MICROALGAE IN AQUACULTURE

F.M. Yusoff[1*] and T. Toda[2]

[1]Department of Aquaculture, Faculty of Agriculture, Universiti Putra Malaysia (UPM), 43400 Serdang, Selangor, Malaysia

[2]Laboratory of Restoration Ecology, Graduate School of Engineering, Soka University, Hachioji, Tokyo, Japan

* Corresponding author email : fatimahyus@gmail.com

Introduction

The aquaculture sector has shown the fastest growth amongst all the various global food production industries, with a record high global production of 114.5 tonnes in live weight in 2018 valued at USD 263.6 billion (2018) (FAO, 2020). It is one of the main driving sectors for sustainable development goals 14 (SDG14) that emphasizes conservation and sustainable use of aquatic resources for sustainable development.

However, the aquaculture industry is still faced with serious problems related to nutritional health such as poor growth and survival in hatchery and grow-out ponds, vulnerability to diseases, and poor production. Nutrition is one of the major determining factors in the success of the aquaculture industry, as it is closely related to the growth, survival, and health of cultured organisms. Feedform the highest portion of the production cost and the use of fish meal in aquaculture is one of the unsustainable practices with a high carbon footprint. Poor quality feeds do not only result in low fish production but are associated with a high waste generation that could cause deteriorating environmental and fish health. Thus, it is very important to improve aquaculture nutrition using environmentally friendly, and highly nutritious feed that could increase precision feeding resulting in maximum production with minimal wastes. One of the approaches to enhance nutrition quality in aquaculture is to use microalgae as feed supplements. Microalgal cells in general are highly nutritious containing biomolecules associated with fast growth and high immunity such as vitamins, antioxidants, and anti-inflammatory, in addition to basic food components such as proteins, carbohydrates, lipids, and trace elements.

The accumulation of carotenoids in fish can also benefit human health which can satisfy the emerging markets of healthy functional foods. In addition, a microalgae culture that consumes CO2 and nutrients improves the environment by decreasing wastes, thus preventing eutrophication in water bodies, and helping to decrease atmospheric carbon content.

The demand for natural and healthier food is increasing worldwide. Commercially, industries related to food and beverages, nutraceuticals, pharmaceuticals, cosmeceuticals, and aquaculture use algal pigments such as beta-carotene, astaxanthin, fucoxanthin, lutein, chlorophylls, phytocyanin, and phycoerythrin. Due to these valuable health-related properties, the global algae products market accounted for USD3.4 billion in 2017 and is expected to reach USD6.09 billion by 2026, growing at a CAGR (compound annual growth rate) of 6.7% (Globe Newswire, 2019). The natural food colour business in 2016 was USD 1.3 billion with a 6.8% annual growth rate and is expected to reach USD1.77 billion by 2021 (Kannaujiya et al. 2017).

Microalgae

Microalgae are valuable sources basic food components such as proteins, carbohydrates, lipids, vitamins, trace elements, and a variety of biomolecules including pigments such as chlorophylls, carotenoids, phycobiliproteins, and phenolic compounds that are associated with fast growth and high immunity (Begum et al 2016).

With an estimated species in the range of 200,000 to several million species, microalgae are ubiquitous microscopic and macroscopic plants in both and freshwater and marine ecosystems (Figure 1). Most species of microalgae have high protein contents that can be valuable sources of protein concentrates, hydrolysates, and bioactive peptides, and together with highly nutritive fatty acids and pigments, make microalgae valuable sources for the development of functional, nutritional, therapeutic, and cosmeceutical commodities (Foo et al 2015, 2017).

Fig.1. Different types of microalgae that can be cultured, freshwater species (F1 -F24) and marine species (M1-M11) (after Khaw et al. 2020)

The presence of polyunsaturated fatty acids (PUFA) such as docosahexaenoic (DHA), and eicosapentaenoic (EPA), and other omega-3 fatty acids which are high in antioxidants renders microalgae as suitable products for immune enhancement in humans and animals (Yusoff et al., 2020). In fact, microalgae can be considered as a potent source for functional foods due to their ability to synthesize compounds with high antioxidative properties. Microalgae have valuable pigments such as astaxanthin, lutein, beta carotene, chlorophylls, and phycobiliproteins.

