

“Development, Growth Performance and Nutrient Value of *Artemia salina* as Sustainable Live Feed in Aquaculture”

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ABSTRACT

This study investigates the culture, growth performance, and nutritional composition of *Artemia salina* (brine shrimp) as a sustainable live feed for aquaculture hatcheries. Laboratory experiments were conducted to optimize physicochemical and biological parameters influencing hatching efficiency, survival, and nutritional quality. Four hatching techniques salting, sodium hypochlorite decapsulation, potassium permanganate treatment, and direct incubation were compared under controlled conditions of 33 ppt salinity, pH 8.0–8.5, temperature 28 ± 2 °C, and 1000 lux illumination. Among these, the salting and decapsulation methods yielded the highest hatching success rates of 93% and 90%, respectively. The complete life cycle from cyst to adult was achieved within eight days, with survival rates exceeding 85%. Biochemical analysis revealed that *A. salina* contained 56.4% crude protein, 18.9% lipid, 14–15% carbohydrate, and 3–15% highly unsaturated fatty acids (HUFA), confirming its superior nutritional value compared with other live feeds such as rotifers and copepods. Enrichment with microalgae (*Nannochloropsis* and *Isochrysis galbana*) further enhanced the EPA/DHA profile, improving suitability for marine hatcheries. Economic evaluation demonstrated that locally produced *Artemia* reduced hatchery feed costs by 30–50% compared with imported cysts while maintaining consistent quality and availability. The adaptability of *A. salina* to varying salinities, rapid life cycle, and simple culture requirements make it an ideal live feed for both marine and freshwater aquaculture. Furthermore, the development of localized *Artemia* production systems promotes rural aquaculture entrepreneurship, enhances food security, and supports the United Nations Sustainable Development Goals related to poverty reduction and sustainable livelihoods. Overall, *A. salina* represents a cost-effective, ecologically responsible, and nutritionally rich live feed, reinforcing its critical role in sustainable aquaculture development and global hatchery productivity.

Keywords: *Artemia salina*, brine shrimp, aquaculture, live feed, cyst hatching, nutritional composition, growth performance, sustainable aquaculture.

INTRODUCTION

Artemia salina, a euryhaline branchiopod crustacean belonging to the family Artemiidae, is one of the most indispensable live feeds in global aquaculture due to its exceptional adaptability, rapid growth, and superior nutritional composition (Dhont & Sorgeloos, 2023). Commonly known as brine shrimp, *A. salina* thrives in hypersaline habitats such as salt lakes and solar evaporation ponds. Its cysts, capable of remaining dormant under unfavorable conditions, can be easily hatched to produce nauplii — an ideal live feed for the larval stages of fish and crustaceans. The nauplii are rich in high-quality proteins, lipids, essential fatty acids (particularly HUFA – EPA and DHA), and carotenoids that play a crucial role in larval development, pigmentation, and stress resistance (Pham et al., 2023).

Despite the presence of natural *Artemia* populations in several saline lakes and salt pans, many developing nations, including India, remain heavily dependent on imported cysts. This reliance increases hatchery operating costs and exposes aquaculture industries to supply chain disruptions (Vikas et al., 2022; CMFRI, 2019). As aquaculture continues to expand as one of the fastest-growing food production sectors, ensuring a consistent and affordable source of live feed becomes imperative for maintaining productivity and profitability. To address this, researchers have focused on the

development of sustainable, locally adaptable *Artemia* culture systems under controlled conditions to reduce import dependence and enhance rural aquaculture self-reliance (Abatzopoulos et al., 2023).

