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A comprehensive review of macroalgae and microalgae synergies: Impacts on growth, development, and immune functions in aquatic animals

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Abstract

Integrating macro and micro algae into aquaculture has emerged as a promising strategy for increasing the growth, development and safety of aquatic animals. This review provides a detailed analysis of the benefits and challenges of using both macro and micro algae in aquaculture and animal health. The emphasis is on their nutritional value, their impact on the environment and their potential for improving disease resistance and water quality. In addition, the review examines current research trends, future directions and possible applications of algal aquaculture systems. The use of algae in aquaculture is not new, but recent advances in cultivation techniques and nutritional composition have made them viable as a food supplement. Macro-algae, such as seaweed, are traditionally used as food and feed in coastal communities, while microalgae are gaining attention for their high nutritional value and bioactive compounds. Combining the two types of algae offers a holistic approach for improving the aquaculture process. In addition, the environmental benefits of algal-based systems are considerable. By using algae to take up nutrients and purify water, aquaculture can reduce its environmental footprint. This is particularly important in a sector under increasing pressure to adopt sustainable practices. The review will look at the details of how macro and micro algae contribute to these objectives and examine case studies where their integration has resulted in better results. Moreover, the economic advantages of algal aquaculture should not be neglected. By reducing reliance on traditional feed sources and minimizing waste, algae-based systems can provide aquaculture operations with cost-effective solutions. This aspect is of key importance for small farmers, who often face financial constraints when it comes to adopting new technologies. In addition to these benefits, algal-based systems can also contribute to food security by providing a sustainable source of protein for the human diet. As global demand for seafood continues to grow, the aquaculture industry needs to find ways of meeting this demand without jeopardizing the environmental sustainability of the sector. Systems based on algae offer a promising solution to this problem.

Keywords: Macro and micro algae, Water quality, Disease resistance, Food security.

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Introduction

Aquaculture, the practice of growing aquatic plants and animals, is a rapidly growing industry in the world. Algae, both macro and micro, has received considerable attention for its nutritional benefits and environmental sustainability. Macro-algae, commonly known as seaweed, and micro-algae are rich in proteins, lipids, carbohydrates, vitamins and minerals, which make them excellent food supplements for aquatic animals. The objective of this review is to examine the effects of the combination of macro and micro algae on the growth, development and safety of aquatic animals and to highlight their potential to transform the aquaculture industry in a more sustainable direction. The growth of aquaculture is driven by the increasing demand for seafood and the need for sustainable food production systems. Traditional feed sources, such as fishmeal and fish oil, are becoming less viable due to environmental concerns and resource depletion (Chen *et al*., 2021). Algae offer a promising alternative, providing essential nutrients while reducing the industry's reliance on wild-caught fish. Moreover, algae-based diets can enhance the nutritional profile of farmed fish, making them healthier for human consumption. In addition to its nutritional benefits, algae have been shown to improve water quality and reduce the waste generated by aquaculture systems. Microalgae are particularly efficient in bio-focal systems, converting nitrogen into microbial protein and reducing the need for external feed inputs (Das and Ghosh, 2023). This approach not only improves water quality but also reduces the impact of aquaculture activities on the environment. In addition, the integration of algae in aquaculture can also help to preserve biodiversity. Algae-based systems can contribute to a healthier marine ecosystem by reducing pressures on wild fish stocks and promoting sustainable aquaculture practices. In addition, algal-based systems may be combined with other sustainable practices such as recirculation aquaculture systems (RAS) in order to further increase their environmental benefits. RAS systems minimize water exchange and waste, which makes them ideal for integrating algae-based feeding systems (Vijayaram *et al*., 2024).

Nutritional benefits of macroalgae

Macroalgae such as *Laminaria*, *Undaria* and *Gracilaria* are known for their high nutritional value. They contain essential fatty acids, vitamins and minerals which may improve the growth parameters, nutritional performance and physiological activity of the fish. Macro algae also contribute to the improvement of the quality of the carcass and the resistance to disease in aquatic animals. For example, the incorporation of seaweed into fish diets has been shown to improve intestinal health and the immune response (Adel *et al*., 2021).

Key Nutrients in macro algae

Proteins: Essential for growth and muscle development.

Fatty Acids: Contribute to improved lipid profiles and energy metabolism.

Vitamins and Minerals: Support immune function and overall health.

Macro-algae are also rich in fiber, which may improve the digestive health of aquatic animals. The fiber content helps to maintain a healthy gut microbiome, which is essential for absorbing nutrients and supporting the functioning of the immune system. In addition, macro-algae contain bioactive compounds such as fucoid and laminarin, which have been shown to have anti-inflammatory and antioxidant properties. The nutritional benefits of macro-algae are well documented, but their use in aquaculture is still under development. Research is ongoing to optimize the incorporation of macro-algae into the diet of different species and to ensure that nutritional needs are met without compromising palatability or digestibility. Moreover, macro-algae can be used in different forms, such as whole seaweed, extracts or processed food, which offers flexibility in dietary formulations. This versatility enables farmers to adapt their feeding strategies to the specific species and production systems in question. Moreover, the use of macro-algae may also improve sensory qualities of fish fillets. By improving the lipid profile and reducing oxidative stress, the macro-algae can contribute to a better taste and texture, which will make the fish more attractive to consumers (Ferreira *et al*., 2021).

