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Recent Trends in Live Feeds for Marine Larviculture: A Mini Review

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In marine larviculture, farmed larvae mainly rely on the alimentation of a group of small-sized phytoplankton and zooplankton referred to as live feed. Under the diversifying demands of human consumption and ornamental aquarium industry, new species of live feed and their innovative production methods are essential focuses for sustainable larviculture of many emerging fish and invertebrate species. The selection of proper live feed for larval feeding is based on several parameters, such as size, morphology, nutritional value, stock density, and growth rate. This review aims to highlight the biological characteristics, production approach, common larviculture applications as well as recent innovations in the aquaculture technology of live feed organisms (microalgae, ciliated protists, rotifer, *Artemia*, copepod, and others).

Keywords: marine larviculture, live feed, microalgae, ciliate, rotifer, *Artemia*, copepod

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INTRODUCTION

The percentage of world aquaculture production over the total fishery resource has increased from 14.6% in 1986 to 46% in 2018 (FAO, 2020). Although aquaculture is a fast-growing industry, one of the bottlenecks is proper rearing of the early life stages of many farmed fish and invertebrate species (Hu et al., 2018; Gallardo et al., 2022). The significant difficulty is the first feeding at larval weaning stage. When larvae deplete yolk reserves and experience transition from endogenous to exogenous feeding, they do not benefit from a well-developed gastrointestinal tract to efficiently digest the formulated diets (Infante and Cahu, 2001; Yúfera and Darias, 2007). The young larvae have limited capacity of predation (detection and capture) due to its immature jaw, muscle, and optical developments (Hu et al., 2018). Moreover, the specific larval feeding behaviors and nutritional requirements should be considered when selecting suitable first feeding ingredients to achieve a successful larviculture production (Rønnestad et al., 2013; Mejri et al., 2021). Contrary to formulated diets, motile and viable phytoplankton and zooplankton provide more bioavailable nutrients and trigger higher predatory responses, and have been recognized as promising exogenous nutrients for marine larvae (Conceição et al., 2010; Nielsen et al., 2017; Kandathil Radhakrishnan et al., 2020). These dietary planktons could live with the farmed larvae in the rearing system, and be ingested by the larvae whenever desire, are thus referred as live feeds.

Most emerging species in marine aquaculture and aquarium industries have a sensitive and small-mouthed larval stage, and their larviculture are very challenging due to a lack of appropriate first feeding protocols. It is of a crucial interest to enhance diversification and innovation within live feed production programs to advance the fast-growing marine larviculture industry. Consequently, the aquaculture technologies of live feed productions are a focus point worldwide (Hansen and Møller, 2021). Here we review recent trends of live feed production at laboratory and industrial scales and discuss challenges and perspectives of its applications.

MICROALGAE

Microalgae plays a fundamental role in aquatic food webs by converting solar energy into bioavailable organic compounds and trophic resources. These micro-sized autotrophs are sustainable food item for aquaculture (Hemaiswarya et al., 2011), and are used as live feeds for several marine organisms such as bivalves (Tahir and Ransangan, 2021; Hassan et al., 2022), zooplankton (Pan et al., 2018; Dayras et al., 2021), larvae of crustacean (Sharawy et al., 2020; Sandeep et al., 2021), and echinoderm (Militz et al., 2018; Gomes et al., 2021). In marine hatcheries, the usage of microalgae could be categorized in three scenarios: (i) direct diet to provide nutrients to early developmental stages (Camus et al., 2021; Dayras et al., 2021); (ii) natural enrichment ingredients to zooplankton live feed organisms (Fu et al., 2021); (iii) water conditioners: microalgae are added to create "green water" which conditions water quality, reduces bacterial loads, increases visual contrast, and prey detection (Basford et al., 2021). Based on a variety of microalgal characteristics (**Table 1**) several aspects should be considered in applications: (i) cell size: that should be compatible to the ingestion capacities of the larvae; (ii) cell structure: property of cell walls or skeletons (e.g., cellulose, SiO_2, or $CaCO_3$) could affect the efficiency of ingestion and digestion; (iii) nutritional profile: content (actual amount) and composition (percentage) of various bioactive nutrients should be taken into account according to the nutritional requirements of their consumers (Borowitzka, 2013; Pan et al., 2018; Dayras et al., 2021). In general, the production of marine microalgal Chlorophytes (e.g., *Nannochloropsis* sp. and *Tetraselmis* sp.) can easily be sustained at high cell concentration and wide environmental conditions. Nevertheless, the thick cellulose cell wall and nutritional deficiency [i.e., low docosahexaenoic acid (DHA), 22: 6n-3, DHA or eicosapentaenoic acid (EPA), 20: 5n-3, EPA] hinder their applicability as live feed for some phytoplankton feeders (Pan et al., 2014). On the contrary, haptophyte and cryptophyte species (e.g., *Isochrysis* sp., *Tisochrysis* sp., and *Rhodomonas* sp.) provide superior nutritional values and higher digestibility due to their balanced polyunsaturated fatty acid (PUFA) profiles and soft cell structures (Latsos et al., 2020; Mai et al., 2021). Unfortunately, those microalgal species are relatively fragile and sensitive toward environmental stressors (e.g., temperature, salinity, and pH variations), and require more time and experienced labor to achieve successful productions. Recent studies focused on how to technically enhance their cell densities by manipulating the culture environments at automated regulations. In the past decade, photobioreactors (PBR) have been developed to produce microalgal biomass for biodiesel production (Peter et al., 2022). Currently many programs of biomass production are used to extract bioactive compounds with an increasing use of diverse systems such as mesh ultra-thin layer, tubular glass, plastic bag, and flat-plate PBRs (Sandmann et al., 2021; Tayebati et al., 2021; Wurm and Sandmann, 2021). Although the PBR might increase production cost, these well programmed systems could realize extremely high cell density for aquaculture purposes (Vu et al., 2019; Tibbetts et al., 2020; Leal et al., 2021). Biotechnology has opened new avenues for microalgal applications, where strain selection including non-genetic as well as genetic modifications facilitate beneficial bioactive compounds (e.g., anti-pathogenic, anti-oxidant, etc.) for farmed aquatic larvae (Kiataramgul et al., 2020). Yet the biosecurity of transgenic microalgae should be carefully evaluated before their large-scale utilization.

CILIATED PROTISTS

Ciliates are a group of single-celled protist, which commonly exist in marine environments worldwide. Some ciliate species are pathogenic for fish, because they experience partially or completely their life cycle in or on the host (Jahangiri et al., 2021). Another group of ciliates appear to be planktonic and they have a potential as live feed in marine hatcheries (Wan-Mohtar et al., 2021). Culture techniques for *Euplotes* sp. and *Fabre* sp. have been developed in recent studies (**Table 1**). Ciliates could rapidly increase their populations by fission when fed on baker's yeast, fermented fish meal, and photosynthetic bacteria (de Freitas Côrtes et al., 2013; Balamuralir, 2020; Teiba et al., 2020). The production of these fast-growing protists does not necessarily rely on a microalgal diet, which greatly enhance the feasibility and convenience for culture maintenance. Most importantly, ciliates are known for their tiny cell size (20–60 μm), which is particularly favorable for small-mouthed larvae (Hill et al., 2020). Indeed, ciliate-based diets have been acknowledged to successfully sustain larvae rearing of several marine ornamental or edible fish species (Nagano et al., 2000; Rhodes and Phelps, 2008; Madhu and Madhu, 2014; Leu et al., 2015). On the other hand, the use of bacteriovorous ciliates for pathogen removal has recently emerged. Lin et al. (2020) noted the remarkable increase of survival rate (approx. 60%) in pathogen challenge trials of grouper larvae when the water containing rich *Vibrio campbellii* was prefiltered by the ciliate *Strombidium* sp.

ROTIFERS

Rotifers are a group of multicellular microorganisms making up a phylum Rotifera. Since the 1970s, species and strains of the genus *Brachionus* have been used as live feed for the first feeding of marine larvae during 3–10 days post hatching (dph) (Lubzens et al., 2001). Although the taxonomy of *Brachionus plicatilis* and *Brachionus rotundiformis* complex remains inconclusive, they are normally referred as SS, S, and L type rotifer based on their size. Rotifers are highly demanded in the current larviculture industry due to the following reasons: (1) reasonable size spectrum (100–250 μm) and slow cruising swimming pattern for first feeding of commercially important fish species (e.g., sea bream and sea

TABLE 1 | Characteristics of different live feed organisms used in marine larviculture.

