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Short communication

Microalgae-Based Biorefineries Integrating Phytoremediation and Wastewater Treatment

[Biorrefinerías integrando Microalgas con Fitorremediación y Tratamiento de Aguas Residuales]

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Abstract

Biorefineries are currently recognized as a sound and environmentally friendly strategy to mitigate the global climate threat. Furthermore, they are now widening their capacity and high added value products are also produced from various types of biomasses. Microalgae-based biorefineries are now recognized as the most promising alternative compared to first and second generation biorefineries. Furthermore, there is a current trend for including the treatment of wastewater as a means of increasing their economic feasibility. On the other hand, the use of aquatic plants for phytoremediation and production of biofuels is also an active research field. However, there is scanty information about the integration of the biomass of microalgae, aquatic plants, and the use of wastewater within a biorefinery. In this short article, a review of the design and implementation of a biorefinery integrating microalgae, aquatic plants, and wastewater to produce biofuels and high-added value products is presented.

Resumen

Las biorrefinerías están reconocidas actualmente como una estrategia ambientalmente amigable para mitigar la amenaza del cambio climático. Actualmente, el concepto incluye también la generación de productos de alto valor agregado a partir de varios tipos de biomasas. Las biorrefinerías basadas en microalgas se reconocen como la alternativa más prometedora en comparación con las biorrefinerías de primera y segunda generación. Además, existe una tendencia actual a incluir el tratamiento de las aguas residuales como medio para aumentar su viabilidad económica. Por otro lado, el uso de plantas acuáticas para la fitorremediación y la producción de biocombustibles es también un campo de investigación activo. Sin embargo, hay poca información sobre la integración de la biomasa de microalgas, plantas acuáticas y el uso de aguas residuales dentro de una biorrefinería. En este breve artículo se presenta una revisión del diseño e implementación de una biorrefinería que integra microalgas, plantas acuáticas y aguas residuales para la producción de biocombustibles y productos de alto valor agregado.

Introduction

The most widely used *"**Biorefinery**"* definition is the one launched by the IEA (International Energy Agency) Bioenergy Task 42: "Biorefinery is the sustainable processing of biomass into a spectrum of marketable products (food, feed, materials, chemicals) and energy (fuels, power, heat)" (IEA, 2014).

The feedstock for biorefineries can be classified into three main groups (Moncada *et al*., 2014): the first generation uses crops; the second generation uses residues and non-edible crops while algae are considered as the third-generation feedstock. Furthermore, algae and especially wastewater-grown microalgae appears as the appropriate feedstock for feasible integrated double purpose systems for production of biodiesel and treatment of the wastewater within a biorefinery (Olguín, 2012).

However, it is clear currently that numerous technological and economic barriers must be overcome to increase the economic feasibility of microalgae-based biorefineries. The key issues to tackle have been identified by different research groups. For example, improvements in the harvesting system, algae farm construction, algae yield, and integrative end-life of the co-products, have been highlighted as key issues (Flesch *et al*., 2013). Moreover, various reports have stressed the need to enlarge the number of value-added products from both, the microalgae and the oil-extracted microalgae biomass in order to increase the economic feasibility of the microalgae-based biodiesel (Brownbridge *et al*., 2014). These authors have also stressed that the production costs depend mainly on factors in the following order: algae oil content > algae annual productivity > plant production capacity > carbon price increase rate > photobioreactor unit capital expenditure.

Microalgae-based biorefinery design at INECOL

In this section, a brief description of the design and performance of a pilot-scale microalgae-based biorefinery integrating phytotechnologies and other wastewater treatment technologies to produce biofuels and high added value products within the circular economy concept is discussed. This biorefinery has been designed and built in the grounds of the Institute of Ecology (INECOL), located in the city of Xalapa, Veracruz, Mexico.

To increase the environmental feasibility, the critical resources such as water and nutrients for microalgae cultivation must be integrated into a 3-R policy (Reuse, Recover, and Recycle). Bearing this objective in mind, the use of phytofiltration to treat the water from an urban river polluted with domestic wastewater has been demonstrated as a feasible option (Robles-Pliego *et al.,* 2015) to recycle water and to recover nutrients to produce plant biomass. Furthermore, a 13,000 L phytofiltration lagoon using *Pistia stratiotes* for the treatment of a polluted river has been evaluated throughout various seasons (Fig. 1) and it has been demonstrated that with a short hydraulic retention time (7-14 days), the quality of the water improved significantly (Olguín *et al.,* 2017).

Figure 1. A phytofiltration lagoon (13,000 L) with *P. stratiotes* is the first module at INECOL's biorefinery.

The biomass of *P. stratiotes* needs to be harvested frequently and it is digested anaerobically for biogas production. A two-phase digestor has been used and it was demonstrated that a good productivity of volatile fatty acids (VFA) was obtained within the range of 1867-2207 mg_{COD}/L during the first stage (Hernández-García *et al*., 2015).

Biohydrogen has been produced at a good yield using *P. stratiotes*. The biomass was first hydrolyzed with ruminal fluid, then it was subjected to a nitrogen-stripping process. Finally, photofermentation with *Rhodospeudomonas palustris* 42OL yielded a Biochemical Hydrogen Potential of 1224 mL/L (Cornelli *et al*., 2017).

The treated water in the phytofiltration lagoon has been used for cultivation of various species of microalgae. A strategy of inducing lipid accumulation by nitrogen deficiency resulted in a very high lipid accumulation of 27.4 % d.w. by *Neochloris oleoabundans*, cultivated using pig waste digestate (Olguín *et al*., 2015a) and 38.5 % d.w. when it was cultivated using stillage's digestate (Olguín *et al*., 2015b).

On the other hand, a strain of *Chlorococcum* sp. was isolated from a wastewater treatment plant and cultivated with pig waste digestates under uncontrolled conditions. In this case, the nitrogen deficiency resulted in accumulation of total carbohydrates in a high percentage (45% d.w.) after 24 days, showing the high potential of this strain for production of bioethanol (Montero *et al.*, 2018).

To increase the economic viability of the biorefinery at INECOL, production of phycocyanin (PC) from *Arthrospira maxima* in a two-phase process, using 2000 L raceways (Fig. 2), has been shown to release PC of high purity (3.7) in the category of reactive grade (García-López *et al*., 2020).

Figure 2. Raceways with *A. maxima*.

Conclusions

The integration of a microalgae-based biorefinery with a phytofiltration lagoon as a first module to treat polluted water from a river and to provide treated water for cultivation of microalgae using agricultural wastes (stillage and pig waste) digestates as source of nutrients has been shown to be a feasibly and novel design. Furthermore, the economic feasibility increased while producing also phycocyanin (reactive grade) from *A. maxima*.

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