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An overview of the impact of electrotechnologies for the recovery of oil and high-value compounds from vegetable oil industry: Energy and economic cost implications

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ABSTRACT

Oil recovery from oilseeds and fruits is one of the food processes where efficiency is the key to ensure profitability. Wastes and by-products generated during oil production process are, on the other hand, a great source of high-added value compounds that could be recovered in turn at a later stage. In many cases, physical extraction processes present efficiency problems or just not profitable, requiring a chemical solvent extraction that could be toxic and difficult to manage from an environmental point of view. Furthermore, the use of high temperatures to improve and/or accelerate the processes (with consequent degradation of thermolabile compounds) is usually required. Therefore, the application of new pre-treatment technologies to replace partially or completely the conventional methods, and to achieve the processes more efficiently and sustainably is of great importance. Electrotechnologies, especially pulsed electric fields and high voltage electrical discharges are some of the most promising techniques. In this review, the main published results are summarized, emphasizing their potential applications and studying their energy and economic cost, a key aspect to assess their industrial viability.

Contents

1. Introduction

The development of more efficient processes is one of the keystones for innovation, competitiveness and development in food industry. The production of vegetable oils from seeds (e.g. sunflower, soybean, corn, rapeseed) and oleaginous fruits (e.g. olive) is one of the food processes where efficiency is a key point to ensure profitability. Low extraction yields are obtained at industrial level in some cases. The average oil yield for all oilseeds is estimated to 25% while for olive rarely exceeds 20–25% (Espínola, Moya, Fernández, & Castro, 2009; Gunstone, 2002; Puértolas & Martínez de Marañón, 2015; Turtelli-Pighinelli & Gambetta, 2012). To maximize yields of vegetable oils extraction, the traditional

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process involves mechanical removal through pressing, centrifugation and/or extrusion, and subsequent chemical extraction using organic solvents such as hexane or ethanol (Xu & Diosady, 2003). Pressing followed by hexane extraction leads to the highest oil yield. The meal contains only about 1–2% residual oil (Thiyam-Hollaender, Eskin, & Matthäus, 2013; Turtelli-Pighinelli & Gambetta, 2012). After their extraction some oils are refined to remove undesirable materials (e.g. phospholipids, monoacylglycerols, diacylglycerols, free fatty acids, pigments). However, this process may also remove valuable minor components, including antioxidants and vitamins such as carotenes and tocopherols (Gunstone, 2002), so the obtained oils are in general of low quality.

In recent years, a great effort is being done to reduce and/or minimize chemical extraction process because although it improves the extraction yield, the quality of oil is modified. For instance, the presence of volatile organic impurities in the final product can compromise the quality and go against the new profile of consumers who are seeking for natural products aiming to have a healthier diet (Michulec & Wardencki, 2005). Furthermore, some of the solvents used are toxic to human health, animal and/or environment (Barba, Puértolas, et al., 2015; Das Purkayastha, Dutta, Kalita, & Mahanta, 2014; Deng et al., 2014). In order to obtain higher oil quality, mechanical processes alone are recommended. For example, olive oil processing involves commonly a crushing/grinding of olives, a phase of kneading or maceration at moderate temperatures to promote the coalescence of the oil droplets, and finally an oil recovery by centrifugation or pressing (Puértolas & Martínez de Marañón, 2015). Exclusive use of mechanical processes does not allow the complete recovery of oil from matrix. An estimated 20% of oil existing in olive is lost in liquid and solid wastes generated during the production process, mainly emulsified with water and in the cells of olive mass after extraction (Aguilera, Beltran, Sanchez-Villasclaras, Uceda, & Jimenez, 2010; Clodoveo & Hachicha Hbaieb, 2013; Moya et al., 2010).

One of the keys to ensure environmental, economic and social sustainability of the industrial activities is to improve the management of wastes and by-products. As mentioned above, the extraction yields in vegetable oil industries rarely exceed 20–25%. This fact involves the generation of at least 750–800 g of direct waste residue per kg of processed fresh material. Consequently, the production of vegetable oils could be considered as one of the food sectors that generate the largest amounts of direct wastes. In fact, the wastes and by-products generated during olive oil production are estimated to 30 million m^3 per year (Niaounakis & Halvadakis, 2006). Besides the huge amount of waste and by-products, the fact that the production of vegetable oils is usually seasonal, along with the important geographical dispersion and small size of the producers, complicate the waste management, and increase their economic cost.

