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Impact of pulsed electric fields and high voltage electrical discharges on extraction of high-added value compounds from papaya peels

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ABSTRACT

Extraction of the nutritionally valuable and antioxidant compounds from papaya peels using conventional aqueous extraction (E) (at 20 °C, 50 °C, and 60 °C) and extraction assisted by pulsed electric field (PEF) or by high voltage electrical discharges (HVED) was studied. Increase of extraction temperature or extraction in basic media (pH = 11) not always resulted in an increase of the yields or TEAC values. E.g., the concentration of proteins and TEAC values at pH = 7 and pH = 11 were noticeably smaller at 60 °C as compared to those measured at 50 °C. HVED-assisted technique showed a higher extraction efficiency of high-added value compounds compared to PEF-assisted extraction. E.g., the concentrations of proteins obtained for the HVED- or PEF-assisted extractions were 60 mg/L and 20 mg/L, respectively (pH = 7 at 20 °C and time of extraction of ≈ 3/4 h). The better efficiency of HVED-assisted extraction can reflect turbulation of suspension and fragmentation of pills provoked by electrical discharges. However, electrical discharges may produce chemical products of electrolysis and free reactive radicals, which can reduce the nutritional quality of high-added value compounds. Application of the two-stage method (PEF + supplementary aqueous extraction at 50 °C) allowed a significant enhancement of the yields and antioxidant capacities of the extracted components from papaya peels even at neutral pH.

1. Introduction

The market demand for tropical fruits has been growing steadily in the last two decades. Global production of tropical fruits (excluding bananas) reached 73.02 million (M) metric tons (t) in 2010. Gaining in popularity worldwide, papaya is now ranked third with 11.22 Mt, or 15.36% of the total tropical fruit production (Evans & Ballen, 2012). Papaya is rich in bioactive compounds, such as phenolic compounds, carotenoids, and vitamin C, which are believed to posses beneficial health effects mainly attributed to their antioxidant properties (Barba, Esteve, & Frigola, 2013; Da Silva et al., 2014; Rivera-Pastrana, González-Aguilar, & Yahia, 2010). In spite of all these advantages, consumption of these fruits generates a great amount of wastes and by-products (either at the farmer, at the processing industry, or from retail), including outer skin wastes that can produce environmental pollution if not properly handled.

Peels and seeds, which are by-products of papaya processing and represent 20 to 25% of the fruit weight, can be used for animal feeding, but usually they are discarded into the environment causing organic pollution (Koubala, Christiaens, Kansci, Van Loey, & Hendrickx, 2014). However, it can be possible to use papaya peels as a good source of valuable compounds, including proteins and different phytochemicals such as phenolic compounds.

Over the last years, phenolic compounds have attracted considerable interest from the food industry mainly due to their antioxidant properties and they can be used as food additives replacing synthetic antioxidants and/or nutraceuticals (Ang, Sia, Khoo, & Yim, 2012; Ng, Ang, Khoo, & Yim, 2012).

Traditional methods of extraction used for recovery of nutritionally valuable compounds from fruit wastes, including papaya by-products, are based on maceration and thermal extraction at high temperatures (>60 °C) alone and/or combined with different solvents, which can be toxic (i.e., hexane, acetone, methanol, etc.) (Mohd Adzim Khalili, Che Abdullah, & Abdul Manaf, 2012; Ng et al., 2012). Moreover, the use of high temperatures can promote nutritional losses. For instance, the increasing need in application of extraction processes has led to deeper interest in new non-conventional methods that can reduce the extraction time, process temperature and solvent consumption and contribute to higher extraction efficiency and lower energy consumption as compared to conventional methods of extraction.

Pulsed electric energy (pulsed electric fields, PEF, and high voltage electrical discharges, HVED) can be useful technologies for the valorization of food wastes and by-products. Recent scientific and practical efforts have shown full correspondence of pulsed electric fields (PEF) techniques with green extraction concept (Vorobiev & Lebovka, 2010).

