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ENHANCEMENT OF CLADOCERA NUTRITION AS LIVE FOOD FOR AQUACULTURE BY UTILISING ESSENTIAL NUTRIENTS FROM VALUABLE PLANT BY-PRODUCT RESOURCES: A REVIEW

FAISAL OTHMAN[1], NABILAH ABDUL HADI[2], HON JUNG LIEW[3] AND NADIAH W. RASDI[1]*

[1]Plankton Responses and Innovation Development Research Interest Group, Faculty of Fisheries and Aquaculture Sciences, Universiti Malaysia Terengganu, 21030 Kuala Nerus, Terengganu, Malaysia. [2]Faculty of Food Science and Agrotechnology, Universiti Malaysia Terengganu, 21030, Kuala Terengganu, Terengganu, Malaysia. [3]Higher Institution Centre of Excellence, Institute of Tropical Aquaculture and Fisheries, Universiti Malaysia Terengganu, 21030 Kuala Nerus, Terengganu, Malaysia.

**Corresponding author: nadiah.rasdi@umt.edu.my*

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ABSTRACT

Aquaculture's rapid growth, driven by rising global demand for fish as a protein source, necessitates the development of sustainable feeding strategies. Zooplankton, particularly cladocerans such as *Moina* and *Daphnia*, serve as essential food sources for larval fish and crustaceans. Accordingly, this review critically examines the potential of Cladocera as live feed and explores methods to enhance their nutritional value and improve larval performance. A comprehensive analysis of existing research was conducted, focusing on cladoceran feeding strategies, larval growth, and enrichment techniques. This includes the use of agro-industrial fruit wastes such as banana and orange peels, natural oil emulsions like garlic oil and coconut oil (CO), and yeast. The findings reveal that this enrichment enhances the protein, lipid, and fatty acid profiles of cladocerans, resulting in improved growth and survival of larval fish. As such, cladocerans are recommended as a superior live feed due to their optimal size, motility, and nutrient content, which can be further enhanced through targeted enrichment. In addition, the review emphasises that the implementation of cladoceran enrichment procedures provides a viable option. Still, challenges remain in standardising enrichment protocols and scaling up production for commercial applications. Therefore, further research and collaboration among researchers, industry stakeholders, and policymakers are essential to integrate Cladocera enrichment into sustainable aquaculture systems.

Introduction

The volumes of worldwide aquaculture output are rising, driven by the sector's development in Asia (Van Riel *et al*., 2023). In 2020, global production of aquatic animals was approximately 178 million tonnes, with the total production predicted to reach 202 million tonnes by 2030 (Fantatto *et al*., 2024). However, accomplishing this necessitates a balanced strategy, integrating species from diverse trophic levels and enhancing aquaculture systems utilising accessible by-products. These solutions can diminish dependence on food-competing feed components and foster more sustainable aquaculture operations (Van Riel *et al*., 2023). In essence, zooplankton play a vital role in aquaculture by providing essential nutrients such as proteins, lipids, fatty acids, amino acids, and vitamins that fulfil a significant portion of the nutritional needs of cultured species. As key components of the food web, they support higher trophic levels and help cycle nutrients throughout the ecosystem (Suhaimi *et al*., 2022a).

Consumer-resource interactions are fundamental ecological processes that control the distribution of nutrients or energy throughout ecosystems and across trophic levels, as well as affecting community structure (Clance *et al*., 2023). Furthermore, preserving zooplankton is crucial for maintaining ecosystem services, such as aquaculture and fisheries, and preventing disruptions to the food chain (Lomartire *et al*., 2021). To optimise the survival rate and developmental performance of larvae, they require a well-balanced and nutritious diet. These consist of commercial diets and oil emulsions designed to enhance the nutritional profile of live feeds. In particular, these enrichment treatments aim to enhance the general health and development rates of fish larvae. The study emphasises the need to improve the nutritional content of live feeds using specific enrichment methods to facilitate the effective development of fish in their early life stages (Kandathil *et al*., 2020).

In aquaculture, the early diet of fish and crustacean larvae must consist of live feed (Rasdi *et al*., 2021a). *Artemia* sp. serves as a widely utilised live feed in aquaculture hatcheries globally. Nonetheless, the implementation of this live feed often faces challenges due to the elevated cost of *Artemia* cysts, suboptimal nutritional quality, and variability in physical characteristics, which are influenced by sources, age, duration of consumption, and culture methods (Ajit, 2021). Note that the nutritional requirements of larvae may not be met solely using *Artemia* sp. (Rasdi & Qin, 2016). Hence, one way to optimise profits is to minimise feed expenses. A comprehensive understanding of the larval nutritional requirements during development will enhance diet formulation and feeding regimens, ultimately improving the quality of larvae and juveniles. Due to the susceptibility of fish larvae, it is consistently challenging to meet nutritional needs when many physiological and metabolic constraints are interconnected, each potentially hindering growth or proper development (Hamre *et al*., 2013). Similarly, fruit debris, such as banana and mango peels, and oil emulsions derived from soybean or fish oil can be supplemented as highly nutritious feed sources. These ingredients provide essential fibre, vitamins, antioxidants, and fatty acids, contributing to improved growth performance and overall fish health (Manju *et al*., 2015; Dawood *et al*., 2022). Therefore, it is crucial to investigate alternative basic materials that are abundant and of high quality, which are essential for the success of fish culture production (Handajani *et al*., 2021).

The growing demand for zooplankton as an alternative food supplement for larval rearing has prompted efforts to improve the nutritional quality of Cladocera. The cultivation of cladocerans enables the collection of several live food organisms within a relatively short time when maintained under optimal temperature, oxygenation, and water quality conditions. Moreover, the cladocerans, *Moina* sp. and *Daphnia* sp., are both significant protein sources, cost-effective to cultivate, and can serve as alternatives to *Artemia*. Remarkably, both species exhibit high reproductive rates, extensive environmental adaptability, and can consume phytoplankton and organic waste substrates (Rasdi *et al*., 2020). Hence, incorporating nutritious artificial feeds may enhance nutritional content by supplementing live feeds, stimulating the feeding behaviours of target species in a co-feeding regime, making them a more viable and sustainable food source for aquaculture larvae (Khan *et al*., 2025). Notably, fruit waste demonstrated greater efficacy in culturing zooplankton, potentially serving as an effective, cost-efficient, and sustainable food source. Moreover, Sulaiman *et al*. (2022) indicated that the fish body composition of hybrid red tilapia in the control demonstrated significantly lower ($p < 0.05$) lipid content than those treatments containing fruit wastes, for example, grated coconut (12.83 ± 0.13a), jackfruit pulp (11.51 ± 0.35), and pineapple skin (11.51 ± 0.35).