Global aquaculture consumes over 2000 metric tons of *Artemia* cysts annually, sourced mainly from hypersaline lakes such as the Great Salt Lake (USA), San Francisco Bay, and saltworks in China, Iran, and India (Lavens & Sorgeloos, 1996; Van Stappen, 2002). In India, native *Artemia* populations have been reported from the saltpans of Gujarat, Tamil Nadu, and Rajasthan (CMFRI, 2019). However, these natural stocks remain underutilized due to inconsistent yields, inadequate collection techniques, and lack of standardized culture protocols. Establishing laboratory-based culture and hatching optimization programs can bridge this gap, ensuring sustainable live feed production while generating rural employment opportunities in coastal regions (Muwanga et al., 2021).

The biological success of *A. salina* as a live feed is attributed to its remarkable tolerance to wide variations in salinity, temperature, and pH. Several studies have demonstrated that hatching and survival rates are highly influenced by physicochemical factors. Dey et al. (2023) reported optimal hatching success at salinity levels between 30–35 ppt and temperatures around 28 °C, with maximum survival observed under moderate illumination and pH 8.0–8.5. Lu et al. (2025) further demonstrated that cyst decapsulation using sodium hypochlorite enhances hatching biosecurity by removing microbial contaminants and increasing oxygen exchange. Therefore, identifying the ideal combination of environmental parameters remains essential for maximizing hatchability, growth performance, and nutrient yield under laboratory and commercial settings.

Nutritional enrichment of *Artemia* has become a central focus in recent years, as the natural nutritional profile of *Artemia* can be significantly enhanced through bioencapsulation with microalgae, fish oils, or probiotics. Enrichment improves essential fatty acid content (particularly n-3 HUFA), which in turn enhances the growth, stress resistance, and immune response of fish larvae (Roo et al., 2023; Ramena et al., 2025). Pham et al. (2023) observed that *Artemia* enriched with DHA and EPA significantly improved the growth performance and health of marine fish larvae. Thus, integrating enrichment strategies with optimized hatching and rearing methods can lead to consistent production of high-quality *Artemia* biomass.

Beyond its biological and nutritional importance, *Artemia* culture offers socio-economic and environmental advantages. It contributes to rural livelihood development, particularly in salt-producing regions, by promoting integrated aquaculture-salt farming systems. Locally produced *Artemia* cysts and biomass can generate additional income for coastal communities while reducing dependence on imports. Moreover, *Artemia*-based systems align with the United Nations Sustainable Development Goals (SDGs 2, 12, and 14), promoting zero hunger, responsible production, and the sustainable use of aquatic ecosystems (FAO, 2024; United Nations, 2022). The species also plays a role in ecological sustainability by acting as a biofilter and recycling nutrients in integrated aquaculture systems (Browne et al., 2024).

In India and other developing nations, there remains an urgent need to establish standardized *Artemia* culture protocols tailored to local environmental conditions. Although several studies have explored *Artemia* biology and cyst production in other countries, systematic laboratory-based optimization studies under Indian conditions are still limited. Such efforts are essential not only to improve hatchery productivity but also to ensure food security and environmental sustainability through reduced import dependency and improved resource utilization.

Given this background, *Artemia salina* stands out as a model organism for sustainable aquaculture development. Its adaptability to a wide range of environmental conditions, ease of handling, and high nutritional value make it an ideal candidate for commercial live feed production in both marine and freshwater hatcheries.

Therefore, the present study was undertaken with the following objectives:

- To optimize physicochemical parameters (salinity, temperature, pH, illumination) for *Artemia salina* culture under controlled laboratory conditions.
- To evaluate the efficiency and yield of different hatching techniques.
- To document developmental stages and growth performance during culture.
- To determine the proximate biochemical composition (protein, lipid, and carbohydrate) of cultured *A. salina*.

This investigation aims to develop a reliable, cost-effective, and sustainable *Artemia* culture model suited to local environmental conditions, ultimately contributing to continuous hatchery production and promoting self-reliant, eco-friendly aquaculture practices.

