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Artemia as a Strategic Live Feed in Fish and Shrimp Hatcheries: Nutritional Value, Enrichment Technologies, and Implications for Larval Growth and Survival: A Literature Review

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ABSTRACT

Background: Live feed availability is a critical factor determining the success of fish and shrimp hatchery operations. Among various live feeds, *Artemia* remains one of the most widely used organisms due to its suitable particle size, high digestibility, ease of storage, and capacity for nutritional enrichment.
Aims: This review aimed to synthesize current knowledge regarding the nutritional value of *Artemia*, its application in hatchery systems, enrichment strategies, and its effects on larval growth and survival in commercially important aquaculture species.
Methods: A systematic literature review was conducted following a structured search of peer-reviewed articles published between 2015 and 2025. Relevant literature was retrieved from Google Scholar, ScienceDirect, SpringerLink, and other scientific databases using predefined keywords related to Artemia, enrichment technologies, hatchery management, and larval performance. Studies were screened based on relevance to fish and shrimp larviculture, nutritional enhancement, and biological performance indicators.
Results: The reviewed studies consistently demonstrated that *Artemia* significantly improves larval growth, specific growth rate, size uniformity, and survival in various aquaculture species, including *Litopenaeus vannamei*, *Penaeus monodon*, *Oreochromis niloticus*, *Lates calcarifer*, and *Clarias gariepinus*. Furthermore, enrichment with highly unsaturated fatty acids (HUFAs), omega-3 fatty acids, microalgae, probiotics, synbiotics, vitamins, and phytogenic compounds substantially enhanced the nutritional quality of *Artemia*, resulting in improved growth performance, immune competence, stress tolerance, and disease resistance.
Conclusions: *Artemia* remains an indispensable live feed in modern hatchery systems. Advances in enrichment technologies have transformed *Artemia* from a conventional live feed into an effective nutrient delivery

platform capable of enhancing larval performance and hatchery productivity. Future development should focus on strengthening domestic *Artemia* production, improving enrichment efficiency, and integrating biosecure hatchery management practices to support sustainable aquaculture development.

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1. Introduction

The aquaculture sector is one of the major contributors to national fisheries production and plays a significant role in providing animal protein, generating employment opportunities, and contributing to foreign exchange earnings. In recent years, economically important cultured species such as Pacific white shrimp (*Litopenaeus vannamei*), black tiger shrimp (*Penaeus monodon*), and Nile tilapia (*Oreochromis niloticus*) have shown continuous production growth in response to increasing domestic and export market demands (Ministry of Marine Affairs and Fisheries, 2025). The success of farming these commodities largely depends on the availability of high-quality seed produced through efficient and sustainable hatchery operations.

Despite significant advances in hatchery technology, the larval stage remains one of the most critical phases in seed production due to its relatively high mortality rate. During early development, larvae possess an immature digestive system, limited swimming ability, and highly specific nutritional requirements that rapidly change according to developmental stage. Consequently, larvae are extremely sensitive to both environmental conditions and feed quality (Conceição *et al.,* 2010). Inappropriate feed particle size, poor nutrient digestibility, and deficiencies of essential fatty acids are frequently identified as major factors limiting larval survival and growth in hatchery systems (Martínez-Soler *et al.,* 2023).

In this context, live feed continues to play a crucial role as the primary nutritional source for fish and shrimp larvae. Compared with formulated feeds, live feed offers several advantages, including appropriate particle size, active movement that stimulates feeding behavior, and superior digestibility. Among the various live feed organisms used in aquaculture, *Artemia* spp. is the most widely utilized worldwide. *Artemia nauplii* have been commercially employed since the 1970s and remain an essential component of marine fish, freshwater fish, and crustacean hatcheries (Lavens & Sorgeloos, 1999).

The popularity of *Artemia* is attributable to several biological and technical advantages. *Artemia* cysts can be stored for extended periods, hatched on demand, produce nauplii of relatively uniform size, and contain high levels of protein and lipids. Furthermore, *Artemia* possesses excellent bioencapsulation capabilities, allowing enrichment with nutrients and functional compounds such as highly unsaturated fatty acids (HUFAs), docosahexaenoic acid (DHA), eicosapentaenoic acid (EPA), vitamins, probiotics, immunostimulants, and microalgae prior to administration to larvae (Lavens & Sorgeloos, 1999; Samat *et al.,* 2020). These characteristics make *Artemia* a strategic live feed during critical stages of larval development.