As human dietary supplements, microalgae pigments such as carotenoids and phycobiliproteins function as anticancer, anti-bacteria, immunity booster, and cardiovascular disease deterrence. Lycopene has been reported to have the capacity to prevent prostate cancer. Microalgae are not only used as food and health products but also as feedstocks for biofuels (Medipally et al. 2015). In addition, microalgae pigments are also used in poultry, livestock, and aquaculture industries. Their high contents of lipids and fatty acids make them valuable alternatives for the replacement of fish meals in livestock and fish feeds. The much-needed polyunsaturated fatty acids (PUFAs) and beta-1,3-glucan, and other biomolecules associated with fish/shrimp health are also found in many microalgae species (Foo et al. 2019).

Applications in Aquaculture

Nutritious and balanced diets can influence the immunity and disease resistance in cultured animals and reduce disease-related economic loss. Dietary supplementation with key amino acids, polyunsaturated fatty acids, vitamins and carotenoids are critical in modulating immune response and productivity of the aquaculture industry.

Most microalgae species have characteristics that are required to be natural supplements in animal feeds including aquaculture. In aquaculture, microalgae can be used as live feeds, formulated feed supplements, health enhancer, water quality bioremediation, growth promoter, and animal color enhancer. Due to their antioxidant and free radical scavenging properties, the best-known function of pigments in aquaculture besides increased growth and enhanced immunity is pigmentation. In fact, there are some pigments, such as fucoxanthin, which are only found in certain microalgae.

Colors play a major role in improving perceived quality, acceptability and willingness to pay for aquaculture products. Colors in organisms are mainly determined by genetic inheritance, but the pigmentation can be greatly influenced by environmental factors and occurrence of diseases. The enhancement of coloration in fish can be due to the proliferation of chromatophores induced by the presence of carotenoids

Carotenoids, which are dependent on diets and body conditions, are responsible for many yellow, orange and red hues in animals including fish and aquatic invertebrates The color of microalgae is influenced by the pigments which are a part of the cell's photosynthetic system and naturally contain high-value compounds such as polyunsaturated acids, fatty acids, chlorophylls, phycobiliproteins and carotenoids. Carotenoids showed better effects on skin pigmentation compared to xanthophylls. In aquaculture, carotenoids function in pigment development, antioxidants and vitamin enrichment, growth and reproduction improvement, cellular protection from photo-damage and health enhancement. In ornamental fish industry, colouration is one of the product main attributes, as demonstrated by the effects of astaxanthin on the fish pigmentation. However, the effects on pigmentation could vary with the pigment sources. Diet supplementation with a photosynthetic bacterium did not significantly enhance the colouration of the Japanese ornamental koi, Cyprinus carpio, compared to a blue-green alga, Spirulina platensis. Astaxanthin and canthaxanthin are responsible for the typical red colour in most fish and thus these two pigments are commonly used in the diet of farmed salmonids for pigmentation enhancement

Microalgae are frequently used in hatchery to enrich zooplankton such as copepods and Artemia as live-feeds, which could be used to increase growth and survival of fish and shrimp larvae. There were significant increases in protein, carbohydrate, ascorbic acid, and β-carotene in Artemia enriched with a green alga, Nannochloropsis oculata. Live feeds such as rotifers and microcrustaceans, like other aquatic consumers do not contain endogenous carotenoids, but can be enriched through their diets. Carotenoid astaxanthin and lutein was used to enrich live-feeds such rotifers and the population was more productive and had higher nutritional contents for healthy development of larval fish compared to rotifers without the carotenoid supplements.

Microalgal pigments are also effective in improving growth and health of many cultured organisms. Lim et al (2019a, b) demonstrated that dietary administration of astaxanthin improves feed utilization, growth performance, survivaland healthof Asian seabass, Lates calcarifer. In addition, supplementary feeding with astaxanthin was also effective in reinforcing fish immunocompetence and disease resistance against Vibrio alginolyticus infection in sea bass (Lim et al. 2021).

