are often constrained by environmental variability, predation, and inconsistent yields. Semi-intensive and intensive culture systems have therefore emerged as more controlled approaches, enabling higher productivity and improved nutritional consistency. Recent innovations in copepod culture focus on optimizing microalgal diets, as the quality and diversity of algal feed directly influence copepod growth, reproduction, and biochemical composition. Controlled photoperiods and temperature regimes have been applied to stabilize reproductive cycles, while automated harvesting systems reduce labour costs and minimize stress-induced mortality. Advances in biotechnology have further expanded possibilities: selective breeding programs aim to enhance copepod fecundity and resilience, while probiotic supplementation has been explored to improve gut health and reduce disease outbreaks in culture systems. Encapsulation techniques and cryopreservation protocols are being developed to extend the shelf life of copepod biomass, facilitating their use in formulated feeds. Moreover, Integrated Multi-Trophic Aquaculture (IMTA) frameworks have demonstrated the potential of coupling copepod production with other trophic levels, thereby reducing waste and enhancing system sustainability (Patil, M. R., & Kamble, A, 2025). Despite these advances, challenges remain in scaling production to meet commercial hatchery demands, particularly in balancing high-density culture with nutritional quality and minimizing cannibalism. Nevertheless, the convergence of ecological engineering, automation, and biotechnological innovation is steadily transforming copepod mass culture from experimental practice into a viable cornerstone of next-generation aquaculture feed systems.

Sustainable and next-generation feed development

The incorporation of copepods into aquaculture feed strategies represents a pivotal step toward achieving sustainability and advancing next-generation nutrition. Unlike conventional live feeds such as Artemia, which are often harvested from wild populations and subject to ecological and supply chain constraints, copepods can be cultured locally, reducing dependency on imports and minimizing environmental footprints. Their superior nutritional profile- rich in essential fatty acids, amino acids, carotenoids, and bioactive compounds—makes them ideal candidates for functional feed formulations that go beyond basic nutrition to actively enhance larval resilience, immunity, and stress tolerance. Recent developments have explored the processing of copepods into freeze-dried powders, encapsulated products, and cryopreserved biomass, enabling their integration into formulated diets and extending their shelf life for hatchery use. Hybrid feed strategies are also gaining traction, where copepods are combined with microalgae, insect meal, or plant-based proteins to create balanced diets that align with circular bioeconomy principles. Such approaches not only diversify nutrient sources but also valorize waste streams, contributing to resource efficiency and ecological sustainability. Furthermore, copepods are increasingly viewed as vehicles for delivering bioactive compounds, probiotics, and immunostimulants, positioning them as functional feed ingredients capable of mitigating disease outbreaks and improving larval robustness under climate stressors. The convergence of copepod-based feeds with precision aquaculture technologies, including AI-driven feed optimization and omics-guided nutritional profiling, underscores their role in shaping the future of aquaculture nutrition (Verma, A. 2025). By bridging nutritional adequacy with ecological responsibility, copepods stand at the forefront of next-generation feed development, offering a pathway toward resilient, cost-effective, and environmentally sustainable aquaculture systems.

Ecological and economic considerations

The adoption of copepods as a primary feed source in aquaculture carries significant ecological and economic implications that reinforce their potential as sustainable alternatives to conventional live feeds. From an ecological perspective, copepod culture reduces reliance on wild-caught Artemia cysts, which are often harvested from fragile saline ecosystems, thereby alleviating pressure on natural habitats and promoting biodiversity conservation. Localized copepod production also minimizes the carbon footprint associated with international feed trade, aligning aquaculture practices with global sustainability goals. Furthermore, copepods can be integrated into circular bioeconomy frameworks, where their culture is coupled with microalgal production or waste valorization systems, enhancing resource efficiency and reducing nutrient discharge into aquatic environments. Economically, while initial investments in copepod mass culture infrastructure may be higher compared to traditional hatchery feeds, long-term benefits include reduced dependency on imports, improved larval survival rates, and decreased costs associated with disease management and feed enrichment. Studies have shown that copepod-fed larvae often exhibit higher growth performance and lower mortality, translating into greater production efficiency and profitability for hatcheries. However, challenges remain in scaling copepod production to commercial levels, particularly in balancing high-density culture with consistent nutritional quality and managing operational costs (Vakati et al., 2023). Policy support, technological innovation, and market incentives will be critical in overcoming these barriers and ensuring that copepod-based feeds are economically viable and ecologically responsible. Ultimately, the integration of copepods into aquaculture systems represents not only a nutritional advancement but also a strategic step toward reducing environmental impacts and enhancing the economic resilience of global aquaculture industries.