Nutrition benefits of microalgae

Micro-algae such as *Nannochloropsis oculata* and *Isochrysis galbana* are rich in protein, lipid and carbohydrate. They have antioxidant properties that help to reduce oxidative stress and improve aquatic animal's health. Micro-algae are also efficient in bio-floc systems, improving water quality by converting nitrogen to microbial proteins. Their high nutritional value makes them an excellent feed supplement for the larval stages of fish and shellfish (Ma *et al*., 2022).

Key nutrients in micro algae

Proteins: High-quality protein sources for aquatic animals.

Lipids: Rich in essential fatty acids, supporting growth and health.

Carbohydrates: Provide energy and support metabolic processes.

Microalgae are particularly beneficial for the early life stages of aquatic animals because of their small size and high nutritional value. They are easily digestible, which makes them ideal for larval and adult feeding. In addition, microalgae can be genetically engineered to improve their nutritional profiles, which offers a promising avenue for further research. The use of microalgae in biofloc systems is also noteworthy. By converting waste nutrients into microbial biomass, these systems reduce the need for external feed inputs and minimize water exchanges, leading to more sustainable aquaculture practices. Moreover, microalgae can be grown on a large scale using photobioreactors that offer controlled conditions for optimum growth. This technology allows the microalgae to be of uniform quality and quantity, which makes it a reliable feed

supplement for aquaculture operations. In addition to its nutritional advantages, the microalgae has potential applications in human nutrition. They are rich in omega-3 fatty acids and other key nutrients, which make them a valuable ingredient in dietary supplements and functional foods (Mota *et al*., 2023).

Effects on growth and development

The combination of macro and micro algae in aquaculture diets has been shown to have a positive impact on the growth and development of aquatic animals. Macro algae provide essential nutrients that increase growth rates and feed conversion ratios, while micro algae contribute to the improved texture and taste of fish fillets. Studies have shown that the incorporation of microalgae such as *Nannochloropsis oculata* and *Isochrysis galbana* into biofloc may increase the protein and fat content of fish such as Nile tilapia (Maghawri *et al*., 2023).

Growth parameters affected by algae

Growth Rate: Enhanced by the nutritional content of algae.

Feed Conversion Ratio (FCR): Improved due to better nutrient utilization.

Body Composition: Algae contribute to improved protein and lipid profiles.

The growth-promoting effects of algae are attributed to their balanced nutrient profile, which promotes optimal metabolic processes in aquatic animals. In addition, the bioactive compounds present in algae can stimulate growth factors and improve overall health, leading to a faster growth rate and a greater efficiency in the production of food. In addition, the incorporation of algae in the diets may improve the sensory characteristics of fish fillets and make them more attractive to consumers. This is particularly important for the aquaculture industry, where consumer preferences are increasingly favoring products with better nutritional profiles and sustainably produced methods. Moreover, algal-based diets can also reduce the environmental impact of aquaculture by minimizing waste and improving water quality. This is in line with the global effort to promote sustainable aquaculture practices that prioritize environmental protection. In addition, the use of algae in aquaculture can support local economies by providing jobs in algae cultivation and processing. This aspect is of particular importance in rural communities where aquaculture is an important economic activity (Karapanagiotidis *et al*., 2022).

Environmental impact and water quality

Micro and micro algae play a key role in maintaining water quality. Microalgae are efficient in the treatment of wastewater by absorbing nitrogen and phosphorus, thus reducing the environmental impact of aquaculture. Macroalgae can also contribute to improving water quality by absorbing excess water nutrients. This makes algal-based systems more sustainable than traditional aquaculture methods (Kashem *et al*., 2023).

Environmental benefits of algae

Nutrient uptake: Algae absorb excess nutrients and reduce eutrophication.

Water purification: Microalgae help to purify water by removing pollutants.

Carbon sequestration: algae contribute to the reduction of CO2 levels by photosynthesis.

The environmental benefits of algae are many. Algae-based systems can reduce the risk of eutrophication and harmful algal blooms by reducing nutrient runoff and improving water quality. This is particularly important in coastal areas where aquaculture activities are frequently concentrated. In addition, the use of algae in aquaculture may contribute to carbon sequestration. As photosynthetic organisms, algae absorb carbon dioxide from the atmosphere, which makes them a valuable tool for greenhouse gas mitigation. In addition, algae-based systems may be integrated with other sustainable technologies such as solar photobioreactors, in order to further increase their environmental benefits. This approach not only reduces the carbon footprint of algal cultivation but also promotes energy independence. Moreover, the environmental sustainability of algae-based systems can be further improved through the adoption of the principles of circular economy. By using waste material as a nutrient for algal growth, these systems can minimize waste and maximize resource efficiency (Parmar *et al*., 2023).

