

Cladocerans as an ideal live-food for fish larviculture towards aquaculture sustainability

ABSTRACT

Aquaculture remains one of the fastest-growing food-producing sectors, challenges for the development of a sustainable and species diverse aquaculture industry is lack of suitable live feeds at the larviculture phase. At present, some live feeds are being harvested from the wild and fed to the larvae and brooders. However, unfortunately, the wild collected live feeds are forming a way to entry of pathogenic organisms, which can cause diseases to the cultivable organisms. In this context, the present review was focussed on the cladocerans, their morphology, collection, identification features and culture methods. The culture of live feeds primarily the cladocerans culture in captive condition is highly essential for country like India. However, viable technologies for the intensive production of marine cladocerans are lacking in aquaculture industry especially in India coupled with the issue of lack of brood stock facility. A comprehensive brood stock facility for marine cladocerans to take up on as commercial scale seems to be the need of hour. Therefore, the culture technology has to be developed for all the possible species of marine cladocerans and pure culture of such species could be maintained and supplied to farmers and researchers of the country for sustainable aquaculture practices.

Keywords: Cladocerans; Taxonomy; Feeding types; Culture methods; Nutritional content.

1. INTRODUCTION

Aquaculture production has improved on a global scale. The 10 nations engaged in commercial aquaculture production are China, Indonesia, India, Vietnam, Bangladesh,

Commented [A1]: Focus on the importance of developing culture technology for intensive production of marine cladocerans in India, as this technology is currently underdeveloped.

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Philippines, South Korea, Egypt, Norway and Japan. Finfish, crustaceans, mollusks, other aquatic animals and algae culture technology output levels have expanded globally between 1990 and 2020. Success of aquaculture depends on the constant supply of healthy live feeds. A disease-free healthy live feeds can be maintained by feeding live-food to the culture stock along with supplemented artificial feeds. Supplemental artificial feeds alone cannot meet all the required elements for the growth of fish. So, larval fishes must be fed with live feeds (Das et al., 2012). Larval rearing is one of the riskiest phases of aquaculture, although it is one of the most profitable ventures. Special planning and strategies are required to overcome the risk of high mortality during their culture (Barad et al., 2017). Zooplankton is required as a first food for many cultivable fishes for others it contributes to faster growth and higher survival. Larvae of fish and shellfish may not prefer the artificial supplemented feed. They require small-size live foods for their nutrition (Lim et al., 2003). Live feeds are a protein-rich, easily digestible meal for fin and shellfish. These live streams can be bought in the market, but they are expensive and might not be offered when needed. Additionally, it will raise the price of production. However, it is simple and affordable to culture these live foods (Conceição et al., 2010).

Among the different types of live feeds available for use in aquaculture, cladocerans are commonly called as water fleas, constitute an ancient clade of branchiopod crustaceans (Olesen, 1998; Olesen, 2014). Most of these are herbivorous filter-feeders. Cladocerans are most commonly available and abundant zooplankton in fresh water lakes and ponds occupying primary consumer level in aquatic trophic system. Being filter feeding organisms, the cladocera ingest particles of varied sizes, including nanoplankton, detritus, bacteria and phytoplankton and the cladocerans are finally devoured as an important naturally available diet for fishes. These organisms

Commented [A3]: Include the latest statistical data on global aquaculture production and the important role of live feed in improving fish larvae survival rates.

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Commented [A6R5]: Add information about how zooplankton, including cladocerans, serve as the first food source for many farmed fish.
What are the most common types of farmed fish that use zooplankton as their first food source?
What are the benefits of zooplankton for the health of farmed fish?
Explain further.

thereby play a crucial role in recycling the nutrients and transfer of energy to higher trophic levels through aquatic food webs (Hall et al., 2007; Balayla and Moss, 2004). They are known to switch between parthenogenetic and sexual reproductions when environmental conditions for growth and reproduction deteriorate (Srivastava et al., 2006). They are relatively tolerant to environmental conditions, that would conform to their opportunistic and potentially invasive nature. As a result, cladocera are distributed globally and mostly occur in temporary or permanent freshwater pools, although a few species have colonized marine or brackish habitats (Richter et al., 2007). Cladocerans play a crucial part in the aquatic food chain by acting as a bridge between lower trophic levels and fish through their grazing activities on picoplankton, nanoplankton and microplankton populations.

