Improvement of Colombian Aquaculture Hydric Sustainability: Application of Phytoremediation Process Under a Circular Economy Scheme

JANET BIBIANA GARCÍA-MARTÍNEZ, CRISÓSTOMO BARAJAS-FERREIRA & VIATCHESLAV KAFAROV

Abstract World water shortage and difficulty in the management of water resources has generated a global alert, which has led to the declaration of the "water crisis". One of the problems arising from difficulties in the efficient management of water resources is a global shortage of food. Within agricultural activities, aquaculture is known for its high-water requirements, in addition, its post-consumption waters have high levels of nitrogen compounds, phosphates and dissolved organic carbon, which must be treated and disposed. Worldwide, several prototypes using microalgae have been used at the laboratory and pilot level. However, gaps in its implementation and operation, in addition to the final quality of post-harvest water are still latent. Due to the above, in this work we propose the evaluation of microalgal biomass production in aquaculture post-consumption waters and its impact on the improvement of water quality. Also, a method is proposed for the reuse of treated water for use in the aquaculture industry as an alternative for the sustainable use of water resources from a perspective of green economy and circular.

Keywords: • Wastewater • Microalgae • Aquaculture • Circular Economy • Green Economy •

CORRESPONDENCE ADDRESS: Janet Bibiana Garcia Martinez, Masters in Chemical Engineering, Industrial University of Santander, Faculty of Physicochemical Engineering, Carrera 27 # 9, Bucaramanga, Colombia, e-mail: bibiana0213@gmail.com. Crisóstomo Barajas-Ferreira, PhD, Professor, Industrial University of Santander, Department of Chemical Engineering, Carrera 27 # 9, Bucaramanga, Colombia, e-mail: cbarajas@uis.edu.co. Viatcheslav Kafarov, PhD, Professor, Industrial University of Santander, Department of Chemical Engineering, Carrera 27 # 9, Bucaramanga, Colombia, e-mail: kafarov@uis.edu.co.

DOI https://doi.org/10.18690/978-961-286-211-4.3 ISBN 978-961-286-211-4
Available at: http://press.um.si.

1 Introduction

Low efficiency in the management of water resources is one of the critical points for the sustainable development of national and global agriculture. According to FAO, in 2050 agriculture will need to produce 60% more food worldwide, which will require high availability of water resources resources (FAO 2014).

Within the agricultural activities, extensive aquaculture is recognized for its ability to solve the food crisis that is looming. However, these processes require high volumes of water.

Wastewater from closed aquaculture systems had high levels of nitrogen and dissolved inorganic phosphorus. The primary responsibility for these high concentrations of nutrients in the food not consumed, since according to Crab et al., (2007). Up to 75% of the food used is maintained in the form of nitrogen and phosphorus in the post-culture water. The latter contributes to the sustained increase in the concentration of organic waste and toxic compounds in aquatic systems (Lananan et al., 2014).

During the last 50 years, significant efforts have been made to remove different nutrients from this wastewater, which prevent the eutrophication of water bodies close to the production systems and allow recirculating the treated water (Crab et al ., 2007). Currently there is a great diversity of biological and chemical methods that have been successfully used in the process of nutrient removal, such as: (1) biological processes for the elimination of nitrogen such as nitrification and denitrification (Boley et al., 2000) and (2) chemical processes as chemical precipitation for the elimination of phosphorus (Ebeling et al., 2003); This last process, although useful, is a less environmentally friendly technique, since it leads to the formation of highly polluting sludge for the environment (Gao et al., 2016).

Although there are conventional treatments for the management of this water, most are high cost and do not generate any added value to the producers. One of the methods that can generate added value is the use of microalgae since they can sequester nutrients and produce biomass enriched with metabolites of industrial interest. The objective of this project is to design and build a recirculation system for aquaculture post-consumption water using microalgae as a phytoremediation system. To achieve the above, we proposed to evaluate the quality of post-consumer water and its viability as a culture medium to be recycled in the process and generate valuable products that are integrated into the production process.

