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CURRENT AND FUTURE PERSPECTIVES OF MICROALGAE-AQUACULTURE IN EGYPT, CASE STUDY: SIMAF-PROTOTYPE-PROJECT

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SUMMARY

Aquaculture is a global industry that supplies essential food to a growing world population and contributes more than 77% of the total Egyptian national fish production. Despite Egypt has a great potential in marine aquaculture, more than 95% of Egyptian aquaculture production is categorized as fresh water aquaculture. Until now, Egypt has no real marine aquaculture and this is attributed to many obstacles. One of these obstacles is the quality and quantity of microalgae in the marine hatcheries. Another obstacle is offering of the adequate aquaculture diet, quality and quantity. In this review, we concern on these two obstacles in relation to the current status and the future perspectives of microalgae as aquaculture feedstock in Egypt. In last few years, microalgae industry is one of the most growing industries over the world and can enhance the Egyptian national income, attributed to the great potential of microalgae production in Egypt, especially with the strong presence of microalgae production strategy keys like diversity of microalgae species in water bodies and land, culture conditions, culture facilities, native isolated strains, scientific and governmental interest, which provides great opportunities for success. The project funded from Academy of Scientific Research and Technology (ASRT) in title (Prototype of Sustainable Marine Integrated Aquaculture Farm for the Production of Seafood, Valuable Bio-Products and Biodiesel, SMIAF-Prototype), therefore, the project SMIAF aims to prepare an ideal prototype for marine sustainable integrated aquaculture farm that completely environmentally-friendly, produce sustainable seafood and highly effective for nutrients removal from aquaculture wastewater and convert these wastes by microalgae, as well as seaweeds, to valuable bio-products at semi-industrial scale, with high economic value.

Keywords: *Microalgae, Aquaculture, marine hatcheries, live food, aquafeed, SMIAF-Prototype-Project.*

INTRODUCTION

Aquaculture is a global important industry that supplies essential food to a growing world population, with an essential role in providing a cheap animal protein. In recent years, aquaculture sector has been greatly developing and is considered one of the most promising industries in Egypt. Subsequently, aquaculture acts as the most important tool for decreasing the current gap between consumption and fish production in Egypt (Ashour *et al*., 2018). Aquaculture contributes more than half of the total world fish production (Subasinghe *et al*., 2009) and provides more than 77% of the total Egyptian national fish production, with total value exceeds USD 2 billion per year and secures more than 580,000 jobs for workers in this sector (GAFRD, 2014). Interestingly, aquaculture yields exceeded one million tonnes annually ranking Egyptian aquaculture 8th among the top fish producing countries in the world in 2014 (FAO, 2016a and b). Despite that Egypt has a great potential in marine aquaculture, more than 95% of Egyptian aquaculture production is categorized as fresh water aquaculture.

Unfortunately, until now, Egypt has no real marine aquaculture and this is attributed to many obstacles, one of these obstacles is the offering of the adequate microalgae, quality and quantity, as live food in the marine hatcheries as a live food, even for zooplankton or marine larvae. Another important obstacle facing marine aquaculture, as well as freshwater aquaculture, is the offering of the adequate aquaculture feed in terms of quality and quantity. In current review, we will concern on these two obstacles in relation to the current status and the future perspectives of microalgae as a feedstock of aquaculture in Egypt.

Microalgae have significant commercial and environmental importance. Microalgae contribute up to 70 % of the oxygen content in the Earth's atmosphere by absorbing CO_2 and releasing O_2 during photosynthesis process. Production of microalgal is environmentally friendly because the biomass can be utilized as a source of biofuels, food, feed, pharmaceuticals, cosmetics and bioactive molecules. Moreover, culture of microalgal can complement approaches *like* aquaculture wastewater treatment or bioremediation, in relation to the serious environmental concerns (Pau *et al*., 2017).

Algae are exists since the birth of the planet and has been reproducing for three billion years and the history of algae utilization goes back to many ancients (Fig. 1). Recently, microalgae have worldwide attracted consideration interest, due to their application potentials in the nutraceutical and bio-pharmaceutical industries, as well as renewable bioenergy. Also, microalgae are renewable, sustainable and economical sources of biofuels, food ingredients and bioactive medicinal molecules (Khan *et al*., 2018). Recently, microalgae production is one of the success modern biotechnologies. FAO (2016b), recorded 89,000 tonnes of farmed microalgae from 11 countries, 88,600 tones were reported from China only (FAO, 2018).