Safety and disease resistance

The use of algae in aquaculture not only improves nutritional profiles but also improves resistance to diseases in aquatic animals. Microalgae have immunostimulant, antioxidant and antimicrobial properties that help to protect aquatic animals against disease. Macro algae has been shown to increase the physiological activity and resistance to disease in fish and to contribute to safer aquaculture practices (Tham *et al*., 2023).

Health benefits of algae

Immune system enhancement: algae stimulate the immune response in aquatic animals.

antioxidant properties: reduce oxidative stress and improve overall health.

Antimicrobial effects: helps to prevent bacterial infections in aquatic animals.

The health benefits of algae are attributed to their bioactive compounds, which can modulate the immune response and protect against pathogenic agents. This is particularly important in aquaculture where outbreaks of diseases may have a significant impact on the economy. In addition, the incorporation of algae in diets can reduce the dependence on antibiotics and other chemicals and promote more sustainable and environmentally friendly aquaculture practices. Moreover, algae-based systems can also promote animal welfare by providing a cleaner environment for aquatic animals. By improving water quality and reducing stress, these systems can improve the overall welfare of fish and other aquatic species. In addition, the use of algae in aquaculture may contribute to food safety by reducing the risk of chemical

contaminants in farmed fish. This aspect is essential for the health and confidence of consumers in aquaculture products (Trevi *et al*., 2023).

Challenges and future directions

Despite the benefits, there are challenges to the use of algae in aquaculture. These include high production costs, variability of nutritional content and the need for optimized growing methods. Future research should focus on the development of cost-effective growing methods, optimization of nutrient composition and the investigation of new applications of algae in aquaculture (Fonseca *et al*., 2023).

Future research directions

Cultivation optimization: Developing efficient and cost-effective methods for growing algae for aquaculture purposes.

Nutritional composition: Conducting further studies to optimize the nutritional composition of algal-based feed for different aquatic species.

Environmental Impact Assessment: Continuously monitoring the environmental impact of algae-based aquaculture systems to ensure sustainability (Khanzadeh *et al*., 2023).

Addressing these challenges will require the cooperation of researchers, industry stakeholders and policy makers. By investing in research and development, the aquaculture industry can exploit the full potential of algal-based systems and move towards more sustainable practices. In addition, future research should also look at the potential of algae in Integrated Multi-Trophic Aquaculture (IMTA) systems. IMTA systems involve growing several species together, such as fish, crustaceans and algae, in order to create a balanced ecosystem. This approach can further increase the environmental benefits of algal aquaculture. Moreover, the development of new technologies such as advanced photobioreactors and genetic engineering tools will be essential to optimize the production of algae and their nutritional content. These technologies can help to reduce production costs and increase the consistency of feed products based on algae. In addition, policy support and regulatory frameworks will be necessary to encourage the adoption of aquaculture practices based on algae. Governments can provide incentives to farmers to move to sustainable systems, which can help drive change in the whole industry (Rombenso *et al*., 2022).

Conclusion

The combination of macro and micro algae offers a sustainable and efficient approach to increasing the growth, development and safety of aquatic animals. Their nutritional benefits, environmental sustainability and the potential to improve disease resistance make them an invaluable part of the modern aquaculture process. By addressing these challenges and exploring new applications, the aquaculture industry can move towards more sustainable, environmentally friendly and health-promoting methods of producing aquatic food products.

Recommendations

Investment in research and development: Encouraging further research into optimizing the cultivation and nutritional composition of algae in aquaculture.

Policy support: Governments should provide incentives for adopting algae-based aquaculture practices.

Industry Collaboration: Encouraging collaboration between researchers, farmers, and policymakers to promote sustainable aquaculture practices (Abdel-Latif *et al*., 2022).

By integrating macro and micro algae into aquaculture practices, the industry can not only improve the health and productivity of aquatic animals, but also contribute to a more sustainable food system. This approach is in line with the global efforts to reduce the impact on the environment while meeting growing demand for seafood. In addition, the adoption of algae-based systems can also support rural development by creating jobs and boosting local economies. This aspect is of key importance for communities where aquaculture is an important economic activity. Moreover, the use of algae in aquaculture may also increase consumer confidence in fish in the aquaculture sector. Promoting sustainable and environmentally friendly practices can help the sector to improve its image and increase the market demand for algae-fed products. In addition, the integration of algae in aquaculture can also support efforts to conserve biodiversity. Algae-based systems can contribute to a healthier marine ecosystem by reducing pressures on wild fish populations and promoting sustainable aquaculture practices (Ahmad *et al*., 2022).

Final thoughts

As the aquaculture sector continues to develop, the integration of macro and micro algal varieties will be crucial to shaping the future of the sector. By adopting sustainable practices and capitalizing on the nutritional and environmental benefits of algae, the sector can ensure that food is healthier and more sustainable for future generations.

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