2 Material and methods

2.1 Microorganism and culture conditions

Chlorella vulgaris and *Scenedesmus obliquus* strains were obtained from Microalgae Culture Collection of Universidad Francisco de Paula Santander (Colombia). The strains were mantained in Bold Basal Media (Andersen, 2005) under light cicle 12:12 (light:dark) and 28ºC ±2.

2.2 Fisheries wastewater

Wastewater was obtained from the culture of *Oreochromis* sp at the laboratory of fish nutrition from Universidad Francisco de Paula Santander. For the cultivation of microalgae, the effluents were filtered twice with a cloth filter.

2.3 Parameters of algae culture

C. vulgaris and *S. obliquus* were inoculated on three different treatments: (1) Sterile wastewater (by autoclaving at 15 psi, 15 min), (2) Non-Sterile wastewater and (3) Non-Sterile wastewater supplemented with CO_2 (1% or 0,006 vvm). All the experiments had a duration of 20 days.

2.3 Analytical methods

Biomass concentration (dry weight basis or DW), total lipids, total carbohydrates and total proteins were monitored using the methods described by Moheimani and Borowitzka (2013). Orthophosphates (PO_4) and nitrate concentrations in wastewater before and after treatment. PO_4 was determined by Vanadomolybdo phosphoric Acid Colorimetric Method (APHA, 2017) and NO_3 by Horiba LAQUATwin Nitrate sensor. Complementary biochemical and microbiological analyses (BOD, COD, total coliforms and faecal coliforms) were carried out at the beginning and end of the experiments.

3 Results

The concentration of biomass produced after 20 days is presented on figure 1. According to the results both algae were able to grow on Non-Sterile media (NS), with the lowest values for both algae (0,9 g/L for *C. vulgaris* and 0,5 g/L for *S. obliquus*) in comparison with the other two treatments. This lower value can be explained by the possible the competition with other microorganisms present in the wastewater, which can predate algae or consume faster the different nutrients present on the media. One interest feature occurs when the media supplemented with CO_2 (NS+CO_2), in this scenario both algae reach its highest biomass concentration (1,5 g/L for *C. vulgaris* and 1,2 g/L for *S. obliquus*). Since CO_2 is the mayor source of carbon for photosynthetic organism, the presence in excess on the wastewater favours the biomass production of algae.

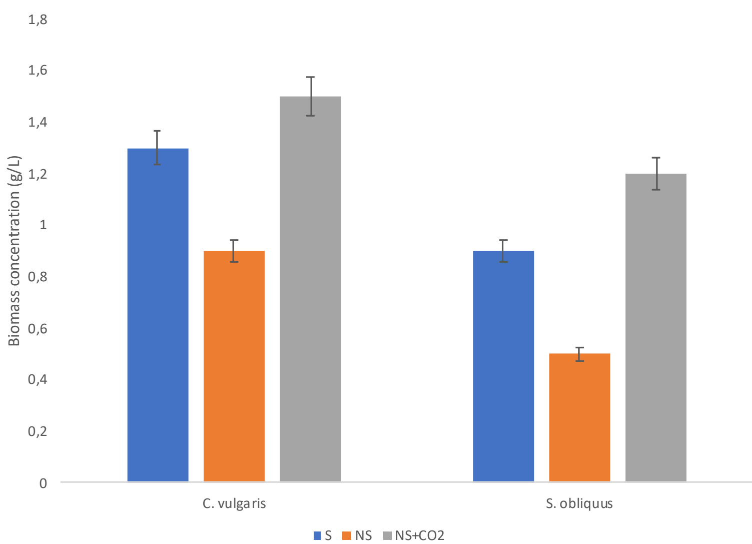

Figure 1: Biomass Concentration for *C. vulgaris* and *S. obliquus*, S: Sterile media; NS: Non-Sterile media. Source: own

On figure 2, the biomass composition for *C. vulgaris* and *S. obliquus* is presented. The results shown that both algae possess a large concentration of proteins (45% w/w), followed by carbohydrates (23-25%) and lipids (12-15%).