Figure 1: History of microalgae utilization in different ancients; Aztec civilization (a) and African communities around Chad Lake (b)

However, despite the important of microalgae, there is no recorded statistical data or industrial microalgae mass production in Egypt, although the important of microalgae in many different fields in our life achieving high economic value. These are major industrial problem needs to reconsider by decision makers and investors. Therefore, the aim of the current review is to insight this problem in relation to the current status and future perspectives for microalgae as aquaculture feedstock in Egypt.

Keys of Microalgae Production:

Microalgae are microscopic unicellular organisms that are found in any type of water (freshwater, brackish, marine, saline and hyper-saline) and capable to convert solar energy via photosynthesis to organic biomass and bioenergy (Priyadarshani and Rath, 2012). Microalgae can grow rapidly under inhospitable and hard conditions.

The success of commercial production of microalgae is limited by some strategic keys *such as* diversity in water bodies and land, culture conditions, culture facilities, native isolated strains, scientific and governmental interest, investments and good marketing. Egypt has a strong potential of most of these strategic keys with weakness of culture facilities and investments. Egypt has a variety in water bodies like Mediterranean Sea, Red Sea, lakes (brackish, saline, hyper-saline and alkaline lakes), Nile River and its tributary, as well as groundwater. In each water-body mentioned, microalgae industry may be established successfully. Beside, agricultural wastewater, sewage water, industrial wastewater and coolants wastewater for petroleum companies, microalgae industry may be established successfully for different multiple industries applications.

Several studies were conducted in the fields of isolated of native microalgal species even from Mediterranean Sea (Abdel Rahman *et al.*, 2010; Ashour *et al*., 2019), lakes (Aly and Gad, 2010; Selim *et al*., 2014; Marrez *et al*., 2014 Abomohra *et al*., 2017; Abdel-Razek *et al*., 2019), freshwater habitats (Mahmoud *et al*., 2015; Mohamed *et al*., 2017; El-Sheekh *et al.*, 2018), wastewater (Rakaiby *et al*., 2012; Mahmoud *et al*., 2016; Eladel *et al*., 2019;) or soil (El-Sheekh *et al*., 2017; 2018). Moreover, several ecological studies were conducted to screening and identify the communities of microalgal species reported in Egyptian different water bodies *like* Mediterranean Sea (Fatma *et al*., 1995;Khairy *et al*., 2015), Red Sea (Nassar *et al*., 2014; Nassar and Khiray, 2014) and lakes (Ali and Khiray, 2012; Khiray *et al*., 2015).

The most important parameters regulating microalgal growth are nutrient quantity and quality, light, pH, turbidity, salinity and temperature. Also, the various factors may be interdependent and a parameter that is optimal for one set of conditions is not necessarily optimal for another (FAO, 1996). Many studies were conducted in the fields of culture of Egyptian native isolated microalgal species with different environmental conditions (Abdel Rahman *et al*., 2008; El-Kassas and El-Sheekh, 2016; Abomohra *et al*., 2014), nutrient limitation (Ashour and Kamel, 2017; Kamil, 2009; Madkour *et al*., 2012; Nour *et al*., 2017, 2015a and 2015b; and Omar *et al*., 2017) and even as aquaculture live food (Abdel Rahman *et al*., 2008 and 2010; and El-Wazzan *et al*., 2009), or as aquaculture powder (Heneash *et al*., 2016) or as a source of biodiesel (Ashour *et al*., 2019; Ashour, 2015).

Microalgae industry is one of the most promising projects in the various fields, beside aquaculture, and has a significant potential to develop the national economy. For these reasons, nowadays, the Egyptian government encourages these projects, particularly attempts for the biofuel production from algal biomass. Some researchers in National Institute of Oceanography and Fisheries (NIOF), Faculties of Agriculture and Faculties of Science, Agriculture Research Center, Institute of Petroleum Research and National Research Centre started in production of microalgae on laboratory scale. More national governmental concern in microalgae, national Egyptian funder organizations *like* Academy of Scientific Research and Technology (ASRT) and Science and Technology Development Fund (STDF), supported and established many microalgae projects at research and semi-industrial scales. Some of these projects have output as a commercial bioproducts produce from microalgae at semi-industrial scale.

