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THE USE OF ARTEMIA FOR AQUACULTURE INDUSTRY: AN UPDATED OVERVIEW

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Abstract

The increasing global population tends many sectors to overcome the food security issue; sustainable aquaculture is one of the systems that reveal the food problem in the world. The aquaculture industry is drastically increasing to offer the growing demand for this food type. The high mortalities threaten this sector during the first larval stages because of the low supplies of suitable feed for the fish larva. Artemia is vital for the aquaculture industry as it is the primary feed source for fish larvae; it is distinguished by its small size, food carrier characteristic, and off-the-shelf food feature. However, the principal source of artemia cysts has been affected by climate change, ultimately affecting artemia cyst production. Consequently, many areas worldwide try to produce artemia locally to satisfy the aquaculture rearing requirements. As a feed transmitter, artemia can be enriched with essential elements to feed the fish larvae; this method increases survivability, growth performance, and other growth indicators for many fish species. This review aimed to update the academia and stakeholders involved in artemia production in relation to the aquaculture industry. An updated overview of artemia production is also presented in the current review.

Key words: live food, enrichment, sustainable aquaculture, larvae feeding

Aquaculture provides sufficient opportunities to relieve hunger, malnutrition, and poverty, promote economic development, and encourage more efficient natural resources usage (Mugwanya et al., 2021). The sustainable development of the aquaculture sector promotes many of the United Nations' sustainable development goals. It achieves goal no. 1, where it ends hunger, provides food security and enhanced nutrition; goal no. 2 through ending poverty; and goal no. 8 by fostering sustainable and comprehensive economic growth. Fish represents around 17% of the animal protein consumed by the world's population (FAO, 2020). Therefore, the productivity of the aquaculture industry is forecast to increase from 40 million tons in 2008 to 82 million tons in 2050 (FAO, 2020). This increase is due to the growing demand of the increasing global population. There are many schemes to accomplish increasing and sustainable aquaculture production. One of these strategies is improving feed quality and feeding programs (Dawood, 2021). High quality and nutrient-balanced feed are essential in transforming fish ontogeny to exogenous feeding (Prusińska et al., 2020).

Larval rearing of aquaculture organisms faces the challenge of providing high quality and sufficient amounts of cysts of the brine shrimp artemia, tiny crustaceans living in natural hypersaline lakes, and solar saltworks (Al Dhaheri and Saji, 2013). Artemia is extensively used for feeding marine and freshwater fish larva using non-hatched decapsulated cysts, fresh nauplii, or nauplii enriched with highly unsaturated fatty acids (HUFA) and vitamins (Rasdi and Qin, 2016). Using artemia nauplii to feed fish larva improved the fish growth and development and reduced the mortality percentage (Łączyńska et al., 2016; Prusińska et al., 2020). *Artemia* sp. is a credible supply of essential nutrients and enzymes, where tiny fish larva can derive their growth and development needs and enzymes that cannot be synthesized effectively by the fish itself (Prusińska et al., 2020).

The demand for artemia cysts, a safe source of nutrients and enzymes, has steadily increased due to the aquaculture development in the late 1970s. The production raised from a few tons to about 3000 metric tons yearly. The Great Salt Lake (GSL) has been the principal source of artemia cysts during the last five decades; however, production has main challenges. One of these problems is the intense El Niño that happened from 1982 to 1984 and led to heavy snow melting water from the neighboring mountains, eventually significantly reducing lake salinity (Lavens and Sorgeloos, 2000). There were prognoses and warnings of relying on one natural source of artemia cysts several times (Nielsen et al., 2017). Therefore, many harvesting companies established other artemia exploitations over the globe.

Earlier review articles were planned to present the nutritional requirements for artemia productivity (Rasdi and Qin, 2016). Also, little updated efforts were conducted to tackle the artemia production status and critical factors affecting its sustainability. However, this review summarizes artemia's importance in feeding the aquaculture industry, its production globally, and the various effects of artemia feed on many fish species.