Additionally, oil emulsions, such as garlic oil, function as stress-resistance additives and growth promoters in sustainable aquaculture

(Kabery *et al*., 2019). Research conducted by Yuslan *et al*. (2021) investigated the effects of supplementing cyclopoid copepods with diverse meals, such as *Chlorella* sp., capsicum, mixed vegetables (carrot and spinach), yeast, and rice bran, on the colouration and feeding rate of *Betta splendens* (Siamese fighting fish). The results indicated that copepods supplemented with mixed vegetables produced darker body colouration in the fish. In contrast, those supplemented with *Chlorella* sp. yielded the best specific growth and survival rates. Essentially, this suggests that enrichment meals can affect both the visual and health characteristics of ornamental fish.

This review focuses on enhancing the nutritional quality of Cladocera as live feed in aquaculture by utilising plant by-products. It critically examines enrichment strategies that incorporate essential nutrients, including fruit waste, yeast, and oil emulsions, to improve the development, survival, and nutritional composition of Cladocera. Therefore, by identifying and evaluating effective enrichment methods, this review offers practical guidance for researchers and aquaculture practitioners. Ultimately, it promotes the application of plant-based by-products as sustainable resources to enhance the utilisation of existing Cladocera species and improve larval nutrition in aquaculture.

Methodology

This study utilised a systematic approach to gather and evaluate pertinent information on improving Cladocera nutrition using fruit waste, commercial diet and oil emulsions for aquaculture purposes. A thorough search was performed across scholarly databases, including Scopus, ScienceDirect, Web of Science, Google Scholar, and PubMed, utilising keywords such as "Cladocera nutrition", "Cladocera enrichment", "live feed in aquaculture", "fruit waste", and "oil emulsions". Studies published from 2010 to 2024 were prioritised, with selective inclusion of previous significant publications. In particular, the inclusion criteria emphasised studies with *Moina* sp. and *Daphnia* sp. as live feed, the enrichment of these organisms with agro-industrial waste, and the assessment of effects on nutritional content, zooplankton performance, and larval fish development. Correspondingly, data from selected papers were retrieved and classified according to enrichment materials, methodologies, and results, including protein and lipid content, fatty acid composition, reproductive success, and larval development and survival rates. Subsequently, the findings were consolidated to assess the effectiveness of enrichment and to identify viable methods for sustainable aquaculture.

Results and Discussion

Cladocera As Live Food Source for Larval Rearing

In aquatic environments, the growth of aquatic organisms is based on the availability of essential nutrients for larval development. These live food organisms serve as the primary resource for aquaculture (Das *et al*., 2012). Cladocerans exhibit high reproductive rates, broad temperature tolerance, and the capacity to thrive on both phytoplankton and organic waste. Two cladocerans, specifically *Daphnia* and *Moina*, are significant as live food sources. In particular, *Daphnia* inhabits freshwater ponds, tanks, and lakes globally. It propels itself with swift, abrupt movements of its two huge antennules. At the same time, *Daphnia* possesses a diverse array of digestive enzymes, including proteases, peptidases, amylase, lipase, and cellulase, which function as exoenzymes in the gastrointestinal tracts of fish and prawns. Moreover, its bigger size compared to *Moina* makes it a suitable live food source for advanced stages of fish. Conversely, *Moina* mainly reside in ephemeral ponds or ditches. It is smaller in size (0.5 mm to 2 mm) than *Daphnia*, yet carries 70% more protein, and thus serves as an effective substitute for *Artemia* in aquaculture hatcheries. As such, *Moina* has been extensively employed as live feed in several hatcheries (Das *et al*., 2012). Commercially formulated feed may not fulfil all these requirements, and in most cases, this will result in a lower survival rate for larvae compared to live food (Santhosh *et al*., 2013). This is mainly attributed to the fact that it has a significant impact on the development, survival, and resistance to environmental conditions during the larval stage (Sontakke *et al*., 2019).

The extensive larval cultivation of most crustaceans requires a significant abundance of plankton to provide for the larval stages, juveniles, and adults, including fish and prawns. Notably, protein-rich, naturally occurring zooplanktonic organisms are required in nurseries and grow-out ponds (Altaff, 2020). Recently, Cladocera have garnered significant attention within the aquaculture industry. *Moina* sp. and *Daphnia* sp. are freshwater Cladocera that contain large amounts of protein and other vital nutrients. Nevertheless, similar to *Artemia*, the fatty acid content does not satisfy the necessary criteria for the nourishment of crustacean and fish larvae. The propagation of Cladocera is mostly conducted in a hatchery environment to provide a reliable and abundant output (Pratiwy *et al*., 2021). Moreover, Cladocera are regarded as excellent alternatives to *Artemia* due to their elevated protein content and economic efficiency in production. Additionally, both species have a higher rate of reproduction and possess the capacity to endure diverse environmental circumstances, as well as the ability to utilise microalgae and organic waste as nutritional sources (Samir *et al*., 2015; Altaff, 2020). Interestingly, these species are in high demand for ornamental fish and prawn seed applications due to their desirability.

In aquaculture, *Moina* is commonly used as live feed for fish and crustacean larvae. The South-East Asia region utilised *Moina macrocopa* and *Moina micrura* for the cultivation of freshwater larvae culture. *Moina* is an ideal option for larval rearing due to its manageable handling, rapid reproduction, advantageous nutritional profile, and adaptability to diverse environmental conditions (Oh & Choi, 2012). Following this, Nakamoto *et al.* (2008) indicated that their research evaluated the nutritional composition of two cladoceran species, *M. macrocopa* and *Diaphanosoma celebensis*, in comparison to *Artemia* for prawn (*Penaeus japonicus*). This reveals that supplementation with *Chlorella* significantly enhanced Eicosapentaenoic Acid (EPA) and Docosahexaenoic Acid (DHA) concentrations in both Cladocera. In a 30-day feeding trial, *P. japonicus* post larvae were given enriched *Moina* and *Artemia* as a control. As a result, prawns fed on Cladocera exhibited significantly greater body lengths compared to those fed on *Artemia*. Meanwhile, the prawns fed on *D. celebensis* demonstrated elevated survival rates.

Daphnia, a species inhabiting freshwater ecosystems, is commonly utilised as a nutritional resource for fish larvae. The lipid composition fluctuates from 20% to 27% and may comprise up to 70% protein (Kandathil *et al*., 2020). Melaku *et al*. (2022) indicated that live *Daphnia* sp. feed is crucial for the development and sustenance of catfish larvae over two weeks. They also noted that it may serve as a replacement for *Artemia* cysts, as the fish larvae grew rapidly and gained significant body weight compared to those fed artificial feed. In contrast to *Moina*, their larger size renders them suitable as live food during the advanced stages of fish development. In particular, *Daphnia magna* is a widely utilised live feed that can attain substantial population densities.