Numerous studies have demonstrated that *Artemia* can significantly improve larval biological performance in terms of both growth and survival. In Pacific white shrimp, nutrient-enriched *Artemia* has been reported to enhance growth performance, specific growth rate, physiological quality, and postlarval survival (Martínez-Soler *et al.,* 2023). Likewise, the combination of *Artemia* with microalgae or HUFA-rich lipid sources has been shown to improve growth, stress resistance, and physiological performance in black tiger shrimp postlarvae (Immanuel *et al.,* 2004; Jaseera *et al.,* 2021). In Nile tilapia and Asian seabass larvae, *Artemia* supplementation has also been associated with increased body length

growth and improved rearing success during early developmental stages (Jusadi *et al.,* 2004; Kailasam *et al.,* 2006).

Despite these advantages, the utilization of *Artemia* in Indonesia still faces several challenges. Most of the national demand for *Artemia* cysts is met through imports, making hatchery industries vulnerable to fluctuations in global prices, product quality, and supply chain disruptions. Furthermore, the use of *Artemia* in many hatcheries remains largely conventional, involving simple hatching and direct feeding without standardized enrichment strategies. This is particularly important because the nutritional quality of *Artemia* is influenced by strain origin, naupliar age, hatching conditions, and enrichment protocols applied before feeding to larvae (Lavens & Sorgeloos, 1999; Martínez-Soler *et al.,* 2023).

Although numerous studies have investigated the use of *Artemia* in specific fish and shrimp species, comprehensive syntheses integrating its nutritional characteristics, enrichment technologies, and biological effects across multiple aquaculture commodities remain limited. Existing reviews generally focus on either nutritional enrichment or species-specific applications without providing a broader evaluation of the role of *Artemia* in contemporary hatchery systems. Furthermore, information regarding the opportunities and challenges associated with *Artemia* utilization in tropical aquaculture, particularly in Indonesia, has not been systematically synthesized. Therefore, a comprehensive review is required to provide scientific evidence supporting the optimization of *Artemia*-based feeding strategies in modern hatchery operations.

On the other hand, comprehensive review studies specifically synthesizing the effects of *Artemia* on the growth and survival of fish and shrimp larvae, particularly within the context of tropical aquaculture in Indonesia, remain relatively limited. Most previous publications have discussed *Artemia* broadly as a live feed without comparatively evaluating its effectiveness across cultured species or reviewing strategies for improving its nutritional quality. Such scientific syntheses are important to support evidence-based decision-making among hatchery operators, researchers, and policymakers.

2. Methods

2.1 Review Protocol

This study employed a systematic literature review approach following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA 2020) guidelines. The review was designed to evaluate the nutritional value of Artemia, enrichment technologies, and their impacts on the growth and survival of fish and shrimp larvae in hatchery systems.

2.2 Literature Search Strategy

Relevant studies were retrieved from Google Scholar, ScienceDirect, SpringerLink, Scopus-indexed journals, and other scientific databases. Searches were conducted using combinations of the following keywords: “Artemia”, “Artemia enrichment”, “live feed”, “hatchery”, “fish larvae”, “shrimp larvae”, “growth performance”, “survival rate”, “bioencapsulation”, “HUFA”, “probiotics”, and “aquaculture”.

2.3 Inclusion and Exclusion Criteria

Studies were included if they:

- were published between 2015 and 2025;
- were peer-reviewed journal articles;
- investigated *Artemia* utilization in fish or shrimp hatcheries;
- evaluated growth performance, survival, nutrition, or enrichment strategies.

Studies were excluded if they:

- focused on non-aquaculture organisms;
- lacked experimental or review relevance;
- were conference abstracts, editorials, or unpublished reports;

did not provide sufficient methodological information.

2.4 Data Extraction and Analysis

Data extracted from eligible studies included species cultured, enrichment treatments, growth indicators, survival rate, and major findings. Information was subsequently categorized into:

1. Nutritional characteristics of *Artemia*;
2. Growth performance responses;
3. Survival responses;
4. Enrichment technologies;
5. Challenges and future prospects.

The collected information was synthesized using a descriptive-comparative approach.

