ARTICLE IN PRESS

Bioresource Technology xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Bioresource Technology

journal homepage: www.elsevier.com/locate/biortech

Review

Electric field-based technologies for valorization of bioresources

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ARTICLE INFO

Keywords:
Ohmic heating
Electric fields
Electro-technologies
Biomass wastes
Extraction

ABSTRACT

This review provides an overview of recent research on electrotechnologies applied to the valorization of bioresources. Following a comprehensive summary of the current status of the application of well-known electric-based processing technologies, such as pulsed electric fields (PEF) and high voltage electrical discharges (HVED), the application of moderate electric fields (MEF) as an extraction or valorization technology will be considered in detail. MEF, known by its improved energy efficiency and claimed electroporation effects (allowing enhanced extraction yields), may also originate high heating rates – ohmic heating (OH) effect – allowing thermal stabilization of waste stream for other added-value applications. MEF is a simple technology that mostly makes use of green solvents (mainly water) and that can be used on functionalization of compounds of biological origin broadening their application range. The substantial increase of MEF-based plants installed in industries worldwide suggests its straightforward application for waste recovery.

1. Introduction

Food security and climate changes represent major concerns in the XXI century. It is estimated that, in 2012, 12.5% of the global population was undernourished, and this ratio increased to 15% in developing countries (FAO et al., 2012). Furthermore, the scarcity of resources demands for a rational use of land, energy, chemicals/fertilizers and water. Therefore, food security, climate changes, health and sustainability issues jumped into the last decades' political agenda and public consciousness.

The multi-valorization of underused bioresources such as agro-food wastes, forestry surplus, seaweeds or microalgae is therefore a desirable approach to meet the bioeconomy challenges. In this line of thought, using biomass as a sustainable renewable feedstock in biorefinery systems is crucial for the transition from a non-biodegradable fossil carbon-based economy to a bio-based economy (Ekman et al., 2013).

1.1. Undervalued bioresources

Numerous products can be obtained and/or valorized from different sources. Exploitable compounds or fractions may include proteins and peptides, polysaccharides or oligosaccharides, fibers, gum exudates, lipids, polyphenols, carotenoids and other secondary metabolites with highly-valued bioactivity. A full (bio)chemical and nutritional characterization and the identification of the relevant fractions for each resource is the first step in most bioresources valorization strategies. Most of the compounds or fractions of interest are intracellular, and appropriate strategies for extraction, separation and further processing of the different exploitable fractions need to be designed to allow a financially and environmentally sustainable valorization of relevant byproducts or wastes (Fig. 1). Target applications cover different sectors such as food, feed, health, cosmetics, bioplastics, biomaterials or (bio)chemicals. The residual final fraction can feed different conversion systems of biorefineries such as fermentative processes (to produce high added-value compounds, bioethanol, bioplastics and/or energy) or thermochemical processes (pyrolysis) (ElMekawy et al., 2013).

Agro-food and forestry wastes, seaweeds and microalgae are biomass-derived resources that can be valorized in a circular bio-based economy approach. Food wastes can be divided according to their source: from vegetable commodities and products or from animal commodities and products; they can come from different stages in the food chain including agricultural production, post-harvest handling and storage, processing, distribution and consumption (Gustavsson et al., 2011). In a report from 2011, FAO has estimated that ca. of 1.3 billion ton of food losses and wastes are produced per year (Gustavsson et al., 2011), coming most of them from vegetable sources (cereals, fruits and vegetables, roots and tubers and oil crops and pulses). The dairy industry is responsible for the highest production of animal-sourced foods, followed by meat and fish industries.

Lignocellulosic residues in biorefineries and green extraction

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https://doi.org/10.1016/j.biortech.2018.01.068
Received 15 November 2017; Received in revised form 11 January 2018; Accepted 15 January 2018

Please cite this article as: Rocha, C.M.R., Bioresource Technology (2018), https://doi.org/10.1016/j.biortech.2018.01.068

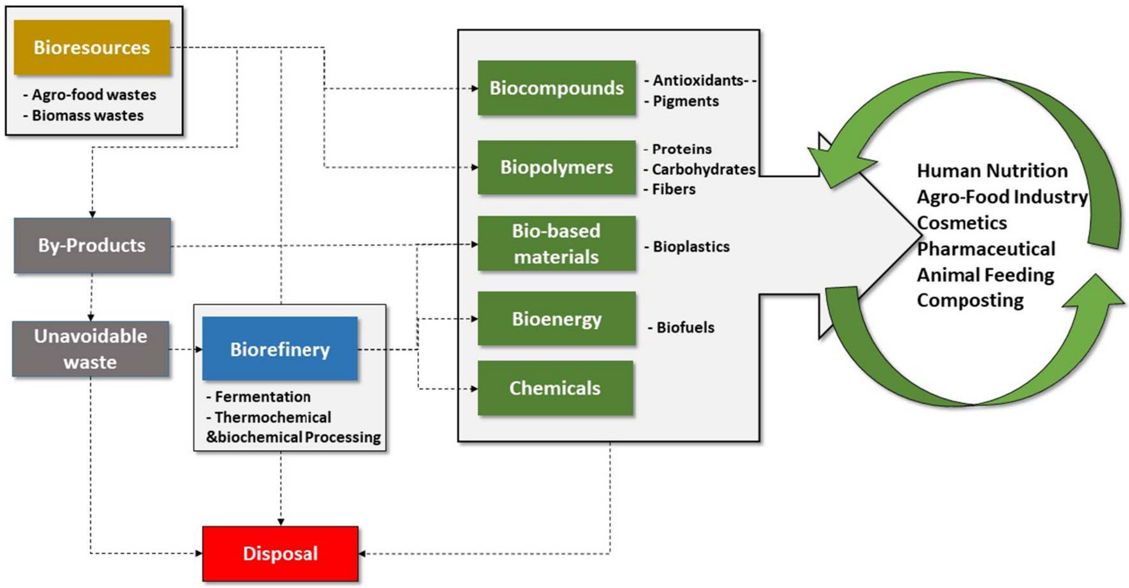

Fig. 1. Byproduct valorization chain.