Aquaculture's Sustainable Feed Resources

Aquaculture is among the most rapidly expanding agricultural industries globally. A precondition for this is a sustained rise in the Earth's population, accompanied by the associated challenges of providing sustenance, as well as the growing global demand for nutritious meals (Velichkova *et al*., 2024). However, the viability of aquaculture predominantly relies on the feed utilised, as it is a significant element in the ecological consequences of aquaculture techniques. Similarly, environmental sustainability has become an increasingly pressing concern. There has been a growing focus on developing an understanding of environmental concerns and implementing methods to reduce the environmental impact of aquaculture (Boyd *et al*., 2020). Considering these perspectives, the aquaculture sector must further pursue alternative components derived from sustainable natural resources. Notably, a substantial rise in production necessitates a swift transition in technology and production systems, enhanced utilisation of naturally available resources, the development of superior alternative feed resources, and the optimisation of available space. The fundamental production processes and factors for advancing sustainable and secure seafood production are also examined.

Sustainable feed resources in aquaculture offer significant benefits, particularly in terms of reducing environmental impact. Hence, by shifting away from traditional feeds that rely on wild fish stocks or extensive land-based agriculture, sustainable alternatives help alleviate the pressure on marine ecosystems and minimise deforestation. This, in turn, lowers the carbon footprint associated with feed production. Additionally, sustainable feed practices improve circularity by incorporating waste and by-products from other industries, fostering a more resource-efficient system. Economically, these alternatives can reduce costs over time by decreasing dependency on expensive, finite resources, such as fishmeal and fish oil (Mustafa, 2022). Furthermore, sustainable feeds contribute to animal health, often providing enhanced nutritional profiles and boosting immune function in farmed species, leading to healthier, more resilient fish populations. This holistic approach benefits both the environment and the aquaculture industry, ensuring a more sustainable and efficient food system.

A study demonstrated that the development of Asian seabass increased when palm oil was supplied as a lipid-rich diet source. The researchers examined the fatty acid content and advised using palm oil in the formulation of a weaning meal for larvae. Accordingly, substituting fish oil with palm oil up to 75% in the micro diets of Asian seabass larvae is viable and can improve growth performance while maintaining survival rates. Consequently, this substitution provides a cost-effective alternative to fish oil while promoting sustainable aquaculture practices by decreasing dependence on fish oil (Safiin *et al*., 2022). Additionally, the impact of processed palm oil on juvenile hybrid grouper (*Epinephelus fuscoguttatus* x *E. lanceolatus*) was evaluated by Yong *et al*. (2022). Moreover, the study was validated by quantitative data about the prevalence of this product in the diet, which will increasingly benefit hybrid grouper in the aquaculture sector.

Studies on trout (*Oncorhynchus mykiss*) examined alternatives to fish oil for nutritional purposes. The research investigated the fatty acid composition, histological characteristics, unidentified immune reaction, and developmental outcomes associated with the use of modified canola oil. Notably, this dietary component is easily digested, fulfilling the requirements of the fish and meeting consumer expectations. Concurrently, Hong *et al*. (2022) supported the appropriateness of administering modified canola oil throughout the whole development cycle of cultivated rainbow trout.

The incorporation of nutrients in feed from fish caught in the wild involves both species used in marine and freshwater fish. This study underscores the significance of alternative aquafeed sources and emphasises the significance of a commonly utilised vegetable oil in numerous underdeveloped countries. For instance, Siddiqua *et al*. (2022) elucidated the dietary composition of groundnut oil, particularly the bioactive phytochemicals and antioxidants, and their cumulative impact on fatty acids, lysozyme activity, and other metabolic parameters in the prominent main carp, *Labeo rohita*. The findings of this study indicated that 60% groundnut oil can enhance fish development, antioxidant capacity, and lysozyme activity, while maintaining fillet nutritional quality. Table 1 presents a comparison of the nutritional composition of various diet types, including commercial diets, common fruit waste, and oil emulsions.

The most frequent alternatives are plant-based. However, current research suggests that organic compounds derived from animals are also nutritionally important. Mustafa (2022) and Malcorps *et al*. (2021) examined the nutritional content of aquaculture processing by-products. As such, EPA and DHA are abundant in the skin, heads, frames, trimmings of seabass (*Dicentrarchus labrax*), gilthead seabream (*Sparus aurata*), carp (*Cyprinus carpio*), and turbot (*Psetta maxima*), along with crude protein, lipid, and additional components conducive to feed formulation. Figure 1 illustrates feed resources used in the aquaculture industry.

Nutritional Enhancement of Cladocera

Enrichment methods have been utilised due to their potential to influence the nutritional content of zooplankton, thereby enhancing the development, survival, and reproductive ability of aquatic species (Samat *et al*., 2020). Protein, lipids, and vitamins are essential dietary ingredients required for fish larvae. Note that the lack of this nutrient can impact development, reproduction, and fish survival, potentially leading to fin erosion and lordosis (Rakesh *et al*., 2021). In addition to fatty acids, first-feeding larvae require amino acids for their primary energy sources (Peña *et al*., 2023). Furthermore, the selection of food sources is crucial in achieving the objective of sustained production of cultured organisms. The performance of fish larvae is contingent upon the availability of live food, which facilitates improved development (Tadeo & Veracruz, 2018). This has been achieved using various diets that incorporate agro-industrial fruit wastes and natural oil emulsions, such as apple by-products, banana peels, citrus fruit waste, grapefruit waste, cod liver oil, and cuttlefish oil (Kandathil *et al*., 2020; Dawood *et al*., 2022).

Recently, fruit waste has been selected as a means of enhancing plankton and has been observed to effectively promote the development and survival of fish. Research conducted by Suhaimi *et al*. (2022b) discovered that including soybean meal and rice bran in the diet of *M. micrura* resulted in improved performance of tilapia larvae. In addition, Yuslan *et al*. (2021) revealed that supplementing the copepod's food with a mixture of carrot and spinach led to improvements in growth rate, survival rate, and colouration enhancement in *B. splendens*. Moreover, a study conducted by Rasdi *et al*. (2020) demonstrates that *Moina*, when

Figure 1: Original illustration of aquaculture's sustainable feed resources

Table 1: Comparison of the nutritional composition of various diet types, including commercial diets, common fruit wastes, and oil emulsions