		Size range as live feed	General culture conditions	Common nutrient/diet	Applications as live feeds	Key nutritional advantages (% total FA or AA)	References
Microalgae	*Isochrysis* sp.	3–6 μm	15–30°C, SNS	Walne's, f/2 medium, agricultural fertilizers	Diet for copepod, rotifer, larvae of bivalves, echinoderms, and phytoplanktivorous fish	1–9% EPA; 8.1–12.5% DHA	Pan et al., 2018; Balakrishnan and Shanmugam, 2021; Shekarabi et al., 2021
	Tisochrysis sp.	3–7.5 μm	18–30°C, SNS			0.6–0.8% EPA; 10–11% DHA	Tato and Beiras, 2019; Dayras et al., 2021; Mai et al., 2021
	Pavlova sp.	4–6 μm	23–20°C, SNS			17.8–33.9% EPA; 3.6–10.2% DHA	Rehberg-Haas et al., 2015; Yang et al., 2020; Dayras et al., 2021; Hassan et al., 2022
	Nannochloropsis sp.	2–4 μm	26–30°C, SNS			26.2–35.2% EPA; 0–0.52% DHA	Pan et al., 2018; Yang et al., 2020
	Tetraselmis sp.	13–15 μm	26–30°C, SNS			4.2–5.2% EPA; 23.6–27.9% ALA	Pan et al., 2018; Lee et al., 2021
	Rhodomonas sp.	7–14 μm	15–25°C, SNS			8–15.8% EPA; 6–8.8% DHA	Latsos et al., 2020; Oostlander et al., 2020; Dayras et al., 2021
Rotifer	*Brachionus* sp.	90–320 μm	25°C, 15–35 ppt	Microalgae (fresh cells, lipolyzed powder or concentrated paste)	First-feeding (2–10 dph) of larval fish and crustacean	Nutritional profile could be manipulated by enrichment	Snell et al., 2019
	Colurella sp.	48–99 μm	22–28°C, 15–34 ppt				Chigbu and Suchar, 2006; Madhu et al., 2016
	Proales sp.	82.7 ± 10.9 μm	25°C, 2–25 ppt				Wullur et al., 2011; Hagiwara et al., 2014
Ciliated Protist	*Euplotes* sp.	60–110 μm	25–32°C, 20–30 ppt	Baker yeast, fermented fish diet, and microalgae	First-feeding (2–10 dph) of small-mouthed larval fish	Nutritional profile could be manipulated by enrichment	Tarangkoon et al., 2018; da Annunciação et al., 2020
	Metacylis sp.	37–50 μm	30°C, 33 ppt				Lee and Choi, 2016
Artemia	*Artemia* sp.	Newly-hatched: 400–500 μm; Enriched: 500–700 μm	28°C, 25–33 ppt	No feeding: nauplii used after hatch or enrichment (fish oil, fish soluble emulsions)	Fish or crustacean larvae at second-stage feeding (>10 dph)	Nutritional profile could be manipulated by enrichment	Figueiredo et al., 2009
Copepod	*Pseudodiaptomus annandalei*/ *P. inopinus*	150–1,100 μm/ 200–800 μm	25–30°C, 15–20 ppt/20°C, 17 ppt	Live microalgae cell (*Isochrysis*, *Rhodomonas/Phaeodactylum*, *Pavlova*, *Tisochrysis*, and *Chlorella*)	Several developmental stages (size range: 60–1,200 μm) for larval fish and crustaceans at different feeding stages	2.9–12.8% EPA, 12.6–57% DHA/ 0.6–24.4% EPA, 1.3–12.7% DHA	Golez et al., 2004; Rayner et al., 2015; Matsui et al., 2021; Nielsen et al., 2021
	Acartia bilobata/ *A. tonsa*	100–1,100 μm/ 100–1,200 μm	25–30°C, 15–20 ppt/ 17–23°C, 27–34 ppt	Live microalgae cell (*Isochrysis/Rhodomonas*)		ND/ 16.5% EPA, 7.9% EPA	Drillet et al., 2008; Pan et al., 2014; Chi et al., 2018; Torres et al., 2022
	Apocyclops royi	100–1,000 μm	25–30°C, 15–20 ppt	Live microalgae (*Isochrysis*, *Rhodomonas*, and *Dunaliella*), baker yeast		1.8–13.4% EPA; 4–35.3% DHA	Chang and Lei, 1993; Pan et al., 2018; Nielsen et al., 2021
	Parvocalanus crassirostris	60–400 μm	21–27°C, 20–36 ppt	Live microalgae (*Tisochrysis*, *Isochrysis*, *Rhodomonas*, *Tetraselmis*, and *Heterocapsa*)		2.8–5.4% EPA; 6.1–22.3% DHA	McKinnon et al., 2003; Alajmi, 2015; Kline and Laidley, 2015; Jackson and Lenz, 2016
	Paracyclopina nana	70–600 μm	18°C, 15 ppt	Live microalgae (*Tisochrysis*, *Rhodomonas*, and *Pavlova*)		2.3–5.5% EPA; 8.9–13.3% DHA	Lee et al., 2006; Dayras et al., 2021
	Bestiolina similis/ *B. amoyensis*	70–560 μm/ <100–<1,000 μm	26–28°C, 29–31 ppt/ 24–26°C, 28 ppt	Live microalgae (*Isochrysis*, *Pavlova*, *Rhodomonas*, and *Tetraselmis/Isochrysis*)		0.6% EPA; 2.5% DHA/ ND	McKinnon et al., 2003; Lian et al., 2018; Camus et al., 2021
Other live feeds	Moon jellyfish *Aurelia aurita*	5 ± 1 cm	22°C, NS	*Artemia* nauplii/wild-captured zooplankton	Lobster phyllosoma larvae, Juveniles of silver pomfret, and threadsail filefish	9.88–17.5% EPA; 1.3–1.8% DHA, 0.8–14.5% glycine	Liu et al., 2015; Wakabayashi et al., 2016b
	Flame jellyfish *Rhopilema esculentum*	2 ± 0.5 cm	22°C, NS			7.8% EPA; 1.36% glycine	Liu et al., 2015
	Fungal-like protists *Schizochytrium* sp.	9–14 μm	30°C, FW	Glucose solution	Diet or enrichment products for copepod, rotifer, and Artemia	40–54% DHA	Ramos-Vega et al., 2018; Guo et al., 2020
	Oyster fertilized egg or trochophore	50-70 μm	27.5-29°C, 35 ppt	No feeding: trochophore used after fertilization	First-feeding (2–10 dph) of small-mouthed larval fish	2.2–5.4% EPA; 2–3.3% DHA	Hur et al., 2008; Basford et al., 2019

FA, fatty acid; AA, amino acid; SNS, sterilized natural seawater; NS, natural seawater; FW, fresh water; EPA, eicosapentaenoic acid (20: 5n3); DHA, docosahexaenoic acid (22: 6n3); ALA, α-Linolenic acid; dph, days post hatching; ND, no data.

bass) (Conceição et al., 2010); (2) parthenogenetic reproduction facilitates high duplication rates (Fu et al., 2021); (3) capacity of tolerating high population densities and environmental variation (Suantika et al., 2003); (4) vector of nutrients or medicine delivery for fish larvae (Eryalcin, 2018; Fu et al., 2021; Safiin et al., 2021). In common batch culture systems, the density of *Brachionus* rotifer peaks during 4–7 day-post-inoculation, then the partial harvest and water exchange are carried out until subsequent inoculation (Sales et al., 2019). A semi-continuous recirculating aquaculture systems (RAS) has been developed to sustain superintensive rotifer cultures (> 5,000 ind./mL) for periodic harvest (Suantika et al., 2000; Suantika et al., 2003). The maintenance of superintensive culture, however, increase the cost of rotifer production due to the equipment requirements of a recirculating aquaculture system (Suantika et al., 2003). Besides environmental control, antioxidants could be fed to rotifers to further improve their stress resistance in high density cultures with deteriorating water quality (Gao et al., 2021). The nutritional enrichment of rotifers is necessary due to the lack of many essential fatty acids for fish larvae at the first feeding stage (Ferreira et al., 2018; Ghaderpour and Estevez, 2020). Several enrichment products and protocols have been developed and evaluated to enhance larval growth and survival by improving ω3 highly unsaturated fatty acid (HUFA) content, and a high DHA/EPA ratio in rotifers (Abu-Rezq et al., 2002). Recently, cultures of very tiny rotifer species (< 100 μm), such as *Proales similis* and *Colurella adriatica*, have been established (**Table 1**) and used particularly for the first feeding of small-mouthed larvae of marine ornamental species (Hagiwara et al., 2014; Madhu et al., 2016; Rebolledo et al., 2021).

