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EFFECTS OF HYDROTHERMAL AND ORGANOLSOLV PRETREATMENTS ON THE CARBON FOOTPRINT OF XYLOOLIGOSACCHARIDES PRODUCTION FROM SUGARCANE

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ABSTRACT

The inclusion of high-value bioproducts in a biorefinery's portfolio is a key strategy for the profitability and sustainability of lignocellulosic crops. One interesting option is to produce xylooligosaccharides (XOS) from the underutilised hemicellulose fraction of biomass. In this work, the greenhouse gas emissions of two different process of XOS production from sugarcane bagasse was estimated using the Life Cycle Assessment approach, evaluating the impact of the pretreatments hydrothermal and organolsolv on the environmental performance. The XOS production was attached to a sugar mill with self-sufficient energy supply. LCA scope was set as cradle-to-gate using 1 kg of XOS as functional unit. XOS CO_{2eq} emissions was estimated as 6.31 $kgCO_{2eq}/kg$ for the case study considering the hydrothermal pretreatment and 7.00 $kgCO_{2eq}/kg$ for the organolsov pretreatment case. Hydrolysis and pretreatment stages were responsible for most part of the environmental footprint due to the chemicals and utilities that were used with energy responsible for a significant proportion of the emissions in both cases. Energy-related variables have the highest impact on the environmental performance of the scenario using hydrothermal pretreatment. For organosolv pretreatment, the most significant variable was ethanol recovery. Therefore, hydrothermal pretreatment is a better option for XOS production from an environmental perspective.

Keywords: Xylooligosaccharides. Sugarcane biorefinery. Life Cycle Assessment.

1 INTRODUCTION

There is a consensus that the climate crisis requires an immediate expansion of the bioeconomy's share in the global production system [1]. In this context, the concept of biorefineries is emerging as an attractive alternative as it can produce energy (in the form of bioelectricity and biofuels) as well as high-value and low-volume bioproducts from biomass as a substitute for petroleum.

Sugarcane plays an important role in the global context of sustainability and socio-economic development as a biorefinery feedstock [2]. These plants generated large quantities of sugarcane bagasse. The implementation of industrial 2G bioethanol plants using sugarcane bagasse, despite its potential, is still not widespread. One challenge is the use of the hemicellulose content (C5 fraction) of this lignocellulosic material, which is still underutilized in industrial processes. The hemicellulose fraction of lignocellulosic materials is mainly composed of xylan, which has great potential as a raw material for the production of xylooligosaccharides (XOS), a value-added molecule. XOS are oligomers formed by 2-7 xylose units, with interesting properties such as anti-inflammatory, antioxidant, anti-tumor and antimicrobial [3]. XOS are attracting increasing interest, reflected in their demand that is growing rapidly in recent years (about 15%/year) because of the growing concern for health and quality of life, increasing demand for healthy products [4].

Milessi et al. [3] studied the XOS production chain from sugarcane bagasse, starting with different pretreatments for hemicellulose extraction, followed by enzymatic hydrolysis of solubilized xylan to XOS, purification and evaluation of the nutritional properties of the final product. A high process conversion (90%) was achieved for XOS processes using hydrothermal and organosolv pretreatments, which also obtained XOS profile with high prebiotic and antimicrobial activities. Since similar XOS yields and productivities were obtained in these two cases of pretreatment, the identification of the most appropriate route for the production of XOS in a sugarcane biorefinery can be done based on the comparison of environmental performance, an important parameter nowadays. The ability to assess the environmental performance of early-stage technologies at industrial scale is critical to support more accurate decision making. In this context, this work analyzed the greenhouse gas emissions (GHG) of two different process of XOS production from sugarcane bagasse, evaluating the impact of the pretreatment step on the overall environmental performance using the Life Cycle Assessment (LCA) approach.

2 MATERIAL & METHODS

The XOS production process was integrated into a sugarcane biorefinery. Details of the process and parameters adopted in the 1G process are described in Longati et al. [5]. When the sugarcane arrives at the industrial unit, it goes through the stages of cleaning, preparation and juice extraction. The extracted juice is sent for the production of 1G ethanol, through the stages of treatment, concentration, fermentation, and distillation. The bagasse is sent to the cogeneration system to produce process steam and electrical energy, where all the thermal needs of the plant are met by burning this bagasse. A fraction of the bagasse is sent to the XOS production, where it undergoes drying, milling, classification, pretreatment, enzymatic hydrolysis [3], distillation, gel chromatography, and freeze-drying [6]. Two scenarios considering two pretreatments were evaluated: hydrothermal and organosolv. Hydrothermal pretreatment was carried out in a solid/liquid ratio of 1:10, 140 psi at 185 °C for 10 min and 300 rpm. Organosolv pretreatment was performed using 50 % of ethanol for 60 min at 170 ◦C with a solid/liquid ratio of 1:10 and 300 rpm. It was considered that 95% of the ethanol is recovered and recycled in the process. Details can be found in literature [3,6].