Type of diet	Diet	Protein (%)	Lipid (%)	Fibre (%)	Moisture (%)	Ash (%)	Reference
Commercial diet	Yeast extract	40.35	7.23	-	-	10.08	Zhao *et al*., 2017
	Brewer's spent yeast	64.1 ± 0.2	1.32 ± 0.04	-	7.70 ± 0.12	14.0 ± 0.2	Vieira *et al*., 2016
Fruit waste	Pomegranate peel	5.57 ± 0.18	4.66 ± 0.34	9.13 ± 0.4	10.32 ± 0.41	3.32 ± 0.22	Ismail *et al*., 2020
	Apple peel	3.20 ± 0.98	10.15 ± 0.24	11.86 ± 0.31	3.23 ± 0.09	4.78 ± 0.01	Nakov *et al*., 2020
	Banana peel	3.76 ± 0.12	5.22 ± 0.11	16.56 ± 0.04	4.93 ± 0.04	8.20 ± 0.15	Khamsaw *et al*., 2024
	Orange peel	16.51 ± 0.40	2.78 ± 0.01	12.47 ± 0.54	10.30 ± 0.01	5.51 ± 0.02	Adewole *et al*., 2014
Oil emulsion	Garlic oil	15.33	0.72	2.10	4.55	4.08	Yusuf *et al*., 2018
	Canola oil	60.90 ± 0.02	12.47 ± 4.22	-	-	-	Suhaimi *et al*., 2022b
	Coconut oil	9.26	39.72	7.22	14.28	1.075	Adaji *et al*., 2020

supplemented with yeast, exhibited the most abundant nutrients in its body composition. This finding suggests that including such enriched *Moina* into the diet of *Penaeus monodon* might potentially enhance its growth performance.

Yeasts are unicellular eukaryotic microorganisms classified within the kingdom Fungi (Prillinger, 2002). Organic materials for energy and carbon are intrinsically associated with the presence of organic matter necessary for microorganisms. Various yeast species, including *Saccharomyces cerevisiae* and *Torulopsis*, serve as a protein supplement in aquatic feed for the cultivation of prawns and marine fish larvae (Mahdy *et al*., 2022). Specifically, *S. cerevisiae* is the predominant yeast utilised in the aquaculture industry, especially for its health-enhancing properties in many fish species. Recently, there has been heightened attention on non-*Saccharomyces* species owing to their potential benefits in aquaculture. In line with this, the use of various materials affects the chemical makeup of distinct yeast species. Similarly, environmental factors, including water parameters, affect the nutritional substances of entire yeast cells (Agboola *et al*., 2021). The utilisation of yeasts as fish feed may represent a more cost-effective and environmentally friendly method in aquaculture biotechnology, leading to a decreased reliance on fishmeal. Notably, yeasts are remarkable, protein-rich unicellular organisms with low toxicity potential, capable of being cultivated on diverse substrates, and generally easy to produce.

Aquaculture is viewed as a sustainable approach to global food diversification, providing nutritious food and substantial business opportunities. Currently, the practicality and profitability of fish farming are being affected by the elevated costs of aquafeed. Conventional feed components account for a significant portion of production expenses, resulting in rising aquafeed prices. Conventional components, such as fish and soybean meals, are experiencing a significant price increase due to heightened demand and restricted supply.

Consequently, alternative components, such as plant by-products, offer a sustainable approach for the aquaculture sector that possess high nutritional value and low cost, and have been advised and implemented in several nations (Dawood *et al*., 2022).

The agricultural industry produces substantial amounts of food waste, including peels from fruits and vegetables such as oranges, bananas, and potato peels, and seed remains from coffee grounds, husks, and nut shells. Fruit waste is recyclable due to its substantial nutritional value, which is beneficial for the livestock and aquafeed sectors (Sulaiman *et al*., 2025). These food wastes comprise a significant quantity of organic matter, including proteins and fatty acids (Di Donato *et al*., 2014). Teshome *et al*. (2021) discovered that fruit waste, including peels, skins, and seeds, is rich in bioactive compounds and provides essential nutrients such as pectin, proteins, fats, fibre, minerals, and vitamins. Furthermore, enriching a mixed diet of carrot and spinach for copepods significantly influences the growth rate, survival rate, and colouration enhancement of *B. splendens* (Yuslan *et al*., 2021; Ashaari *et al*., 2024).

Fish oil is utilised at a concentration of 2-3 per cent in feed to enhance development and feed conversion efficiency. Essentially, oil provides nutritional energy and essential fatty acids for aquatic creatures. Commercial dietary formulations and lipid emulsions of Highly Unsaturated Fatty Acids (HUFA)-rich diets exhibit significantly higher HUFA levels than algae or yeast when used as a rotifer supplement (Kandathil *et al*., 2020). Simultaneously, rotifers are frequently supplemented with DHA, Protein SELCO®, and oil emulsions (Kotani *et al*., 2010; Hamre, 2016). Utilising oil emulsion enrichment is one method to increase the nutritional value of rotifers. However, such enrichers are costly. Commercial emulsions often exhibit more stability and a defined HUFA composition. The most efficacious emulsions were generated from (n-3) HUFA-rich fish oils and combined with egg and saltwater (Kandathil *et al*., 2020).

Garlic (*Allium sativum*) has been utilised to enhance the development and resilience of various livestock and fish (Diab *et al*., 2017). In line with this, coconut oil (CO), or virgin CO, can enhance antioxidant enzyme activity while diminishing lipid peroxidation. The high concentration of Monounsaturated Fatty Acids (MUFAs) (65%) in CO did not interfere with cholesterol biosynthesis and transport, thereby facilitating the mobilisation of protein for bodily protein synthesis (Febri *et al*., 2021). Additionally, CO supplementation positively influences productivity and associated gene expression in orange-spotted grouper (Tseng & Lin, 2020). Ding *et al*. (2020) indicated that varying doses of dietary CO have enhanced the specific development rate of yellow croaker (*Larimichthys crocea*).

Enhancement of Zooplankton Quality with Yeast

Yeast has been proven to be an effective feed substrate for large-scale cultivation of *Moina* (Kang *et al*., 2006). Rasdi *et al*. (2021a) reported that *P. monodon* exhibited the maximum growth rate of 17.22% and a survival rate of 91.78% when provided with *Moina*-enriched yeast. Meanwhile, yeast-enriched *Moina* sp. demonstrated superior nutritional content, potentially enhancing growth performance. Moreover, the proper nourishment of *Moina* sp. guaranteed the sufficient transfer of nutrients to the *Macrobrachium rosenbergii* larvae culture. Correspondingly, the utilisation of yeast for supplementation to *Moina* sp. indirectly aided the aquaculture industry in decreasing production costs, hence preserving time and manpower.

