Environmental hotspots analysis of the second-generation polylactic acid (PLA) based on wheat straw.

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1. Introduction

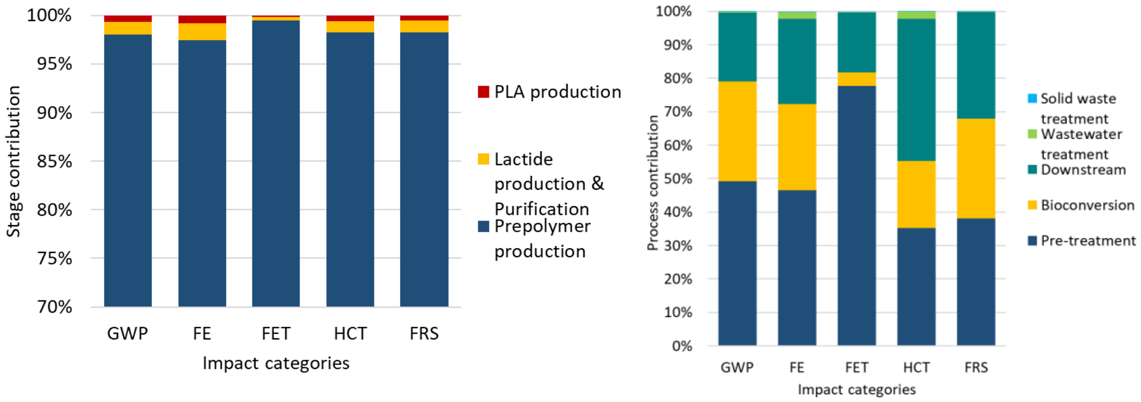
Switching from petrochemicals to bio-based products is an urgent prerequisite to reduce the consequences of the climate crisis on the planet. Plastic pollution is one of the major threats, and its production is expected to continue to grow to meet the increasing demand for food worldwide. Bioplastics appear as a renewable source with similar characteristics to their fossil counterparts but avoiding their depletion. Of these, polylactic acid (PLA) is one of the most widely used biopolymers, due to its mechanical properties and renewable origin to produce compostable bio-based plastic for food packaging. This work aims to estimate the potential environmental feasibility of a second generation (2G) PLA production from wheat straw. Thus, it is intended to determine those factors that may restrict the environmental feasibility of the biorefinery process as additional criteria in the development of the conceptual design. In addition, the identification of environmental hotspots will allow reducing the environmental burdens of these stages by proposing improvement plans to achieve a sustainable biorefinery platform.

2. Materials and methods

The attributional Life Cycle Assessment (LCA) methodology, through a cradle-to-gate approach, was performed following the ISO 14040-14044 guidelines (ISO, 2006a; 2006b). The wheat cultivation stage is carried out in Apulia, Italy, and an economic allocation was used to distribute the environmental burdens between wheat grain and straw. Regarding the process modelling, an annual production capacity of 40,000 tons of PLA was considered for the platform. The biorefinery plant consists of different stages such as pre-treatment of straw, lactic acid production and PLA production. In the pre-treatment section, the straw is milled and sent to a thermal hydrolysis for hemicellulose fractionation. Thermal hydrolysis is performed with high-pressure (19 bar) at 210°C and considering a biomass-to-stream ratio of 1:2 (Al-Zuhair et al., 2013). The solid and liquid fractions are separated by filtration. The solid stream proceeds to enzymatic hydrolysis, which is carried out at 50°C using 20 $mg \cdot g^{-1}$ of cellulose of Cellic® CTec3 cellulase (Novozymes, Bagsvard, Denmark) at 20% wt of total solids loading (Lopes *et al*., 2019). The sugar solution obtained is sent to the lactic acid (LA) production stage. The LA and PLA production processes were performed following the work of Ioannidou *et al.* (2022). Impact categories such as Global Warming (GW - kg CO2 eq), Freshwater Eutrophication (FE - kg P eq), Freshwater Eco-toxicity (FET - kg 1,4-DCB), Human carcinogenic toxicity (HCT- kg 1,4-DCB) and Fossil Resource Scarcity (FRS – kg oil eq) were evaluated. For this purpose, the ReCiPe v1.07 (H) impact method (Huijbregts *et al*., 2017) and Simapro® 9.4 software (Pré Sustainability, 2021) were used. The environmental burdens evaluated were expressed in terms of 1 kg of PLA produced (i.e., functional unit).

3. Results and discussion

The environmental profile of the 2G PLA was 1.42 kg CO_2eq in the GW category, 0.90 g P eq in FE, 183.39 g 1,4-DCB in FET, 68.55 g 1,4-DCB in HCT, and 0.41 kg oil eq. Results show that the lactic acid production (i.e., prepolymer production) was the main contributor to the environmental burdens of the biorefinery (see Fig. 1a). This is due to the pre-treatment of wheat straw, the fermentation process, or the downstream process (the recovery of pure L-lactic acid), depending on the impact category evaluated (see Fig. 1b). Focusing on the GW profile, 2G PLA achieves better performance than first-generation PL. For example, from the Ecoinvent® 3.8v database (Wernet *et al*., 2016), PLA derived from maize/corn-grain implies GHG emissions with a range between 2.83 and 3.05 kg CO_2eq per kg of product.



a) Stage contribution in the PLA production   b) Process contribution in the LA production

Figure 1. Hotspot analysis in the 2G PLA biorefinery

4. Conclusions

Process modelling of prospective biorefinery systems allow estimating the environmental feasibility at an early stage of design and development. In this way, the promotion of the new valorisation pathway could be reached addressing those processes that represent the environmental hotspots in the promotion of a bioeconomy model. In the production of the second-generation PLA, the LA production stage represents the main contributor of the biorefinery platform and the pre-treatment of wheat straw as source of fermentable sugars and the downstream process were the main responsible of these outcomes.

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