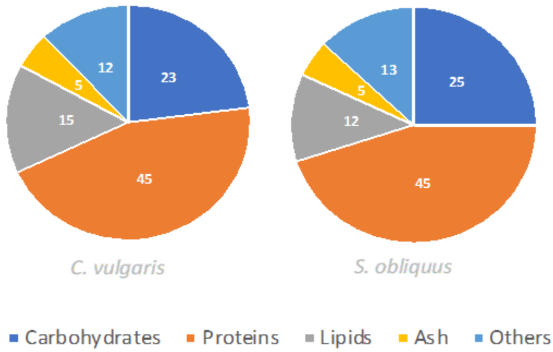

Figure 2: Biomass Composition for *C. vulgaris* and *S. obliquus*, Source: own

The quality of the wastewater after the culture of both algae is shown on figure 3. This results allow to understand that the algae can drastically reduce several parameters such as CDO and BDO_5, while NO_3 and PO_4 (>95%) is almost completely removed from the water.

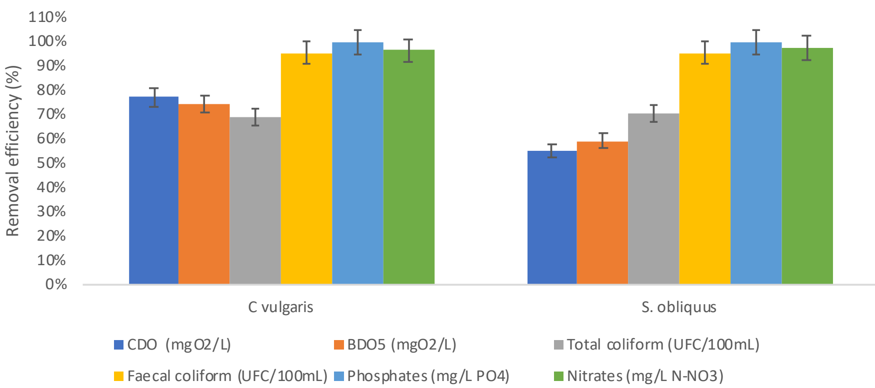

Figure 3: Removal efficiency (%) *C. vulgaris* and *S. obliquus*, source: own.

4 Discussion

Extensive research has shown that algae can be easily produced in wastewater and this allows the production of biomass for high-value products, and the remediation of hazardous nutrients such as nitrogen, phosphates, and others (Ma et al., 2016; Rawat et al., 2011).

In the present study, it was possible to determine high removal rates of COD, BDO_5, nitrates and orthophosphates with efficiencies closer to 100% in the removal of nitrogen compounds. Highlighting the high efficiency in the elimination of nitrates is essential. This high value may point to the fact that culture conditions could be forcing the algae to synthesize nitrogen and phosphate-dependent metabolites (such as proteins and chlorophylls) (Venckus et al., 2017). At a global scale, it is possible to find clear and concrete examples of the use of this type of wastewater for the production of microalgal biomass as a suitable source of food, feed and biofertilizers. Ansari et al., (2017) Guldhe et al., (2017) evaluated at laboratory scale production of *Chlorella sorokiniana*, *Ankistrodesmus falcatus Scenedesmus obliquus* and post-consumption tilapia water in South Africa using heterotrophic and mixotrophic strategies. Milhazes-Cunha and Otero (2017) demonstrated the feasibility of using algae cultures in conjunction with anaerobic systems for the reuse of treated water into the fisheries. The only technology scaled up to a considerable volume (13 m3) is located in Belgium, the MaB-flocSBRs system developed by the researchers of the University of Gent in consortium with the Ecole des Métiers de l'Environnement (EME, France) (Van Den Hende et al., 2011; Van Den Hende et al., 2014).

