Journal of Cleaner Production 244 (2020) 118765

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Letter to the editor

“Algaquaculture” integrating algae-culture with aquaculture for sustainable development

A recently published paper entitled “Analysis of aquaponics as an emerging technological innovation system” discussed the integration of aquaculture with hydroponics (aquaponics) for sustainable development (König et al., 2018). In such an integrated system, wastes secreted by aquatic animals are assimilated by plants, of which the growth consumes some essential nutrients, and water treated by plants is recycled for aquaculture (König et al., 2018). As for technological principles, aquaponics is based on the nutrients recycling from fish excretions for plants growth, and the simultaneous clean-water regeneration for fish rearing, creating a mutual benefit (König et al., 2018). Besides the research of König et al. (2018), many other studies have intensively evaluated the potential application of aquaponics in terms of nutrients recovery and environmental protection (Nhan et al., 2019). Undeniably, this emerging technology could alleviate a couple of problems in traditional aquaculture and reduce the production cost of aquatic animals to some extent. We would like to highly commend the authors on this interesting study and, at the same time, discuss the existed problems in aquaponics and propose a novel concept of “Algaquaculture”, which might be a new development trend of aquaculture in the near future owning to its significant advantages.

The system applied in the work of König et al. (2018) is a typical aquaponics system, of which the industrial or commercial implementation has a couple of problems associated with the nutrients recovery and energy consumption. First, the nitrogen uptake rate and capacity of vegetables or other leafy plants are very low (Nhan et al., 2019). In the study of Nhan et al. (2019), watercress which was employed for nitrogen assimilation contained low protein contents, ranging from 2.0 mg/100 g to 2.9 mg/100 g (Elhadi, 2019), and yielded less than 508 g WW/m^2 biomass. Under the assumption that all the nitrogen resources assimilated by watercress are converted to protein, nitrogen assimilation rate of watercress could not be higher than 2.36 mg/m^2. Same problem was reported by Wongkiew et al. (2018) that found 300 L growth bed (1.5 $m^2 \times 0.2$ m) with 24 pots of plants was only able to clean up effluent from 17 fish, resulting in a very large floor area of hydroponics. Owning to the low nitrogen assimilation rate, a large space and a long hydraulic retention time (HRT) are also required for hydroponics to recover nitrogen in aquaculture effluent. Second, oxygen depletion, a serious problem of aquaculture, caused by the respiration of aquatic animals is not solved by the aquaponics system. Most of aquaponics systems improved the content of dissolved oxygen (DO) in aquaculture by aeration pumps, which have high energy consumption and operation cost (Fang et al., 2017; Yogev et al., 2016). Third, the aquaculture still relies on traditional feed, which accounts for a large portion of the total cost of aquatic animals rearing. In addition to the high cost, the excessive addition of antibiotics or medicines in traditional aquaculture feed is another problem faced by aquaponics industry. Fourth, the economic performance of aquaponics is doubted since the market demand fluctuation occurs sometimes and the economic values of most vegetables are not high in many countries.

Aiming at solving aforementioned problems in aquaponics, a novel concept of “Algaquaculture”, which is a combined word referring to an integration of algae-culture with aquaculture, has been proposed. Hydroponics system of aquaponics is replaced by algae-culture system, in which algae, instead of plants, convert nutrients in aquaculture effluent to value-added biomass. As shown in Fig. 1, algaquaculture, generally, consists of four sub-sections, including aeration bio-pump by algae, aquaculture with self-sustainability function, algae-based wastewater remediation, and exploitation of value-added algal biomass. (1) Fresh algae cells, which continuously fix carbon dioxide and supply oxygen by photosynthesis, acting like an aeration bio-pump, are added into aquaculture system. Furthermore, as algae become the dominant species in water body, the risk of cyanobacterial bloom, which threatens the survival of aquatic animals by reducing content of DO or releasing toxins, could be reduced to a lower level. (2) Consortia consisted of algae and water-borne bacteria are able to degrade solid wastes of aquatic animals by secreting extracellular enzymes. At the same time, algae can efficiently uptake the nutrients from water body, improving the self-purification ability of aquaculture system and yielding value-added biomass. Previous studies have widely reported the great performance of algal-bacterial consortia in water-quality control (Addy et al., 2017; Fang et al., 2018). (3) As the aquaculture effluent flows through the algae-culture system, nutrients in effluent could be assimilated by algal cells, producing value-added biomass rich in protein, polyunsaturated fatty acids (PUFA), polysaccharides, and natural pigments. According to previous studies, in a real-world application, to control the biomass production cost, two algae-culture methods, including fungi-assisted biomass production and revolving algal biofilm (RAB), were frequently applied (Gross et al., 2015; Zhou et al., 2012). The method of fungi-assisted biomass production refers to the culture of suspended algal cells in effluent followed by the use of filamentous fungi for biomass collection. The method of RAB refers to the immobilization of algae by biofilm, on which the biomass could be collected directly by using scrapers at low cost (Gross and Wen, 2014). Mechanisms of both methods have been fully documented (Gross et al., 2015; Zhou et al., 2012). (4)

