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Comparative environmental Life Cycle Assessment of integral revalorization of vine shoots from a biorefinery perspective

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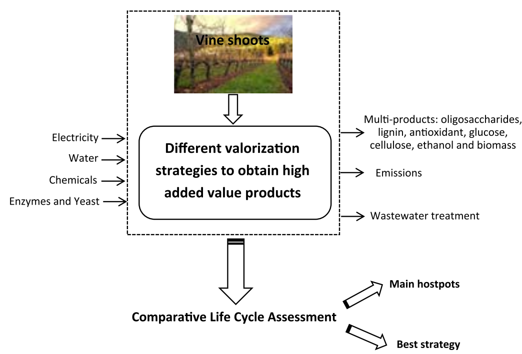
GRAPHICAL ABSTRACT



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ABSTRACT

The use of vine shoots as feedstock in biorefining activities to obtain bioproducts under efficient and optimized conditions could be crucial to make future high added value compounds and processes more sustainable. In this study, five different potential valorization scenarios from vine shoots differing on diverse extraction and delignification steps were assessed from an environmental perspective using the Life Cycle Assessment methodology to identify the most sustainable biorefining route. The main findings from this study reported that an increment on the number of valorization steps involved higher energy and chemical requirements deriving on worse environmental profiles. Scenarios incorporating fermentation of the glucose liquors or organosolv delignification performed the worst profiles. Autohydrolysis, concentration and freeze drying and enzymatic hydrolysis were the main responsible stages of the environmental burdens. Further research should be focused on optimizing chemicals and electricity requirements to develop greener systems.

1. Introduction

Nowadays, the society is facing important challenges mainly related with the substitution of petroleum based materials by renewable ones. In this way not only the high dependence on finite-fossil fuels consumption could be reduced but also the unstable production of petroleum based materials and the derived environmental impacts, as the greenhouse gases (GHGs) emission (Spiridon et al., 2016). Therefore, numerous initiatives are being developed to promote the production and use of bioresources-based alternatives instead of petrochemical ones (Cherubini and Ulgiati, 2010; Gullón et al., 2016). In this sense, biomass could be considered as a sustainable alternative raw material to produce

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biomaterials and bioproducts because of its abundant availability, diversity and recyclability (Spiridon et al., 2016).

It has been demonstrated that the use of bioresources instead of petrochemicals for the production of biofuels (González-García et al., 2010) and biofoams (González-García et al., 2016a) causes lower GHGs emission. Nevertheless, there are concerns regarding their benefits in terms of other environmental impact categories, as the use of the land could change due to the cultivation activities related with the biomaterial-feedstock production, mainly in areas with significant social value (Searchinger et al., 2008). Therefore, a sustainability study should be required so as to identify the situations in which the use of bioresources could be environmentally feasible over petrochemical alternatives.

The use of lignocellulosic biomass residues and wastes from agro-food-industrial, agricultural and forestry activities could be considered as a potential alternative for the manufacture of added value products instead of using dedicated crops. The employment of biomass residues could avoid the derived negative impact from the cultivation phase of crops and it could give a solution to residual streams which must be managed in a sustainable manner without entering in confrontation with food and feed availability. In fact, all these residues, which are generated in billions of tons a year, represent a renewable source available to be used for further applications (Forster-Carneiro et al., 2013). The use of residues is probably the lowest cost form of available biomass, but the range of costs can considerably vary depending on the residue as they involved items such as harvest, salaries and transportation (Gallagher et al., 2003). Furthermore, the removal of biomass residues from croplands could also derive on negative consequences closely related to the loss of soil organic carbon content as well as to the reduction of crops yields (Wilhelm et al., 2007).

The composition of the lignocellulosic residues changes depending on the feedstock species and origin. However, in general lines, they are mainly constituted by cellulose, hemicellulose and lignin as well as by organic extractives and inorganic minerals (Dávila et al., 2016; Thakur and Thakur, 2015) and they can be considered as attractive biorenewable polymers (from now, biopolymers) which could replace the traditional synthetic ones (Thakur and Thakur, 2015). For that reason, biorefineries based on these lignocellulosic materials are drawing special attention (Dávila et al., 2016; González-García et al., 2017) for different applications from biomedical to automotive (Thakur and Thakur, 2015). Examples of lignocellulosic biorefineries viable at industrial scale are Borregaard Company and Envergent Technologies. Borregaard Company, is a Norwegian company which in the 1930s started the production of bioethanol by the fermentation of the sugar obtained from spruce wood. It is organized into five production sections, such as: cellulose and bioethanol, lignin-based binding and dispersing agent, fine chemicals for the pharmaceutical sector, vanillin for the food sector and microfibrillated cellulose. Envergent Technologies is a corporate between Honeywell's UOP and Ensyn Corporation, established in 2008 in Des Plaines, Illinois. Ensyn is the proprietary of the Rapid Thermal Processing (RTP™) technology. Nowadays, there are seven commercial RTP plants in the United States and Canada. These biorefining industries are converting residual biomass (mainly wood and agricultural wastes) into more than 30 added value products encompassing green fuels, chemicals, food flavorings, adhesive resins for construction, etc. (Sillanpää and Ncibi, 2017).