methods for phytochemicals from plant-based materials have been widely studied subjects in the last years and were the aim of several recent reviews (e.g.(Ameer et al., 2017; Gillet et al., 2017). Nevertheless, plant-based materials are also sources of other potentially exploitable compounds, including non-animal-sourced protein, enzymes, polysaccharides (such as pectin or starches), essential oils, coloring or flavoring agents and dietary fibers.

Animal-based wastes are usually rich in high quality proteins (Marcet et al., 2016). They are also good sources of proteolytic enzymes (e.g. pepsin and trypsin), collagen, gelatin, keratin, chitosan (from shrimp or crab shells), polyunsaturated fatty acids (from fish oil) and peptone (Baiano, 2014). Further specific applications include the use of amino acids, hormones, fibrinogen, albumins, insulin, among others. Lactic acid, oligosaccharides, peptides, proteins and lactulose represent major compounds present in dairy wastes (Mirabella et al., 2014).

Seaweeds are important marine bioresources being used in human consumption, hydrocolloids extraction, fertilizers, extracts for cosmetics and pharmaceuticals, biofuels and wastewater treatment (McHugh, 2003). The hydrocolloids extraction sector is the main focus of seaweed processing industry but emerging applications include production of high added-value bioactive compounds (e.g. anti-oxidant or anti-tumoral), and the use of seaweed protein for food and feed and the extraction of pigments for different applications. Besides polysaccharides and proteins, carotenoids and phenolic compounds constitute other compounds with potentially important bioactive features. Such compounds may also be obtained from residues from hydrocolloids industries and seaweed tides (such as green tides), and from sustainable seaweed production in integrated multitrophic aquaculture systems and urban coastal waters using native seaweeds. In both latter cases, seaweeds are applied as biofilters, using solar energy and the excess of nutrients to produce high amounts of new biomass while purifying the effluents (Kim et al., 2014).

The ability of microalgae to fix CO_2 has been proposed as a method of removing CO_2 from flue gases (e.g. from power plants) (Abbasi and Abbasi, 2010). Approximately half of the dry weight of microalgae biomass is carbon derived from CO_2 (Chisti, 2008). Considering the current carbon emissions' global market, the valorization of compounds resulting from microalgae growth appears as a straightforward solution to help coping with the algal biomass generated from CO_2 removal processes, while providing a renewable source of valuable compounds that does not compete with forest and does not imply water scarcity or soil erosion. Microalgae have the extra advantage of showing rapid growth under optimal conditions. Certain species of microalgae are extremely rich in lipids (that may exceed 80% in microalgae dry weight) while others have the ability to produce high levels of carbohydrates (instead of lipids) as reserve polymers (Mussatto et al., 2010). Furthermore, they can be used as a source of food and feed proteins – single cell protein (Smetana et al., 2017), pigments for food and cosmetics or other minor valuable compounds (Matos, 2017).

1.2. *Current status of technologies for bioresource valorization*

Traditionally, solvent solid-liquid extraction (TSE) is used for most fractioning processes. The correct choice of solvents to achieve good extraction yields with a high concentration in the target compound depends on the target's solute solubility and polarity. This choice includes frequently organic compounds such as dichloromethane, ethanol, and methanol. Heat and/or agitation are usually side-by-side with TSE, both to increase the solute's solubility and increase the mass transfer rate, though minimum damage to the target compound has to be assured (e.g. avoiding oxidation and/or thermal degradation). Besides issues such as the molecular affinity between solvent and solute and mass transfer, other factors should not be overlooked such as the need for a co-solvent, environmental safety, human toxicity and financial feasibility. Traditional water or organic solvent extractions are time-consuming processes that often require high solvent and energy consumptions and generate large amounts of waste.

Issues such as growing environmental concerns and petroleum shortage as well as increasing oil price instability caused by geopolitical conflicts (causing increased costs of chemicals and energy) have boosted the search for alternative environmentally friendly extraction and fractioning methodologies, aiming at reducing energy and chemicals consumption, waste generation and operational time, while increasing overall yield, selectivity and quality of the extract. Studied alternative technologies include accelerated solvent extraction, subcritical water extraction, pulsed electric fields, supercritical fluid extraction, enzyme-assisted extraction or digestion and extrusion. The search for alternative solvents led to the use of ionic liquids, deep eutectic solvents and surfactants, as greener or more efficient options. However, downstream processing may be a problem as some of these solvents are not easily separated from the target compounds. Also, renewable solvents that can be produced from biomass such as bioethanol, terpenes, glycerol or ethyl lactate are being considered (Chemat et al., 2012). In addition, the trend is to use the least solvent possible,