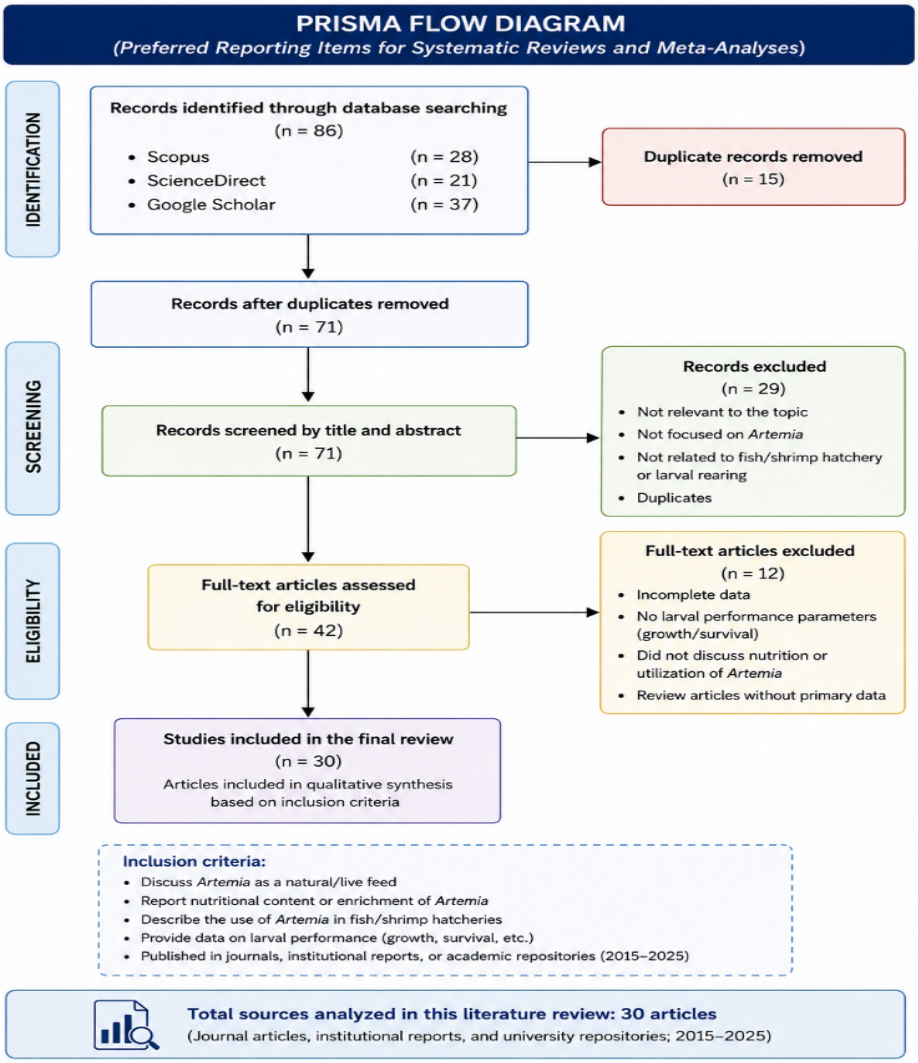


Figure 1. Prisma Flow Diagram

3. Results and Discussion

3.1 Effects of *Artemia* on the Growth Performance of Fish and Shrimp Larvae

The literature review revealed that the use of *Artemia* as a live feed exerts a positive effect on the growth performance of fish and shrimp larvae across various aquaculture species. Growth enhancement is generally reflected by improvements in final body weight, total length, specific growth rate (SGR),

and size uniformity of larvae and juveniles. These benefits are primarily associated with the high protein content, balanced essential amino acid profile, and the ability of *Artemia* to serve as a carrier of additional nutrients through enrichment techniques. Several studies have also demonstrated that *Artemia* enriched with highly unsaturated fatty acids (HUFA), omega-3 fatty acids, and microalgae promotes superior growth performance compared with non-enriched *Artemia* or formulated feeds. A summary of studies investigating the effects of *Artemia* on the growth performance of fish and shrimp larvae is presented in Table 1.

Table 1. The survival rate (SR) of African catfish larvae during the rearing period

Number	Experimental Species	*Artemia* Treatment	Effects on Growth Performance	References
1	Various species	*Artemia* enrichment strategies	Improved growth performance associated with increased DHA and EPA contents	Ramena *et al.*, 2025
2	*Clarias microstomus* × *Clarias gariepinus*	Synbiotic-enriched *Artemia*	Enhanced larval growth and gut health while improving feed efficiency	Lingoh *et al.*, 2025
3	*Litopenaeus vannamei*	Synbiotic bio-encapsulated *Artemia*	Enhanced growth performance	Yudiati & Azhar, 2024
4	*Litopenaeus vannamei*	Nutrient-supplemented *Artemia*	Increased specific growth rate (SGR) and postlarval growth	Nur *et al.*, 2024
5	*Lates calcarifer*	n-3 HUFA-enriched *Artemia*	Increased final weight and specific growth rate	Pham *et al.*, 2023
6	*Litopenaeus vannamei*	HUFA-enriched *Artemia*	Improved growth performance and physiological quality of postlarvae	Martínez-Soler *et al.*, 2023
7	*Litopenaeus vannamei*	*Artemia* enriched with fructooligosaccharides	Produced the best growth performance among treatments	Nurbaeti & Putra, 2023
8	*Litopenaeus vannamei*	Different feeding levels of *Artemia*	Significantly affected growth performance	Kahfi *et al.*, 2023
9	*Litopenaeus vannamei*	HUFA- and selenium-enriched *Artemia*	Increased final length, final weight, and specific growth rate	Pham *et al.*, 2022
10	*Carassius auratus*	Spirulina-enriched and canthaxanthin-enriched *Artemia*	Improved growth performance, pigmentation, health status, and immune responses	Elshafey *et al.*, 2023
11	Various species	Enriched *Artemia* and *Moina*	Improved growth performance	Joshua *et al.*, 2022
12	*Litopenaeus vannamei*	*Artemia* enriched with *Sargassum* extract	Improved growth performance and immune status of postlarvae	Amrullah *et al.*, 2022