This system aims to treat Lucioperca waters with microalgae to recirculate the most substantial amount of medium used and use biomass for biogas production. The algal biomass produced on aquaculture water treatment can also be used as live feed for various stages of growth in marine filters (Ferreira et al., 2008), as food for larvae of some gastropods (during their stages of growth), and also as food for some crustaceans and some fish species in their earliest growth stages (Brown and Robert, 2002). Another possible use is as indirect food, especially for the production of zooplankton (i.e., brine shrimp and rotifers) which are essential food for several carnivorous larvae (Welladsen et al., 2014). In recent decades, a large number of microalgae species have been studied as a source of nutrients in aquaculture, with only a small number of species being exploited (Guedes and Malcata, 2012). Other possible uses may be the generation of biofuels and soil conditioners (Alobwede et al., 2019).

5 Conclusions.

It was possible to combine the removal of hazardous nutrients (such as nitrate and orthophosphates) from wastewater and high-valuable algal biomass from the two strains evaluated (C. vulgaris and S. obliquus) with a good concentration of proteins and lipids, which can be used on a further process of valorisation. These two algae were able to adapt rapidly and growth, obtaining a high consumption of both nitrate and phosphate. It is possible to highlight that the cultivation of these two algae in the wastewater significantly reduced the physicochemical and microbiological values. However, C. vulgaris presented the highest rate of COD, BOD_5 and coliforms. Finally, these results allow us to establish a solution focused on the circular economy for wastewater from fish farming, which has the potential to limit the environmental impact generated by the excessive use of fresh water and the disposal of high volumes of effluents. This will substantially reduce the emission of hazardous nutrients to water bodies and will allow the reuse of both water and the recirculation of these nutrients in the same agricultural systems, generating more sustainable and sustainable processes.

Acknowledgments

The Authors thanks to Universidad Industrial de Santander for providing materials and equipment for successfully conclude this research.

References

Alobwede, E., Leake, J. R., & Pandhal, J. (2019). Circular economy fertilization: Testing micro and macro algal species as soil improvers and nutrient sources for crop production in greenhouse and field conditions. *Geoderma*, *334*, 113-123. https://doi.org/10.1016/j.geoderma.2018.07.049

Andersen, R.A., Berges, J.A., Harrison, P.J. & Watanabe, M.M., (2005). Appendix A—Recipes for Freshwater and Seawater Media In Andersen R.A.(Ed). *Algal Culturing Techniques*, 437-438. Burlington, MA: Elsevier Academic Press.

Ansari, F. A., Singh, P., Guldhe, A., &Bux, F. (2017). Microalgal cultivation using aquaculture wastewater: integrated biomass generation and nutrient remediation. *Algal Research*, 21, 169-177. https://doi.org/10.1016/j.algal.2016.11.015

Boley, A., Müller, W. R., & Haider, G. (2000). Biodegradable polymers as solid substrate and biofilm carrier for denitrification in recirculated aquaculture systems. *Aquacultural engineering*, 22(1-2), 75-85.https://doi.org/10.1016/S0144-8609(00)00033-9

Brown, M., Robert, R., (2002). Preparation and assessment of microalgal concentrates as feeds for larval and juvenile pacific oyster (Crassostrea gigas). *Aquaculture* 207, 289–309. https://doi.org/10.1016/S0044-8486(01)00742-6

Crab, R., Avnimelech, Y., Defoirdt, T., Bossier, P., & Verstraete, W. (2007). Nitrogen removal techniques in aquaculture for a sustainable production. *Aquaculture*, 270(1-4), 1-14. https://doi.org/10.1016/j.aquaculture.2007.05.006

Ebeling, J. M., Sibrell, P. L., Ogden, S. R., & Summerfelt, S. T. (2003). Evaluation of chemical coagulation–flocculation aids for the removal of suspended solids and phosphorus from intensive recirculating aquaculture effluent discharge. *Aquacultural Engineering*, 29(1-2),23-42. https://doi.org/10.1016/S0144-8609(03)00029-3

FAO (2014) The state of world fisheries and aquaculture 2014. Food and Agriculture Organization of the United Nations. Fisheries and Aquaculture Dept, Rome