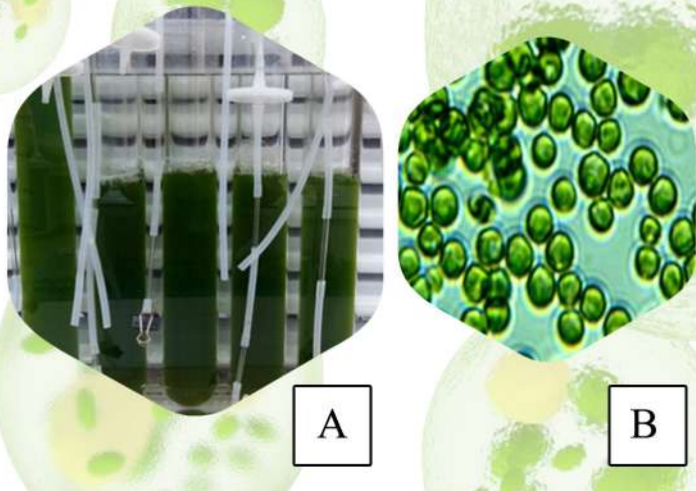

Fig.2. Chlorella vulgaris (green algae) culture (A) and cells (B)

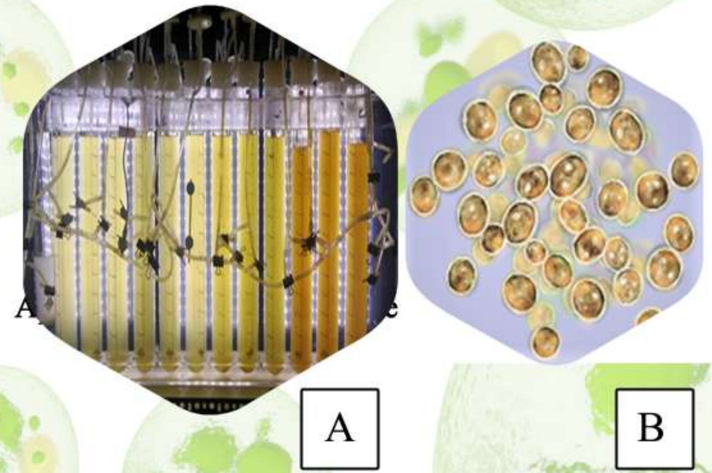

Fig.3. Isochrysisgalbana culturein column photobioreactors (A) and I. galbana cells (B)

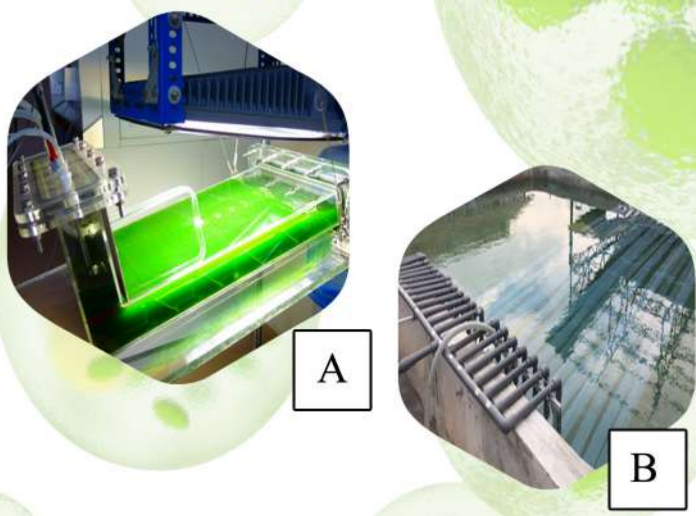

Fig.4. A prototype of the Cradle photobioreactor of the SATREPS-COSMOS project (A) and Outdoor bag photobioreactor in a pond, which can be integrated with fish culture. Placement of culture bags in the water keeps the bags cool and avoid damage from the sun (B)

Acknowledgements

Most of the studies related to this article were funded under the SATREPS-COSMOS (JPMJSA1509) project.