Artemia is a natural food

In the 18th century, artemia was first introduced and had been widely used in many biological fields (Sorgeloos, 1980). The usage of artemia as a food supply was found by Seale, Gross, and Rollefsen from 1933 to 1939, where they discovered that 0.4 mm artemia nauplius larva is a prime food source for the fish in the early stages. Consequently, it significantly impacted hatchery production (Sorgeloos, 1980; Ζαχίδου, 1995). Brine shrimp, genus artemia, is a small crustacean of "Anostraca" order of the class "Branchiopoda" belonging to the "Metazoa" kingdom.

Artemia is a genus that includes both sexual and obligatory parthenogenetic ancestors, with six sexual artemia species currently known. Most of them are found in salt lakes in Eurasia or the Mediterranean, where artemia species split from patrimonial species over 80 million years (Naganawa and Mura, 2017). Artemia species are divided into the Old World and New World varieties (Table 1).

Table 1. The Old World and New World varieties of artemia (Camara, 2020; Belmonte et al., 2012)

Old World varieties	New World varieties
Artemia salina (from the Mediterranean Basin)	*Artemia franciscana* (from the Americas and the Caribbean)
Artemia tibetiana (from the Tibetan Plateau)	*Artemia persimilis* (Camara, 2020)
Artemia urmiana (from Lake Urmia in Iran and Ukraine)	
Artemia sinica (from China and Mongolia)	

Artemia is distinguished by its ability to live in hypersaline environments worldwide. Artemia has adapted to live in adverse conditions of high temperatures, low oxygen levels, complex ionic composition (sulfate, chloride, or carbonate-rich water), desiccation, and massive ultraviolet conditions (Camara, 2020). Artemia has a limited generation period, reaching maturity in 8 days (Treece, 2000) or less than 20 days (Camara, 2020) after roughly 15 molts. Of up to 250 embryos per brood, fecundity concentrations are seen in artemia females (maximum 20 broods per lifetime). They reproduce both oviparously (production of encysted dormant embryos) and ovoviviparously (direct generation of free-living nauplii) (Camara, 2020).

Zooplankton, usually the natural diet of fish and shrimp larvae, is either economically unfeasible or technically impossible to achieve (Ayón et al., 2008). Consequently, early explorers' efforts to rear marine fish were hampered by a lack of larval food supplies that were insufficient and unsuitable (Kideys et al., 2000). Live foods are the critical source of nutrition for cultured fish larvae, and they are essential when rearing altricial marine fish larvae. Altricial larvae remain primarily immature until the yolk sac is depleted. The digestive system is still simple at first feeding, without an intestine, and most protein absorption occurs in hindgut epithelial cells. This digestive system cannot be formulated to help larvae survive and mature in most cases. Since brine shrimp nauplii are easy to hatch, they are the most convenient live foods available for aquaculture. Reduced mortality and increased growth rates are observed among many fish species when artemia are used during larval rearing.

Artemia is one of the most functional food for fish larvae because it has many advantages. It is supplied as an off-the-shelf food in the form of dormant cysts; these cysts can be quickly hatched (Sorgeloos, 1980). Artemia can be hatched in any quantity at any time. Artemia is a filter feeder shrimp that grows rapidly, where it feeds on small-size food, for instance: microalgae, bacteria (Toi et al., 2013), and organic manure in the water stream; artemia can also be used as a feed source in the forms of juvenile and adult artemia to fulfill the feeding requirements of the new species of marine aquaculture. *Artemia franciscana* meta-nauplii were used to feed the fish (Lim et al., 2000), anemones, crustaceans, seahorses, soft corals, clownfish, and cephalopods.