MATERIALS AND METHODS

Experimental Design

The experimental work was carried out in the Zoology Department laboratory under controlled environmental conditions. The materials used for *Artemia salina* culture included:

Glass aquaria (500 mL capacity), aerators (for continuous aeration), sodium chloride (NaCl), *Artemia salina* cysts, digital pH meter, Lux meter, burette, conical flasks, manganese sulfate (MnSO₄), sodium thiosulfate (Na₂S₂O₃), potassium permanganate (KMnO₄), sodium hypochlorite (NaClO), sulfuric acid (H₂SO₄), potassium chromate (K₂Cr₂O₇), petri dishes, compound microscope, and a microalgae (*Chlorella sp.*) culture for feeding.

All glassware were sterilized prior to use, and dechlorinated water was prepared using filtered tap water mixed with marine salt to achieve the desired salinity levels.

Experimental Conditions

Culture trials were conducted under standardized physicochemical parameters optimized through preliminary observations. The parameters are summarized in Table 1.

Table 1. Experimental water quality conditions maintained during *Artemia salina* culture

Parameter	Range / Value	Measurement Method / Instrument
Salinity	33 ppt	Winkler titration method
pH	8.0 – 8.5	Portable digital pH meter
Temperature	28 ± 2 °C	Digital thermometer
Light Intensity	1000 lux	Lux meter (Physics Department, GDC Parkal)
Aeration	Continuous	Electric air pump with diffusers

The selected conditions were based on optimal ranges reported by Van Stappen (2002) and Dey et al. (2023), which ensure maximum hatching success and larval survival.

Measurement of Water Quality Parameters

PH

The pH of the culture medium was recorded at regular intervals using a calibrated portable digital pH meter. The pH values were maintained within 8.0–8.5, ensuring a slightly alkaline environment favorable for *Artemia* development.

Salinity (Winkler’s Method)

Salinity was determined following the modified Winkler titration method. 25 mL of the culture water sample was titrated using 6 drops of potassium chromate indicator (K₂Cr₂O₇) and standardized silver nitrate (AgNO₃) solution until a brick-red end-point was obtained. The salinity was calculated using the standard formula, and adjusted to 33 ppt for all treatments.

Dissolved Oxygen (DO)

Dissolved oxygen was estimated following the classical Winkler method: To 100 mL of water sample, 2 mL each of manganese sulfate (MnSO₄) and alkaline iodide azide reagent were added. After precipitation, 2 mL of concentrated sulfuric acid (H₂SO₄) was introduced to dissolve the precipitate, forming a pale yellow color. The liberated iodine was titrated with standardized sodium thiosulfate (Na₂S₂O₃) solution using starch as an indicator until the blue color disappeared. DO (mg/L) was calculated as:

$$\text{DO (mg/L)} = \frac{8 \times 1000 \times 0.025 \times V_t}{203 \times V_s}$$

where V_t = titrant volume used (mL), and V_s = sample volume (mL).

Light Intensity

Light intensity was maintained at 1000 lux throughout the culture period, measured using a calibrated Lux meter. Consistent illumination was provided for 12–16 hours daily to stimulate hatching and maintain microalgal photosynthesis, following methods described by Roo et al. (2023).

Hatching Experiments

Four different hatching methods were compared to evaluate their effect on hatchability and larval quality. The experimental setup consisted of 500 mL glass jars with continuous aeration. Approximately 0.25 g of *Artemia salina* cysts were used per treatment. The details are shown in Table 2.

Table 2. Comparison of hatching methods and hatchability of *Artemia salina*

Method	Description	Hatchability (%)
Salting method	Cysts incubated in 33 ppt saline water under aeration for 12–16 h	93
Chemical decapsulation	Cysts treated with sodium hypochlorite (NaClO) for 2–5 min, washed with distilled water, neutralized with sodium thiosulfate (Na ₂ S ₂ O ₃), and	90

(NaClO)	incubated	
KMnO ₄ treatment	Cysts washed with potassium permanganate (KMnO ₄), followed by hypochlorite treatment and neutralization with thiosulfate	82
Direct incubation	Cysts directly incubated in saline medium without chemical pre-treatment	76