13	*Gadus macrocephalus*	HUFA- and DHA-enriched *Artemia*	Improved overall growth performance	Choi *et al.*, 2021
14	*Penaeus monodon*	*Artemia* combined with *Aurantiochytrium* microalgae	Enhanced larval growth performance	Jaseera *et al.*, 2020
15	*Litopenaeus vannamei*	*Artemia*, liquid artificial feed, and powdered artificial feed	Produced the best growth performance and feed utilization efficiency	Putri *et al.*, 2020
16	*Litopenaeus vannamei*	*Artemia* enriched with n-3 LC-PUFA	Enhanced growth performance during larval stages	Ahmadi *et al.*, 2019
17	*Macrobrachium americanum*	*Artemia* combined with *Chaetoceros calcitrans*	Produced the highest growth enhancement	Méndez-Martínez *et al.*, 2018
18	*Litopenaeus vannamei*	Lysine- and methionine-enriched *Artemia*	Improved growth performance and stress resistance	Bahabadi *et al.*, 2018
19	*Macrobrachium rosenbergii*	*Artemia* as larval feed	Supported larval growth and development	Yong *et al.*, 2018
20	*Clarias gariepinus*	*Artemia nauplii* combined with formulated feed	Improved growth performance	Onura *et al.*, 2018

The high survival rate observed in Treatment A indicates that enrichment of *Tubifex* worms with vitamin C at 2.5 g L^{-1} effectively improved larval viability during the rearing period. This improvement may be attributed to the role of vitamin C as an antioxidant that enhances immune function, maintains physiological balance, and helps larvae cope with environmental stress during early development. Vitamin C is also involved in tissue formation, collagen synthesis, and the enhancement of non-specific immune responses, thereby reducing mortality during the larval rearing stage (Kumari & Sahoo, 2005; Wan *et al*., 2014). Vitamin C enhances immune function by stimulating leukocyte activity, increasing phagocytic capacity, promoting antioxidant defense systems, and reducing oxidative stress. Furthermore, vitamin C contributes to collagen synthesis and tissue repair, thereby improving the integrity of epithelial barriers that serve as the first line of defense against pathogens. These mechanisms collectively improve disease resistance and survival in fish larvae.

Adequate vitamin C availability enables metabolic processes to proceed more efficiently, allowing nutrients and energy derived from feed to be utilized more effectively for maintaining physiological functions. Consequently, larvae exhibit greater resilience to environmental fluctuations and stress conditions during culture. These findings are consistent with those reported by Sembiring *et al*., (2025), who demonstrated that dietary vitamin C supplementation increased the survival rate of African catfish by 76.6% compared with unsupplemented treatments. Similarly, Ghughuskar (2012) reported that vitamin C supplementation improved physiological performance and stress resistance in fish larvae, which are particularly vulnerable to environmental changes.

Although Treatment B exhibited a higher SR than the control, increasing the vitamin C concentration to 3.5 g L^{-1} did not result in better survival compared with Treatment A. This finding suggests that vitamin C requirements during the larval stage have an optimal threshold, and excessive supplementation may not necessarily provide additional physiological benefits. Excessive vitamin C levels may reduce

nutrient utilization efficiency and potentially disrupt metabolic balance, thereby increasing physiological stress in larvae. Previous studies have reported that the effectiveness of vitamin C supplementation largely depends on its suitability to the physiological requirements of the cultured organism (Ai *et al*., 2006; Sunarto *et al*., 2008).

