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Bioresource utilisation by sustainable technologies in new value-added biorefinery concepts – two case studies from food and forest industry☆

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ABSTRACT

This paper presents a trans-disciplinary assessment of new and innovative biorefinery concepts producing high-value chemical compounds from residues from agriculture, food and forest industries. There is a significant potential of biomass residues in Sweden suitable for the extraction of various compounds, including upgrading by biocatalytic processes, in addition to current energy generation. Two examples presented are quercetin extracted from onion waste by pressurised hot water in conjunction with enzymatic hydrolysis, and betulin from birch bark extracted by liquid CO_2 containing ethanol. Inherent in these two extraction processes and production routes is the ability to show good environmental performance from a life cycle perspective. Extraction of high-value compounds also provides possibilities for innovation in the current agricultural, food and forest industry potentially leading to socio-economical benefits.

1. Introduction

Concern about climate change and scarcity of resources has brought environmental and sustainability issues into focus both on the political agenda and in the consciousness of the general public. One of the most important questions is the dependence of our economy on fossil oil. This fossil feedstock is not only used for energy generation and transport, but also for the production of the major part of all materials and chemicals that we now rely on. One option to provide a more sustainable base for the economy would be the transition to a bio-economy in which the importance of biotechnology and biomass-based production to generate economic output is significantly greater than today (OECD, 2009). To make this transition not only possible but also sustainable, new technologies and efficient utilisation of biomass resources with good environmental performance in biorefineries will be necessary (Kamm and Kamm, 2007; Cherubini, 2010; de Jong et al., 2012). A biorefinery has parallels to a petroleum refinery in the sense that several products such as chemicals, biofuels and bio-based energy carriers are produced from one single raw material and that the production steps are integrated. In recent years much political focus has been on the development of biofuels, but also the market for bio-based chemicals is projected to increase significantly (Dornburg et al., 2008). To optimally utilise biomass resources, biorefineries that first extract valuable compounds using sustainable technologies and thereafter convert the biomass into other bio-based chemicals, biofuels and energy carriers should be implemented (Ragauskas et al., 2006; Clark et al., 2006). Technologies of importance will be those based on white biotechnology and on the principles of green chemistry (Hatti-Kaul et al., 2007).

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Cultivating crops, for example with the purpose of production of biofuels gives a considerable contribution to environmental impact (Börjesson and Tufvesson, 2011). Utilising biomass residues as feedstock in biorefineries, is a promising option to further increase the sustainability of biorefineries, because this feedstock normally does not cause increased land-use competition with food production and potential, negative indirect land-use changes (see e.g. Searchinger et al., 2008; Berndes et al., 2011).

From a Swedish perspective, the utilisation of residues as raw material could increase profits both in the agriculture and in the forest industry. These are important industrial branches, which for several years have experienced decreasing real prices of their products in combination with increased prices of raw materials (Statistics Sweden, 2010a, 2010b). This has increased their motivation to find new value-added processes and products, especially targeting their low value by-products and waste streams, to increase their product portfolio. In addition to being inspired by university research, also political incentives influence the industry and the innovations realised (Fischer et al., 2003).

In this article an inventory of the key wastes and by-products from agriculture, food and forest industry sectors, feasible to use as input materials in biorefinery concepts in Sweden, are presented. Today, these raw materials are mainly used in the production of heat and power, animal feed or biogas by anaerobic digestion. However, it is known that these materials may also contain high-value compounds such as antioxidants, pigments and other molecules of interest. Antioxidants are compounds that prevent oxidation, for example, oxidative damage in biological systems caused by free radicals, and oxidation processes occurring in food, cosmetic and bulk chemical products (Halliwell, 1990). Some of the antioxidants are also valuable pigments that could pertinently replace chemically synthesized ones.

Two of the residues identified, onion waste from the food industry and birch bark from the forest industry, have been more thoroughly investigated with the aim to increase their current value as energy feedstock or animal feed to an additional value as feedstock for both energy and chemical compounds. In the first case, glycosylated antioxidants have been extracted from onion waste using pressurised hot water as a solvent. After the extraction, the quercetin glucosides are hydrolysed to the most active antioxidant form, quercetin, using thermostable β-glucosidase in a hot water process. Quercetin is known as a powerful antioxidant, for instance, *in vitro* studies have shown that quercetin may have a positive effect against cancer (Murakami et al., 2008), cardiovascular- (Cook and Samman, 1996) and neurodegenerative diseases (Ono et al., 2006).