Ferreira, M., Maseda, A., Fábregas, J., Otero, A., (2008). Enriching rotifers with "Premium"microalgae. Isochrysis aff. galbana clone T-ISO. *Aquaculture* 279, 126–130. https://doi.org/10.1016/j.aquaculture.2008.03.044

Gao, F., Li, C., Yang, Z. H., Zeng, G. M., Feng, L. J., Liu, J. Z., & Cai, H. W. (2016). Continuous microalgae cultivation in aquaculture wastewater by a membrane photobioreactor for biomass production and nutrients removal. *Ecological engineering*, 92, 55-61. https://doi.org/10.1016/j.ecoleng.2016.03.046

Guedes, A.C., Malcata, F.X., (2012). Nutritional value and uses of microalgae in aquaculture.
Aquaculture, 59 – 78.

Guldhe, A., Ansari, F. A., Singh, P., &Bux, F. (2017). Heterotrophic cultivation of microalgae using aquaculture wastewater: a biorefinery concept for biomass production and nutrient remediation. *Ecological Engineering*, 99, 47-53. https://doi.org/10.1016/j.ecoleng.2016.11.013

Lananan, F., Hamid, S. H. A., Din, W. N. S., Khatoon, H., Jusoh, A., & Endut, A. (2014). Symbiotic bioremediation of aquaculture wastewater in reducing ammonia and phosphorus utilizing Effective Microorganism (EM-1) and microalgae (*Chlorella*sp.). *International Biodeterioration & Biodegradation,* 95, 127-134. https://doi.org/10.1016/j.ibiod.2014.06.013

Ma, X., Zheng, H., Addy, M., Anderson, E., Liu, Y., Chen, P., Ruan, R., (2016). Cultivation
of Chlorella vulgaris in wastewater with waste glycerol: strategies for improving nutrients removal and enhancing lipid production. *Bioresour. Technol.* 207, 252–261. https://doi.org/10.1016/j.biortech.2016.02.013

Milhazes-Cunha, H., & Otero, A. (2017). Valorisation of aquaculture effluents with microalgae: The Integrated Multi-Trophic Aquaculture concept. *Algal Research*, 24, 416-424. https://doi.org/10.1016/j.algal.2016.12.011

Moheimani, N.,Borowitzka, M., Isdepsky, A., and Fon, S., (2013). Standard methods for measuring growth of algae and their composition. In M.A. Borowitzka, & N. R. Moheimani. (Ed.), *Algae for Biofuels and Energy*, 265- 284. New York London: Springer

Rawat, I., Ranjith Kumar, R., Mutanda, T., Bux, F., (2011). Dual role of microalgae: phycoremediation of domestic wastewater and biomass production for sustainable biofuels production. *Appl. Energy* 88, 3411–3424. https://doi.org/10.1016/j.apenergy.2010.11.025

Statsoft, INC., 2004.STATISTICA (data analysis software system), Avaiable in: www.statsoft.com.

Van Den Hende, S., Beelen, V., Bore, G., Boon, N., &Vervaeren, H. (2014). Up-scaling aquaculture wastewater treatment by microalgal bacterial flocs: from lab reactors to an outdoor raceway pond. *Bioresource technology*, 159, 342-354. https://doi.org/10.1016/j.biortech.2014.02.113

Van Den Hende, S., Vervaeren, H., Desmet, S., & Boon, N. (2011). Bioflocculation of microalgae and bacteria combined with flue gas to improve sewage treatment. *New biotechnology*, 29(1), 23-31. https://doi.org/10.1016/j.nbt.2011.04.009

Venckus, P., Kostkevičienė, J., andBendikienė, V., (2017). Green algae *Chlorella vulgaris* cultivation in municipal wastewater and biomass composition. *Journal of Environmental Engineering and Landscape Management*, 25(*1*), 56-63. https://doi.org/10.3846/16486897.2016.1245661

Welladsen, H., Kent, M., Mangott, A., Li, Y., (2014). Shelf-life assessment of microalgae concentrates: effect of cold preservation on microalgal nutrition profiles. *Aquaculture*
430, 241–247. https://doi.org/10.1016/j.aquaculture.2014.04.016