Additionally, it was noted that similar enrichment techniques might be utilised to improve the nutrition of prawn larvae in culture (Rasdi *et al*., 2020). Yeast *S. cerevisiae* is extensively studied as a food source for zooplankton due to its provision of vitamins, carbohydrates, and proteins, with a size range of 4 μm to 5 μm. Furthermore, this food supply is readily prepared and economically priced, necessitating no cultivation. The commercial lyophilised yeast *S. cerevisiae* was administered to *M. micrura* at a concentration of 1.25 mg/L (Ocampo *et al*., 2010). Natural food resources are essential for the nutrition enhancement and production of *M. micrura*. Furthermore, the quantity of lipids in the diet also affects population growth and reproductive rates. The HUFA composition of *M. micrura* fluctuates with the culture medium, although it can be enhanced nutritionally by adding emulsified lipids (Kandathil *et al*., 2020). Additionally, Turcihan *et al*. (2022) highlighted that *Daphnia* nourished with a baker's yeast diet exhibited increased EPA buildup by the conclusion of the trial. Table 2 illustrates the improvement in zooplankton quality using yeast.

Enhancement of Cladoceran with Fruit Waste

It is estimated that fruit waste and products total around 100 million tonnes, presenting management challenges for industry stakeholders (Marić *et al*., 2018; Fierascu *et al*., 2020). Furthermore, research indicates that it serves as an advantageous enrichment for aquaculture species due to its bioactive components and exogenous enzymes (Dawood *et al*., 2022; Habotta *et al*., 2022). For example, the peel of Chinese yams, a by-product of fruit processing, possesses characteristics that may eradicate harmful bacteria in fish digestion by enhancing good microbiota in their digestive systems.

Moreover, pineapple peel contains bromelain, a proteolytic enzyme that enhances digestibility and strengthens the body's system in tilapia (Yuangsoi *et al*., 2018; Sukri *et al*., 2021; Van Doan *et al*., 2021). The by-products of the papaya plant include enzymes specific to the *Carica* papaya plant. In addition, banana peels are rich in dietary fibre and phenolic compounds, exhibiting potent antioxidant, antimicrobial, and antibacterial activities. They encompass fibre, which facilitates digestion, in addition to vitamins C and B6, potassium, magnesium, and antioxidants (Naksing, 2020). Moreover, their peels are notably abundant

Table 2: Improvement of the quality of zooplankton using yeast

Zooplankton	Yeast Enrichment	Result	References
Moina sp.	Yeast	*P. monodon* had the highest growth rate (17.22 ± 0.10%) and survival rate (91.78 ± 1.67%) when fed on *Moina*-enriched yeast. *Moina*-enriched yeast performed best in terms of prawn biochemical components. The average values for protein, fat, moisture, and ash were 64.04 ± 0.40%, 4.91 ± 2.43%, 16.89 ± 2.75%, and 10.38 ± 2.05%, respectively.	Rasdi *et al*., 2021b
Moina macrocopa	Yeast	The study discovered that *M. macrocopa* culture with 12 mg/L yeast produced the most offspring per female (45.3 ± 4.6), broods per female (4.0 ± 0.0), and offspring per brood (11.3 ± 1.2). *M. macrocopa* culturing without enrichment produced the fewest offspring and the highest maturity age.	Khammungkun *et al*., 2023
Filinia longiseta	Yeast	Yeast (7500 ± 820.99 individuals), fry booster (7622 ± 317.71 individuals), and fish waste significantly enhanced the population expansion of *F. longiseta* more effectively than a diet only including rice bran and *Chlorella* after six days of cultivation.	Castro *et al*., 2024
Tisbe furcata	Yeast	In this study, introducing yeast and maize flour to the feeds resulted in increased *T. furcata* population densities without harming the ecosystem in the tanks.	Wang *et al*., 2017

Table 3: The use of fruit and vegetable waste for fish and crustacean culture

Fruit and Vegetable Waste Enrichment	Species Tested	Result	References
Pineapple peel, pineapple crown, jackfruit peel, jackfruit pulp, grated coconut, mixed fruit wastes.	Hybrid red tilapia (*Oreochromis* sp.) and Malaysian mahseer (*Tor tambroides*).	Results revealed that tilapia fed with jackfruit pulp (16.68 ± 0.02 g) and grated coconut (15.51 ± 0.12 g) had significantly higher weight gains compared to the control (13.80 ± 0.05 g). Higher tilapia survival rates (96.0-96.7%) were observed in grated coconut, pineapple skin, and jackfruit pulp compared to other treatments (<93.0%). Body weight gains in mahseer were significantly higher within the varied diet (7.70 ± 0.17 g) and jackfruit pulp (6.87 ± 0.08 g) compared to the control (6.07 ± 0.11 g).	Sulaiman *et al*., 2022
Orange, pineapple, sweet lime	*Labeo rohita* fingerlings	The 25% pineapple waste diet had higher Specific Growth Rate (SGR) (1.50), FCR (2.09), and PER (1.19) growth compared to the other groups.	Deka *et al*., 2003
Noni (*Morinda citrifolia*) fruit extract	*Litopenaeus vannamei* juvenile	The study of shrimp fed a 1.5% noni extract diet exhibited the highest final weight, weight gain, daily weight gain, and SGR across all groups.	Phan *et al*., 2023
Capsicum, mixed vegetable (carrot + spinach) and rice bran	*Betta splendens*	The present study illustrated that enriched cyclopoid copepods, supplemented with rice bran, capsicum, and a mixture of vegetables (carrot and spinach), can effectively enhance the colouration and feeding rate of *B. splendens*.	Yuslan *et al*., 2021
Carrot, water spinach, and lettuce	*Penaeus monodon* post-larvae	The study revealed that *P. monodon* post-larvae had the highest SGR when fed with copepod-enriched water spinach (11.28 ± 0.38%). Enhancing copepods and feeding *P. monodon* resulted in water spinach with the highest protein and lipid material compared to other enrichments.	Naman *et al*., 2021

in phytochemicals that provide antioxidant and anti-inflammatory benefits. They may also demonstrate antibacterial and antifungal properties (Ansari *et al*., 2023). For example, the use of 5% banana peel flour in the fish diet enhanced the wellness of rohu, *L. rohita* (Giri *et al*., 2016).

The orange peel probably supplied supplementary nutrients and bioactive substances that enhanced the fish's general health and growth. Incorporating orange peel into the diets of Nile tilapia and European sea bass improved their growth, respectively (Sulaiman *et al*., 2022). Meanwhile, Salem *et al*. (2019) asserted that administering orange peel to gilthead seabream at concentrations from 2.9 ppm to 5.5 ppm of body weight for 60 days contributed to the maintenance of optimal fish health. Furthermore, lemon peel may serve as an economical source of vitamin C to enhance the nutritional value of fish diets. Moreover, it is widely recognised that incorporating plant-derived bioactive substances into fish meals enhances fish digestive health. Overall, the orange peel supplement enhanced the absorptive surface in their gastrointestinal tracts, facilitating greater nutrient absorption from their sustenance.