One of these projects is a project funded from ASRT established in NIOF in title: (Prototype of Sustainable Marine Integrated Aquaculture Farm for the Production of Seafood, Valuable Bio-Products and Biodiesel, SMIAF-Prototype). SMIAF-Prototype project aims to prepare an ideal prototype for marine sustainable integrated aquaculture farm that completely environmentally-friendly, produce sustainable seafood and highly effective for nutrients removal from aquaculture wastewater and convert these wastes by microalgae, as well as seaweeds, to valuable bio-products at semi-industrial scale, with high economic value. Microalgae cultured on nutrient load exist in aquaculture wastewater, in combination with IMTA concept, are the magic combine solution that can resolve many problems of marine aquaculture with highly positive impact. By using this prototype, treated effluents can safely recirculate back to the fish ponds. Also, this prototype can resolve many problems in our private sector, in regarding to reduce the imported microalgae bioproducts, with increase the profit. Through SMIAF-Prototype-project, many algal products will be produced in different field at semi-industrial scale *like* aquaculture diet feed additives, human food supplement, phycocolloids from seaweeds, cosmetics products (2 submitted patents), biofertilizers and biocides (one granted & 4 submitted patents) and biodiesel. Interestingly, through this project, national granted patent in title (System for Harvesting Microalgae) will be establishing at semi-industrial scale. The microalgae products (aquaculture, biofertilizer, animal feed additive, food supplement, cosmetics, *etc*.) are very required for Egyptian local marketing for Egyptian community (Egyptian population is more than 100 million people).

Importance of microalgae in Marine hatcheries:

Many hundred microalgae species have been tested as live food in marine hatcheries, but about 10 species only have gained widespread use in aquaculture. Appropriate microalgae species must have number of keys attributes to be useful aquaculture species. These keys like they must have (1) an appropriate size for ingestion (from 1 to 15 µm for filter feeders and 10 to 100 µm for grazers); (2) readily digested; (3) rapid growth rate; (4) easy and stable to mass culture; (5) adapted to local environmental conditions; (6) cultured under nutrient limitation; and (7) have a good nutrient composition (Brown, 2002).

A Chinese proverb "Big fish eat little fish, little fish eat shrimp, shrimp eat mud" is dedicated to microalgae and their importance in the food pyramid and a source of medicine. Microalgae comprise the base of the food chain in the marine environment. Therefore, microalgae are necessary in the commercial rearing of various species of marine organisms as a food source for all growth stages of bivalve, molluscs, larval stages of some crustacean species, and very early growth stages of some fish species. Furthermore, microalgae are used to produce mass quantities of zooplankton (rotifers, copepods, and brine shrimp) which serve in turn as food for larvae and early-juvenile stages of crustaceans and fish (FAO, 1996), as shown in Fig. 2**.** For all aquatic communities, microalgae are the best feedstock of protein (essential, non-essential amino acids & peptides), lipid (PUFAs, AA, EPA, DHA & phospholipids), carbohydrates (mono and poly-saccharides), minerals (macro and micro-nutrient) and vitamins (A, B, C, E, riboflavin, folic acid, nicotinic acid & biotin). Moreover, microalgae have varieties of pigments (chlorophylls, phycobiliproteins, phycocyanin, carotenoid, astaxanthin, xanthophylls, lutein & phytol) and bioactive molecules (terpenoids, alkaloid, phenol & hydrocarbons) which in term have different biological activities like antimicrobial, probiotics, antibiotics, antioxidants activities and vaccines (Fig. 2).

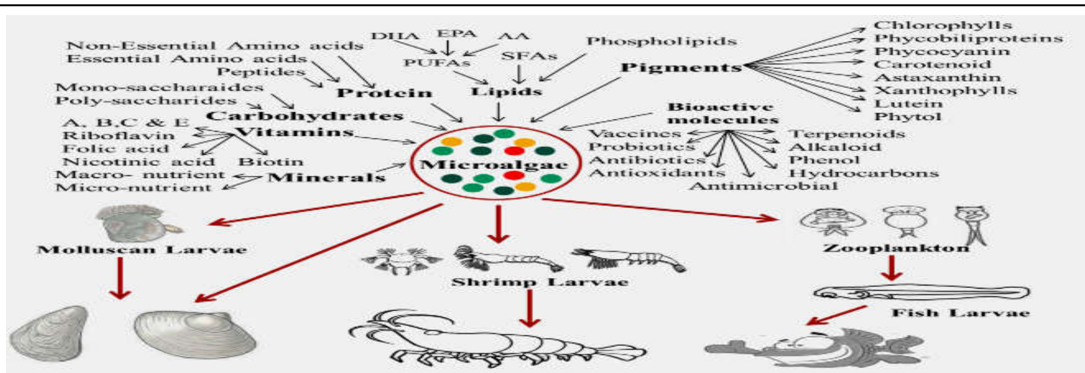

Figure 2: Nutritional value of microalgae which in term serve as feedstock for aquatic

Microalgae are varied in the biochemical compositions between the classes and even inside the species. Protein and lipid is always the major organic constituent and ranging between 15-70 % of dry weight. All the organic and inorganic constituent of microalgae species are varying more within a strain, depending on culture conditions and nutrient limitations (Abdel Rahman *et al*., 2008; Ashour and Kamel, 2017).