Proper larval-feeding constitutes a major management aspect during the farming of fishes. In aquaculture system, successful rearing of larvae is a requisite step to ensure subsequent better fish production that greatly depends on supplementation of live feed organisms enriched with essential nutrients. The availability of appropriate quantities of lipids, proteins, carbohydrates, vitamins and minerals via their diet is essential for rearing success of fish larvae (Kanazawa, 2003; Alam and Watanabe, 2015). Poor growth, low feed efficiency, anaemia and high mortality are associated with deficiency of required nutrients (Sargent et al., 1999; Olivotto et al., 2003). Some earlier research revealed better survivability and growth of fish larvae were fed with cladocerans. Thus the cladocerans are good and cheap live food instead of expensive artificial feed. Generally, the success of fish hatchery is linked to the readily available live feeds like zooplankton (in their habitat). Due to their increased nutritional content and economic viability for mass production, cladocerans have been chosen as live feed sources in larval fish rearing. The cladocerans are considered to be an essential energy sources

Commented [A7]: Expand on how cladocerans function as a bridge between lower trophic levels and fish through their grazing activities.

particularly for larval nutrition towards optimal growth as well as maintenance of metabolism because of their higher contents of proteins and fats (Rasdi et al., 2020). These creatures are favoured as live feed by early larval fish due to their smaller sizes and increased locomotive action, in addition to their nutrients contents. The jerky movement of cladocerans make them more visible to fish larvae (Balayla and Moss, 2004; Kim et al., 2008). Moreover, the mass-cultured cladocerans would be possessing a broad spectrum of digestive enzymes such as proteinases, peptidases, amylases, lipases and cellulose besides adequate protein-content that are useful for larval developments (Bogut et al., 2010). Their high levels of proteins, free amino acids, fats and micronutrients were already reported in most cladoceran species. Further, many earlier studies affirmed the better survivability and growth of fish larvae were fed with cladocerans. Thus, the cladocerans can serve as good and cheap live food (instead of expensive artificial feed). Cladocerans are important and frequent members in the plankton community (Korhola and Rautio, 2001; Kumar et al., 2005) and they act as mediators between primary producers and higher trophic levels. The changes in the marine zooplankton-abundance and composition would alter the structure of pelagic food webs (Katechakis and Stibor, 2004).

1.1. Origin and Morphology

So far, over 620 known taxa of cladocera have been identified in freshwater ecosystems (Kim et al., 2008) that represent four orders: Anomopoda, Ctenopoda, Haplopoda and Onychopoda. Among cladocerans, *Daphnia* (**Fig. 1**) genus is considered to be of crucial for their ability to determine water quality through a key role in biomass transfer between phytoplankton and planktivorous fish. There are only eight cladoceran species that inhabit marine environments, and they belong to crustacea-phylum in the class, Branchiopoda by 2-orders: Ctenopoda and Onychopoda (Egloff et al., 1997) and five

genera: *Penilia*, *Evadne*, *Pleopis*, *Podon* and *Pseudevadne*. But *Penilia avirostris* is the single representative of Ctenopoda and the remaining marine species are members of the Onychopoda, family Podonidae (Onbe, 1999). They are distributed widely from estuaries to open ocean and from tropic to arctic seas (Kim and Onbe, 1989). Therefore, marine cladocerans are adapted to neritic environments rather than offshore deep-sea environments because the seasonality of sea bottom temperature induces their hatching at optimal temperatures (Onbe and Ikeda, 1995).

Commented [A8]: Add information about the global distribution of cladocerans and their adaptation to various environments.