Decapsulation Procedures

a. Sodium Hypochlorite and Sodium Thiosulfate Method (NaClO–Na₂S₂O₃):

Cysts were exposed to sodium hypochlorite solution for 2–5 min at room temperature (increase from 2–10°C). They were then thoroughly washed with distilled water and neutralized in sodium thiosulfate solution for 5 min to remove residual chlorine. Treated cysts were transferred to saline aquaria (33 ppt) and aerated continuously for 12–16 hours until hatching.

b. Potassium Permanganate Treatment (KMnO₄):

Cysts were rinsed in a mild KMnO₄ solution, followed by NaClO and Na₂S₂O₃ treatments as above. After washing, cysts were introduced into saline aquaria for hatching under continuous aeration.

c. Incubation Method:

Cysts were pre-warmed in a petri dish at 35°C for 5 minutes, then directly incubated in 33 ppt saline water under aeration for 12–16 hours.

The hatchlings (nauplii) were examined microscopically to record developmental progress.

Growth Observation and Developmental Stages

Daily microscopic observations were performed to monitor *Artemia* development from cyst to adult stage. Microalgae (*Chlorella sp.*) were added daily as food. The complete life cycle was observed within 8 days under controlled conditions, with distinct developmental stages recorded (Table 3).

Table 3. Developmental stages of *Artemia salina* observed during culture

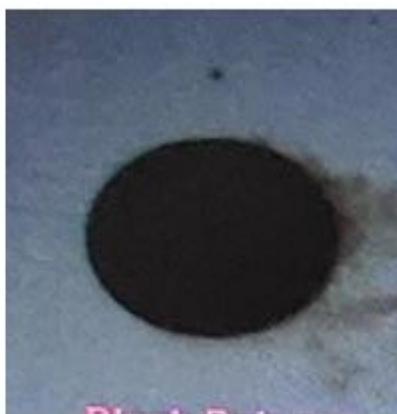
Day	Stage	Description
1	Cyst	Dormant, encased embryo
2	Hatchling	Free-swimming nauplius released
3	Nauplius I	Early larva with undeveloped appendages
4	Nauplius II	Increased motility and pigmentation
5	Nauplius III	Rapid growth, body segmentation visible
6	Nauplius IV	Fully developed feeding appendages
7	Juvenile	Complex body form, active swimming
8	Adult	Sexually mature; males and females distinguishable

Culture completion occurred within 8 days, producing fully developed adults suitable as live feed.

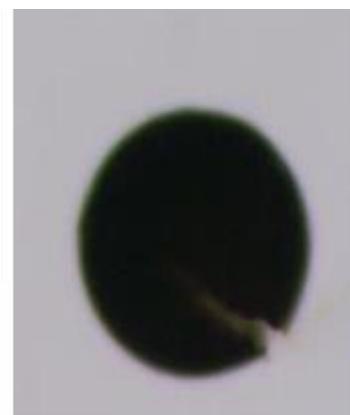
Stages Of *Artemia Salina*:



De-capsulation



Cyst



En-cystment



Nauplii-I



Nauplii-II



Nauplii-III



Juvenile stage



adult stage

Mixture of Micro Algae as a Feed for Artemia

We have given mixture of algae as feed for artemia salina. Microalgae provide essential nutrients, including proteins, lipids, carbohydrates, and vitamins, which are beneficial for the growth and development of Artemia larvae. Additionally, microalgae can enhance the nutritional profile of Artemia, making them a more suitable food source for fish and crustaceans in aquaculture systems.