This resulted in enhanced growth and development in the fish. Studies exploring the use of fruit waste to enhance Cladocera are now in preliminary phases, emphasising sustainable aquaculture and improved nutrient cycling. However, the direct utilisation of fruit waste as an enrichment medium is less extensively reported than alternative methods. Hence, further studies are required to determine the most effective treatments and fermentation techniques for fruit waste, ensuring the provision of stable, bioavailable nutrients for zooplankton. Table 3 illustrates the utilisation of fruit and vegetable waste in fish and crustacean culture.

Enhancement of Zooplankton with Oil Emulsion

The enhancement of live feed using commercial oil-emulsion products is a prevalent technique (Eryalçın, 2018). Numerous studies have evaluated the dietary compositions of copepods and enhanced *Artemia* (Van der Meeren *et al*., 2008). Accordingly, the primary fatty acids in copepods are DHA, EPA, and palmitic acid, whereas the principal fatty acids in *Artemia* enhanced with Super SELCO and DHA SELCO are DHA, EPA, and oleic acid (Samat *et al*., 2020). In addition to the total quantity of HUFA, the dietary DHA/EPA ratio is proposed to influence the typical development and growth process of specific fish species (Matsunari *et al*., 2013).

The DHA and EPA ratio for copepods averaged between 1.83 and 5.5, while the ratio for *Artemia* enhanced with DHA SELCO varied from 1.4 to 2.2 (Van der Meeren *et al*., 2008). Notably, commercial emulsions have enhanced stability and efficacy, mostly composed of HUFA-rich emulsified fish oils. Nonetheless, while these types of enrichment formulas exhibit poor efficiency, they serve as cost-effective options in developing nations (Kandathil *et al*., 2020). For instance, the freshwater Cladocera *M. micrura* exhibited elevated levels of DHA and EPA, along with a higher DHA/EPA ratio, when enriched with the commercial emulsion Maxepa MERCK (Delhi, India), in conjunction with egg yolk and gelatine (Singh *et al*., 2019). Table 4 presents the improvement in the quality of Cladocera using oil emulsion.

Biological and Cultural Practices of Cladocera (Moina micrura)

The cultivation of Cladocera enables the swift acquisition of multiple live food species in a brief timeframe, contingent upon the provision of appropriate temperature, aeration, and water quality. Furthermore, Cladocera, particularly *Moina* sp. and *Daphnia* sp., provide significant protein ingredients that are economically viable to farm and may serve as an alternative to *Artemia*. Accordingly, both species exhibit rich fecundity, possess extensive ecological adaptability, and demonstrate efficiency in consuming phytoplankton and organic detritus (Rasdi *et al*., 2020).

Table 4: Improvement of the quality of zooplankton using oil emulsion

Zooplankton	Types of oil emulsions	Target hosts	Findings	References
Artemia franciscana	Trashfish *Odonus niger* liver oil emulsion	Giant tiger prawn (*Penaeus monodon*) post-larvae	The Polyunsaturated Fatty Acid (PUFA) content of the post-larvae fed lipid-enriched *Artemia nauplii* increased from 29.72% (by weight) in the control group to 44.13% (by weight), thus promoting the survival rate and the SGR of the post-larvae.	Immanuel *et al*., 2004
Daphnia magna	Cod liver oil emulsion	Persian sturgeon (*Acipenser persicus*) larvae	HUFA content of *Daphnia* was increased, and pH stress resistance of the larvae was enhanced.	Abedian Kennari *et al*., 2007
Daphnia magna	Canola oil emulsion	Caspian kutum (*Rutilus Frisii kutum*) larvae	*D. magna* fatty acid profile was significantly increased, thus enhancing the weight gain, SGR, and survival (93.33%) of the larvae.	Fereidouni *et al*., 2013
Artemia	Sunflower oil and cod liver oil emulsion	Giant freshwater prawn (*Macrobrachium rosenbergii*) post larvae	Sunflower oil-enriched *Artemia* exhibit better growth-promoting capabilities in *M. rosenbergii* early post-larvae than those of cod liver oil-enriched *Artemia.*	Bhavan *et al*., 2013
Artemia urmiana	Fish, sunflower, canola and soybean oils emulsions	Rainbow trout, *Oncorhynchus mykiss*	The EPA (6.77 ± 1.04%) and DHA (0.65 ± 0.11%) in the fish fed with enriched *Artemia* with the fish oil were the highest compared to other oil emulsions. The survival rate of the fish was highest in the treatment of canola oil at the temperature of 20°C (99.67 ± 1.34).	Agh *et al*., 2016
Moina macrocopa	Canola oil emulsion mixes with *Chlorella* sp.	-	The survival rate (109.97 ± 32.85%) and generation times (54.42 ± 8.75 days) of *M. macrocopa* fed on the mixed diet were substantially higher than when fed with *Chlorella* sp. solely or with canola oil only.	Rasdi *et al*., 2021c
Brachionus plicatilis	Palm oil emulsion	Asian seabass (*Lates calcarifer*) larvae	The rotifer supplemented with palm oil had a substantial impact on the fed larvae's fatty acid profiles and body proximate composition.	Safiin *et al*., 2021
Artemia franciscana	DHA oil emulsion	European seabass (*Dicentrarchus labrax*) larvae	PUFA levels, specifically EPA, in the larvae were increased when they were enriched with the oil emulsion for 2 hours, and their survival, feed conversion ratio, and protein efficiency ratio were not significantly affected.	El-Sayed *et al*., 2022

Figure 2: Lateral view of *Moina* sp. under a compound microscope at 100x magnification (photo taken in July 2024)

Moina, a diminutive aquatic microcrustacean, is ubiquitously distributed globally due to the ease with which their eggs can be transferred to new environments (Petrusek *et al*., 2004). Furthermore, the *Moina* reproductive cycle encompasses sexual and asexual phases (Rottmann *et al*., 2018). Under ideal circumstances, population growth predominantly occurs through parthenogenesis, an asexual reproduction method in which embryos develop without fertilisation. This yields exclusively female progeny, hence facilitating fast propagation and population expansion (Azuraidi *et al*., 2013). By contrast, in unfavourable climatic conditions, reproduction occurs in male progeny and resting eggs with an additional layer of shell, referred to as ephippia (Rottmann *et al*., 2018).

M. micrura is a common and significant zooplankton (Azuraidi *et al*., 2013; Vignatti *et al*., 2013) and an extensively recognised live food primer appropriate for nurturing aquatic species larvae (Azuraidi *et al*., 2013; Gogoi *et al*., 2016). This includes freshwater prawn *M. rosenbergii* (Das *et al*., 2007), white prawn, *Litopenaeus schmitti* (Martin *et al*., 2006), loaches, *Misgurnus anguillicaudatus* (Wang *et al*., 2008), and catfish *Heterobranchus longifilis*. Concurrently, Figure 2 below illustrates the lateral aspect of *Moina* sp. observed using a compound microscope at 100x magnification.