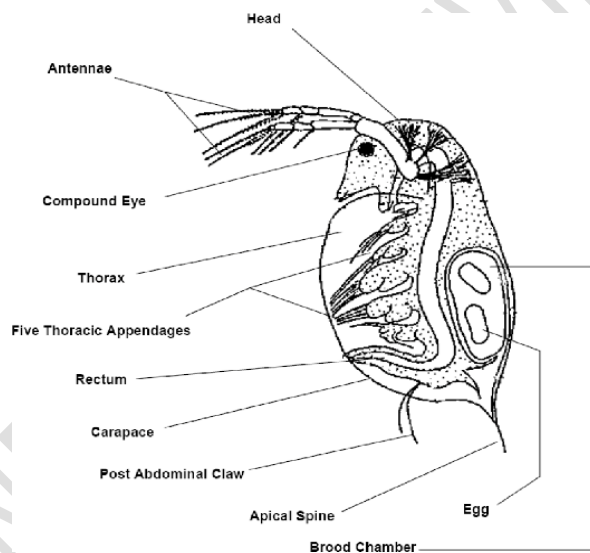


Fig 1: Schematic morphology of cladocerans

1.2. Marine Cladocerans

Marine cladocerans are tiny crustaceans that occur mostly in coastal pelagic waters (Tang et al., 1995). Unlike their freshwater counterparts, marine cladocerans are always

considered as a subordinate component of the zooplankton, coming behind the copepods (Egloff et al., 1997). Most marine cladocerans are restricted to coastal waters, where they make up a significant part of the zooplanktonic community at given periods. This confers on these animals a major trophodynamic role, as they can be an important food item for carnivorous zooplankton, as well as to pelagic fish and their larvae (Cheng & Chao, 1982). Despite their high densities, marine cladocerans may disappear from the planktonic population during certain seasons of the year, which in temperate regions is generally during winter (Kim et al., 1989a). However, Kim et al. (1989b) reported the marine cladocerans may play a significant role in trophodynamic pathways of the plankton community during the periods of their high abundance, where their densities could reach up to 50,000 and 100,000 individuals m^{-3} (Platt, 1977; Bryan and Grant, 1979). Rocha (1982) found marine cladocerans as the second most abundant group of zooplankton community. Despite their numerical abundance in plankton communities both in temperate and warm waters, the marine cladocerans have received only very little attention in the past when compared to massive work done on the marine copepods (Onbe, 1985).

2. GENERAL CHARACTERISTICS

The seven species of marine cladocerans belongs to the Podonidae family. Podonids are characterized by a reduced carapace into a dorsal pouch and with presence of 4 pairs of elongated, prehensile trunk appendages. Each of the seven species could be differentiated by number of setae present on the exopods of the thoracic appendages (Egloff et al., 1997). Only one species of marine cladoceran, *Penilia* species belongs to the family Sididae. The eight species of marine cladocerans are; *Penilia avirostris*, *Evadne nordmanni*, *Evadne spinifera*, *Pseudevadne tergestina*, *Pleopis polyphemoide*, *Pleopis schmackeri*, *Podon leuckartii* and *Podon intermedius* (Table 1).

Commented [A9]: Explain further the trophodynamic role of marine cladocerans and how they can be an important food source for carnivorous zooplankton and pelagic fish.

Commented [A10]: Add information about the specific morphological characteristics of marine cladoceran species and how they can be distinguished based on the number of setae on the exopods of the thoracic appendages.