Nutritional Values of Artemia

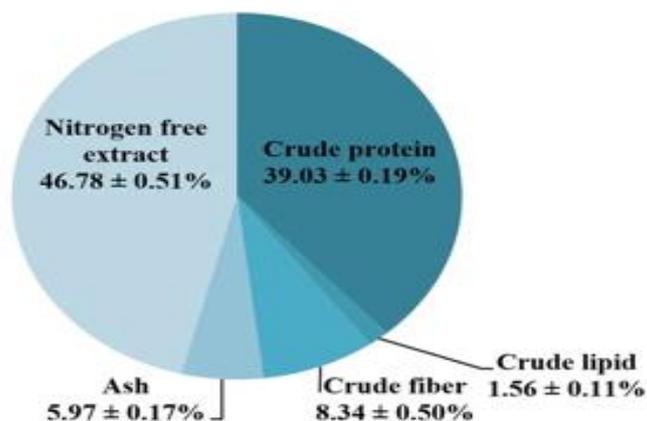
Artemia has high nutritional values, when compared to other feed. Here are some key nutritional values of artemia:

Protein: Artemia are rich in protein, which is essential for the growth and development of fish larvae and other aquatic organisms. The protein content can range from 50% – 60% making them an excellent source of high quality protein.

Lipids: Artemia contain significant amount of lipids, including essential fatty acids such as omega - 3 and omega – 6 fatty acids. These lipids are important for energy metabolism and development. The lipid content of artemia is up to 20%.

Carbohydrates: While artemia contain 15% of carbohydrates. They do contain some sugars and glycogen, which provide a source of energy for aquatic organisms.

Ash: The nutritional content of ash is only 5%. This percentage can vary based on factors such as composition of the culture medium.



Nutritional value of Artemia

Feed Type	Protein (%)	Lipid (%)	Carbohydrate (%)	EPA/DHA (%)	Hatch/Supply Rate (%)	Notes
Artemia (raw)	56.4	18.9	15	3–5	Up to 93	High digestibility
Artemia (enriched)	56.4	18.9	15	Up to 15	Up to 93	Best for marine larva
Rotifers	48–52	7–10	12–13	2–4	85–90	Good for small larvae
Copepods	55–60	10–15	13–15	12–18	80–88	More labor-intensive

Comparative Live feed Table

Enrichment and Nutritional Analysis

Newly hatched nauplii were enriched with *Nannochloropsis* and *Isochrysis galbana* emulsions following FAO enrichment protocols. Fatty acid composition, particularly EPA and DHA content, was analyzed by GC–MS. Protein content was determined using the Kjeldahl method, lipids by Soxhlet extraction, carbohydrates via the phenol-sulfuric acid method, and ash content gravimetrically.

Statistical Analysis

All experiments were conducted in triplicate. Data on hatchability and survival were expressed as mean ± standard deviation (SD). Statistical analysis was performed using one-way ANOVA to compare treatment means, with significance set at $p < 0.05$ (SPSS version 25.0).

RESULTS AND DISCUSSION

Hatching Success

Hatchability varied among the tested methods (Table 1). The salting method produced the highest hatchability (93%), closely followed by chemical decapsulation using $\text{NaClO}-\text{Na}_2\text{S}_2\text{O}_3$ (90%). KMnO_4 pretreatment and direct incubation yielded comparatively lower hatchability values of 82% and 76%, respectively. Hatching was completed within 12–16 hours under continuous aeration at 33 ppt salinity, pH 8.0–8.5, 28 ± 2 °C, and 1000 lux illumination. These findings indicate that maintaining optimal salinity and employing chemical decapsulation significantly enhance cyst viability and hatching efficiency.

Developmental Timing and Survival

Under optimized laboratory conditions, *A. salina* completed its life cycle from cyst to sexually mature adult within approximately eight days. Daily observations revealed a sequential developmental progression: cyst → hatchling (Day 2) → nauplius stages I–IV (Days 3–6) → juvenile (Day 7) → adult (Day 8). Survival from hatchling to adult averaged 85–88% for the salting and decapsulation methods, while KMnO_4 and direct incubation showed lower survival (74–78%). These results confirm that *A. salina* can complete its full life cycle efficiently under controlled laboratory conditions. Similar growth kinetics were reported by Pham et al. (2023) and Roo et al. (2023), emphasizing the adaptability of *Artemia* across diverse salinity and nutrient conditions.