Cellulose is the most abundantly available bioresource and its demand is continuously increasing due to its environmental friendly, biodegradable and biocompatible nature (Watkins et al., 2015). Nowadays, cellulose finds several applications as building materials, paper, textiles, as well as clothing (Brinchi et al., 2013). Another rising application of cellulose is as reinforcement in composite materials (Watkins et al., 2015). In the last two decades the employment of cellulose to obtain energy has been extensively exploited, as great efforts have been performed to improve the conversion of cellulose to ethanol, methane and in the most recent years to hydrogen (Menon and Rao, 2012).

After cellulose, the second most abundant renewable polysaccharide on the earth is the hemicellulose (Gullón et al., 2016). Thus, it could offer a sustainable alternative for materials, chemicals and fuels production (Kemppainen et al., 2014). However, the use of this biopolymer is not so extended than other natural polysaccharides (e.g. chitosan, cellulose and starch) mainly because its heterogeneous composition makes its application difficult at industrial scale (Gullón et al., 2016). Nevertheless, in recent years, numerous research activities have been developed to integrate this attractive, renewable and cheap polysaccharide in the industry under a biorefinery approach specifically to produce prebiotic functional food ingredients (Nabais et al., 2010; Dávila et al., 2016; González-García et al., 2016b). The employment of hemicelluloses for the production of films (Hartman et al., 2006) and hydrogels (Gullón et al., 2016) as well as their use as food additives (González-García et al., 2017) are attracting special interest.

After cellulose, lignin is the next most abundant natural polymer in the nature. Lignin possesses chemical and physical properties that make it an excellent candidate to substitute any product obtained from petrochemical sources; moreover, it is a natural and biorenewable feedstock, obtainable at an affordable cost. Lignin can be used as emulsifiers, dyes, synthetic floorings, sequestering, binding, thermosets, dispersal agents, paints and fuels to treatments for roadways (Watkins et al., 2015).

Within the different activities carried out in the agricultural sector, viticulture requires special interest since it is one of the most spread crops in the world (Nabais et al., 2010) and specifically in countries such as Spain (Dávila et al., 2016). The wine sector involves the production of a large amount of residues such as pomace, grape stalks and vine shoots (Benetto et al., 2015; Dávila et al., 2017a), all of them with multiple applications. Pomace or grape march is primarily used for animal feed and fertilizer (Gómez et al., 2010; Vaccarino et al., 1992) although studies can be found regarding its use for compost (Fernández et al., 2008) and even for the production of pellets (Benetto et al., 2015). Grape stalks can be used as metal sorbent (Miralles et al., 2008; Valderrama et al., 2010). Regarding vine shoots, they are considered novel biomass agricultural residues (Sánchez et al., 2002; Max et al., 2010; Sánchez-Gómez et al., 2017) and their management under a biorefinery perspective is attracting notice (Nabais et al., 2010; Dávila et al., 2016). These wastes have been traditionally poorly exploited. Vine shoots are usually burned in the field to prevent proliferation of phytopathogens (Sánchez et al., 2002) or even left in the field as organic fertilizer (Jiménez Gómez et al., 1993; Peralbo-Molina and Luque de Castro, 2013) since their economic value is very small (Peralbo-Molina and Luque de Castro, 2013). Thus, one of the main challenges for the wine sector is to identify strategies to increase the added value of the vast amount of vine shoots produced. Numerous studies are available in the literature focused on the valorization of vine shoots to obtain high added value products, such as activated carbon (Nabais et al., 2010), polyphenols (Gullón et al., 2017), ethanol (Jiménez et al., 2007), lactic acid and/or xylitol (Rivas et al., 2007). However, to the best of our knowledge, the environmental sustainability of these production schemes has not been assessed yet. Only one environmental study has been published with special focus on the environmental footprints of different production schemes of soluble saccharides of polymeric and oligomeric nature from woody residual streams (González-García et al., 2016b) using the Life Cycle Assessment (LCA) methodology. This methodology is used to understand and address the environmental impacts throughout a production system (ISO 14040, 2006).

In this study, the assessment of the environmental impacts derived from the valorization of vine shoots from the wine sector into high added value products has been performed considering five different and alternative valorizing schemes. The evaluation of the schemes would permit the identification of environmental *hotspots* responsible of the largest environmental impacts. These scenarios differ on the extraction, delignification and/or hydrolysis routes and are based on