Artemia is believed to be a non-selective filter feeder; it can consume a broad spectrum of food, for example, protozoa, microalgae, bacteria, and detritus fragments (Toi et al., 2013). The optimum food size for artemia meta-nauplii is roughly 16.0 µm; however, it can range from 6.8 to 27.5 µm (Chaoruangrit et al., 2017). The adult brine shrimp can consume food particles of less than 50 µm (Nevejan et al., 2018). However, there are many advantages of using artemia in the rearing of fish larvae; brine shrimp enrichment is essential for the lack of nutritional value of artemia. There are various procedures to enhance nauplii's nutritional value (Kandathil Radhakrishnan et al., 2020). Artemia nauplii filter enrichment compounds passively; any particle of adequate size found in the food is loaded into their digestive system. Consequently, nauplii may serve as carriers for enrichment products to the fish larvae. The outputs can be altered according to the related elements, such as the aimed organisms' needs and the enrichment diets (Kandathil Radhakrishnan et al., 2020). High-quality meals are the key factor in promoting fish larvae culture; these diets should be easily digested and provide nutritional elements to maintain the fish's lifespan, ideal growth, and immune system. Lipids and fatty acids are the leading energy providers for fish embryos and larvae. These components' availability during endogenous feeding is drastically decreased. So, it is essential to feed the fish larvae with live prey with adequate nutrients. Indeed, artemia has low percentages of EPA (eicosapentaenoic acid) and DHA (docosahexaenoic acid). Therefore, it should be enriched with essential lipids rich in fatty acids to fulfill the fish larvae's food requirements. Some artemia nauplii have a shortage of eicosapentaenoic acid (EPA; 20:5n-3) and docosahexaenoic acid (DHA; 22:6n-3) (Akbary et al., 2011). Highly unsaturated fatty acids (HUFA) with carbon chain lengths of 20 and 22, of both the n-3 and n-6 sequences and polyunsaturated fatty acids (PUFA) with carbon chain lengths of 18 are the most common essential fatty acids (EFA) for fish. Therefore, these fatty acids should be supplied in the artemia feed to cover the fish's needs, as these acids cannot be synthesized by the fish (Akbary et al., 2011). HUFA should be included in the artemia feed using various natural algae levels, oil emulsions, or commercial enrichment products (Kandathil Radhakrishnan et al., 2020). In addition, there are many ways to overcome the variable nutritional value of artemia by choosing the appropriate strains, applying decapsulated cysts whenever possible, and using the freshly hatched nauplii.

Artemia production around the world

Cysts were first commercially harvested in the early 1950s from the saltworks at San Francisco Bay (SFB) beaches in California and the Great Salt Lake (GSL) in Utah in the USA. Artemia was sold low to the aquarium pet trade (Islam et al., 2019). Cyst values rose dramatically in the middle of the 1970s due to increased demand from new hatchery operations of marine larvae fish, lower GSL harvests, and likely simulated shortages by some commercial firms (Lavens and Sorgeloos, 2000). Consequently artemia cyst production has steadily risen from a few metric tons per year to nearly 3000 metric tons per year after the enhancement of the market for marine aquaculture at the end of the 1970s (Litvinenko et al., 2015) (Figure 2). The Great Salt Lake (GSL) has come to be the primary provider of artemia cysts to the aquaculture business since the 1970s. It has been focused on several speculations about its ability to support a rising aquaculture industry (Lavens and Sorgeloos, 2000). GSL cysts dominated the world market from the mid-1980s onwards. Over the years, GSL has provided more than 90% of the world's commercial harvest of brine shrimp cysts. Litvinenko et al. (2015) revealed that the highest annual cyst densities of the artemia water column in GSL fluctuated from 80 cysts per liter to more than 240 from 2007 to 2019. The cyst dry harvest quantities from the GSL also varied from 1995 to 2018, between a few tons to more than 2000 tons. GSL produced 1000–2000 tons of artemia cysts, followed by 900 tons in China and 550 tons in Russia. A sufficiently high-hatching product has been available to meet the rapidly growing market needs (Lavens and Sorgeloos, 2000). Cyst provision by GSL was a critical situation, according to Bengtson et al. (2018), because the costs of brine shrimp cysts were raised owing to the low yield quantities from GSL, ultimately affecting the larvae-culture market. Artemia production has faced various challenges worldwide, including the difference in the cyst's properties, the variation of the nourishment aspects of nauplii between artemia sources, and the environmental conditions that affected artemia production for several years in some sites (Bengtson et al., 2018).

Aquaculture development is mainly dependent on the continued existence of cyst stocks. There are numerous studies on the quantities of cyst supplies that exist worldwide and the cyst required to meet the global aquaculture industry (Van Stappen et al., 2020). There are research studies that investigated artemia production in various places.