ARTEMIA

Artemia is a genus of aquatic crustaceans in the class Branchiopoda, which dominates in hypersaline habitats (e.g., inland salt lakes). During dry seasons, *Artemia* starts to produce floating resting eggs (aka cysts) due to extreme hypersaline stress. The cysts are collected and processed (purification and dehydration), then canned in dark and cold conditions for further storage and distribution. Although *Artemia* are not naturally accessible food items for most marine or brackish larvae, they are extensively used in larviculture industry due to the following reasons: (i) durable cysts and manipulable hatching: obtain nauplii at desirable timepoints for larval feeding; (ii) size suitability: first naupliar stage of various *Artemia* species is ranging 400–500 μm offering preferable size for second-staged larval feeding (7–14 dph); (iii) vector of nutrients or medicine delivery systems (enrichment needed before use) (Eryalcin, 2018). *Artemia franciscana* (**Table 1**) is one of the most utilized species due to its smaller body size and first-ranked annual production (1,000–2,000 tons) from the Great Salt Lake of Utah, United States. Whereas the production from hypersaline lakes in West Siberia, Russia and Kazakhstan, and salt works at Bohai Bay, China are ranked second or third cyst production areas of *Artemia parthenogenetica* and *A. franciscana*, respectively (Litvinenko et al., 2015). Other production areas, such as Brazil (Camara, 2020), Vietnam (Le et al., 2019), Iran (Manaffar et al., 2020), and Tunisia (Sellami et al., 2020), also contribute certain amounts of cyst production. Due to the high market demand, Artemia Reference Centers have been established at Ghent University, Belgium in 1978, and at Tianjin University of Science and Technology, China in 2018 to promote applications of Artemia globally. Climate change and pollution have significant impacts on the harvest yield of cysts and consequently the price (Guong and Hoa, 2012; Santos et al., 2018; Van Stappen et al., 2020). Proper managements of culture conditions in salt work production (especially in Bohai Bay, China and Mekong Delta, Vietnam) should be addressed to stabilize both cyst and salt production, which might encourage a better socio-economic perspective for Artemia farming and their global supply (Manaffar et al., 2020).

COPEPODS

Planktonic copepods are naturally accessible and preferable live feeds for fish or invertebrate larvae in the marine environment and are used as live feeds in aquaculture hatcheries (Drillet et al., 2011; Santhanam et al., 2019; Fernández-Ojeda et al., 2021). Species from the orders Calanoida, Cyclopoida, and Harpacticoida are commonly selected and cultivated for larval feedings. Copepods provide wide windows of prey size (60–1,500 μm) due to their species diversity and 12 developmental stages (six nauplii, five copepodites, and adult). Their jerky swimming pattern attracts a higher predatory response of fish larvae (Burbano et al., 2020). Remarkably, the nutritional advantages (great contents of ω3 HUFA) make these zooplankters favorable for larviculture even without an additional enrichment process (Matsui et al., 2021). In Taiwan and Vietnam, copepods are commonly harvested from outdoor earthen ponds after fertilization (Su et al., 2005; Blanda et al., 2015; GrØnning et al., 2019). Outdoor combined-species cultures might be feasible and cost effective, but the concerns of unstable production, species composition, and risks in pathogenic transmission have hindered the applications of copepods (Chang et al., 2011; Blanda et al., 2017). On the other hand, mono-species indoor copepod cultures of various species were established at either laboratory or intensive scales (**Table 1**), which facilitate copepod biomass of economic feasibility and biosecurity for larviculture industry (Abate et al., 2016; Santhosh et al., 2018). Particularly, the success in "micro-sized" copepod production (i.e., adult < 1 mm and nauplii < 80 μm, such as in *Parvocalanus* sp., *Bestiolina* sp., and *Paracyclopina* sp.) have opened bright avenues for the larviculture of marine ornamental fish (Kline and Laidley, 2015; Callan et al., 2018; Zeng et al., 2018; Dayras et al., 2021; Wang L. et al., 2021), which are considered as challenging but necessary for trade and conservation demands. Instead of maintaining the culture, resting eggs and cryopreservation are alternative approaches to obtain alive copepods (Kaviyarasan and Santhanam, 2019; Pan et al., 2020; Wilson et al., 2021). Although the cold stored production of a specific copepod species (*Acartia tonsa*) seems to be applicable and commercialized, induction and storage protocol of various dormant copepod species and stages should be further optimized to universally apply their novelties by the industry.

OTHER LIVE FEEDS

Heterotrophic *Schizochytrium* sp., *Halophytophthora* sp., and *Salispina* sp. (**Table 1**) are a group of unicell or filamentous microorganisms containing great amounts of PUFAs (Estudillo-del Castillo et al., 2009; Su et al., 2021). The spray-dried powder of these microorganisms implicates great potential as alternative or supplementary diets to microalgae for the feeding and enrichment of zooplanktonic live feeds (Eryalçın, 2019). Besides holoplankton, some sessile marine organisms could be used as live feeds at their early developmental stages of planktonic life forms. Fertilized eggs and trochophore of bivalves, such as oyster (*Crassostrea* sp.) and blue mussel (*Mytilus* sp.), could be obtained by strip spawning (Scarpa, 2002; Turan and Kling, 2018). They are of a suitable size (40–60 μm) and great ω3 HUFAs contents, thus particularly supportive for the first-feeding of small-mouthed fish such as grouper and other reef species (Liao et al., 2001; Basford et al., 2019). Planktonic barnacle nauplii (100–150 μm) are also considered as potential live feeds (López et al., 2010; Basford et al., 2019). Cladocera species (e.g., *Daphnia* sp., *Moina* sp., and *Ceriodaphnia* sp.) could be cultivated with low cost using aquaculture biofloc technology and fermented animal wastes (da Silva Campos et al., 2020; Rasdi et al., 2020; Turcihan et al., 2022), and serve as live feeds for many freshwater fish larvae such as tilapia (Herawati et al., 2015), catfish (Vu and Huynh, 2020), and ornamentals like Betta fish (Kwon et al., 2013) and freshwater angelfish (Farhadian et al., 2014). Notably, studies have also indicated the feasibility of using water flea as live feed in marine larviculture of fish (Kamrunnahar et al., 2019) and shrimp (Mona et al., 2017). Jellyfish are used as live feed for the phyllosoma larvae of lobster (Palinuridae and Scyllaridae) (Goldstein and Nelson, 2011; Wakabayashi et al., 2012, 2016a), Threadsail filefish (Miyajima et al., 2011), and silver pomfret juveniles (Wang Q. et al., 2021).

DISCUSSION AND FUTURE PERSPECTIVES

Despite their wide applications in marine larviculture, the widely used live feeds (*Brachionus* rotifers and *Artemia*) show several limitations. The diversification and establishment of new live feed culture (especially micro-sized copepod and rotifer species) is promoting research programs and industrial applications. Production of dormant live feed (e.g., copepod resting eggs) is an ongoing program, and this is expected to pave the road for the marine larviculture industry. Future programs should target both indoor and outdoor aquaculture systems using appropriate RAS techniques with artificial intelligence (AI) technology to optimize both prey and larval culture performances. Developing technology and management of both virus free and bacterial free live feed for larviculture. Transferring scientific technology of live feed from academic achievements to stakeholders such as the aquaculture industry and farmers. Both scientists and farmers should work closely together to ensure the upscaling of pilot studies and maintain a required feedback cycle between industrial needs and their declination as scientific research challenges.

AUTHOR CONTRIBUTIONS

Y-JP wrote the first draft of the manuscript. H-UD, J-SH, and SS contributed to manuscript revision with Y-JP. All authors contributed to conception, design of the mini review, and approved the submitted version.

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REFERENCES

Abate, T. G., Nielsen, R., Nielsen, M., Jepsen, P. M., and Hansen, B. W. (2016). A cost-effectiveness analysis of live feeds in juvenile turbot *Scophthalmus maximus* (Linnaeus, 1758) farming: copepods versus *Artemia*. *Aquac. Nutr.* 22, 899–910. doi: 10.1111/anu.12307

Abu-Rezq, T., Al-Abdul-Elah, K., Duremdez, R., Al-Marzouk, A., James, C. M., Al-Gharabally, H., et al. (2002). Studies on the effect of using the rotifer, *Brachionus plicatilis*, treated with different nutritional enrichment media and antibiotics on the growth and survival of blue-fin sea bream, *Sparidentex hasta* (Valenciennes), larvae. *Aquac. Res.* 33, 117–128. doi: 10.1046/j.1365-2109.2002.00658.x

Alajmi, F. F. (2015). *Developing Intensive Culture Techniques for the Tropical Copepod Parvocalanus Crassirostris as a Live Feed for Aquaculture*. Ph.D thesis, Australia: James Cook University.