In the second case, a mixture of antioxidants and betulin, a triterpenoid compound, have been extracted from birch bark using liquid carbon dioxide mixed with ethanol. Betulin has anti-inflammatory as well as anti-bacterial properties (Zuco et al., 2002; Yogeeswari and Sriram, 2005; Paduch et al., 2007), which is already recognised and betulin is used as additive in many cosmetic products. Furthermore, both *in vitro* and *in vivo* studies have proved that betulinic acid is a potent agent against a certain line of cancer and HIV (Fujioka et al., 1994; Pisha et al., 1995; Cichewicz and Kouzi, 2004).

After processing, the remaining waste can be utilised for energy purposes as today, and in some cases be recycled as biofertilisers for cultivated land. Thus, the suggested extraction processes should be seen as complementary technologies, which could be integrated in the existing industry infrastructure.

2. Design of studied biorefinery concepts

This work has a trans-disciplinary approach and the methods applied cover analytical chemistry, biotechnology and environmental systems studies. The biorefinery concept according to this paper means value addition to by-products by technologies based on extraction and enzymatic conversion with environmentally compatible solvents and processes. An overview of the biorefinery concepts considered is shown in Fig. 1a and b.

This paper is divided into three following sections. Section 3 describes the work to find suitable raw materials that can be used as feedstock in future biorefinery applications. To enhance the value of the identified waste and by-products, novel technologies have been developed and existing technologies have been adapted to be more suitable for these specific types of materials. These technologies and how they have been applied to the two selected raw materials, onion waste and birch bark, are described in Section 4. Sustainability is one of the main drivers for the development of

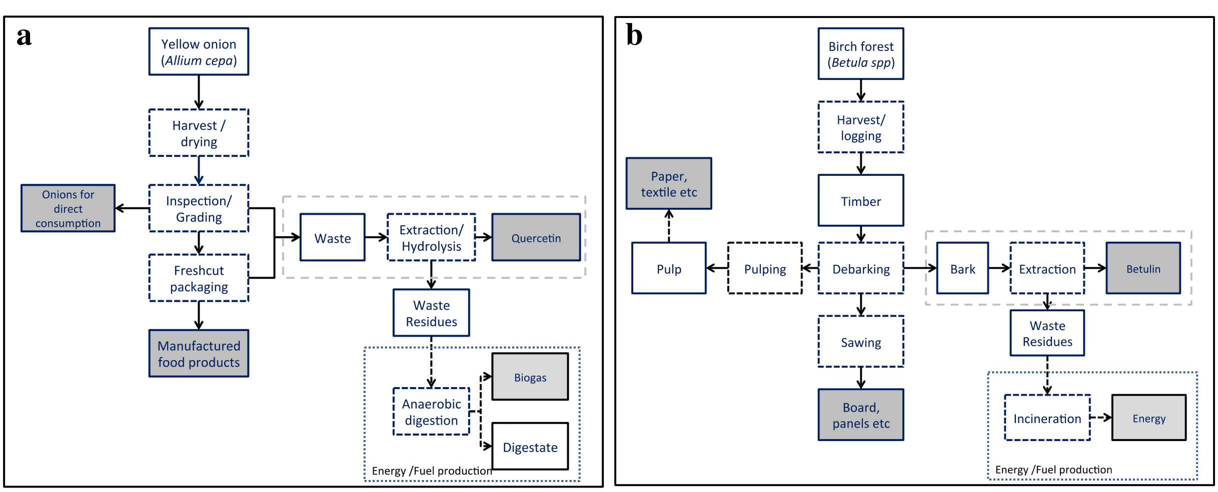

Fig. 1. a. Schematic flowchart of an agricultural biorefinery concept using yellow onion as raw material. Products are shown in grey. Black dashed boxes show methodologies, and the value added processing step (including its raw material and product is boxed (grey dashed line). Waste residues after the extraction/hydrolysis step can be utilized in energy or fuel production, here exemplified by anaerobic digestion (dotted box). b. Schematic flowchart of a forest biorefinery concept using birch as raw material. Products are shown in grey. Black dashed boxes indicate methodologies. The value added processing step (including its raw material and product is boxed (grey dashed line). Waste residues after the extraction/hydrolysis step can be utilized in energy or fuel production, here exemplified by incineration (dotted box) currently in use for energy production. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)