Table 1: Special characteristics for identification of marine cladocerans over the worldwide

Species	Characteristics	Size
<i>Penilia avirostris</i>	Free edges of carapace spined, the inferior-posterior angle of carapace bears a larger spine. Six pairs of legs, the most posterior reduced. Antenna projected forward. Adult copulatory organs longer than the post-abdomen. Female head with prominent rostral point; antennulae small and truncated. Male head rounded; antennulae long as carapace. Male first leg with a strong distal hook.	Female 0.5-1.2 mm. Male 0.7-0.9 mm.
<i>Evadne nordmanni</i>	Body triangular in shape with a small terminal spine. Brood pouch elliptical if containing numerous embryos; otherwise, triangular. Locomotory muscles of the antennae contiguous. Exopodites of legs I-IV respectively with 2,2,1 and 1 setae.	Female 0.4-0.7 mm. Male 0.3-0.7 mm.
<i>Evadne spinifera</i>	Body oval in shape with a long terminal spine. Oval brood pouch. Locomotory muscles of the antennae separate. Exopodites of legs I-IV respectively with 2,2,2 and 1 setae.	Female 0.5-0.7 mm. Male 0.6-0.7 mm.
<i>Pseudevadne tergestina</i>	Body oval in shape. Brood pouch from hemispherical to semioval. Exopodites of legs I-IV respectively with 2,3,3 and 1 setae.	Female 0.7-1.0 mm. Male 0.6-0.8 mm.
<i>Pleopis polyphemoides</i>	Body small. Caudal furca short, in outline almost an equilateral triangle. Antennae: exopod segments 1-4 with 0,1,2,4 swimming setae. Exopods of thoraciclimbs 1-4 with 3,3,3,2 setae, respectively. Female brood chamber varying from hemispherical to spherical. Resting eggs small, spherical, 0.15-0.21 mm in diameter; greenish-brown; numerous small pores scattered throughout outer egg membrane; perimeter obscured with the ornamentation of membrane.	Female 0.3-0.7 mm. Male 0.2-0.6 mm.
<i>Pleopis schmackeri</i>	Body hemispherical, with shallowest cervical groove in genera <i>Podon</i> and <i>Pleopis</i> . Caudal furca slender, sharply pointed. Antennae: exopod of segments 1-4 with 0,1,2,4 setae. Exopods of thoracic limbs 1-4 with 4,4,4,2 setae, respectively, the most numerous in the marine	Female 0.34 - 0.87 mm. Male 0.43-0.46 mm.

	Podonidae (<i>Pleopis schmackeri</i> , exopods). Resting eggs unknown.	
<i>Podon leuckartii</i>	Large body. Brood pouch rather small and hemispherical. Caudal claws very protruding. Exopodites of the antennae with 4 joints and 4 swimming setae. Exopodites of legs I-IV respectively with 1,1,1 and 2 setae.	Female 0.8-1.0 mm. Male 0.7-1.0 mm.
<i>Podon intermedius</i>	Large body. Brood pouch large and oval. Caudal claws protruding. Exopodites of the antennae with 4 joints with 0, 1, 2 and 4 swimming setae. Exopodites of legs I-IV respectively with 2,1,1 and 2 setae.	Female 1.0-1.2 mm. Male 0.8-0.9 mm.

2.1 Population dynamics of marine cladocerans

The annual cycles of their abundance have been reported for many populations of marine cladocerans and the pattern of occurrence is believed to be dependent primarily on the intensity of water temperature (Onbe, 1977). However, the exact biological and/or physiochemical factors that govern the population dynamics of marine cladocerans are not fully understood. Marazzo et al. (2003) quantified the birth rates of marine cladocerans based on the egg-ratio model of Paloheimo (1974). *Penilia avirostris* birth rates fluctuated, which revealed that changes in water temperature and brood size both had an impact on population density variations. In addition, species rates of birth, death and embryonic development play a significant role in population size. Environmental factors include deterioration of feeding conditions, decrease in water temperature, changes in population density and changes in photoperiod (Onbe, 1985). Despite the numerous experimental studies, the mechanisms of environmental sex determination in cladocerans remain unclear.

2.2 Reproduction

The rate of cladocerans reproduction is being determined according to the descriptions given by Onbe (1978a,b) and the individuals observed are being classified as;

Commented [A11]: Explain further about environmental factors that influence the population dynamics of marine cladocerans, such as water temperature and feeding conditions.