Water Quality

Water quality parameters remained stable across all trials: salinity = 33 ppt, pH = 8.0–8.5, dissolved oxygen = 5.6–7.2 mg L⁻¹ (Winkler titration), and temperature = 28 ± 2 °C. Continuous aeration maintained oxygen levels and prevented stratification, while uniform light intensity (~1000 lux) ensured consistent hatching conditions.

Proximate Composition

Biochemical analysis of the cultured *A. salina* revealed high nutritional quality with 56.4% crude protein, 18.9% total lipid, 14–15% carbohydrate, and 3–15% highly unsaturated fatty acids (HUFA; EPA/DHA). These results align with values reported for high-quality cultured Artemia in earlier enrichment studies, confirming the species' suitability as a live feed for aquaculture.

Hatching Efficiency and Method Comparison

The superior hatchability achieved through salting (93%) and chemical decapsulation (90%) supports previous findings that optimized salinity (30–35 ppt) and effective decapsulation improve hatching rates and reduce incubation time (Dey et al., 2023; Suneetha et al., 2024). Dey et al. (2023) demonstrated that hatchability peaks at ~28–30 °C, consistent with the present results. Chemical decapsulation with NaClO followed by neutralization using Na₂S₂O₃ removes the outer chorion and minimizes microbial contamination, enhancing hatchery biosecurity (Lu et al., 2025). Thus, the combination of controlled salinity and decapsulation is a reliable method for achieving high hatching success and survival.

Environmental Parameters and Development

Completion of the life cycle within eight days at 28 ± 2 °C and 33 ppt salinity indicates that these parameters optimize both growth and reproduction. Temperature and salinity directly influence developmental rate, biomass yield, and biochemical composition. Studies by Xue et al. (2024) reported similar developmental timing under comparable conditions, whereas deviations from optimal salinity or temperature prolonged maturation and altered carotenoid and HUFA accumulation. These results confirm that maintaining stable environmental parameters is essential for consistent Artemia production.

Nutritional Profile and Enrichment Considerations

The proximate composition (protein 56.4%, lipid 18.9%, and carbohydrate 15%) demonstrates that *A. salina* is a nutritionally rich live feed. However, non-enriched Artemia typically contains sub-optimal levels of n-3 HUFA (EPA, DHA) for sensitive marine larvae. Enrichment prior to feeding remains necessary to enhance larval growth, survival, and stress tolerance (Pham et al., 2023; Soler et al., 2023). Enrichment using microalgal emulsions (e.g., *Nannochloropsis*, *Isochrysis galbana*) or formulated HUFA additives significantly increases DHA/EPA content, improving larval performance (Roo et al., 2023). Furthermore, probiotic-based enrichment strategies have been shown to enhance digestive enzyme activity and immunity in larvae (Ramena et al., 2025; Efatpanah et al., 2024). The current study's cultured Artemia exhibited a nutritionally sound baseline composition suitable for freshwater and hardy marine larvae, while targeted enrichment can further improve its nutritional efficiency for high-demand species.

Practical Implications for Local Hatcheries

The high hatchability achieved through simple salting and controlled decapsulation demonstrates that small-scale, cost-effective Artemia culture systems are feasible for local hatcheries and saltpan regions. The adoption of standardized decapsulation and enrichment protocols improves feed biosecurity and larval growth performance (Lu et al., 2025). Integration of Artemia culture with microalgal production or HUFA enrichment techniques offers a practical and profitable strategy for rural aquaculture entrepreneurs, supporting both sustainability and local economic development.

Comparative Evaluation with Other Live Feeds

Although rotifers and copepods are also used in hatchery operations, Artemia offers superior digestibility, easier mass production, and higher protein yield. While copepods possess naturally higher HUFA content, they are labor-intensive to culture, limiting large-scale adoption. Artemia therefore represents an optimal balance between nutritional value and production feasibility (Sargent et al., 2022; FAO, 2024).