Wastes from the production of vegetable oils are rich in compounds such as polyphenols, phytosterols, carotenoids, tocopherols, fatty acids, or proteins, which may have some interest either for their technological function (e.g. texturing, coloring), nutritional properties (e.g. vitamins, proteins), or having a positive effect on human or animal health (e.g. bioactive compounds, antioxidants) (Das Purkayastha et al., 2014; Dermeche, Nadour, Larroche, Moulti-Mati, & Michaud, 2013; Galanakis, 2012; Naziri, Nenadis, Mantzouridou, & Tsimidou, 2014). Based on their functions, these compounds could be used as natural ingredients in the pharmaceutical or food industries, allowing the valorization of the generated wastes. Recovering these compounds basically involves their removal by processing systems that do not affect their functionality and later their purification and stabilization steps, to be used as ingredients. The common used technique is solid–liquid extraction involving solvents and usually assisted with temperature to improve process efficiency (Puértolas, Luengo, Álvarez, & Raso, 2012). However, in many cases, high-added value compounds are difficult to recover, leading to low extraction yields or involving long extraction times (Barba, Puértolas, et al., 2015). Moreover, as mentioned above for oil recovery, most of the solvents used are harmful for human, animals, and environment (Barba, Grimi, & Vorobiev, 2014; Deng et al., 2014).

To avoid these issues, numerous works have been devoted in recent years to evaluate different non-conventional technologies, which could preserve the product's quality, shorten the treatment time, decrease the temperature, and reduce the solvent consumption (Barba, Puértolas, et al., 2015; Chemat & Strube, 2015; Deng et al., 2014; Roselló-Soto et al., 2015; Vorobiev & Lebovka, 2011a). Among others, electrotechnologies, especially pulsed electric fields (PEF) and high voltage electrical discharges (HVED), used as pre-treatments based on electroporation and electrical breakdown, respectively, have shown great potential to improve the competitiveness of vegetable oil industry. The use of green solvents, low energy consumption, and promising potential to recover seed oils and valuable compounds from meals make them competitive alternatives for conventional processes. The aim of this review is to summarize the main results reporting the impact of electrotechnologies to improve the extraction yields in vegetable oil industry, and to recover bioactive compounds from their wastes and by-products. An emphasis on their potential applications and energy cost is discussed in order to evaluate their industrial viability aspects.

2. Basic principles of pulsed electric fields (PEF)

PEF technology consists of applying intermittent (<300 Hz) electric fields of moderate to high intensity (0.1–50 kV/cm) and short duration (from few μs to several ms) (Mohamed & Amer Eissa, 2012; Puértolas et al., 2012; Ravishankar, Zhang, & Kempkes, 2008; Toepfl & Heinz, 2011). These electric fields cause the electroporation of eukaryotic and prokaryotic cells, forming reversible or irreversible pores in their cell membranes (Barba, Puértolas, et al., 2015; Barba, Boussetta et al., 2015; Barba, Grimi, et al., 2015; Teissie, Golzio, & Rols, 2005).

Irreversible electroporation improves the extraction processes (Puértolas et al., 2012). Generally, membrane permeabilization induced by electric field strength is dependent on cell geometry and size. Critical electric fields strength in the range of 1–2 kV/cm are used for plant cells (cell size 40–200 μm) and in the range of 12–20 kV/cm are used for microorganisms (cell sizes 1–10 μm) (Heinz, Alvarez, Angersbach, & Knorr, 2001). However, according to the empirical studies, from a practical point of view this electric field is also dependent on the hardness of the treated material. In fact, while for soft plant tissues or materials (e.g. mesocarp or pericarp of some fruits), electric field strength between 0.1 and 10 kV/cm is sufficient to obtain good results, hard materials (e.g. seeds) require higher electric field strength (10–20 kV/cm) to be efficient (Boussetta et al., 2012; Boussetta, Soichi, Lanoisellé, & Vorobiev, 2014; Sarkis, Boussetta, Tessaro, Marczak, & Vorobiev, 2015).

PEF equipment is basically constituted of an electrical generator that produces electrical pulses (usually square or exponential decay) of suitable voltage (<50 kV) and current (<1 kA), and a treatment chamber in which the product is placed and the pulses are discharged. The treatment chamber requires at least two electrodes, one connected to the generator (high voltage) and the other one to ground, separated by an insulation material (e.g. polytetrafluoroethylene). The electric field is generated due to the difference of potential (Fig. 1), and it not only depends on the electrical pulse characteristics, but also on the morphology, the electrode configuration, and conductivity of the product (Heinz et al., 2001). There are two types of chambers: 1) static; that are usually designed with parallel electrodes as shown in Fig. 1, and are very useful for basic research level, and 2) dynamic or continuous flow; allowing continuous treatment of materials, and designed to meet the industrial requirements. Moreover, besides electric field strength (0.1–10 kV/cm for soft materials, and 10 to 20 kV/cm for hard materials), pulse duration (μs–ms), and frequency (<300 Hz, corresponding to the number of pulses applied per second), the other important parameters defining the effectiveness of the treatment are the treatment time (μs–ms, corresponding to the number of applied