Commented [A12]: Include further information about the reproductive cycle of cladocerans and how they adapt to unfavourable environmental conditions through gamogenetic reproduction.

parthenogenetic (females bearing parthenogenetic embryos) and gamogenetic (females bearing males and resting eggs). The females brood pouches are carefully dissected with a fine needle in order to determine the stages of parthenogenetic embryo development. Premature and mature embryos are being separately considered. For *Penilia*, the embryonic stages XI-XII are considered as mature, whereas the other stages are considered premature. For *Pseudevadne*, the stages I-II are classified as premature and the stages III-IV are considered mature. For example, the developmental biology of *Penilia* sp. was studied and developmental stages are shown in **Fig-2**.

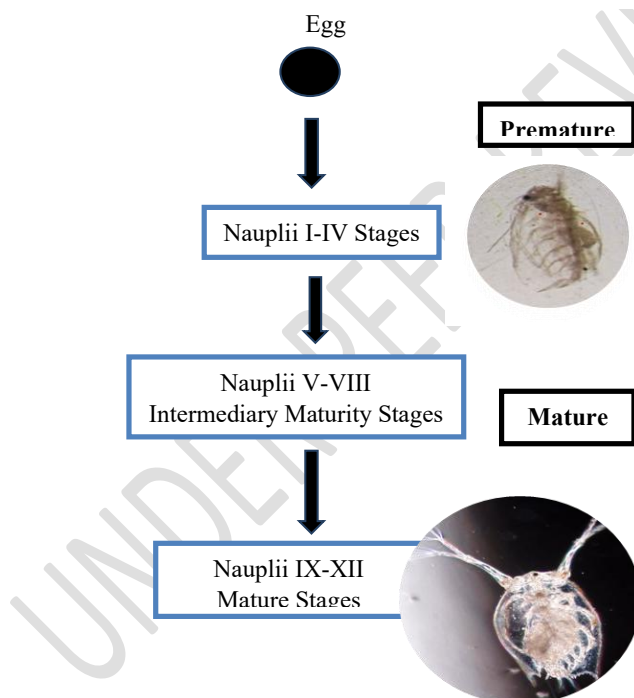


Fig 2: Developmental Stages of marine cladoceran (*Penilia* sp.)

3. CLADOCERANS CULTURE

The crustaceans-cladocerans are the major component of mesozooplankton (zooplankton having a body size of 0.2 ± 2 mm), and they exhibit significant grazing pressure on phytoplankton. While copepods tend to dominate crustacean zooplankton in most marine habitats, the cladocerans, particularly *Daphnia* spp., do so in many lakes. Generally, the cladoceran gradient consisted of seeding densities of 5 - 40 individuals per litre but the copepod gradient consisted of seeding densities of 5 - 160 individuals per litre (Sommer et al., 2001). The observed explosive increase in their densities is being related to their high reproductive potential in parthenogenetic generation. At given periods, when environmental conditions become unfavourable, these females produce both males and females. Following copulation and fertilization, the female generally produces a single large egg, called a "resting egg", with a resistant external membrane. The animal developing from this egg is always a female, thus restarting the parthenogenetic cycle (Barth, 1972). According to Nogueira et al. (1988), the marine cladocerans (*Penilia* and *Pseudevadne* genera) in Guanabara Bay were found to exhibit a wide-ranging seasonal density variation.

3.1 Culture Methods

The marine cladocerans were isolated from the plankton mixture and maintained separately in 2L glass beaker and provided with phytoplankton diets. Subcultures were made from this stock in three sets by providing three different phytoplankton diets viz *Chlorella* sp., *Nannochloropsis* sp. and *Dunaliella* sp. Small-scale culture is also useful for maintaining pure cultures because there is less chance of the cultures becoming contaminated with competitors such as protozoans, rotifers, copepods or predators of fish larvae or fry.