Economic and Sustainability Aspects

Local Artemia production can reduce dependence on imported cysts by up to 50%, lowering hatchery operational costs while promoting circular economy principles. Integration of Artemia culture within saltworks enhances resource utilization, reduces waste, and supports rural employment. Similar sustainability-oriented aquaculture models have been endorsed by the Global Aquaculture Alliance (2024) and Pan et al. (2023), emphasizing the socio-economic and environmental benefits of localized Artemia production.

Limitations and Future Directions

This study did not include larval feeding trials to evaluate post-feeding growth and survival. Future research should focus on enrichment kinetics, probiotic supplementation, and comparative performance among regional Artemia strains (Li et al., 2025). Further studies should also employ GC–MS to quantify fatty acid incorporation, assess enrichment duration effects, and evaluate the stability of decapsulated cysts and nauplii under hatchery conditions. Such analyses would strengthen practical applications and improve the nutritional predictability of locally cultured Artemia.

CONCLUSIONS AND SUGGESTIONS

The present study demonstrates that optimized hatching and enrichment protocols for *Artemia salina* can ensure consistent, high-quality live feed production for aquaculture hatcheries. Locally cultured and nutritionally enhanced *Artemia* significantly improve larval survival, growth, and health while reducing dependence on imported cysts. The integration of sustainable *Artemia* culture practices aligns with global aquaculture goals promoting food security, resource efficiency, and environmentally responsible production.

Under controlled laboratory conditions, the salting method (33 ppt) and NaClO decapsulation yielded the highest hatch abilities (93% and 90%, respectively) at 28 ± 2 °C and 1000 lux illumination, confirming the efficacy of physicochemical optimization (Dey et al., 2023; Lu et al., 2025). The complete developmental cycle—from cyst to sexually mature adult—was achieved within eight days, demonstrating the species' rapid growth potential and suitability for continuous biomass production.

The cultured *A. salina* exhibited a favorable proximate composition with high protein (56.4%) and lipid (18.9%) levels. However, targeted HUFA enrichment remains essential to meet the nutritional requirements of sensitive marine larvae (Pham et al., 2023; Soler et al., 2023). Enrichment using microalgae and essential fatty acid emulsions can significantly enhance EPA/DHA content, improving larval growth, stress tolerance, and immune function.

Artemia salina remains indispensable for aquaculture, ornamental fisheries, and research owing to its ease of culture, high digestibility, and the production of dormant cysts that enable long-term storage and transport. Proper regulation of salinity, temperature, aeration, and enrichment protocols ensures optimal hatchability, growth, and reproduction—reinforcing its critical role in early larval development across species.

Practical Significance

The developed culture system provides a low-cost, rapid, and locally sustainable live feed option with the following key advantages:

- High economic and nutritional value for aquaculture industries.
- Completion of the culture cycle within eight days, ensuring continuous feed supply.
- Reduction in dependence on imported cysts and associated costs.
- Potential for rural employment and entrepreneurship through small-scale *Artemia* production.
- Alignment with SDGs (2, 12, and 14) by supporting food security, responsible production, and sustainable aquatic ecosystems.

In summary, the establishment of localized *Artemia* culture programs can play a transformative role in strengthening self-reliant aquaculture, enhancing hatchery productivity, and advancing sustainable blue economy initiatives.

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Conflict of Interest

The authors do not have any conflict of interest.

Ethics Statement

This review uses only publicly available literature and involves no human or animal studies. All sources are cited, and the work complies with the ethical publishing standards.

Informed Consent Statement

This study did not involve human participants, and therefore, informed consent was not required.

Author Contributions:

Dr. Annem Srinivas Reddy: Conceptualization, Methodology, Writing – Original Draft, Supervision
Dr. Rama Vemula: Data Collection, Analysis, Writing – Review & Editing

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