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Extraction assisted by pulsed electric energy as a potential tool for green and sustainable recovery of nutritionally valuable compounds from mango peels

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ABSTRACT

The study compares the efficiency of conventional aqueous extraction at different temperatures (20–60 °C) and pH (2.5–11) and extraction assisted by pulsed electric energy (pulsed electric fields, PEF or high voltage electrical discharges, HVED) of nutritionally valuable compounds found in mango peels. Exponential decay pulses with initial electric field strengths of ≈13.3 kV/cm and ≈40 kV/cm for PEF and HVED treatments were used, respectively. The impact of temperature on aqueous extraction of proteins and carbohydrates was not significant. The highest values of nutritionally valuable and antioxidant compounds (7.5 mM TE) were obtained for aqueous extraction (T = 60 °C, pH 6) but extracts were unstable and cloudy. The application of two-stage procedure PEF + supplementary aqueous extraction (+SE) that include PEF-assisted extraction as the first step, and +SE at 50 °C, pH 6 during 3 h as the second step, allowed a noticeable enhancement of the yields of TPC (+400%) even at normal pH.

1. Introduction

Nowadays, there is a growing demand for tropical fruits. Global production of these (excluding bananas) reached 73.02 million (M) metric tonnes (t) in 2010. Among these, mango is one of the most important, now ranked second with 38.6 Mt, only behind banana production (Evans & Ballen, 2012). A large number of epidemiological studies have associated consumption of tropical fruits and their products with decreased risks of degenerative diseases such as cancer and coronary heart disease (Hansen, Purup, & Christensen, 2003). These beneficial effects have been mainly attributed to the presence of health promoting bioactive compounds such as carotenoids, flavonoids, phenolic compounds and vitamins (Barba, Esteve, & Frigola, 2013; Gardner, White, McPhail, & Duthie, 2000).

Several mango-derived products are commercialized such as juices, purées, fresh-cut mango slices. However, during processing, a large amount of food wastes and by-products are generated either at the farm, at the processing industry or from retails each year, including outer peels wastes that could cause environmental pollution if not properly handled. Economics of processing tropical crops could be improved by developing higher-value uses for their by-products. Reports have been made about tropical fruit by-products containing high levels of various health enhancing substances that can be extracted to provide nutraceuticals (Gorinstein et al., 2011). In addition, the full utilization of fruits could lead the industry to a lower-waste agribusiness, increasing industrial profitability. The use of the entire plant tissue could have economic benefits to producers and a beneficial impact on the environment, leading to a greater diversity of products (Peschel et al., 2006). This fact has led to both food technologists and food industry to find new ways to valorise these products.

Mango peels constitute one of the most attractive fruit by-products. They have an important content of antioxidants such as phenolic compounds, which can be a useful alternative to reduce synthetic antioxidants. These antioxidants can be also used as food additives and nutraceuticals among other applications (Ajila, Naidu, Bhat, & Rao, 2007; Kim et al., 2010). Moreover, mango peels are a great source of proteins, carbohydrates and pectin, with different food and pharmaceutical applications (Garcia-Magana,

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Garcia, Bello-Perez, Sayago-Ayerdi, & de Oca, 2013; Malviya & Kulkarni, 2012).

In this line, it is of a paramount importance to develop extraction methods, which can recover these compounds from mango peels. Traditionally, methods based on maceration and heat extraction in different solvents, which in some cases can be toxic (i.e. hexane, acetone, methanol, etc.), have been used to recover nutritionally valuable compounds from fruit wastes and by-products (Wang & Weller, 2006). However, the need for increasing extraction processes has led to study deeper new non-conventional methods. These methods can reduce the extraction time and allow decreasing temperature and solvent consumption as well as to achieve higher efficiency and lower energy consumption compared to conventional methods.

In the last two decades, the use of electrotechnologies, such as pulsed electric fields (PEF) and high voltage electric discharges (HVED), have been shown to be promising for intracellular extraction from plant food materials (Fincan, DeVito, & Dejmek, 2004; Lebovka, Vorobiev, & Chemat, 2011; Soliva-Fortuny, Balasa, Knorr, & Martín-Belloso, 2009; Vorobiev & Lebovka, 2010), by-products (Bluhm & Sack, 2008; Boussetta & Vorobiev, 2014; Luengo, Alvarez, & Raso, 2013), and bio-suspensions (Grimi et al., 2014). The application of PEF or HVED may cause lethal damage to cells or induce sublethal stress by transient permeabilization of cell membranes and electrophoretic movement of charged species between cellular compartments. Different aspects regarding the application of electrotechnologies for disintegration of soft cellular tissues have been intensively discussed in literature (Manas & Vercet, 2006; Vorobiev & Lebovka, 2006). Pulsed generators used at high field strengths (>20 kV/cm) for microorganisms inactivation in liquid foods (Barba et al., 2012; Toepfl, Heinz, & Knorr, 2007; Zulueta, Barba, Esteve, & Frígola, 2013) can, in some cases, be used at lower field strengths (<1 kV/cm) for the extraction from solid foods (Parniakov, Lebovka, Van Hecke, & Vorobiev, 2014). PEF treatment has the potential to be used as pretreatment, thus facilitating subsequent extraction of nutritionally valuable compounds combined with other techniques (Rajha, Boussetta, Louka, Maroun, & Vorobiev, 2014).