Commented [A13]: Add information about the importance of maintaining water quality and other environmental parameters in cladoceran cultures to ensure rapid and sustainable population growth.

The mass culture of cladocerans made using small-scale culture. Approximately 100-200 individuals were taken and inoculated into 10L capacity white bucket containing seawater. The water quality parameters were maintained properly. The required quantity of mixed phytoplankton diet was given. Semi-continuous cultures can be maintained for 7 days by weekly intervals, partial harvests of organism were taken, water changes and regular feeding was maintained for keeping the population in a state of rapid growth. Eventually, the organism cultures will fail to respond to additional fertilization. When it is evident that they are not reproducing well, the organism should be completely harvested and a new culture started again for mass production.

Commented [A14]: Explain in more detail the culture methods used for marine cladocerans, including the water quality parameters that must be maintained.

Commented [A15]: Discuss further the importance of semi-continuous culture and how to maintain a rapidly growing population.

4. FEEDING STRATEGIES

Proper feeding constitutes a major management aspect in fish-farming. In aquaculture system, successful rearing of larvae is a vital step to ensure better production that greatly depends on supplementation of live feed organisms enriched with essential nutrients. For fish larvae to successfully mature, their food must have enough levels of lipids, proteins, carbohydrates, vitamins and minerals. The frequently applied live feed organisms in fish farming are *Artemia salina*, rotifers and cladocerans (Rath Rajendra Kumar, 2011). It has also been proposed that food availability may have an impact on *P. avirostris* seasonal dynamics. According to Lipej et al. (1997) and Calbet et al. (2001), during warm periods, the water column is stratified, nutrients and chlorophyll concentrations are relatively low above the pycnocline, pico and nanoplanktonic autotrophs exist in large quantities. According to Atienza et al. (2006), *Penilia avirostris* is a filter feeder that preferentially consumes nanoflagellates. The larger abundance of these organisms causes a higher availability of food that is quickly tapped. The most important factor governing the nutritional quality of live feeds (for aquaculture practices) is the availability of essential fatty acids content, particularly

eicosapentanoic acid (EPA) and docosahexanoic acid (DHA), collectively called as highly unsaturated fatty acids (HUFA). In recent years, much emphasis has been given to enhance the nutritional status of live food organisms through various techniques of enrichment and bioencapsulation.

The nutrient which are lacking or present insufficiently in food organisms can be made available by allowing them to grow for a defined period in a medium containing appropriate quantities of those required nutrients. Of late, various kinds of micro-particulate and emulsified formulations are being used for boosting these live-foods with essential fatty acids and other crucial components, including pigment and vitamins. Previous studies have revealed the feeding habits of cladocerans (**Table 2**).

Commented [A16]: Add information about the importance of essential fatty acids in live feed and how enrichment techniques can improve the nutritional status of live feed organisms.

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Table 2: Food and Feeding Habits of cladocerans

Species name	Different Diets	Size (µm)	Findings	References
<i>Ceriodaphnia quadrangular</i>	<i>Ankistrodesmus falcatus</i> <i>Dictyosphaerium pulchellum</i> <i>Scenedesmus quadricauda</i> <i>Staurastrum gracile</i>	2.5 - 50	Feeding rate and Cell concentration	Ganf and Shiel (1985)
<i>Penilia avirostris</i>	Diatoms	4 - 12	Growth and Biomass	Turner et al. (1988)
<i>Penilia avirostris</i>	Nanoplankton	2 - 20	Ingestion rate and Growth	Atienza et al. (2008)
	Dinoflagellates			
	Ciliates			
	Picoflagellates	<2		
<i>Penilia avirostris</i> ,	Picoplankton	1	Grazing factor and	Katechakis et al. (2004)
<i>Podon intermedius</i> and	Nanoplankton	2.5		
<i>Evadne nordmanni</i>	Cyanobacteria	5	Clearance rate	
<i>Penilia avirostris</i>	Cyanobacteria			
	Ciliates sp.			
	<i>Nitzschia longissima</i> and	>37.5	Growth and Biomass	Jagger et al. (1988)
	<i>Rhizosolenia</i> spp. and long-chain diatoms (<i>Skeletonema costatum</i> and <i>Thalassiosira</i> sp.).			
<i>Podon intermedius</i>	Diatoms	<15->60	Ingestion rate and Biomass	Katechakis & Stibor (2004)
	<i>Leptocylindrus minimus</i>			
	<i>Leptocylindrus danicus</i> and <i>Skeletonema costatum</i>			
<i>Daphnia</i> sp.	Phytoplankton and Detritus	>7 15-30	Feeding behaviour and Population densities	Kenneth Irvine (1986)
<i>Daphnia cucullata</i>	Phytoplankton	<7	Grazing and Assimilation rate	Bohrer and Lampert (1988)
<i>Daphnia cucullata</i>	Phytoplankton	20-30 4.8 - 7	Ecological indicator	Karpowicz et al. (2020)
<i>Daphnia</i>		3 - 12		