The major bottlenecks faced include limited commercialisation, irregular supply, reliance on skilled labour and high production costs. Although successful industrial models such as CFEED in Norway demonstrate that large-scale production is feasible. In India, policy support through initiatives like PMMSY (Pradhan Mantri Matsya Sampada Yojana) aims to reduce dependence on imported artemia and strengthen live feed production. Demand from the ornamental fish sector, where nutrition directly influences market value. Integrating copepod culture with microalgae enrichment has also been shown to enhances nutritional quality.

Table 1: Comparative evidence: Artemia vs Rotifers vs Copepods

Characteristics	Artemia	Rotifer	Copepods
Size Fit	Larger	Moderate	Broad Range
Motility	Moderate Swiming	Motile Corona	Zig-Zag Response
Nutrition	Variable HUFA	HUFA Low	Naturally High HUFA, Carotenoids, Vitamins
Enrichment	Essential	Essential, Rapid Degradation	Optional
Culture Ease	Easy Cyst Hatching	Very Easy, High Density	Complex, Density Limits
Overcomes	Variable Pigmentation	Variable Survival	Higher Survival and Colouration

5. Conclusion

Aquaculture plays a vital role in future food security, but is challenged by sustainable feed innovation, robust disease control and climate adaptation. Copepods represent the cornerstone of next-generation aquafeed development. When compared to conventional feeds, copepod provides larval growth, pigmentation, immunity and survival, showing nutritional completeness, biodegradability and ecological relevance. Thus, it will reduce dependence on fishmeal and artemia imports. Beyond aquaculture, copepod bioactives hold translational potential for nutraceutical and therapeutic applications, positioning them as major contributors to food security and bioeconomy innovation.

6. Future Scope

The use of copepods in commercial settings is rare. Thus, conscious efforts need to be made to upscale the copepod culture to commercial levels to ensure production of are liable, continuous supply of copepods on a large scale.

1) Although harpacticoid copepods are relatively easy to culture at high densities, their use in marine fish larviculture has been limited, mainly because of their benthic nature, which thus limits their access to foraging fish larvae unlikethe entirely pelagic calanoid copepods. In order to bridge the widened gap, future research is needed on the practicality, reliability and cost-effectiveness of using harpacticoid copepods for commercial fish larviculture.
2) Cyclopoids, e.g. Apocyclops sp. and Oithona sp., have been used in only a few studies (Støttrup2003), mainly because some species have been observed to prey directly on fish larvae while some are unable to be digested by the larvae. However, more research is needed to investigate the potential of other cyclopoid species that could be used successfully as live feed for marine aquaculture.
3) Without any iota of doubt, marine copepods are a potential source of live feed for marine fish larviculture. On the other hand, the technology to culture marine copepods economically and high density is still in the research stage. Intensive research is therefore needed in copepod culture engineering to enhance the appropriate culture techniques that will promote the practicality and cost-effectiveness of using marine copepods in the aquaculture industry.
4) Future research is needed to identify an optimal feeding practice that would maximise productivity for any copepod species of aquaculture interest.

References

[1] Department of Fisheries, Government of India. (2020). *Pradhan Mantri Matsya Sampada Yojana (PMMSY) – Guidelines*. Https://pmmsy.dof.gov.in
[2] FAO. (2020). *The State of World Fisheries and Aquaculture 2020: Sustainability in Action*. Https://doi.org/10.4060/ca9229en
[3] CMFRI. (2021). *Annual Report 2020–21*. Central Marine Fisheries Research Institute. Https://www.cmfri.org.in
[4] NBFGR. (2020). *Indigenous Ornamental Fish Diversity of India*. National Bureau of Fish Genetic Resources.
[5] Taw, A., Gunasekaran, G., & Pavithra, K. (2024). *Impact of Mesocyclops aspericornis Enriched with Microalgae Diet on Ornamental Fish*.
[6] Philip, T.R., Duraivel, P.K., Kareem, A., Radha, V. (2025). *Merits of Apocyclops dengizicus as Sustainable Live Feed*. Biotech, 15(10):565. Doi:10.1007/s13205-025-04565-2
[7] Pan, Y.J., Dahms, H.U., Hwang, J.S., Souissi, S. (2022). *Recent Trends in Live Feeds for Marine Larviculture: A Mini Review*. Front Mar Sci, 9:864165. Doi:10.3389/fmars.2022.864165
[8] Kassim Z, John A, Keng L, Farahiyah N, Hidayah N. Sustainable Technique for Selected Live Feed Culture [Internet]. Sustainable Aquaculture Techniques. InTech; 2014. https://doi.org/10.5772/57212
[9] Girijavallabhan, K G and Gopinathan, C P and Varghese, Molly and Prema, D (2000) *Culture of live feed organisms.* In: Marine Fisheries Research and Management. CMFRI; Kochi, Kochi, pp. 688-703.
[10] Pan Y-J, Dahms H-U, Hwang J-S and Souissi S (2022) Recent Trends in Live Feeds for Marine Larviculture: A Mini Review. Front. Mar. Sci. 9:864165. doi: 10.3389/fmars.2022.864165