Traditionally in aquaculture, live microalgal species are utilized as feed for several aquatic organisms, and it is very important to enhance the production of high nutritional quality as and quantity of cultured microalgae (Abdel Rahman *et al*., 2008 and 2010; and El-Wazzan *et al*., 2009). Microalgae production is the most critical points in marine hatcheries because it involves main factors of risk that makes it non impregnable. The production of microalgae as live food in marine hatcheries are represent in more than half of the total production costs of the marine larvae production (Canavate and Fernandes-Dıaz 2001). In the past decades, these problems have promoted many studies on the development of food sources alternative to live microalgae (fresh cultures), such as micro-particulate diets (Amjad and Jones 1992), micro-encapsulated and inert food (Medina-Reyna *et al*. 2005), yeasts (Heneash *et al*., 2016), microalgae paste (Ashour *et al*., 2019), and microalgae concentrates preserved by several techniques (Brown and Robert 2002). Among all these alternative food sources, microalgae concentrates, such as paste, presented promising results in the total or partial (mixed diet) substitution of the traditional food source (Nunes *et al*., 2009). The potential of microalgae paste varies according to species and depends highly on its resistance to the harvest process and storage (Heasman *et al*., 2000). The concentrate can be obtained by different methods among which centrifugation has presented good results (Robert *et al*. 2001). Interestingly, through SMIAF-Prototype project, funded from ASRT and established in NIOF, national granted patent in title (System for Harvesting Microalgae) will be establishing at semi-industrial scale for harvesting of microalgae from water column to be a paste concentrate. This granted patent has presented good results in comparison to centrifugation, in addition to reducing the power consumption, regarding to reducing production cost.

Microalgae as Feedstock for Aquaculture Diets:

Sustainable extension of aquaculture necessitates finding alternatives to fishmeal because of environmental, food security, and financial drawbacks of these ingredients. These drawbacks of fish meal and fish oil have motivated aquafeed producers to reduce their use of forage fish via partial substitution of fishmeal with terrestrial plant ingredients. Moreover, aquafeed manufactures now facing actual rises in fishmeal due to the competition for aquafeed ingredients from producers of feeds of other animals, human food supplements and pharmaceuticals (Hardy, 2010). Microalgae companies increasingly seek markets for defatted biomass that is left over after extracting omega-3 rich oil for human consumption and/or crude oil for biodiesel production. Such a protein rich co-product is a promising alternative to unsustainably sourced fishmeal in aquaculture diets (Sarker *et al*., 2018).

In Egypt, several studies were conducted on the utilization of microalgae as feed additive and/or partial replacement of fishmeal in aquaculture diets (Abu-Zead 2001; Dawah *et al*., 2002; El-Hindawy *et al*., 2006; Badwy *et al*., 2008; Abdel-tawwab *et al*., 2008; Khalil *et al*., 2018). According to literature, the used microalgae species were *Chlorella* and *Scenedesmus* and *Spirulina,* due to the extensive study on these three species, in particular in Egyptian Universities, Institutions and Research Centers. These three species were utilized and evaluated in diets of Nile Tilapia *Oreochromis niloticus* and achieved good results in enhancing *O. niloticus* growth parameters and feed utilization. On the other hand, some diet factories, ornamental and marine fish hatcheries have imported large quantities of *Spirulina* to utilize in aqua-diets. Nowadays, there are some farms of Spirulina in Egypt at small-scale and all these farms working using open pond system. However, these farms facing some problems, especially in harvesting, drying, bacterial contamination and lowing of productivity, attributed to a sustainable scientific production system, as well as lack of culture facilities.

CONCLUSION

Microalgae industry is one of the most growing industries over the world in last few years and can enhance the Egyptian national income, attributed to the great potential of microalgae production, especially with the strong presence of strategic production keys *like* diversity in water bodies and lands, native isolated strains, culture conditions and scientific and governmental interest, which provides great opportunities for success this industry. The weakness and strategic key limiting this industry in Egypt is the absence of specialist companies produce culture facilities which negatively affects the production quality and quantity of Egyptian *Spirulina* farms in the private sector. Another strategic key limiting this industry in Egypt is absence of the investments in this important field, which serve also in the field of biofertilizers, human food supplement, pharmaceutical, cosmetics, biofuels and bioactive molecules.

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