https://doi.org/10.1016/j.jclepro.2019.118765
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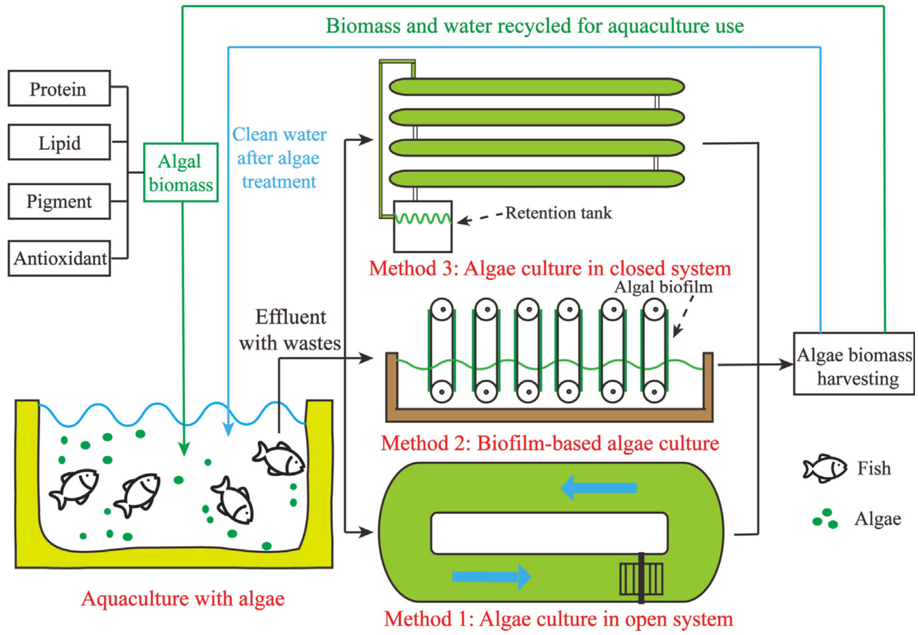

Fig. 1. Scheme of "algaquaculture".

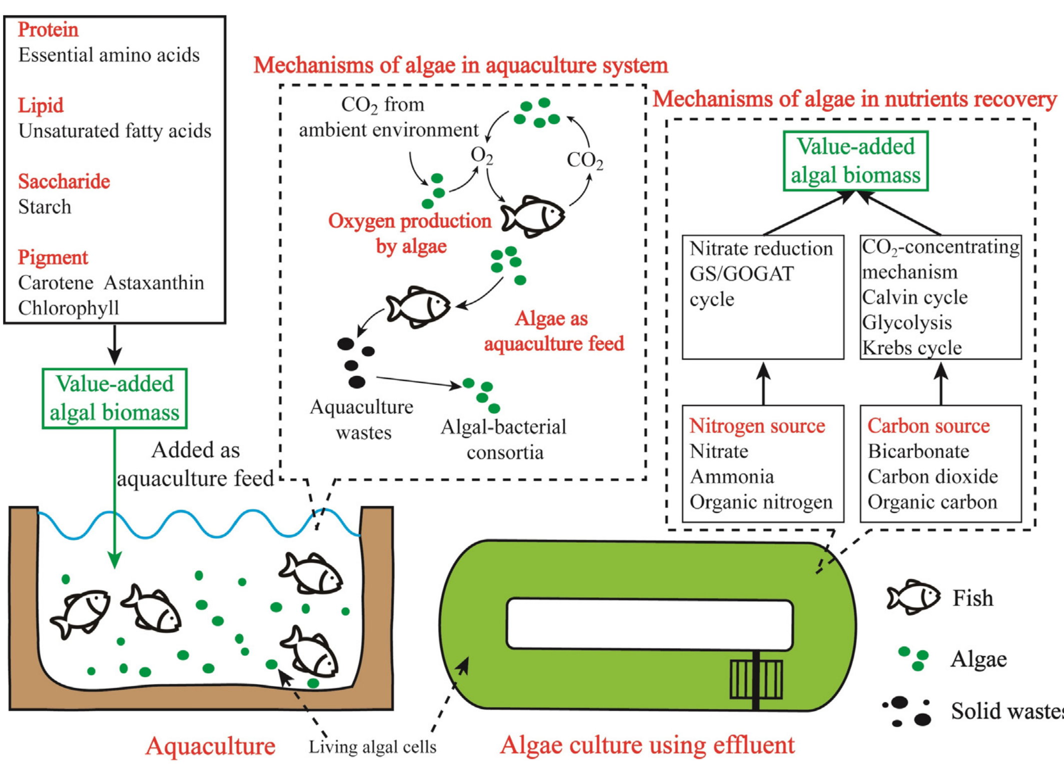

Fig. 2. Mechanisms in the "Algaquaculture" system.