3.2 Effects of *Artemia* on Larval Survival Rate

In addition to promoting growth, the use of *Artemia* has been widely reported to enhance the survival rate (SR) of fish and shrimp larvae. High survival performance is generally attributed to the appropriate prey size, high digestibility, active swimming behavior that stimulates feeding activity, and the presence of essential nutrients that support larval health and immune competence. Recent studies have further demonstrated that *Artemia* enriched with probiotics, synbiotics, vitamins, and microalgae can improve resistance to environmental stress and pathogenic infections. A summary of studies evaluating the effects of *Artemia* on larval survival is presented in Table 2.

Table 2. Summary of studies reporting the effects of *Artemia* on survival rate in fish and shrimp larvae

Number	Experimental Species	*Artemia* Treatment	Effects on Survival Rate	References
1	*Litopenaeus vannamei*	Synbiotic bio-encapsulated *Artemia*	Improved survival and enhanced resistance against AHPND	Yudiati & Azhar, 2024
2	*Litopenaeus vannamei*	*Artemia* enriched with fructooligosaccharides	Produced the highest survival rate and enhanced digestive enzyme activities	Nurbaeti & Putra, 2023
3	*Litopenaeus vannamei*	Different feeding levels of *Artemia*	Significantly affected larval survival	Kahfi *et al.*, 2023
4	*Litopenaeus vannamei*	HUFA- and selenium-enriched *Artemia*	Increased larval survival rate	Pham *et al.*, 2022
5	*Litopenaeus vannamei*	*Artemia* enriched with *Sargassum* extract	Improved survival rate and immune response	Amrullah *et al.*, 2022
6	*Litopenaeus vannamei*	*Artemia* nauplii enriched with *Halorubrum* archaea	Improved survival and pathogen challenge tolerance	Xie *et al.*, 2021
7	*Gadus macrocephalus*	HUFA- and DHA-enriched *Artemia*	Improved overall larval survival	Choi *et al.*, 2021
8	*Penaeus monodon*	*Artemia* combined with *Aurantiochytrium* microalgae	Significantly increased larval survival	Jaseera *et al.*, 2020
9	*Litopenaeus vannamei*	*Artemia* combined with *Phronima* sp.	Improved survival performance	Herawati *et al.*, 2020
10	*Litopenaeus vannamei*	*Artemia*, liquid artificial feed, and powdered artificial feed	Produced the highest survival rate among feeding treatments	Putri *et al.*, 2020
11	*Clarias gariepinus*	*Artemia* combined with Skretting dry feed	Produced the highest survival rate and improved larval performance	Zarau *et al.*, 2019

12	*Seriola dumerili*	n-3 HUFA-enriched *Artemia*	Improved larval survival and reduced skeletal deformities	Roo *et al.,* 2019

Survival rate (SR) is one of the most important indicators of hatchery success because it directly determines the number of marketable juveniles produced. During the larval stage, mortality is typically high due to the incomplete development of digestive organs, immature immune systems, and high sensitivity to environmental fluctuations. Consequently, the provision of high-quality live feed is essential for minimizing mortality. Based on the synthesis presented in Table 2, the use of *Artemia* consistently exerts positive effects on larval survival across a wide range of fish and shrimp species (Lavens & Sorgeloos, 1999).

In shrimp culture, numerous studies have demonstrated the important role of *Artemia* in improving larval survival, particularly when enriched with functional nutrients. Jaseera *et al.,* (2021) reported that co-feeding *Artemia* with the DHA-rich microalga *Aurantiochytrium* sp. significantly improved the survival of black tiger shrimp (*Penaeus monodon*) larvae. This microalga is rich in DHA, EPA, and natural antioxidants that contribute to enhanced resistance against environmental stress. These findings indicate that *Artemia* functions not only as a source of energy but also as an effective carrier of bioactive compounds that support larval viability.

In Pacific white shrimp (*Litopenaeus vannamei*), various *Artemia* enrichment strategies have also resulted in substantial improvements in survival rate. Xie *et al.,* (2021) reported that *Artemia* bioencapsulated with the probiotic archaeon *Halorubrum* enhanced postlarval survival and resistance to pathogenic challenges, likely through modulation of gut microbiota and stimulation of non-specific immune responses. Similarly, Yudiati and Azhar (2024) demonstrated that synbiotic bioencapsulated *Artemia* improved both survival and resistance against Acute Hepatopancreatic Necrosis Disease (AHPND), one of the most destructive diseases affecting intensive shrimp farming.