Balakrishnan, J., and Shanmugam, K. (2021). Lowering the culture medium temperature improves the omega-3 fatty acid production in marine microalga *Isochrysis* sp. CASA CC 101. *Prep. Biochem. Biotechnol.* 51, 511–518. doi: 10.1080/10826068.2020.1833345

Balamuralir, R. S. (2020). Experimental evaluation of diets for culture of a potential live feed, *Euplotes* sp. (Protozoa, Ciliophora) Uttar Pradesh. *J. Zool.* 4, 140–146.

Basford, A. J., Makings, N., Mos, B., White, C. A., and Dworjanyn, S. (2021). Greenwater, but not live feed enrichment, promotes development, survival, and growth of larval *Portunus armatus*. *Aquaculture* 534:736331. doi: 10.1016/j.aquaculture.2020.736331

Basford, A. J., Mos, B., Mishina, T., and Dworjanyn, S. A. (2019). Oyster larvae as a potential first feed for small-mouthed ornamental larval fish. *Aquac. Environ. Interact.* 11, 657–669. doi: 10.3354/aei00338

Blanda, E., Drillet, G., Huang, C. C., Hwang, J. S., Højgaard, J. K., Jakobsen, H. H., et al. (2017). An analysis of how to improve production of copepods as live feed from tropical Taiwanese outdoor aquaculture ponds. *Aquaculture* 479, 432–441. doi: 10.1016/j.aquaculture.2017.06.018

Blanda, E., Drillet, G., Huang, C. C., Hwang, J. S., Jakobsen, H. H., Rayner, T. A., et al. (2015). Trophic interactions and productivity of copepods as live feed from tropical Taiwanese outdoor aquaculture ponds. *Aquaculture* 445, 11–21. doi: 10.1016/j.aquaculture.2015.04.003

Borowitzka, M. A. (2013). High-value products from microalgae—their development and commercialisation. *J. Appl. Phycol.* 25, 743–756. doi: 10.1007/s10811-013-9983-9

Burbano, M. F., Torres, G. A., Prieto, M. J., Gamboa, J. H., and Chapman, F. A. (2020). Increased survival of larval spotted rose snapper *Lutjanus guttatus* (Steindachner, 1869) when fed with the copepod *Cyclopina* sp. and *Artemia* nauplii. *Aquaculture* 519:734912. doi: 10.1016/j.aquaculture.2019.734912

Callan, C. K., Burgess, A. I., Rothe, C. R., and Touse, R. (2018). Development of improved feeding methods in the culture of yellow tang, *Zebrasoma flavescens*. *J. World Aquac. Soc.* 49-3, 493–503. doi: 10.1111/jwas.12496

Camara, M. R. (2020). After the gold rush: A review of *Artemia* cyst production in northeastern Brazil. *Aquac. Rep.* 17:100359. doi: 10.1016/j.aqrep.2020.100359

Camus, T., Rolla, L., Jiang, J., and Zeng, C. (2021). Effects of microalgal food quantity on several productivity-related parameters of the Calanoid copepod *Bestiolina similis* (Calanoida: Paracalanidae). *Front. Mar. Sci.* 8:812240. doi: 10.3389/fmars.2021.812240

Chang, W. B., and Lei, C. H. (1993). Development and energy content of a brackish-water copepod, *Apocyclops royi* (Lindberg) reared in a laboratory. *Bull. Inst. Zool. Acad. Sin*. 32, 62–81.

Chang, Y. S., Chen, T. C., Liu, W. J., Hwang, J. S., Kou, G. H., and Lo, C. F. (2011). Assessment of the roles of copepod *Apocyclops royi* and bivalve mollusk *Meretrix lusoria* in white spot syndrome virus transmission. *Mar. Biotechnol.* 13, 909–17. doi: 10.1007/s10126-010-9352-5

Chi, X., Javidpour, J., Sommer, U., and Mueller-Navarra, D. (2018). Tracking fatty acids from phytoplankton to jellyfish polyps under different stress regimes: a three trophic levels experiment. *Front. Ecol. Evol.* 6:118. doi: 10.3389/fevo.2018.00118

Chigbu, P., and Suchar, V. A. (2006). Isolation and culture of the marine rotifer, *Colurella dicentra* (Gosse, 1887), from a Mississippi Gulf Coast estuary. *Aquac. Res.* 37, 1400–1405. doi: 10.1111/j.1365-2109.2006.01572.x

Conceição, L. E., Yúfera, M., Makridis, P., Morais, S., and Dinis, M. T. (2010). Live feeds for early stages of fish rearing. *Aquac. Res.* 41, 613–640. doi: 10.1111/j.1365-2109.2009.02242.x

da Annunciação, W. F., Ohs, C. L., and Tsuzuki, M. Y. (2020). Influence of food concentration and abiotic parameters on population density growth of the ciliated marine protozoan *Euplotes* sp. under controlled conditions. *Aquac. Res.* 51-2, 523–534. doi: 10.1111/are.14397

da Silva Campos, C. V. F., da Silva, Farias, R., da Silva, S. M. B. C., Severi, W., et al. (2020). Production of *Daphnia similis* Claus, 1876 using wastewater from tilapia cultivation in a biofloc system. *Aquacu. Int.* 28, 403–419. doi: 10.1007/s10499-019-00470-7

Dayras, P., Bialais, C., Sadovskaya, I., Lee, M. C., Lee, J. S., and Souissi, S. (2021). Microalgal diet influences the nutritive quality and reproductive investment of the cyclopoid copepod *Paracyclopina nana*. *Front. Mar. Sci.* 8:697561. doi: 10.3389/fmars.2021.697561

de Freitas Côrtes, G., Tsuzuki, M. Y., and Melo, E. M. C. (2013). Monoculture of the ciliate protozoan *Euplotes* sp. (Ciliophora; Hypotrichia) fed with different diets. *Acta Sci. Biol. Sci.* 3, 15–19. doi: 10.4025/actascibiolsci.v35i1.11795

Drillet, G., Frouël, S., Sichlau, M. H., Jepsen, P. M., Højgaard, J. K., Joarder, A. K., et al. (2011). Status and recommendations on marine copepod cultivation for use as live feed. *Aquaculture* 315, 155–166. doi: 10.1016/j.aquaculture.2011.02.027

Drillet, G., Jepsen, P. M., Højgaard, J. K., Jørgensen, N. O., and Hansen, B. W. (2008). Strain-specific vital rates in four *Acartia tonsa* cultures II: life history traits and biochemical contents of eggs and adults. *Aquaculture* 279, 47–54. doi: 10.1016/j.aquaculture.2008.04.010

Eryalcin, K. M. (2018). Effects of different commercial feeds and enrichments on biochemical composition and fatty acid profile of rotifer (*Brachionus Plicatilis*, Muller 1786) and *Artemia franciscana*. *Turk. J. Fish. Aquat. Sci.* 18, 81–90. doi: 10.4194/1303-2712-v18_1_09

Eryalçın, K. M. (2019). Nutritional value and production performance of the rotifer *Brachionus plicatilis* Müller, 1786 cultured with different feeds at commercial scale. *Aquac. Int.* 2, 875–890. doi: 10.1007/s10499-019-00375-5

Estudillo-del Castillo, C., Gapasin, R. S., and Leaño, E. M. (2009). Enrichment potential of HUFA-rich thraustochytrid *Schizochytrium mangrovei* for the rotifer *Brachionus plicatilis*. *Aquaculture* 293, 57–61. doi: 10.1016/j.aquaculture.2009.04.008

FAO (2020). *The State of World Fisheries and Aquaculture 2020*. Rome: Food and Agriculture Organization.