<i>carinata</i>				
<i>Penilia</i>	Diatoms,	>2.5	Grazing and	Wong et al.
<i>avirostris</i>	Cryptophytes,	<20	Pigments	(2006)
	Chlorophytes and		analysis	
	Dinoflagellates			

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5. Biochemical profiles

Cladocerans have been considered to be the live feed sources in larval fish culture because of their higher nutritional value. The cladocerans practically serve as an essential energy source particularly for larval nutrition towards optimal growth as well as maintenance of metabolism, due to their higher contents of proteins and fats (Hall, 1964; Vijver berg, 1989). In addition to nutrient composition, these organisms are preferred as live feed by early larval fish due to their smaller sizes and higher locomotive behavior. The jerky movement of cladoceran make them more visible to fish larvae (Murugan & Moorthy, 1990). In addition, cladocerans are easily raised through mass culture and contain a variety of digestive enzymes, including proteinases, peptidases, amylases, lipases and even cellulose in addition to being good sources of protein for larval growth. The majority of cladoceran species were found to have high levels of proteins, free amino acids, lipids and micronutrients. **Table 3** displays the nutritional value of cladocerans according to previously published studies.

Commented [A17]: Include further data on the biochemical profiles of various cladoceran species and how their protein and fat content can support optimal fish larval growth.

Table 3: Nutritional value of cladocerans

Cladoceran - Species	Protein (%)	Carbohydrate (%)	Lipid (%)	Moisture (%)	Ash (%)	References
<i>Daphnia pulex</i>	50	20 - 27	10 - 20	-	-	Lehman and Naumoski (1985)
<i>Bosmina longispina</i> <i>Evadne nordmanni</i>	42.5 - 49.9	9.3 - 10.8	12 - 14	-	-	Walve and Larsson (1999)
<i>Daphnia magna</i>	27.1	-	10.28	-	12.5	Cauchie et al. (1999)
<i>Moina micrura</i>	52.4	-	-	89	-	Ovie and Ovie (2006)
<i>Diaphanosoma excisum</i>	57.3	-	-	89.3	-	
<i>Brachionus calyciflorus</i>	50.3	-	-	91.6	-	
<i>Daphnia magna</i>	39.24	-	18.70	-	-	Bogut et al. (2010)
<i>Daphnia laevis</i>	-	-	22.1%	-	-	
<i>Daphniopsis tibetana</i>	-	-	26.52%	-	-	Farhadian et al. (2012)
<i>C. quadrangular</i>	-	-	12.3%	-	-	
<i>Daphnia</i> sp.	39.68	16.23	24.99	-	28.15	Gogoi et al. (2018)
<i>Moina</i> sp.	66.33	19.83	10.82	-	3.02	