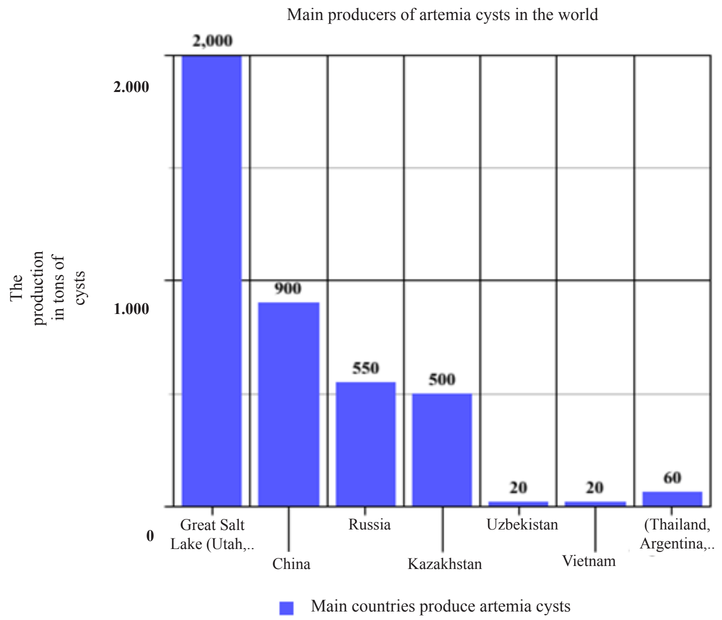

Figure 2. This graph illustrates the main producers of artemia in the world, including Great Salt Lake (Utah, USA), Russia, Kazakhstan, Uzbekistan, China, Vietnam, Thailand, Argentina, Brazil, and other salt ponds and lakes in the world with their production of artemia cysts in tons (Litvinenko et al., 2015)

A research study investigated Russia's position in terms of world cyst stocks and the approach for boosting them. However, Russia's share of global cyst harvesting has not yet reached 20%; the production is slightly affected by the year's dryness with stable production (against the GSL). The harvest of cysts in Russia is increasing; on the contrary, commercial cyst extraction in Russia could be improved to use available resources better. To increase production, the following actions must be taken: perform advanced techniques of harvesting with sustainable usage of the production areas through improved collecting, processing, storage, and enclosure ways; investigate new sources of the cyst production, such as Crimea; improve the quality of artemia biotopes by developing technologies and water administration methods (i.e., managing water salinities and quantities) (Litvinenko et al., 2015).

China is considered the main consumer of artemia, with more than half of the global production of artemia (Hasan, 2016). However, China's artemia pond production remains unstable and unpredictable. It is still necessary to develop appropriate techniques tailored to the surrounding environment, such as fertilization techniques. Limited information was available about how introduced *Artemia franciscana* populations develop to their new conditions or how their performance can be improved, for instance: selective breeding, which is dissimilar to Vietnam's case. Local-related considerations diminished improvements in this field. The first is the bulk density of most salt production sites which is hard to control to increase artemia production. Besides, the salt production sector management, controlled mainly by large businesses, may reduce progress. However, it also may advantage from the large scale (e.g., assisting the investment of processing facilities). Finally, the complexity and instability of the Chinese artemia market, with a wide range of differently priced domestic and imported artemia cyst products, led to the discouragement of supply and demand conditions to produce high-quality cysts in the local Chinese market (Van Stappen et al., 2020).

Van Stappen et al. (2020) clarified that China witnessed variations in prices of commercial cyst products from 1993 to 2017, from 10 USD/kg dry product reaching its peak to more than 70 USD in 2000 to 30 USD in 2017. In addition, there was an increasing demand for cysts during the same period from more than 200 tons in 1993. It reached its maximum at about 1600 tons in 2011 and 2012, and started to decrease again to around 1000 tons in 2017.