Farhadian, O., Kharamannia, R., Mahboobi Soofiani, N., and Ebrahimi Dorche, E. (2014). Larval feeding behaviour of angel fish *Pterophyllum scalare* (Cichlidae) fed copepod *Eucyclops serrulatus* and cladoceran *Ceriodaphnia quadrangula*. *Aquac. Res.* 45, 1212–1223. doi: 10.1111/are.12065

Fernández-Ojeda, C., Muniz, M. C., Cardoso, R. P., dos Anjos, R. M., Huaringa, E., Nakazaki, C., et al. (2021). Plastic debris and natural food in two commercially important fish species from the coast of Peru. *Mar. Pollut. Bull.* 173:113039. doi: 10.1016/j.marpolbul.2021.113039

Ferreira, M., Cortina-Burgueño, Á, Freire, I., and Otero, A. (2018). Effect of nutritional status and concentration of *Nannochloropsis gaditana* as enrichment diet for the marine rotifer *Brachionus* sp. *Aquaculture* 491, 351–357. doi: 10.1016/j.aquaculture.2018.03.024

Figueiredo, J., van Woesik, R., Lin, J., and Narciso, L. (2009). *Artemia franciscana* enrichment model - How to keep them small, rich and alive? *Aquaculture* 294, 212–220. doi: 10.1016/j.aquaculture.2009.05.007

Fu, Z., Yang, R., Zhou, S., Ma, Z., and Zhang, T. (2021). Effects of rotifers enriched with different enhancement products on larval performance and jaw deformity of golden pompano larvae *Trachinotus ovatus* (Linnaeus, 1758). *Front. Mar. Sci.* 7:1232. doi: 10.3389/fmars.2020.626071

Gallardo, P., Bueno, G. W., Araneda, C., and Benfey, T. (2022). Status of Atlantic halibut (*Hippoglossus hippoglossus*) aquaculture production technology in Chile. *Aquac. Rep.* 22:100958. doi: 10.1016/j.aqrep.2021.100958

Gao, Y. S., Chen, Y. K., Wang, Q. J., Wang, G. Q., Lin, L. L., Chen, X. M., et al. (2021). L-carnitine can improve the population growth and anti-stress ability of rotifer (*Brachionus rotundiformis*) under ammonia stress. *Aquac. Rep.* 20:100622. doi: 10.1016/j.aqrep.2021.100622

Ghaderpour, S., and Estevez, A. (2020). Effect of short-term rotifer enrichment with marine phospholipids on growth, survival, and composition of meager (*Argyrosomus regius*) larvae. *Front. Mar. Sci.* 7:1082. doi: 10.3389/fmars.2020.579002

Goldstein, J. S., and Nelson, B. (2011). Application of a gelatinous zooplankton tank for the mass production of larval Caribbean spiny lobster, *Panulirus argus*. *Aquat. Living Resour.* 24, 45–51. doi: 10.1051/alr/2011100

Golez, M. N., Takahashi, T., Ishimarul, T., and Ohno, A. (2004). Post-embryonic development and reproduction of *Pseudodiaptomus annandalei* (Copepoda: Calanoida). *Plankton Biol. Ecol.* 51, 15–25.

Gomes, A., Lourenço, S., Santos, P. M., Raposo, A., Mendes, S., Gonçalves, S. C., et al. (2021). Effects of single and mixed-diatom diets on growth, condition, and survival of larvae of the sea urchin *Paracentrotus lividus* (Lamarck, 1816). *Aquac. Int.* 29, 1069–1090. doi: 10.1007/s10499-021-00676-8

GrØnning, J., Doan, N. X., Dinh, N. T., Dinh, K. V., and Nielsen, T. G. (2019). Ecology of *Pseudodiaptomus annandalei* in tropical aquaculture ponds with emphasis on the limitation of production. *J. Plankton Res.* 41, 741–758. doi: 10.1093/plankt/fbz053

Guo, D. S., Tong, L. L., Ji, X. J., Ren, L. J., and Ding, Q. Q. (2020). Development of a strategy to improve the stability of culture environment for docosahexaenoic acid fermentation by *Schizochytrium* sp. *Appl. Biochem. Biotechnol.* 19, 881–894. doi: 10.1007/s12010-020-03298-7

Guong, V. T., and Hoa, N. M. (2012). "Aquaculture and agricultural production in the Mekong Delta and its effects on nutrient pollution of soil and water," in *The Mekong Delta System*, eds F. G. Renaud and C. Kuenzer (Dordrecht: Springer), 363–393. doi: 10.1007/978-94-007-3962-8_14

Hagiwara, A., Wullur, S., Marcial, H. S., Hirai, N., and Sakakura, Y. (2014). Euryhaline rotifer *Proales similis* as initial live food for rearing fish with small mouth. *Aquaculture* 432, 470–474. doi: 10.1016/j.aquaculture.2014.03.034

Hansen, B. W., and Møller, S. (2021). A bibliometric survey of live feed for marine finfish and shrimp larval production. *Aquac. Res.* 52, 5124–5135. doi: 10.1111/are.15460

Hassan, M. M., Parks, V., and Laramore, S. (2022). Variation in filtration and ingestion rates among different microalgae species by hard clam, *Mercenaria mercenaria*, larvae and post-set juveniles. *Aquac. Res.* 53, 684–688. doi: 10.1111/are.15585

Hemaiswarya, S., Raja, R., Ravi Kumar, R., Ganesan, V., and Anbazhagan, C. (2011). Microalgae: a sustainable feed source for aquaculture. *World J. Microbiol. Biotechnol.* 27, 1737–1746. doi: 10.1007/s11274-010-0632-z

Herawati, V. E., Hutabarat, J., and Radjasa, O. K. (2015). Growth and survival rate of tilapia (*Oreochromis niloticus*) larvae fed by *Daphnia magna* cultured with organic fertilizer resulted from probiotic bacteria fermentation. *HAYATI J. Biosci.* 22, 169–173. doi: 10.1016/j.hjb.2015.08.001

Hill, M., Pernetta, A., and Crooks, N. (2020). Size matters: a review of live feeds used in the culture of marine ornamental fish. *Asian Fish. Sci.* 3, 161–174. doi: 10.33997/j.afs.2020.33.2.007

Hu, J., Liu, Y., Ma, Z., and Qin, J. G. (2018). "Feeding and development of warm water marine fish larvae in early life," in *Emerging Issues in Fish Larvae Research*, ed. M. Yúfera (Cham: Springer), 275–296. doi: 10.1007/978-3-319-73244-2_10

Hur, Y. B., Min, K. S., Kim, T. E., Lee, S. J., and Hur, S. B. (2008). Larvae growth and biochemical composition change of the Pacific oyster *Crassostrea gigas*, larvae during artificial seed production. *J. Aquac.* 2, 203–212.

Infante, J. Z., and Cahu, C. L. (2001). Ontogeny of the gastrointestinal tract of marine fish larvae. *Comp. Biochem. Physiol. Part C* 130, 477–487. doi: 10.1016/s1532-0456(01)00274-5

Jackson, J. M., and Lenz, P. H. (2016). Predator-prey interactions in the plankton: larval fish feeding on evasive copepods. *Sci. Rep.* 6, 1–11. doi: 10.1038/srep33585

Jahangiri, L., Shinn, A. P., Pratoomyot, J., and Bastos Gomes, G. (2021). Unveiling associations between ciliate parasites and bacterial microbiomes under warm-water fish farm conditions–a review. *Rev. Aquac.* 13, 1097–1118. doi: 10.1111/raq.12514

Kamrunnahar, K., Md, A., Jeong, U. C., and Kang, S. J. (2019). Mass culture of *Moina macrocopa* using organic waste and its feeding effects on the performance of *Pagrus major* larvae. *Egypt. J. Aquat. Res.* 45, 75–80. doi: 10.1016/j.ejar.2019.02.001

Kandathil Radhakrishnan, D., AkbarAli, I., Schmidt, B. V., John, E. M., Sivanpillai, S., and Thazhakot Vasunambesan, S. (2020). Improvement of nutritional quality of live feed for aquaculture: An overview. *Aquac. Res.* 51, 1–17. doi: 10.1111/are.14357

Kaviyarasan, M., and Santhanam, P. (2019). "A technique on the culture and preservation of marine copepod eggs," in *Basic and Applied Zooplankton Biology*, eds P. Santhanam, A. Begum, and P. Pachiappan (Singapore: Springer), 197–208. doi: 10.1007/978-981-10-7953-5_6

Kiataramgul, A., Maneenin, S., Purton, S., Areechon, N., Hirono, I., Brocklehurst, T. W., et al. (2020). An oral delivery system for controlling white spot syndrome virus infection in shrimp using transgenic microalgae. *Aquaculture* 521:735022. doi: 10.1016/j.aquaculture.2020.735022

Kline, M. D., and Laidley, C. W. (2015). Development of intensive copepod culture technology for *Parvocalanus crassirostris*: optimizing adult density. *Aquaculture* 435, 128–136. doi: 10.1016/j.aquaculture.2014.09.022