6. Applications and Constraints in Cladocerans Culture

Cladocerans play a significant role in aquaculture as food sources, major grazers in freshwater habitats and models for studies on ecotoxicology. Maintaining healthy stocks and accurately diagnosing pathogens like parasites are just two of the numerous criteria that contribute to the successful and dependable production of cladocerans as food for aquaculture species. The applications and constraints of cladocerans culture in aquaculture industry are illustrated in **Table 4**. The un-regulated anthropogenic activities in inland waters could be of major risk factor in the loss of its zooplankton diversity. Furthermore, selective predation by aquaculture fishes may also affect the diversity of large zooplankton like moinids and sidids (Martin et al., 2006). Removal of macrophytes in water may also a reason of the diminished diversity of small

cladocerans like bosminids and chydorids in Philippines. Cosmopolitan records should be carefully examined because many of the described taxa represent the different species. Cladocerans are also host to a diversity of epibiont taxa including filamentous bacteria, fungi, algae, ciliates and rotifers (Mehdipour et al., 2011). Heavy coatings of epibionts can be a weight burden, increase drag (Korhola and Rautio, 2001), reduce population growth, and those on the thoracic limbs can lower the resistance of their host to oxygen deficiency (Palanichamy, 1996). Among the parasitic taxa infecting cladocerans are bacteria, fungi, microsporidia, cestodes and nematodes, which may cause behavioral changes (Balayla and Moss, 2004; Kumar et al., 2005) and reduced egg production (Youji et al., 2008).

Commented [A18]: Explain further about the application of cladocerans in aquaculture and the challenges faced in their production, such as culture contamination and disease.

Table 4: Applications and Constraints of Cladocerans culture

Applications of cladocerans	Constraints in Cladocerans culture
<ul style="list-style-type: none"> Rich in proteins and Essential amino acids High nutritional value Rich in enzymes production: Amylase, Protease, Peptidase and Cellulase High reproduction rate Tolerate in saline environments Survived in poor water quality conditions 	<ul style="list-style-type: none"> Feeding habits and Food availability Culture methods Water quality parameters Culture contamination Diseases

7. Future Research Strategies

Live feed culture is an important practical solution for larval rearing towards sustainable aquaculture. However, it is not easy to maintain a steady supply of adequate quantities of live feeds at appropriate times for intensive culture systems. Sometimes, live feed also act as a carrier of diseases to the fish-larvae and therefore, maintenance of hygiene is very important during their production. The new technology of enrichment

process is a costly affair for poor and medium level farmers. Similarly, the high infrastructure and labour requirement along with the variable cost for live feed production underlines the need to develop suitable modified culture technology. Nutritional status of the live feed organisms needs to be summarised for feeding different larval stages of fishes. Therefore, more research thrust should be given on suitability of many of the available live food organisms. The number of species discovered worldwide could quadruple as a result of current developments in molecular phylogenetics and microscopy. These developments are currently being used to study the identification of specimens using other morphological features that were previously thought to be irrelevant (Elmoor-Loureino, 2006).

8. Conclusion

The high price of Artemia cysts, fish production has become more expensive, necessitating the use of less expensive alternative diets with comparable nutritional value. The lack of acceptable live feeds for feeding the fish at their various stages of production has impeded the industrialization of aquaculture. The current review informs readers of recent advancements in the use of various live food organisms in fish and shellfish intensive production. In addition to giving farmers and exporters a better alternative for feeding their fish, the availability of on-grown live food would also open up the prospect of improving the performance and quality of the fish through bioencapsulation.

Ethical approval

Not applicable.

Commented [A19]: Add suggestions for further research on modified culture technology and the importance of summarising the nutritional status of live feed organisms for various stages of fish larvae.

Commented [A20]: Include a summary of the importance of developing cheaper alternative live feeds and how this can improve fish performance and quality through bioencapsulation.

Highlights

- ✓ The present review discusses the importance of cladocerans in relation to live-food potential in fish-larviculture.
- ✓ Their feeding habits, biology, nutritional values and constraints are discussed.
- ✓ The current prospects and challenges of cladocerans are discussed.

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