Modern biorefineries for obtaining high demanded products for sustainable agriculture

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Climate change, the depletion of non-renewable resources, population growth, and social inequality are some of the great challenges today (Sangwan & Bhatia, 2020). According to the International Energy Agency (IEA), the energy demand is expected to grow by 50% in 2030. Then. the use of non-renewable resources (e.g., minerals and fossil fuels) and renewable resources (e.g., biomass, wind, solar) will triple (NICR, 2013). From this, the impact of humans on the environment increased social inequality, reducing access to basic needs for well-being (i.e., food, water, education, energy) because of the excessive use of natural resources (Hawks et al., 2000). Consequently, the demand for food has constantly increased, which implies improvement in agricultural and livestock production systems. The agricultural sector depends on using fertilizers based on nitrogen, phosphorus, and potassium. On the other hand, the livestock sector seeks to increase livestock productivity per hectare. In this sense, the search for alternatives for the production of biofertilizers and livestock vaccines has been studied from biomass. The concept of biorefinery through residual biomass provides a sustainable solution for producing biofertilizers seeking to minimize the environmental impact. This work aims to evaluate five routes to obtain sustainable agricultural products with high demand in the market.

The routes to obtain sustainable agricultural products in high demand in the market were evaluated based on the conceptual design of processes by calculating technical, economic, and environmental indicators. The production of microalgae biomass as a biofertilizer (i.e., *Chlorella minutissima*), growth stimulator, and promoter from bacteria of the *Azotobacter genus*, biochar, *Pasteurella*-based vaccines, and recombinant vaccine were the agricultural products analyzed. The conceptual design of processes was carried out using the methodology proposed by Cardona et al., (2016). The simulation of agricultural products was carried out using Aspen Plus v.9.0 software. The operating conditions and production performances were taken from open literature. The technical indicators calculated were production performance, carbon conversion efficiency, technical energy consumption, and electrical energy consumption. The assessed economic indicators were operating costs and capital costs. The reagents, labor, depreciation, maintenance, and administrative costs were calculated as operating costs. Capital costs were calculated using Aspen Economic Analyzer v.9.0 software. The assessed environmental were the carbon footprint and the water footprint. The SimaPro v8.3.0 software, the Ecoinvent v1.3 database, and the ReciPe Mindpoint Hierarchical method were used. Finally, three biorefinery scenarios were proposed and evaluated to demonstrate the sustainability of biomass valorization routes to obtain agricultural products. Biorefineries were proposed to recover waste from fruit and vegetable collection centers in Colombia. The composition model of fruit and vegetable collection centers reported by Ortiz-Sanchez et al., (2023) was considered.

The results of the technical indicators of the five routes to obtain agricultural products with high market demand were lower than the production of biochar and microalgal biomass in the case of the production of vaccines and growth stimulators from bacteria. This behavior was attributed to the technological development level of the assessed routes. In the case of vaccines and growth stimulators, the microorganisms used have low substrate conversion yields compared to the production of microalgal biomass. On the other hand, biochar production has better conversion yields using incomplete combustion technology (i.e., slow pyrolysis). The energy consumption of the routes for obtaining vaccines was higher than the processes for obtaining biofertilizers and growth stimulators. This same trend was observed in economic indicators. The biochar production route had the lowest operating and capital costs compared to those processes addressed to produce vaccines, biofertilizers, and growth stimulants. However, biochar production presented higher carbon footprint emissions in environmental terms. The water footprint for producing vaccines, biofertilizers, and growth stimulators was up to 2.5 times greater. Finally, the biorefinery scenarios based on organic waste from the collection center demonstrated the sustainability of the routes for obtaining agricultural products. In economic and social terms, the biorefineries involving biochar production presented the greatest feasibility. However, biochar production had the lowest environmental performance. Instead, biorefineries involving the production of vaccines and microalgal biomass presented the lowest environmental impact.

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