Another study described the distribution of *Artemia francescana* in northeastern Brazil. They found that exploitation-induced selection threatens the new aquaculture business in northeastern Brazil. Thus, advanced management techniques with an eye on the circumstances of selection triggered by exploitation are needed to manage the artemia sources. The harvesting effect on the genetic variation of *Artemia francescana*'s and its characteristics should be assessed. That methodology would present the necessary data for developing a management strategy for continuously harvesting the brine shrimp cyst in Brazilian salt fields (Camara, 2020).

In the mid-1980s, Vietnam was inoculated with artemia to improve cysts and biomass production for larviculture and early stages of aquaculture varieties. Hence, artemia growers sought to produce cysts seasonally in the Mekong Delta, especially in Soc Trang and Bac Lieu provinces. Research institutions and universities, notably Can Tho University, widely disseminated the technical knowledge among the local communities of artemia farmers. Artemia pond production in Vietnam has grown into a flourishing industry, allowing salt-producing residents to raise a significant substitute income with a short profit and reasonable investment. Artemia growers, who are usually in insufficient financial flexibility and/or limited land possession, face inconsistent profitability. There is a sensitivity to variations in the costs and requirements for cysts in Vietnamese aquaculture. Since the beginning of the 2000s, the yearly raw cyst production has increased consistently from 15–20 to 50–60 tons, where yields have been covered from 50–70 kg raw cysts per 'crop'. Currently, Vietnamese hatcheries demand around 400–500 tons of artemia dry cysts annually, and only a tiny portion of this requirement is met by Mekong Delta production (Van Stappen et al., 2020).

Since 2014, lowered efficiency has begun by integrating unusual weather conditions (narrower dry durations and increasing temperatures) and farmers' unwillingness to implement enhanced production methods; however, total production relatively increased until 2016 due to the culture area's extension. Finally, farmers' associations require long-term assistance from extension workers with appropriate scientific knowledge in partnering with governmental authorities, aquaculture policymakers, and universities. Farmers themselves lack the education, financial, and infrastructural resources to be involved in experimental efforts to improve production schemes (Van Stappen et al., 2020).

Finally, the massive scale of industrial salt operations in the whole world impedes the best artemia conditions, for instance: phytoplankton densities, which do not allow for proper management and monitoring. However, salt producers in broad areas have adequate knowledge and scientific training and belief in the advantages of artemia productivity in the salt yield system. They may be hesitant to effectively apply procedures that aim to increase the artemia production since it might affect the salt returns targeted by the business strategy.

Small scale units provide more intensive and much-moderated production where experimental designs can be applied. Consequently, large production ponds can enhance the local or regional artemia sources by applying the successful experimental schemes of small units. We did not find a precise number of the international demand for artemia cysts at present; however, we conclude from the current cases of China, which consumes 50% of the global artemia cysts, and Vietnam that the artemia cyst production is not adequate and there should be increased efforts to satisfy the aquaculture needs.

Enrichment of artemia with various compounds

Minerals and irons play a significant role in various biological operations that include controlling the acid-base balance, a composite of natural compounds, like hormones, enzymes, and DNA, oxygen transportation, skeletal formation, provision of energy, regulation of the cell cycle, medium metabolism, preservation of colloidal systems (Anderson and McLaren, 2012; Kandathil Radhakrishnan et al., 2020).

Archaea is usually dominant in aquaculture environments, particularly haloferax adapted to a diverse range of salinities, and it is flexible to use various organic compounds for cell growth. Sui et al. (2020) studied the effect of growing haloferax in bio-floc under specific circumstances to enrich the artemia, where sucrose was used to generate the haloferax growth at a C/N ratio of 10 by feeding artemia with four different feeding percentages. Haloferax-based bio-floc helped to enhance artemia biomass, which predominated the culture. However, more research should investigate its effect on the artemia reproductive traits.

Cavrois-Rogacki et al. (2020) assessed the effect of various Se enrichment schemes of diverse sources on the fatty acids enhancement of artemia nauplii. They found that using seleno-yeast Sel-Plex is appropriate to enrich artemia with specific levels of Se. Artemia nauplii were enhanced with 12 mg Sel-Plex per liter for 4 hours before being fed with LC-PUFA-rich marketable diets for 24 hours. Artemia with Se levels is likely to be in the natural prey with high percentages of essential fatty acids. Although, inorganic Se was not an excellent mechanism for enriching artemia nauplii, even by enhancing phospholipid vesicles.