Apart from probiotic and synbiotic applications, enrichment with essential nutrients has also proven effective. Nur *et al.,* (2024) reported that Pacific white shrimp larvae fed nutrient-supplemented *Artemia* achieved the highest survival rate of 78.40%. This finding suggests that improvements in the nutritional quality of live feed directly influence larval viability during critical developmental stages. Essential nutrients such as amino acids, vitamins, phospholipids, and highly unsaturated fatty acids (HUFAs) play important roles in cell membrane formation, energy metabolism, and immune system development (Conceição *et al.,* 2010; Nur *et al.,* 2024).

Several studies have also demonstrated that combining *Artemia* with additional live feed organisms can further improve survival. Herawati *et al.,* (2020) reported that the combination of *Artemia* and *Phronima* sp. resulted in higher survival rates compared with the control treatment. Likewise, Amrullah *et al.,* (2022) demonstrated that bio-enrichment of *Artemia* with *Sargassum* extract significantly improved survival, growth performance, and immune status of Pacific white shrimp postlarvae. *Sargassum* contains bioactive polysaccharides, antioxidants, and immunostimulatory compounds that can be transferred to larvae through bioencapsulation.

At the commercial hatchery scale, routine use of *Artemia* has been shown to maintain consistently high survival rates in penaeid shrimp larval production systems (Lavens & Sorgeloos, 1999; Sorgeloos *et al.,* 2001). These findings highlight that despite the availability of various modern microdiets, Artemia remains an indispensable component of commercial hatchery operations due to its reliability and consistent performance. Such stability is associated with its high palatability, suitable particle size, and superior digestibility compared with inert feeds (Dhont *et al.,* 2013).

Similarly, Putri *et al.,* (2020) reported that the use of *Artemia*-based live feed in Pacific white shrimp hatcheries resulted in higher survival rates compared with alternative feeding treatments. This finding suggests that under tropical hatchery conditions, *Artemia* remains an effective tool for reducing early-

stage mortality and improving seed production output. From a physiological perspective, the positive effects of *Artemia* on survival can be explained through several mechanisms. First, *Artemia nauplii* possess an appropriate size and active swimming behavior that facilitate prey capture and increase feed intake, thereby reducing the risk of starvation. Second, their high protein, lipid, and energy contents support basal metabolism and tissue repair processes. Third, enrichment techniques enable *Artemia* to function as a vector for functional nutrients such as DHA, EPA, vitamin C, probiotics, immunostimulants, and antioxidants that strengthen larval defense mechanisms. Fourth, live feeds generally remain more stable in the water column than finely powdered formulated feeds, which rapidly disintegrate and deteriorate water quality (Lavens & Sorgeloos, 1999; Conceição *et al.,* 2010).

Nevertheless, the effectiveness of *Artemia* in improving larval survival is influenced by several factors, including cyst quality, hatching success, naupliar age at feeding, feeding density, hatchery sanitation, and water quality management. Poor-quality *Artemia* or excessive feeding can increase organic loading and stimulate the proliferation of opportunistic bacteria. Therefore, the successful application of *Artemia* should be accompanied by appropriate hatchery management practices to maximize its biological benefits.

Overall, the studies summarized in table 2 demonstrate that *Artemia* makes a substantial contribution to improving survival rates of fish and shrimp larvae, particularly when enriched with nutrients and bioactive compounds. Modern enrichment strategies have transformed *Artemia* from a conventional live feed into an efficient delivery system for nutritional and health-promoting agents. These findings reaffirm the importance of *Artemia* as a key component of modern hatchery technology and its considerable potential to enhance hatchery productivity in Indonesia.

3.3 *Artemia* Enrichment Strategies for Improving Larval Growth and Survival

The synthesis of studies on growth performance and survival rate indicates that the effectiveness of *Artemia* as a live feed is strongly influenced by its nutritional quality. In modern hatchery practices, *Artemia* is no longer administered solely in its conventional form but is increasingly modified through enrichment techniques to enhance its content of essential nutrients and bioactive compounds. Consequently, *Artemia* has evolved into a precision nutrient delivery vehicle capable of transporting functional substances directly to fish and shrimp larvae through bioencapsulation mechanisms (Lavens & Sorgeloos, 1999).

In general, *Artemia* enrichment strategies can be classified into five major categories: (1) lipid enrichment, (2) nutrient enrichment, (3) probiotic and synbiotic enrichment, (4) microalgal enrichment, and (5) phytogenic enrichment. Each category serves specific physiological purposes and exerts distinct biological effects on cultured organisms.

3.3.1. Lipid Enrichment (HUFAs, DHA, EPA, and Omega-3 Fatty Acids)

Lipid enrichment is the most widely applied strategy, particularly involving highly unsaturated fatty acids (HUFAs) such as DHA and EPA. This approach is necessary because the natural DHA content of *Artemia* is relatively low, despite the critical importance of these fatty acids for neural development, retinal formation, cell membrane integrity, and larval growth in marine fish and shrimp species (Conceição *et al.,* 2010).