The main aim of the present research study is to explore the feasibility of PEF and HVED to recover nutritionally valuable compounds from mango peels. Moreover, the effects of PEF pretreatment combined with mild temperature (50 °C) as a potential tool to extract nutritionally valuable compounds from mango peels will be also evaluated.

2. Materials and methods

2.1. Samples

Mango peels were obtained from mango fruits (*Mangifera indica* L.) purchased at a local supermarket (origin Peru) and used immediately. Mango peels were removed from the pulp and manually chopped into square pieces of 6 ± 1 mm^2. A suspension of mango peels (solid/liquid ratio = 1/10) in distilled water was prepared immediately before experiments. The dry matter content, measured by drying 25 g of the mango peels at 105 °C to constant weight, was about 30 wt%.

2.2. Pulsed electric treatments

PEF and HVED treatments were done using the high voltage pulsed power 40 kV–10 kA generator (Tomsk Polytechnic University, Tomsk, Russia) in cylindrical batch treatment chamber and different types of electrodes (Fig. 1). PEF treatment was carried out between two plate electrodes (d = 110 mm) with 3 cm distance between them (Fig. 1a). HVED treatment was done using electrodes in needle-plate geometry. The distance between the stainless steel needle (d = 10 mm) and the grounded plate (d = 25 mm) electrodes was fixed at 1 cm. Mango peel suspension (300 g) was introduced between the electrodes before treatment. Treatment comprised the application of n successive pulses (n = 1–2000). The damped oscillations with effective decay time $t_i \approx 0.5 \pm 0.1$ μs and the exponential decay of voltage $U \propto \exp(-t/t_i)$ with effective decay time $t_i \approx 8.3 \pm 0.1$ μs were observed in HVED and PEF treatment modes, respectively (Fig. 1b). The initial voltage peak amplitude was U = 40 kV and the corresponding electric field strengths E were ≈13.3 kV/cm and ≈40 kV/cm for PEF and HVED treatments, respectively. The distance between pulses was Δt = 2 s.

The initial temperature before PEF or HVED treatments was 20 °C and the final temperature after electrical treatment never exceeded 35 °C. Suspension temperature was controlled by

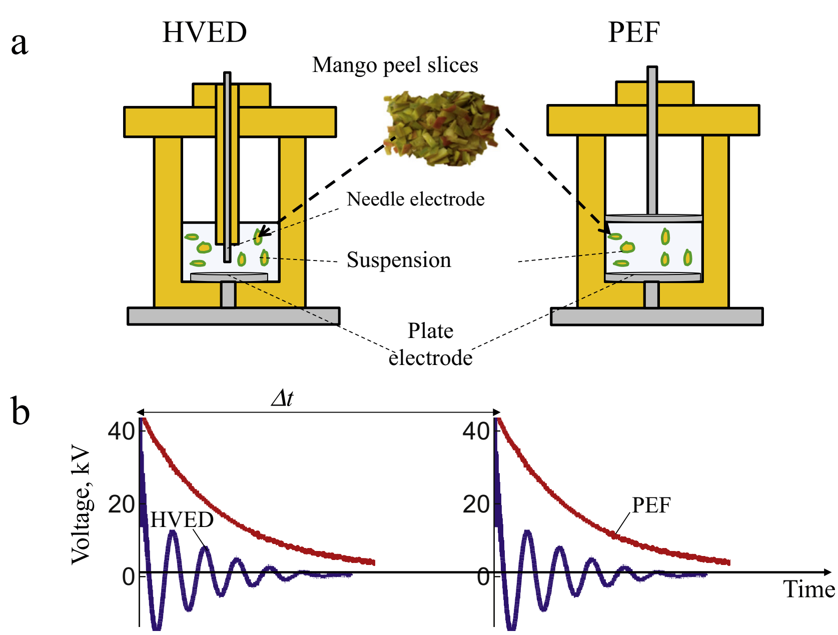

Fig. 1. PEF and HVED treatment chambers (a) and pulsed protocols (b).