The *Moina* sp. species has gained considerable significance in aquaculture. In particular, *Moina* sp. has been employed as a nutritional resource for the rearing of crustaceans and fish during their larval and post-larval phases. Due to its high protein and nutritional content, *Moina* sp. is a great option for live food compared to *Artemia*. Moreover, the utilisation of freshwater zooplankton, specifically *M. macrocopa*, may provide greater benefits for the sustenance of freshwater species compared to saltwater *Artemia* (Poynton *et al*., 2013). Although comprehensive study and cultivation efforts have been undertaken for *M. macrocopa* and *M. siamensis*, information concerning *M. micrura* remains scarce. Most investigations have been conducted in temperate laboratory environments, which vary in cultural parameters including food concentration, food type, culture volume, and nutritional circumstances (Benider *et al*., 2002; Sipauba-Tavares & Bachion, 2002; Martinez-Jeronimo *et al*., 2007; Chen *et al*., 2015).

Nonetheless, the advantages of *M. micrura* include its smaller body size compared to both *M. macrocopa* and *M. siamensis*, making it an excellent source of live sustenance for feeding fish larvae. Interestingly, it can thrive in both freshwater and brackish environments (Saint-Jean & Bonou, 1994; Rodmongkoldee *et al*., 2020) and possesses a high protein level, ranging from 49.31% to 75.29% (Saengphan *et al*., 2016). This is comparable to *Artemia* protein content, which ranges between 53.7% and 60.5% (Peykaran *et al*., 2014). Since *Artemia* spp. must be provided as sustenance for nursing aquatic species, utilising locally sourced live feed is more cost-effective and efficient.

M. micrura Nutritional Enhancement as Live Food for Larval Rearing

M. micrura are diminutive freshwater crustaceans that have garnered attention for their importance in aquaculture, particularly in the larval development of many marine species (Azani & Rasdi, 2021). Furthermore, *M. micrura* possesses numerous attributes that render it advantageous in aquaculture. Primarily, they are nutritionally dense and possess a high protein concentration, which is crucial for the development of larval marine species in hatcheries. In addition, *M. micrura* is frequently utilised as live nourishment for marine fish, prawns, and other species during their initial developmental phases. At the same time, the diminutive size and elevated nutritional value of *M. micrura* render them an optimal food source, as they may be easily ingested by larvae, facilitating their growth and survival. In recent years, the fish market has emerged as a highly profitable segment of the aquaculture sector. This sector encompasses a range of enterprises, including collectors, breeders, exporters, importers, and marketers (Ghosi *et al*., 2020).

The nutritional supplementation of *Moina* as a live feed is necessary to improve their nutritional content, particularly regarding vital fatty acids. *Moina* are used to raise prawns, red sea bream larvae, and various catfish species, including the catfish (*Clarias macrocephalus*) (Nakamoto *et al*., 2008). Essentially, it is considered a cost-effective and suitable substitute for *Artemia* in the rearing of red sea bream larvae (Kamrunnahar *et al*., 2019).

Natural food resources are vital for the nutrition of *Moina* enhancement and production (Sayali *et al*., 2010). The rates of population growth and reproduction are contingent upon the lipids obtained from the diet (Müller *et al*., 2000). Zooplankton can accumulate up to 40% lipids in their dry weight, with 98% of these lipids derived from ingested food, while only 2% can be synthesised (Turcihan *et al*., 2022). The (n-3) HUFA composition of *Moina* fluctuates with the growth medium. Nevertheless, it can be substantially enhanced with the use of emulsified lipids (Kandathil *et al*., 2020). As such, *Chlorella vulgaris* has been utilised as a feeding medium in *M. macrocopa* cultures (José Luis *et al*., 2015).

To enhance the fatty acid content, it is essential to shift the organic waste diet, and an agricultural supplementation meal should replace *C. vulgaris* prior to offering *M. macrocopa* to fish fry (Tomonari *et al*., 2016). Building on this, rice bran serves as a viable nutritional substrate for *Moina*, comprising diverse nutrients such as protein (12%-13%), lipids (16%-20%), linoleic acid (6.35%-6.85%), α-linolenic acid (0.2%-0.27%), vitamin B, and minerals, predominantly calcium and iron (6%-9%) (Faria *et al*., 2012). The technique of enrichment is a more prevalent method for growing fish larvae. It facilitates the development of commercial cultivation in freshwater and marine environments. This underscores the necessity to create more uniform and economically viable products and technologies for industry. Consistent with this, the fatty acid content of *Daphnia* may serve as an indicator of their dietary composition. That is, the most nutritionally significant essential fatty acids in phytoplankton are effectively transmitted across the plant-animal interface within planktonic food webs (Brett *et al*., 2012).

Nutritional Requirements, Feed Formulation, and Feeding Practices for Freshwater Prawn Macrobrachium Rosenbergii

The freshwater prawn, *M. rosenbergii* (De Man, 1879), is the largest palaemonid shrimp globally and is classified within Animalia, Arthropoda, Malacostraca, Decapoda, and Palaemonidae (Wowor & Ng, 2007; Tan & Wang, 2022). *M. rosenbergii* originates from the Indo-Pacific area, predominantly located in Malaysia, Thailand, India, and Myanmar (Aflalo *et al*., 2012; Gao *et al*., 2020; Jiang *et al*., 2020; Mostafiz *et al*., 2020). *M. rosenbergii* has emerged as a world food due to its high level of protein, palatable flavour, and substantial size (Banu & Christianus, 2016; Islam *et al*., 2017). Over the past two decades, methods in the agricultural industry have been investigated and advanced in more than 40 countries (Iketani *et al*., 2011).

M. rosenbergii has specific nutritional requirements to support its growth, development, and overall health. The key nutrients include protein, lipids (fats), carbohydrates, vitamins, minerals, and amino acids. Note that the protein content should be in the range of 35% to 40% to be suitable for growth. The optimum protein requirement reviewed by different authors for *M. rosenbergii* is 30%. It is also suggested that the estimated protein requirement of *M. rosenbergii* should be between 35% and 38% in the diet (Nesara & Paturi, 2018). Following this, the requisite characteristics of larval feeds are determined by their aquatic environment and are primarily influenced by the form and developmental stage of the larvae. This is particularly true regarding the mouth, digestive system, sensory systems, and swimming muscles. To ensure success, a designed diet for larval fish must be appealing and encourage feeding, appropriately sized for ingestion, easily digestible, and incorporate soluble nutrients while maintaining relative stability in aqueous environments. Note that the efficacy of devised diets for fish larvae has been predominantly inadequate, exhibiting elevated mortality and malformation rates compared to live feeding (Retnani *et al*., 2019). Moreover, advancements in live food enrichment techniques have enhanced the significance and efficacy of live food organisms in the cultivation of aquatic larval creatures.