Harvested algal biomass could be added into aquaculture system to partly replace traditional feed. As a consequence, the flows of water and nutrients could form closed-cycles in algaquaculture. As reported by Kiron et al. (2004), value-added compositions, such as antioxidants, in algal biomass could enhance the immunity of aquatic animals and prohibit the overuse of antibiotics or medicines in aquaculture. In addition, algal biomass could be used as raw materials in industries to produce value-added products, such as protein supplement, animal feed, edible oil rich in PUFA, and food-grade pigments (see Fig. 2).

In the aspects of technology and economic value, this novel algaquaculture has six advantages over traditional aquaponics. First, in most cases, algae have much better performance than plants, particularly vegetables, in nutrients removal. For example, the removal rates of ammonia in wastewater by microalgae-based treatment can reach 19.1 mg/day/L (Wang et al., 2015). Additionally, algae, which can survive in wastewater with 300–500 mg/L ammonia, are more tolerant to the ammonia-rich environment (Lu et al., 2018). Thus, the algaquaculture system is expected to have better performance in nutrients recovery and create a more favorable environment for fish rearing than traditional aquaponics system. Additionally, to treat a certain amount of aquaculture wastewater, the algae system with high nutrients removal efficiency will have smaller size, resulting in lower construction and operation costs, than plants system. Second, algal-bacterial consortia in algaquaculture could convert solid wastes to low-molecular-weight and assimilable nutrients while plants in aquaponics may not efficiently digest some solid wastes secreted by aquatic animals. Sometimes, bacterial infection caused by the accumulation of wastes may be devastating to the plants in aquaponics (Fang et al., 2018). Third, recently developed RAB and fungi-assisted biomass production technologies effectively simplified the algae-culture procedure and reduced the biomass harvesting cost, improving the feasibility of integrating algae-culture with aquaculture in a real-world application. In this novel system, since the algae are directly used for fish rearing, there is no need to obtain highly concentrated biomass. After simple thickening treatment, the algae paste can be used for aquaculture, lowering the cost of algae biomass collection. Fourth, compared with vegetables harvested from aquaponics, algal biomass harvested from algaquaculture contains more value-added compositions with high market demand and price. To our knowledge, in the market, the prices of algal astaxanthin and algal powder for food or feed use could reach $15000/kg and $3000/kg, respectively (Hwang et al., 2019; Spolaore et al., 2006). In a real-world application, to reduce the risks of algal toxicity, only the feed-grade algal species, such as *Chlorella* sp., *Spirulina* sp., and *Haematococcus* sp. with value-added compositions can be used for aquaculture. Additionally, the dominant algal species in algaquaculture should be monitored to avoid the bloom of toxic algae and the threats to fish growth. Fifth, plants commonly used in aquaponics are not salt-tolerant species, limiting the application of aquaponics in seawater fish rearing. This problem could be solved by the algaquaculture, which uses either freshwater algae (*Chlorella* sp., *Scenedesmus* sp. *Haematococcus* sp., etc.) or marine algae (*Dunaliella salina*, *Nannochloropsis* sp., etc.). Thus, in terms of aquatic animals rearing, the application range of algaquaculture would be much wider than that of aquaponics. Last but not the least, as harvested algal biomass is used as aquaculture feed to prohibit the overuse of antibiotics and medicines, food safety and meat quality of aquatic animals will be improved (Han et al., 2019; Yang et al., 2019). As a result, the market acceptance and profitability of algaquaculture products will be much higher than those of traditional aquaponics. Owning to the great advantages mentioned above, we believe that algaquaculture may be a new development trend in the aquaculture industry.

Although this novel concept is expected to bring technical breakthrough to aquaculture industry, to improve its practical-feasibility in a real-world application, more progresses are needed in the aspects of algal strains screening, algae-growth system design, algae biomass harvesting, algae-based nutrients recovery, and algae-based feed exploitation. Additionally, based on the lab-scale research, the performance of a pilot-scale algaquaculture system should be tested to improve the feasibility of this novel concept in practice. In the foreseeable future, with the advancement in lab research and the implementation in practice, the novel concept of algaquaculture can truly solve the problems in traditional aquaculture and promote the industry upgrade.

In conclusion, we expect that this letter could attract researchers attention to algaquaculture, a novel concept having great potential of being applied to address the problems of traditional aquaponics and upgrade aquaculture industry in the coming future.

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Limin Yang
Department of Environment Science and Engineering, Zhongkai University of Agriculture and Engineering, Guangzhou, 510225, China

Ruolan Wang
School of Food Science and Technology, Henan University of Technology, Zhengzhou, 475001, China

Qian Lu[*], Hui Liu[**]
Department of Environment Science and Engineering, Zhongkai University of Agriculture and Engineering, Guangzhou, 510225, China

* Corresponding author. Department of Environment Science and Engineering, Zhongkai University of Agriculture and Engineering, Guangzhou, 510225, China.

** Corresponding author.
E-mail addresses: qianlu1960@foxmail.com (Q. Lu), liuhui@zhku.edu.cn (H. Liu).

6 April 2019
Available online 7 October 2019

Handling editor; Giovanni Baiocchi