Amino acids play an essential role in accelerating larval growth and development; amino acids are needed mainly to preserve the tissues' optimal concentrations to reach the effective growth rate and ideal consumption of amino acids (Tacon and Cowey, 1985; Tonheim et al., 2000). Tonheim et al. (2000) examined the difference between two enrichment protocols to enhance artemia with free amino acids (FAA). The first protocol is by direct feeding, where FAA is dissolved straight in the culture water, and the second is by adding FAA enclosed in the liposome's capsulation to the water. The experiment proved the capability of enriching artemia nauplii with free methionine. The fish larvae can be fed with a high FAA rate by the enriched artemia nauplii since free methionine retention in the nauplii.

Despite the importance of artemia nauplii as live food in rearing marine fish larvae, they have a shortage of two essential fatty acids (EFA): eicosapentaenoic (EPA) and docosahexaenoic (DHA) (Morais et al., 2007). Thus, highly unsaturated fatty acids (HUFA) compromise artemia nutritional deficiency.

Effect of artemia on various fish species

Animal nutrition requires selenium (Se), a trace element, which has many functions relating to animal production, fertility, and illness prevention (Hefnawy and Tórtora-Pérez, 2010; Tórtora-Pérez, 2010). It is added to the artemia enrichment feeds. It is a crucial component of glutathione peroxidase (GPx), an enzyme that regulates antioxidant status in finfish by lowering hydrogen peroxide and hydroperoxides to their primary elements (Pacitti et al., 2015). Using selenium to enrich artemia has a considerable impact on the fish's progress; thus, research was conducted by Juhász et al. (2017) to investigate the optimum quantities to feed the artemia with selenium and its effect on red drum (*Sciaenops ocellatus*) larvae. The study showed that a medium amount of ~4 mg/kg dry matter of *Artemia* sp. could improve the growth and performance levels of *Sciaenops ocellatus* larvae. However, the research claimed that higher rates might negatively affect larvae rearing.

Kamaszewski et al. (2014) studied the effectiveness of EFA-enriched artemia on growth, durability, and digestive enzyme actions in Atlantic sturgeon larvae, from hatching to the early juvenile phase. The results showed the beneficial impact of EFA-enriched artemia on the survival percentage of Atlantic sturgeon larvae. It probably accelerated the progress of the intestinal brush border, but further research is needed to verify this claim.

Boglino et al. (2012) studied the impact of six enriching artemia products for live prey, frequently used to hatch Senegalese sole, with graded ratios of n-3 polyunsaturated fatty acids (PUFA) and graded DHA/EPA degrees on larval functioning and skeletogenesis. These products are Easy Selco© (INVE, ES), Multigain© (BioMar, MG), RP), Red Pepper© (Bernaqua, Easy Selco© (INVE) half diluted with olive oil (ES/2), Aquagrow DHA© (ABN, AGD), and Aquagrow Gold© (ABN, AGG) with the last two being diluted by a third with olive oil. They revealed that they could enhance proper larval growth and quality; however, they reacted with different degrees of improving larval development and improvement of Senegalese sole. Each product showed its accumulation model per every fatty acid; thus, there is no optimal product for larval growth and durability. Nevertheless, the AGG diet is considered the best to improve larval performance. Its fatty acids profile is well-balanced among the other diets for Senegalese sole larvae (Vajargah et al., 2021).

Akbary et al. (2011) examined enriching artemia with vitamin C and EFA on the rainbow trout larvae growth, survival, and resilience to high-temperature conditions. The results showed that the synergistic effect of EFA and vitamin C led to lower mortality rates, high resistance to stress conditions, and improved the growth of the rainbow trout fish larvae.