References

1. Begum H, Yusoff FM, Banerjee S, Khatoon H, Shariff M (2016) Availability and utilization of pigments from microalgae. Critical Food Reviews in Food Science and Nutrition 56 (13):2209-2222.

2. FAO. 2020. The State of World Fisheries and Aquaculture (2020) Meeting the sustainable development goals. FAO, Rome.

3. Foo SC, Yusoff FM, Ismail M, Basri M, Chan KW, Khong NMH, Yau SK (2015) Production of fucoxanthin-rich fraction (FxRF) from a diatom, Chaetoceroscalcitrans (Paulsen) Takano 1968. Algal Res 12:26-32 Foo SC, Yusoff FM, Ismail M, Basri M, Yau SK, Khong NMH, Chan KW, Ebrahimi M (2017). Antioxidant capacities of fucoxanthin-producing algae as influenced by their carotenoid and phenolic contents. Journal of Biotechnology 241:175-183.

4. Foo, SC, Yusoff FM, Mustapha Umar Imam, JhiBiau Foo, Norsharina Ismail, Nur Hanisah Azmi, Yin Sim Tor, Nicholas MH Khong, Maznah Ismail. (2019). Increased fucoxanthin in Chaetoceroscalcitrans extract exacerbates apoptosis in liver cancer cells via multiple targeted cellular pathways. Biotechnology Reports. 21: e00296. Corres. Author

5. Globe newswire (2019) The algae products – Global market outlook (201 7- 2026). Research and Market.

https://www.researchandmarkets.com/research/wfblsc/global_algae?w=12.

6. Khaw SY, NMH Khong, Noor Azmi Shaharuddin and Fatimah Md. Yusoff. (2020). A simple 18S rDNA approach for the identification of cultured eukaryotic microalgae with an emphasis on primers. Journal of Microbiological Methods. 172 (2020) 105890.

7. Kannaujiya VK, Sundaram S, Sinha RP (2017) Phycobiliproteins: Recent Developments and Future Applications. Springer Nature, Singapore. https://doi.org/10.1007/978-981-10-6460-9.

8. Lim KC, Yusoff FM, Shariff M, Kamarudin MS (2018) Astaxanthin as feed supplement in aquatic animals. Reviews in Aquaculture 10(3):738-773.

9. Lim KC, Yusoff FM, Shariff M, Kamarudin MS (2019b) Dietary administration of astaxanthin improves feed utilization, growth performance and survival of Asian seabass, Lates calcarifer (Bloch, 1790). Aquaculture Nutrition. 25 (6): https://doi.org/10.1111/anu.1296.

10. Lim KC, Yusoff FM, Shariff M, Kamarudin MS. (2019b) Dietary supplementation of astaxanthin enhances hemato-biochemistry and innate immunity of Asian seabass, Lates calcarifer (Bloch, 1790). Aquaculture 512 (2019): https://www.sciencedirect.com/science/article/pii/S0044848619305319.

11. Lim KC, Yusoff FM, Shariff M, Kamarudin MS (2021). Dietary astaxanthin augments disease resistance of Asian seabass, Lates calcarifer (Bloch, 1790), against Vibrio alginolyticus infection. Fish & Shellfish Immunology, 11490-101.https://doi.org/10.1016/j.fsi.2021.03.025.

12. Medipally SR, Yusoff FM, Banerjee S, Shariff M (2015) Microalgae as sustainable renewable energy feedstock for biofuel production. Biomed Res Int 2015:519513.

13. Yusoff FM, Nagao N, Imaizumi Y, Toda T (2019) Bioreactor for Microalgal Cultivation Systems: Strategy and Development. In: Rastegari A., Yadav A., Gupta A. (eds) Prospects of Renewable Bioprocessing in Future Energy Systems. Biofuel and Biorefinery Technologies, vol 10 pp.117-159. Springer Nature, Cham

14. Yusoff FM, Banerjee S, Nagao N, Imaizumi Y, Shariff M, Toda T (2020) Use of Microalgae Pigments in Aquaculture. In: Jacob-Lopes E., Queiroz M., Zepka L. (eds) Pigments from Microalgae Handbook. Springer, Cham.pp 471-513. https://doi.org/10.1007/978-3-030-50971-2_19