Kwon, O. N., Park, K. Y., and Park, H. G. (2013). The rotifer *Brachionus calyciflorus* and water flea *Moina macrocopa* as alternative foods for production of the fighting fish *Betta splendens*. *Korean J. Fish. Aquat. Sci.* 46, 393–398. doi: 10.5657/KFAS.2013.0393

Latsos, C., Van Houcke, J., and Timmermans, K. R. (2020). The effect of nitrogen starvation on biomass yield and biochemical constituents of *Rhodomonas* sp. *Front. Mar. Sci.* 7:900. doi: 10.3389/fmars.2020.563333

Le, T. H., Hoa, N. V., Sorgeloos, P., and Van Stappen, G. (2019). *Artemia* feeds: a review of brine shrimp production in the Mekong Delta, Vietnam. *Rev. Aquac.* 11, 1169–1175. doi: 10.1111/raq.12285

Leal, E., de Beyer, L., O'Connor, W., Dove, M., Ralph, P. J., and Pernice, M. (2021). Production optimisation of *Tisochrysis lutea* as a live feed for juvenile Sydney rock oysters, *Saccostrea glomerata*, using large-scale photobioreactors. *Aquaculture* 533:736077. doi: 10.1016/j.aquaculture.2020.736077

Lee, K. W., and Choi, Y. U. (2016). Population growth of a tropical tintinnid, *Metacylis tropica* on different temperature, salinity and diet. *J. Korea Acad. Ind. Coop. Soc.* 17, 322–328. doi: 10.5762/KAIS.2016.17.9.322

Lee, K. W., Park, H. G., Lee, S. M., and Kang, H. K. (2006). Effects of diets on the growth of the brackish water cyclopoid copepod *Paracyclopina nana* Smirnov. *Aquaculture* 256, 346–353. doi: 10.1016/j.aquaculture.2006.01.015

Lee, W. K., Ryu, Y. K., Choi, W. Y., Kim, T., Park, A., Lee, Y. J., et al. (2021). Year-round cultivation of *Tetraselmis* sp. for essential lipid production in a semi-open raceway system. *Mar. Drugs* 19:314. doi: 10.3390/md19060314

Leu, M. Y., Sune, Y. H., and Meng, P. J. (2015). First results of larval rearing and development of the bluestriped angelfish *Chaetodontoplus septentrionalis* (Temminck & Schlegel) from hatching through juvenile stage with notes on its potential for aquaculture. *Aquac. Res.* 46, 1087–1100. doi: 10.1111/are.12265

Lian, G., Wang, Y., Sun, R., and Hwang, J. S. (2018). *Species Diversity of Marine Planktonic Copepods in China's Seas*. Beijing: China Ocean Press.

Liao, I. C., Su, H. M., and Chang, E. Y. (2001). Techniques in finfish larviculture in Taiwan. *Aquaculture* 200, 1–31. doi: 10.1016/s0044-8486(01)00692-5

Lin, H. Y., Yeh, W. Y., Tsai, S. F., Chiang, K. P., Lin, J. H. Y., Tsao, C. C., et al. (2020). Biological protective effects against *Vibrio* infections in grouper larvae using the *Strombidium* sp. NTOU1, a marine ciliate amenable for scaled-up culture and with an excellent bacteriovorous ability. *Front. Mar. Sci.* 7:373. doi: 10.3389/fmars.2020.00373

Litvinenko, L. I., Litvinenko, A. I., Boiko, E. G., and Kutsanov, K. (2015). *Artemia* cyst production in Russia. *Chin. J. Oceanol. Limnol.* 33, 1436–1450. doi: 10.1007/s00343-015-4381-6

Liu, C. S., Chen, S. Q., Zhuang, Z. M., Yan, J. P., Liu, C. L., and Cui, H. T. (2015). Potential of utilizing jellyfish as food in culturing *Pampus argenteus* juveniles. *Hydrobiologia* 754, 189–200. doi: 10.1007/s10750-014-1869-6

López, D. A., López, B. A., Pham, C. K., Isidro, E. J., and De Girolamo, M. (2010). Barnacle culture: background, potential and challenges. *Aquac. Res.* 41, 367–375. doi: 10.1111/j.1365-2109.2010.02508.x

Lubzens, E., Zmora, O., and Barr, Y. (2001). "Biotechnology and aquaculture of rotifers," in *Rotifera IX: Proceedings of the IXth International Rotifer Symposium*, eds L. Sanoamuang, H. Segers, R. J. Shiel, and R. D. Gulati (Khon Kaen: Springer), 337–353. doi: 10.1007/978-94-010-0756-6_44

Madhu, K., and Madhu, R. (2014). Captive spawning and embryonic development of marine ornamental purple firefish *Nemateleotris decora* (Randall & Allen, 1973). *Aquaculture* 424, 1–9. doi: 10.1016/j.aquaculture.2013.12.027

Madhu, K., Madhu, R., Mohandas, M. P., and Vijayan, M. T. (2016). Isolation, identification and culture of the marine rotifer *Colurella adriatica* Ehrenberg, 1831 (Family: Lepadellidae) from Andaman & Nicobar Islands: A promising live feed for larval rearing of high value shellfishes and finfishes. *J. Mar. Biol. Assoc. India* 58, 5–12.

Mai, T. D., Lee-Chang, K. J., Jameson, I. D., Hoang, T., Cai, N. B. A., and Pham, H. Q. (2021). Fatty acid profiles of selected microalgae used as live feeds for shrimp postlarvae in Vietnam. *Aquac. J.* 1, 26–38. doi: 10.3390/aquacj1010004

Manaffar, R., Abdolahzadeh, N., MoosaviToomatari, G., Zare, S., Sorgeloos, P., Bossier, P., et al. (2020). Reproduction and life span characterization of *Artemia urmiana* in Lake Urmia, Iran (Branchiopoda: Anostraca). *Iran J. Fish. Sci.* 19, 1344–1358.

Matsui, H., Sasaki, T., Kobari, T., Waqalevu, V., Kikuchi, K., Ishikawa, M., et al. (2021). DHA accumulation in the polar lipids of the euryhaline copepod *Pseudodiaptomus inopinus* and its transfer to red sea bream *Pagrus major* larvae. *Front. Mar. Sci.* 8:632876. doi: 10.3389/fmars.2021.632876

McKinnon, A. D., Duggan, S., Nichols, P. D., Rimmer, M. A., Semmens, G., and Robino, B. (2003). The potential of tropical paracalanid copepods as live feeds in aquaculture. *Aquaculture* 223, 89–106. doi: 10.1016/s0044-8486(03)00161-3

Mejri, S. C., Tremblay, R., Audet, C., Wills, P. S., and Riche, M. (2021). Essential fatty acid requirements in tropical and cold-water marine fish larvae and juveniles. *Front. Mar. Sci.* 8:557. doi: 10.3389/fmars.2021.680003

Militz, T. A., Leini, E., Duy, N. D. Q., and Southgate, P. C. (2018). Successful large-scale hatchery culture of sandfish (*Holothuria scabra*) using micro-algae concentrates as a larval food source. *Aquac. Rep.* 9, 25–30. doi: 10.1016/j.aqrep.2017.11.005

Miyajima, Y., Masuda, R., Kurihara, A., Kamata, R., Yamashita, Y., and Takeuchi, T. (2011). Juveniles of threadsail filefish, *Stephanolepis cirrhifer*, can survive and grow by feeding on moon jellyfish *Aurelia aurita*. *Fish. Res.* 77, 41–48. doi: 10.1007/s12562-010-0305-8

Mona, M. H., El-Gamal, M. M., Razek, F. A., and Eldeen, M. N. (2017). Utilization of *Daphnia longispina* as supplementary food for rearing *Marsupenaeus japonicus* post larvae. *J. Mar. Biol. Assoc. India* 59:74.