Studies have shown that the use of enriched *Artemia* during larval and postlarval stages of Pacific white shrimp promotes superior growth performance compared with lower-quality live feeds or non-enriched *Artemia* (Martínez-Soler *et al.,* 2023; Nur *et al.,* 2024). Furthermore, enrichment with L-lysine and DL-methionine has been reported to improve growth performance and stress resistance (Bahabadi *et al.,* 2018). In marine fish culture, Pham *et al.,* (2023) also demonstrated that HUFA-enriched *Artemia* significantly improved the growth performance of Asian seabass larvae. These findings indicate that lipid enrichment represents a primary strategy for enhancing larval growth, particularly in marine species

with high HUFA requirements. Therefore, the use of non-enriched *Artemia* in marine fish and shrimp hatcheries may compromise seed quality.

3.3.2. Nutrient Enrichment (Vitamins, Minerals, and Amino Acids)

In addition to lipid supplementation, enrichment with essential nutrients such as vitamins, minerals, amino acids, and proteins has been shown to improve larval performance. Nur *et al.,* (2024) reported that nutrient-supplemented *Artemia* produced the highest survival rate (78.40%) in Pacific white shrimp larvae. Likewise, Jusadi *et al.,* (2004) found that enrichment of *Artemia* with specific lipid sources significantly enhanced the growth of Nile tilapia larvae. This enrichment strategy generally aims to improve energy metabolism, tissue formation, and feed utilization efficiency. In tropical hatchery systems, nutrient enrichment is particularly relevant because fluctuating environmental conditions often increase the maintenance energy requirements of larvae.

3.3.3. Probiotic and Synbiotic Enrichment

Recent developments have highlighted the use of *Artemia* as a vehicle for delivering beneficial microorganisms. Xie *et al.,* (2021) reported that *Artemia* enriched with the archaeon *Halorubrum* improved survival and pathogen challenge tolerance in Pacific white shrimp postlarvae. Similarly, Yudiati *et al.,* (2024) demonstrated that synbiotic bioencapsulated *Artemia* enhanced survival and resistance against AHPND. Delivering probiotics and synbiotics through *Artemia* is considered more effective than direct water application because microorganisms can enter the digestive tract together with the feed. This strategy is particularly promising for modern shrimp farming systems that are highly susceptible to *Vibrio*-associated diseases and other bacterial infections. Given increasing concerns regarding antibiotic resistance, probiotic enrichment is expected to become a key hatchery technology in the future.

3.3.4. Microalgal Enrichment

Microalgae represent one of the most promising enrichment materials because they are rich sources of DHA, EPA, pigments, vitamins, and natural antioxidants. Jaseera *et al.,* (2021) demonstrated that the combination of *Artemia* and *Aurantiochytrium* sp. significantly improved both growth performance and survival of black tiger shrimp larvae. The major advantage of microalgal enrichment lies in its natural origin, environmental sustainability, and comprehensive nutritional profile. Consequently, microalgae are increasingly viewed as a sustainable alternative to commercial fish oil-based enrichment emulsions.

3.3.5. Phytogenic and Seaweed-Based Enrichment

Another emerging enrichment strategy involves the use of plant-derived or seaweed-based extracts. Amrullah *et al.,* (2022) reported that bio-enrichment of *Artemia* with *Sargassum* extract improved survival, growth performance, and immune responses of Pacific white shrimp postlarvae. Seaweeds contain sulfated polysaccharides, phenolic compounds, and antioxidants that function as natural immunostimulants. This approach is particularly relevant for Indonesia due to its rich marine biodiversity. The utilization of locally available resources such as *Sargassum*, *Gracilaria*, and other aquatic herbal products could reduce dependence on imported enrichment products while promoting greater self-sufficiency in hatchery operations.

3.4 Challenges in the Utilization of *Artemia* in Indonesia

Although *Artemia* has long been recognized as one of the most important live feeds in fish and shrimp hatcheries, its utilization in Indonesia continues to face a number of multidimensional challenges encompassing the availability of raw materials, product quality, technological capacity, economic efficiency, and human resource readiness. These constraints directly affect hatchery performance, seed

quality consistency, and the competitiveness of the national aquaculture sector. Therefore, a critical evaluation of the limitations associated with *Artemia* utilization is essential for formulating more adaptive and sustainable development strategies.