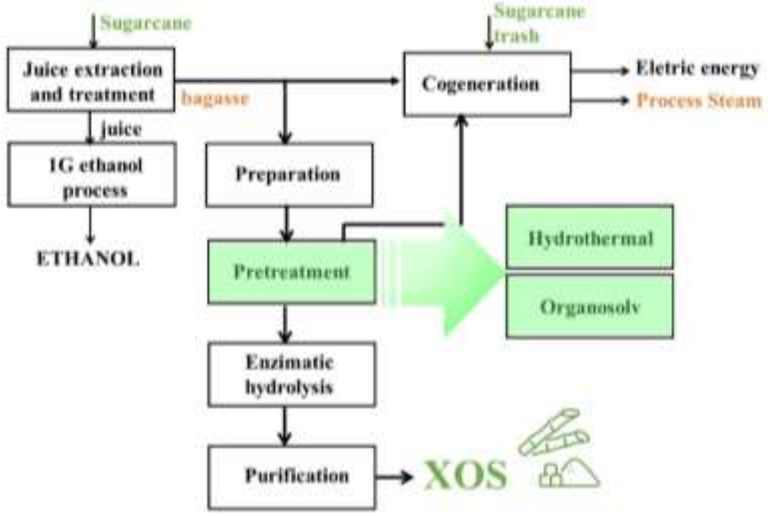

Figure 1 Simplified process flowsheet of the XOS production integrated in the sugarcane biorefinery for the two pretreatments: hydrothermal and organosolv.

EMSO (Environment for Modelling, Simulation and Optimization), a free equation-oriented simulator, was used to model and simulate the process. By inserting equations and data from SimaPro together with the mathematical models of the process units in EMSO, the CO_2 emissions of the process using the LCA methodology were obtained [7].

The climate change impacts were chosen as the environmental metric, which was carried out through using the life cycle assessment (LCA) approach. This metric is indicated in Renovabio, a Brazilian federal biofuels policy [8]. The cradle-to-gate GHG emissions of the production of XOS from bagasse as raw material was calculated using LCA methodology. The functional unit was defined as 1 kg of XOS. Impacts are allocated based on mass. The 2007 Intergovernmental Panel on Climate Change (IPCC) Global Warming Potentials (GWPs) method was employed to convert GHG emissions to CO_2-equivalent (CO_{2eq}) emissions. SimaPro 8.4 software and Ecoinvent database 3.0 [9] were used to obtain the datasets of the main inputs used in the evaluated product system. The life cycle impact assessment was carried out using the CML-IA baseline V3.04 (World 2000) method. LCA inventory of inputs, outputs and emissions was performed based on process simulation under a cradle-to-gate scope.

3 RESULTS & DISCUSSION

The simulation was performed considering the implementation of the XOS production process integrated to an existing plant of 1G ethanol. Using a cradle-to-gate approach, the emissions from XOS production were estimated to be 6.31 kg CO_{2eq}/kg XOS and 7.00 kg CO_{2eq}/kg XOS for the hydrothermal and organosolv pretreatment scenarios, respectively (Figure 2a). Therefore, hydrothermal pretreatment is a better option for XOS production from an environmental perspective, Hydrolysis and pretreatment steps were the main contributors to XOS production emissions in both scenarios, as shown in Figure 2a. The difference observed in the emissions are related to the chemicals (types and amount) and utilities used in each case, especially in the pretreatment step. While the hydrothermal pretreatment only used utilities to keep high pressure and temperature, the organolsov pretreatment used utilities and chemicals (ethanol) to improve the lignocellulosic materials accessibility. These two steps were also the stages with the highest contribution in the utilities' consumption (hot utility for pretreatment and cold utility for hydrolysis). Energy was responsible for a significant portion of the CO_{2eq} emissions as shown in Figure 2b.

In both cases assessed, the values of emissions were lower than those reported in literature by van Heerden et al.[10], which were estimated to be between 9.21 kg CO_{2eq}/kg XOS and 11.39 kg CO_{2eq}/kg XOS for a plant located in the Africa. Besides the geographical difference (the present study considers the Brazilian context), the process performance parameters vary considerably due to process uncertainties, differences between biomasses and differences in the process mainly due to the technologies considered in both works.

A sensitivity analysis (Figures 2c and 2d) was conducted to identify the process variables that most impact on the CO_{2eq} emissions of the processes. The sensitivity analysis indicated that energy related variables impact more significantly on the overall environmental performance in the process using hydrothermal pretreatment. On the other side, in the process using organosolv pretreatment the percentual of ethanol recuperation was the variable which most impacts the emissions.