Nagano, N., Iwatsuki, Y., Kamiyama, T., and Nakata, H. (2000). Effects of marine ciliates on survivability of the first-feeding larval surgeonfish, *Paracanthurus hepatus*: laboratory rearing experiments. *Hydrobiologia* 432, 149–157. doi: 10.1023/A:1004094825739

Nielsen, B. L. H., Gréve, H. V. S., and Hansen, B. W. (2021). Cultivation success and fatty acid composition of the tropical copepods *Apocyclops royi* and *Pseudodiaptomus annandalei* fed on monospecific diets with varying PUFA profiles. *Aquac. Res.* 52, 1127–1138. doi: 10.1111/are.14970

Nielsen, R., Nielsen, M., Abate, T. G., Hansen, B. W., Jepsen, P. M., Nielsen, S. L., et al. (2017). The importance of live-feed traps–farming marine fish species. *Aquac. Res.* 48, 2623–2641. doi: 10.1111/are.13281

Oostlander, P. C., van Houcke, J., Wijffels, R. H., and Barbosa, M. J. (2020). Optimization of *Rhodomonas* sp. under continuous cultivation for industrial applications in aquaculture. *Algal Res.* 47:101889. doi: 10.1016/j.algal.2020.101889

Pan, Y. J., Déposé, E., Souissi, A., Hénard, S., Schaadt, M., Mastro, E., et al. (2020). Assessments of first feeding protocols on the larviculture of California grunion *Leuresthes tenuis* (Osteichthyes: Atherinopsidae). *Aquac. Res.* 51, 3054–3058. doi: 10.1111/are.14637

Pan, Y. J., Sadovskaya, I., Hwang, J. S., and Souissi, S. (2018). Assessment of the fecundity, population growth and fatty acid composition of *Apocyclops royi* (Cyclopoida, Copepoda) fed on different microalgal diets. *Aquac. Nutri*. 24, 970–978. doi: 10.1111/anu.12633

Pan, Y. J., Souissi, S., Souissi, A., Wu, C. H., Cheng, S. H., and Hwang, J. S. (2014). Dietary effects on egg production, egg-hatching rate and female life span of the tropical calanoid copepod *Acartia bilobata*. *Aquac. Res.* 45, 1659–1671. doi: 10.1111/are.12113

Peter, A. P., Koyande, A. K., Chew, K. W., Ho, S. H., Chen, W. H., Chang, J. S., et al. (2022). Continuous cultivation of microalgae in photobioreactors as a source of renewable energy: Current status and future challenges. *Renew. Sust. Energ. Rev.* 154:111852. doi: 10.1016/j.rser.2021.111852

Ramos-Vega, A., Rosales-Mendoza, S., Bañuelos-Hernández, B., and Angulo, C. (2018). Prospects on the use of *Schizochytrium* sp. to develop oral vaccines. *Front. Microbiol.* 9:2506. doi: 10.3389/fmicb.2018.02506

Rasdi, N. W., Arshad, A., Ikhwanuddin, M., Hagiwara, A., Yusoff, F. M., and Azani, N. (2020). A review on the improvement of cladocera (*Moina*) nutrition as live food for aquaculture: Using valuable plankton fisheries resources. *J. Environ. Biol.* 41, 1239–1248. doi: 10.22438/jeb/41/5(SI)/MS_16

Rayner, T. A., Jørgensen, N. O. G., Blanda, E., Wu, C. H., Huang, C. C., Mortensen, J., et al. (2015). Biochemical composition of the promising live feed tropical calanoid copepod *Pseudodiaptomus annandalei* (Sewell 1919) cultured in Taiwanese outdoor aquaculture ponds. *Aquaculture* 441, 25–34. doi: 10.1016/j.aquaculture.2015.01.034

Rebolledo, U. A., Sarma, N., de Oca, G. A. R. M., del Carmen, Monroy-Dosta, M., Tello-Ballinas, J. A., et al. (2021). The potential use of the euryhaline rotifer *Proales similis* for larval rearing of the freshwater pike silverside *Chirostoma estor estor*. *Aquaculture* 534:736246. doi: 10.1016/j.aquaculture.2020.736246

Rehberg-Haas, S., Meyer, S., Lippemeier, S., and Schulz, C. (2015). A comparison among different *Pavlova* sp. products for cultivation of *Brachionus plicatilis*. *Aquaculture* 435, 424–430. doi: 10.1016/j.aquaculture.2014.10.029

Rhodes, M. A., and Phelps, R. P. (2008). Evaluation of the ciliated protozoa, *Fabrea salina* as a first food for larval red snapper, *Lutjanus campechanus* in a large scale rearing experiment. *J. Appl. Aquac.* 20, 120–133. doi: 10.1080/10454430802197383

Rønnestad, I., Yúfera, M., Ueberschär, B., Ribeiro, L., Sæle, Ø, and Boglione, C. (2013). Feeding behaviour and digestive physiology in larval fish: current knowledge, and gaps and bottlenecks in research. *Rev. Aquac.* 5, S59–S98. doi: 10.1111/raq.12010

Safiin, N. S. Z., Mustafa, S., Ching, F. F., and Shapawi, R. (2021). Palm oil-based enrichment diets for the rotifer, *Brachionus plicatilis*, improved the performance of Asian seabass (*Lates calcarifer*) larvae. *Front. Mar. Sci.* 8:613312. doi: 10.3389/fmars.2021.613312

Sales, R., Derner, R. B., and Tsuzuki, M. Y. (2019). Effects of different harvesting and processing methods on *Nannochloropsis oculata* concentrates and their application on rotifer *Brachionus* sp. cultures. *J. Appl. Phycol.* 31, 3607–3615. doi: 10.1007/s10811-019-01877-8

Sandeep, K. P., Avunje, S., Dayal, J. S., Balasubramanian, C. P., Sawant, P. B., Chadha, N. K., et al. (2021). Efficiency of different microalgae as monospecific and bispecific diets in larval rearing of *Penaeus indicus* with special reference to growth, nutrient composition and antimicrobial activity of microalgae. *Aquac. Res.* 52, 5146–5154. doi: 10.1111/are.15382

Sandmann, M., Smetana, S., Heinz, V., and Rohn, S. (2021). Comparative life cycle assessment of a mesh ultra-thin layer photobioreactor and a tubular glass photobioreactor for the production of bioactive algae extracts. *Bioresour. Technol.* 340:125657. doi: 10.1016/j.biortech.2021.125657

Santhanam, P., Jeyaraj, N., Jothiraj, K., Ananth, S., Kumar, S. D., and Pachiappan, P. (2019). "Assessing the efficacy of marine copepods as an alternative first feed for larval production of tiger shrimp *Penaeus monodon*," in *Basic and Applied Zooplankton Biology*, eds P. Santhanam, A. Begum, and P. Pachiappan (Singapore: Springer), 293–303. doi: 10.1007/978-981-10-7953-5_12

Santhosh, B., Ranjan, R., Raju, S. S., Kalidas, C., Gopakumar, G., Gopalakrishnan, A., et al. (2018). "Cost estimate and financial analysis of a medium scale copepod culture unit," in *Culture Techniques of Marine Copepods*, eds B. Santhosh, M. K. Anil, F. Muhammed Anzeer, K. S. Aneesh, V. Mijo, G. Gopakumar, et al. (Kerala: Indian Central Marine Fisheries Research Institute), 123–131.

Santos, M. R., Vieira, N., and Monteiro, N. M. (2018). High temperatures disrupt *Artemia franciscana* mating patterns and impact sexual selection intensity. *Estuar. Coast. Shelf Sci.* 207, 209–214. doi: 10.1016/j.ecss.2018.04.015

Scarpa, J. (2002). General method for the production of developmentally-arrested bivalve trochophore larvae as a potential food for marine fish larvae. *J. Appl. Aquac*. 12, 1–11. doi: 10.1300/J028v12n04_01

Sellami, I., Naceur, H. B., and Kacem, A. (2020). Study of cysts biometry and hatching percentage of the brine shrimp *Artemia salina* (Linnaeus, 1758) from the Sebkha of Sidi El Hani (Tunisia) according to successive generations. *Aquac. Stud.* 21, 41–46. doi: 10.4194/2618-6381-v21_1_05

Sharawy, Z. Z., Ashour, M., Abbas, E., Ashry, O., Helal, M., Nazmi, H., et al. (2020). Effects of dietary marine microalgae, *Tetraselmis suecica*, on production, gene expression, protein markers and bacterial count of Pacific white shrimp *Litopenaeus vannamei*. *Aquac. Res.* 51, 2216–2228. doi: 10.1111/are.14566

Shekarabi, S. P. H., Mehrgan, M. S., Razi, N., and Sabzi, S. (2021). Biochemical composition and fatty acid profile of the marine microalga *Isochrysis galbana* dried with different methods. *J. Microbiol. Biotechnol. Food Sci.* 2021, 521–524.