3.4.1. High Dependence on Imported *Artemia* Cysts

One of the most fundamental issues is the heavy reliance of Indonesian hatcheries on imported *Artemia* cysts. Most of the industry's demand is supplied by major producing countries such as the United States, China, Kazakhstan, and Vietnam. This dependency makes domestic *Artemia* prices highly susceptible to exchange rate fluctuations, international transportation costs, global logistics disruptions, and changes in international trade dynamics. Under certain circumstances, increases in cyst prices can substantially raise seed production costs, particularly for small- and medium-scale hatchery enterprises.

3.4.2. Limited Competitiveness of Domestic Production

Indonesia possesses considerable ecological potential for *Artemia* production through salt ponds, hypersaline environments, and arid coastal areas. However, domestic production remains relatively limited and is still unable to meet national demand. Major constraints include low cyst productivity, the absence of superior tropical strains, limited harvesting and post-harvest technologies, and insufficient investment in upstream production systems. As a result, the country remains highly dependent on imported products to support hatchery operations.

3.4.3. Variability in Nutritional Quality and Lack of Product Standardization

The nutritional composition of *Artemia* is influenced by strain origin, geographical source, naupliar age, and handling practices. Variations in protein, lipid, DHA, EPA, and energy contents may result in inconsistent growth and survival responses among larvae. In practice, many hatcheries do not routinely assess the nutritional quality of *Artemia* before use, leading to variability in hatchery performance. For sensitive species such as Asian seabass, groupers, Pacific white shrimp, and black tiger shrimp, the availability of essential fatty acids is particularly critical for larval development. The use of non-enriched *Artemia* may therefore increase the risk of slow growth, developmental abnormalities, and elevated mortality rates.

3.4.4. Uneven Adoption of Enrichment Technologies

Although numerous studies have demonstrated the effectiveness of enrichment in improving larval growth and survival, the adoption of these technologies remains limited in many hatcheries. Small-scale hatchery operators often use *Artemia* directly without enrichment due to financial constraints, inadequate facilities, or limited technical knowledge. Consequently, the potential biological benefits of enriched *Artemia* are not fully realized in many production systems.

3.4.5. Biosecurity Risks and Microbial Contamination

As a live feed organism, *Artemia* may also act as a carrier of undesirable microorganisms if hatching and handling procedures are not properly managed. Contamination by opportunistic bacteria such as *Vibrio* spp. may occur during cyst hydration, hatching, enrichment, or subsequent distribution to larval rearing tanks. This risk is particularly important in intensive shrimp hatcheries, where bacterial and viral diseases represent major production constraints. Therefore, the use of *Artemia* should be integrated with strict biosecurity protocols, including cyst disinfection, equipment sanitation, water quality management, and routine microbiological monitoring.

3.4.6. Limited Human Resource Capacity and Knowledge Transfer

Another challenge relates to gaps in human resource capacity. While hatchery technicians are generally familiar with the practical use of *Artemia*, many still have limited understanding of larval nutrition, enrichment protocols, and data-based evaluation of live feed quality. As a result, *Artemia* utilization is often based on traditional practices and empirical experience rather than standardized scientific approaches. Strengthening technical training and knowledge dissemination programs is therefore essential to improve hatchery performance and support the adoption of advanced feeding technologies.

Overall to reduce dependence on imported cysts, future research should focus on the domestication and mass production of locally adapted Artemia strains. Moreover, establishing national quality standards for Artemia cysts and enrichment products may contribute to more consistent hatchery performance. Government support through research funding, technology transfer programs, and public-private partnerships could further accelerate the development of a sustainable domestic Artemia industry.

4. Conclusion

The present review confirms that Artemia remains one of the most effective and versatile live feeds used in fish and shrimp hatcheries. Its favorable nutritional composition, high digestibility, appropriate prey size, and capacity for bioencapsulation make it particularly suitable for supporting early larval development. Evidence synthesized from recent studies demonstrates that Artemia significantly improves growth performance, survival, stress resistance, and overall larval quality, especially when combined with enrichment strategies involving HUFAs, microalgae, probiotics, synbiotics, and phytogenic compounds. Despite these advantages, challenges related to imported cyst dependency, quality variability, limited domestic production, and uneven adoption of enrichment technologies remain important constraints in Indonesia. Future efforts should prioritize domestic Artemia production, advanced enrichment technologies, and biosecure hatchery management to enhance the sustainability and competitiveness of aquaculture production systems.

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6. Conflict of Interest Declaration

The authors declare that there is no conflict of interest regarding the publication of this article. The Authors confirmed that the paper was free of plagiarism.

7. Author Contribution Statement

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