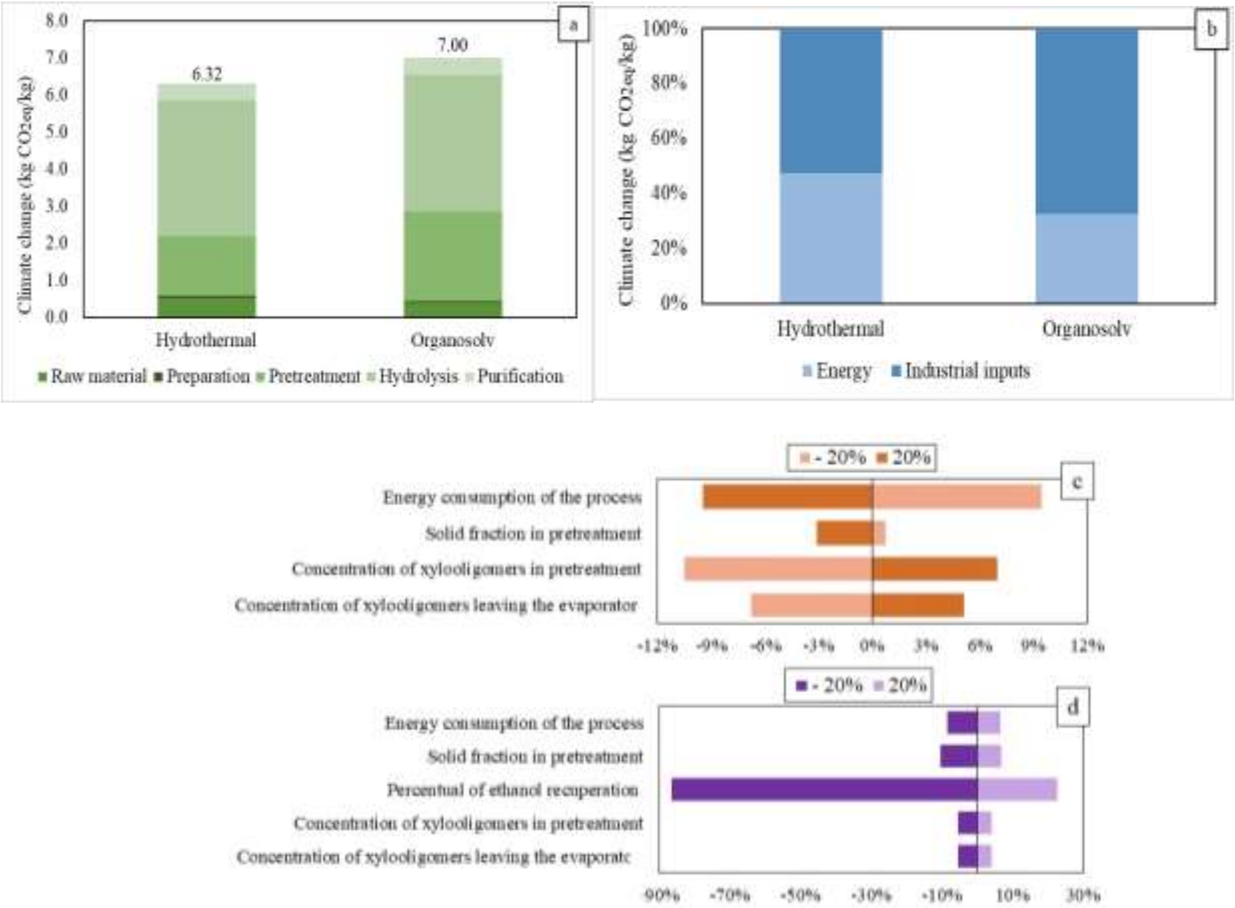

Figure 2 a) CO_{2eq} emissions per stage of the XOS production process for each scenario, (b) energy contribution for CO_{2eq} emissions for each scenario of XOS production, (c) sensitivity analysis of hydrothermal pretreatment scenario, and (d) sensitivity analysis of organolsov pretreatment scenario.

4 CONCLUSION

The CO_{2eq} emissions of XOS production were estimated as 6.31 $kgCO_{2eq}$/kg for the case study considering the hydrothermal pretreatment and 7.00 $kgCO_{2eq}$/kg for the case study considering the organolsov pretreatment. Hydrolysis and pretreatment stages were responsible for most part of the environmental footprint due to the chemicals and utilities that were used, with energy being responsible for a significant proportion of the emissions in both cases. Sensitivity analyses showed that energy-related variables have the highest impact on the environmental performance of the scenario using hydrothermal pretreatment. For the organosolv pretreatment case, the variable with the most significant impact was ethanol recovery

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