Snell, T. W., Johnston, R. K., and Matthews, A. B. (2019). Utilizing *Brachionus* biodiversity in marine finfish larviculture. *Hydrobiologia* 844, 149–162. doi: 10.1007/s10750-018-3776-8

Su, C. J., Ju, W. T., Chen, Y. M., Chiang, M. W., Hsieh, S. Y., Lin, H. J., et al. (2021). Palmitic acid and long-chain polyunsaturated fatty acids dominate in mycelia of mangrove *Halophytophthora* and *Salispina* species in Taiwan. *Bot. Mar.* 64, 503–518. doi: 10.1515/bot-2021-0030

Su, H. M., Cheng, S. H., Chen, T. I., and Su, M. S. (2005). "Culture of copepods and applications to marine finfish larval rearing in Taiwan," in *Copepods in Aquaculture*, eds C. S. Lee, P. J. O'Bryen, and N. H. Marcus (Oxford: Blackwell Publishing), 183–194. doi: 10.1002/9780470277522.ch14

Suantika, G., Dhert, P., Nurhudah, M., and Sorgeloos, P. (2000). High-density production of the rotifer *Brachionus plicatilis* in a recirculation system: consideration of water quality, zootechnical and nutritional aspects. *Aquac. Eng.* 21, 201–213. doi: 10.1016/S0144-8609(99)00031-X

Suantika, G., Dhert, P., Sweetman, E., O'Brien, E., and Sorgeloos, P. (2003). Technical and economical feasibility of a rotifer recirculation system. *Aquaculture* 227, 173–189. doi: 10.1016/s0044-8486(03)00502-7

Tahir, A., and Ransangan, J. (2021). Key selections for microalgae, the indispensable live feed in bivalve hatchery: a brief review. *Egypt. J. Aquat. Biol. Fish.* 25, 821–846. doi: 10.21608/ejabf.2021.206882

Tarangkoon, W., Mahae, N., and Tanyaros, S. (2018). The effect of different feed types on the growth rate and biochemical composition of the marine ciliate *Euplotes* sp. *J. Fish. Environ.* 42, 24–32.

Tato, T., and Beiras, R. (2019). The use of the marine microalga *Tisochrysis lutea* (T-iso) in standard toxicity tests; comparative sensitivity with other test species. *Front. Mar. Sci.* 6:488. doi: 10.3389/fmars.2019.00488

Tayebati, H., Pajoum Shariati, F., Soltani, N., and Sepasi Tehrani, H. (2021). Effect of various light spectra on amino acids and pigment production of *Arthrospira platensis* using flat-plate photobioreactor. *Prep. Biochem. Biotechnol.* [Epub Online ahead of print]. doi: 10.1080/10826068.2021.1941102

Teiba, I., Okunishi, S., Yoshikawa, T., Ikenaga, M., El Basuini, M. F., Santander-de Leon, S. M. S., et al. (2020). Use of purple non-sulfur photosynthetic bacteria (*Rhodobacter sphaeroides*) in promoting ciliated protozoan growth. *Biocontrol. Sci.* 25, 81–89. doi: 10.4265/bio.25.81

Tibbetts, S. M., Patelakis, S. J., Whitney-Lalonde, C. G., Garrison, L. L., Wall, C. L., and MacQuarrie, S. P. (2020). Nutrient composition and protein quality of microalgae meals produced from the marine prymnesiophyte *Pavlova* sp. 459 mass-cultivated in enclosed photobioreactors for potential use in salmonid aquafeeds. *J. Appl. Phycol.* 32, 299–318. doi: 10.1007/s10811-019-01942-2

Torres, G. A., Merino, G. E., and Prieto-Guevara, M. J. (2022). Continuous egg separation of the copepod *Acartia tonsa*. Implications for increasing adult density at an intensive level. *Aquac. Rep*. 22:100995. doi: 10.1016/j.aqrep.2021.100995

Turan, G., and Kling, L. J. (2018). Size distribution, fatty acid composition and short-term storage studies on Blue mussel (*Mytilus edulis*) trochophores. *Ege J. Fish. Aquat. Sci.* 35, 279–287. doi: 10.12714/egejfas.2018.35.3.07

Turcihan, G., Okyar, M. I., Zeybek, Y. G., and Eryalçın, K. M. (2022). *Effect of Different Feeds on Reproduction Performance, Nutritional Components and Fatty acid Composition of Cladocera Water Flea (Daphnia magna)*. New Jersey, NJ: Wiley. doi: 10.1111/are.15759

Van Stappen, G., Sui, L., Hoa, V. N., Tamtin, M., Nyonje, B., de Medeiros Rocha, R., et al. (2020). Review on integrated production of the brine shrimp *Artemia* in solar salt ponds. *Rev. Aquac.* 12, 1054–1071. doi: 10.1111/raq.12371

Vu, M. T. T., Jepsen, P. M., Jørgensen, N. O., Hansen, B. W., and Nielsen, S. L. (2019). Testing the yield of a pilot-scale bubble column photobioreactor for cultivation of the microalga *Rhodomonas salina* as feed for intensive calanoid copepod cultures. *Aquac. Res.* 50, 63–71. doi: 10.1111/are.13868

Vu, N. U., and Huynh, T. G. (2020). Optimized live feed regime significantly improves growth performance and survival rate for early life history stages of pangasius catfish (*Pangasianodon hypophthalmus*). *Fishes* 5:20. doi: 10.3390/fishes5030020

Wakabayashi, K., Nagai, S., and Tanaka, Y. (2016a). The complete larval development of *Ibacus ciliatus* from hatching to the nisto and juvenile stages using jellyfish as the sole diet. *Aquaculture* 450, 102–107. doi: 10.1016/j.aquaculture.2015.07.020

Wakabayashi, K., Sato, H., Yoshie-Stark, Y., Ogushi, M., and Tanaka, Y. (2016b). Differences in the biochemical compositions of two dietary jellyfish species and their effects on the growth and survival of *Ibacus novemdentatus* phyllosomas. *Aquac. Nutr.* 22, 25–33. doi: 10.1111/anu.12228

Wakabayashi, K., Sato, R., Ishii, H., Akiba, T., Nogata, Y., and Tanaka, Y. (2012). Culture of phyllosomas of *Ibacus novemdentatus* (Decapoda: Scyllaridae) in a closed recirculating system using jellyfish as food. *Aquaculture* 330, 162–166. doi: 10.1016/j.aquaculture.2011.12.005

Wang, L., Wang, S., Zeng, C., Wang, Y., and Zeng, C. (2021). Effects of food concentration and photoperiod on egg production, female life expectancy and population dynamics of the paracalanid copepod, *Bestiolina amoyensis*. *Front. Mar. Sci.* 8:788744. doi: 10.3389/fmars.2021.788744

Wang, Q., Zeng, J., Wang, Y., Zhao, J., Ma, L., Shi, Z., et al. (2021). Alternations in the liver metabolome, skin and serum antioxidant function of silver pomfret (*Pampus argenteus*) is induced by jellyfish feeding. *3 Biotech* 11, 1–10. doi: 10.1007/s13205-021-02702-1

Wan-Mohtar, W. A. A. Q. I., Ibrahim, M. F., Rasdi, N. W., Zainorahim, N., and Taufek, N. M. (2021). Microorganisms as a sustainable aquafeed ingredient: A review. *Aquac. Res.* 53, 746–766. doi: 10.1111/are.15627

Wilson, J. M., Ignatius, B., Santhosh, B. P., Sawant, P. B., and Chadha, N. K. (2021). Induced quiescence in eggs of the tropical calanoid copepod *Acartia tropica*: Effect of different storage conditions. *Aquac. Res*. 5, 467–474. doi: 10.1111/are.15588

Wullur, S., Sakakura, Y., and Hagiwara, A. (2011). Application of the minute monogonont rotifer *Proales similis* de Beauchamp in larval rearing of seven-band grouper *Epinephelus septemfasciatus*. *Aquaculture* 315, 355–360. doi: 10.1016/j.aquaculture.2011.02.025

Wurm, H., and Sandmann, M. (2021). Establishment of a simple method to evaluate mixing times in a plastic bag photobioreactor using image processing based on freeware tools. *BMC Res. Notes* 14:470. doi: 10.1186/s13104-021-05892-2

Yang, Y., Du, L., Hosokawa, M., and Miyashita, K. (2020). Total lipidcontent, lipid class and fatty acid composition of ten species of microalgae. *J. Oleo Sci.* 69, 1181–1189. doi: 10.5650/jos.ess20140

Yúfera, M., and Darias, M. J. (2007). The onset of exogenous feeding in marine fish larvae. *Aquaculture* 268, 53–63. doi: 10.1016/j.aquaculture.2007.04.050

Zeng, C., Shao, L., Ricketts, A., and Moorhead, J. (2018). The importance of copepods as live feed for larval rearing of the green mandarin fish *Synchiropus splendidus*. *Aquaculture* 491, 65–71. doi: 10.1016/j.aquaculture.2018.03.011

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