Barbel (*Barbus barbus*), a freshwater fish, was examined by Prusińska et al. (2020) to study the effect of feeding the barbel's larva and juvenile with artemia enriched with PUFA on their overall performance. The outcomes revealed that the feed utilization and growth rates increased with increased intestinal enterocytes area. Consequently, the nutrient absorption enhanced with a better EPA/DHA ratio boosted neutrophil count, maintaining immunity and improving fatty acid profile.

Jamali et al. (2018) examined the impact of feeding green terror cichlid (*Aequidens rivulatus*) larvae with lecithin enhanced *Artemia franciscana* nauplii. The experiment displayed that the enriched artemia decreased the mortality rate, increased the weight and length gain, and improved the growth performance and nutritional value of green terror cichlid larvae. Furthermore, feeding on enhanced artemia accelerated the fish acceptance of commercial feed.

The performance of Pacific cod larvae was examined after feeding on enriched artemia (4:1 DHA: EPA ratio) by Choi et al. (2021), where they found that artemia nauplii contributed to an increase in the survival and growth rates of Pacific cod larvae and their resilience to air exposure pressure.

High mortality rates and skeletal anomalies are most common in the earlier periods in the aquaculture of greater amberjack (*Seriola dumerili*). Therefore, Roo et al. (2019) studied the role of enhancing artemia with n-3 HUFA on the greater amberjack larvae; the TFA (trans fatty acids) within the range of 12–17% improved the growth, reduced skeleton anomalies, and the mortality rate.

Putra et al. (2018) investigated the effect of gamat emulsion to improve the artemia's influence on the growth of white shrimp, *Litopenaeus vannamei* larvae. The study revealed that 10 ml/L gamat emulsion extract fed to artemia nauplii could boost the weight and length gain and the survival percentage of the white shrimp larvae without a considerable contribution to the specific growth rate.

Macrobrachium americanum larvae is a freshwater shrimp that can be affected by feeding on essential nutrients. Pérez-Rodríguez et al. (2018) studied the impact of enriched artemia with microalgae on the progress of *Macrobrachium americanum*. They recommended providing artemia with *Chaetoceros calcitrans* microalgae as a feed source for *Macrobrachium americanum* larvae; thus, the growth, growth rates, and survivability are improved.

Enriching artemia with fatty acids is a strategy to improve the progress of fish larvae. Francis et al. (2019) tested the effect of enriched artemia with long-chain polyunsaturated fatty acids (LC-PUFA) on Murray cod larvae. The study showed higher growth rates and fatty acid profiles than the larvae fed on un-enriched artemia.

Vitamin C has beneficial roles in tissue repairing and generating enzymes of specific neurotransmitters; Vajargah et al. (2021) examined the effect of vitamin C on *Sepia pharaonis* by enhancing artemia with it and feeding it to the fish. The results indicated that enriched artemia with vitamin C boosted the growth performance and survival rates of *Sepia pharaonis.*

Bacillus subtilis is one of the microorganisms used to enhance the artemia before feeding the fish. A study was performed by Rezaei Aminlooi et al. (2019) to test the impact of enriched artemia with *Bacillus subtilis* on the performance of ornamental fish, *Poecilia latipinna*. *Bacillus subtilis* has a respectable effect on the reproductive, gastrointestinal tract microflora and the resilience of *Poecilia latipinna* to *Aeromonas hydrophila.*

Carballo et al. (2018) performed a study on vitamin C and iron's impact on Senegalese sole larvae (*Solea senegalensis*). Results showed that vitamin C and iron integration improved the fish larval physiological operations. These advancements include growth, total antioxidant capacity, and metamorphosis. In addition, the interaction between iron and vitamin C regulated stress and iron metabolic functions, according to gene expression profiles.

Conclusion

To summarize, artemia is an excellent live food that can fulfill the nutritional needs of fish larva in the early stages of growth. However, there are many trials to expand artemia production worldwide that have been affected by various factors in the last decades. Although, there is increasing demand for artemia production to supply the aquaculture industry. The production problems in many countries refer to the necessity of international collaboration to improve this industry through knowledge exchange. Many researches revealed the importance of enriching artemia to improve their growth and the fish larvae. More research is needed to identify the quantity and enrichment protocols suitable for various artemia and fish species.

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