Conventional live feeds utilised in aquaculture have been deficient in important fatty acids and amino acids, particularly DHA, which are crucial for the embryonic development of fish (Neri *et al*., 2020). The generation of fish and crustacean larvae has consistently relied on *Artemia* seed production for essential nutrition. Therefore, research on alternative live feed for larval generation is essential (Uppanunchai *et al*., 2015; Neri *et al*., 2020). Cladocerans have garnered interest as an alternative for *Artemia* during the post-larval cultivation of freshwater prawns and fish fry, due to the resilience of *Moina* sp. to fluctuations in culture conditions and predation (Kushniryk *et al*., 2015; Manklinniam *et al*., 2018). The study of feeding on freshwater larvae utilising *Artemia*, *Moina*, and *Daphnia* has been conducted due to their high protein content, which is essential for larval development, as well as their varied enzymes for digestion and fatty acid composition (Macedo & Pinto-Coelho, 2001; Yuslan *et al*., 2021). Specifically, *M. micrura* has demonstrated potential as a supplementary feed to *Artemia* for augmenting the production of *M. rosenbergii* (Loh *et al*., 2012; Kandathil *et al*., 2020). Live food, including copepods, rotifers, and *Artemia*, supplies sufficient nutrition to produce larvae of finfish and crustaceans (Drillet *et al*., 2008). Nonetheless, the enhancement of development and sustenance in hatchery larvae necessitates additional nutritional sources beyond commercially available live feed, such as rotifers and *Artemia*, to meet the size and nutritional requirements of certain larval species for optimal development efficacy (Solgaard *et al*., 2007; Rasdi *et al*., 2021a).

During the early larval feeding phase, all fish needed protein-rich and nutritious diets for maximum development and growth. The initial application of prepared meals has demonstrated limited efficacy during larval cultivation. Live feeds are increasingly preferred in both freshwater and marine aquaculture due to their digestibility, superior dietary profile, consistent availability, and ability to provide a complete diet, in contrast to synthetic feeds (Koven *et al*., 2001). Intensive cultivation of marine fish requires live feeds (*Artemia*, Cladocera, and copepods). However, these species are deficient in certain vital nutrients critical for the optimal developmental performance of fish larvae (Rajkumar & Kumaraguru, 2006). Nevertheless, nutritional manipulation for live feed is achievable through enhancement and bioencapsulation methods, which deliver vital nutrients, probiotics, and medicines (Samat *et al*., 2020). Moreover, the fortification of live feed with diverse critical nutrients has demonstrated enhancements in growth, survival rates, and stress resilience across multiple organisms (Rehberg-Haas *et al*., 2015; El Kertaoui *et al*., 2017; Cavrois-Rogacki *et al*., 2020; Samat *et al*., 2020; Morshedi *et al*., 2022).

Conclusions

Aquaculture has been recognised as a sustainable method for global food diversification, offering nutritional benefits and significant commercial prospects. Notably, the viability and economic success of aquaculture depend on a reliable supply of live feed. Hence, enrichment methods have been employed to enhance the nutritional content of zooplankton, thereby improving the development, survival, and capabilities of aquatic species. The study indicated that increased food concentrations had a positive effect on body growth, survivorship, and reproductive output. Accordingly, *D. magna* individuals cultivated in environments with abundant food resources exhibited increased size, enhanced survival rates, and greater offspring production relative to those in nutrient-poor conditions. Following this, food availability is a significant factor affecting the life history traits and overall fitness of this species.

Furthermore, this paper highlights the importance of using zooplankton, specifically *Moina* sp., as feed in aquaculture and argues that enhancing *Moina* sp. is crucial for supplying adequate nutrients to improve the growth efficiency of crustacean and aquatic larvae. In addition, the findings indicate that *Moina* sp. is a suitable candidate for live feed applications. The small size and erratic motions of cladocerans make them more attractive to larval fish, enhancing absorption and digestion. However, this differs from *Artemia*, as its size and movement may not be optimally compatible with all fish larvae (Chakraborty *et al*., 2023). Moreover, diverse feeding techniques have significantly improved the nutritional content of *Moina* sp.

Additionally, enrichment strategic planning is a widely utilised method for the cultivation of fish and crustacean larvae. This facilitates the progress of extensive cultivation for both aquaculture species. In line with this, the creation of standardised and economically efficient resources and methodologies for aquaculture is essential. Although the application of *Moina* sp. as a sustainable live feed presents various advantages, challenges persist in standardising enrichment techniques and ensuring cost-effectiveness. Correspondingly, effective enrichment methods improve the fatty acid profile, protein content, and overall nutritional composition of *Moina* sp., thereby increasing the survival and growth rates of fish and crustacean larvae. Still, large-scale production necessitates optimised methodologies to guarantee sustainable and economically viable yields. Similarly, the development of sustainable cultivation methods is essential to reduce ecological impacts, including nutrient pollution and the overexploitation of natural plankton resources. Therefore, addressing the cost-effectiveness of enrichment techniques is essential for promoting their widespread adoption in both small-scale and commercial aquaculture operations.

Simultaneously, Cladocera have consistently been regarded as a significant food source for plankton-feeding fish, making them very nutritious and useful as live feed (Chakraborty *et al*., 2020). The utilisation of Cladocera, specifically *Moina* sp., as a sustainable live feed carries important implications on both local and global scales. Hence, increased fishery yields support food security and economic stability, particularly in developing regions where aquaculture plays a crucial role. Furthermore, the generation of employment opportunities within the aquaculture and feed production industries has the potential to stimulate economic growth. Decreased dependence on unsustainable fishmeal sources alleviates stress on wild fish populations, while enhanced water quality in aquaculture systems can be attained through effective nutrient utilisation by zooplankton. Similarly, Cladocera presents a viable and economical substitute for *Artemia* as a live feed in aquaculture.

Despite challenges in large-scale production, advancements in cultivation techniques and nutritional enrichment strategies may improve their significance in commercial aquaculture. For example, *Daphnia* and other cladocerans exhibit life history traits, such as parthenogenesis, early maturity, iteroparity, early reproductive effort, and the formation of resting eggs. These enable them to swiftly capitalise on advantageous environmental conditions and ensure that a diminished population can rebound from significant mortality events (Porter *et al*., 1983). Nonetheless, further research is required to enhance enrichment techniques and standardise methodologies for optimising the advantages of *Moina* sp. as a live feed. In line with this, policy frameworks must be developed to encourage sustainable practices while maintaining economic viability. Additionally, collaboration among researchers, industry stakeholders, and policymakers can enhance innovation and improve live feed production, thereby promoting the sustainability of global aquaculture. Essentially, by addressing existing challenges and utilising technological advancements, *Moina* sp. can play a crucial role in the future of sustainable aquaculture.

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Conflict of Interest Statement

The authors declare that they have no conflict of interest.

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