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This concept assumes using of renewable plant resources and alternative solvents (water or agro-solvents (ethanol, methyl esters of fatty acids of vegetable oils)), reduction of energy consumption and unit operations, production of high quality and purity of extracts (non-denatured and biodegradable) and extract co-products instead of wastes (Chemat, Vian, & Cravotto, 2012). Moreover, methods assisted by pulsed electric energy can allow the increase of the yield and quality of the extracted compounds, thus decreasing the time and temperature of extraction operations (Boussetta & Vorobiev, 2014; Cholet et al., 2014; Donsi, Ferrari, & Pataro, 2010; Knorr et al., 2011; Luengo, Alvarez, & Raso, 2013; Martin-Belloso & Soliva-Fortuny, 2011; Vorobiev & Lebovka, 2006).

Rather interesting is the combination of PEF treatment and traditional solvent extraction and regulation of extraction efficiency of valuable compounds (total phenolic compounds and proteins) by variation of the temperature and pH of the medium. Note that the impact of highly acidic or highly basic pH on the aqueous extraction efficiency can be positive or negative. Moreover, proteins extracted by alkali are not always suitable as food ingredients, probably, due to irreversible denaturation during the process of their isolation (Tan, Mailer, Blanchard, & Agboola, 2011). As far as solubility is often considered to be a prerequisite for food applications of proteins, it is an important drawback that protein isolates using alkaline extraction have poor solubility at neutral pH and poor functionalities (Tan et al., 2011).

The main aim of the present research was to evaluate the potential of PEF and HVED for the extraction of nutraceuticals and antioxidant compounds from papaya peels. The effects of pH (2.5–11) and temperature (20-60 °C) variations on extraction of nutritionally valuable compounds were studied. Finally, two-stage extraction including PEF treatment combined with supplementary aqueous extraction (SAE) at mild temperature (50 °C) was also tested.

2. Materials and methods

2.1. Samples

Papaya fruits (*Carica papaya* L.) were purchased at a local supermarket (origin Ecuador) and used immediately. The papaya peels were carefully removed from the pulp and manually chopped into square pieces of 5 ± 1 mm^2. Aqueous suspension (1/10 solid/liquid ratio) was prepared by addition of papaya peels into deionized water. The deionized water with electrical conductivity σ_w of ≈ 0.18 μS/cm was obtained using Elix advantage water purification system E-POD (Merck Millipore, France). The dry matter content, as determined by drying 25 g of the papaya peels at 105 °C to constant weight, was about 20% (*w*/*w*).

2.2. Treatment by pulsed electric energy (PEF and HVED)

PEF and HVED treatments were done using the same high voltage pulsed power 40 kV–10 kA generator (Tomsk Polytechnic University, Tomsk, Russia), 1-L cylindrical batch treatment chamber and different types of electrodes (Fig. 1a). PEF treatment was carried out between two plate electrodes with 3 cm distance between them. HVED treatment was done using electrodes of needle-plate geometry. The distance between the stainless steel needle (∅ = 10 mm) and the grounded plate (∅ = 25 mm) electrodes was fixed at 1 cm (Fig. 1a). The volume of papaya peel suspension in the treatment chamber between the electrodes was 300 mL.

Electric treatment comprised application of n successive pulses (n = 1–2000) with initial voltage peak amplitude U = 40 kV. The time delay between sequential pulses was $\Delta t \approx 6.8$ s. Such long time delay was required for avoiding the overheating of suspension. The damped oscillations with effective decay time $t_p = 0.5 \pm 0.1$ μs and the exponential decay of voltage $U \propto \exp(-t/t_p)$ with effective treatment time t_p = 10.0 ± 0.1 μs were observed in HVED and PEF treatment modes, respectively (Fig. 1b). The initial temperature before PEF or HVED treatment was T_i = 20 °C and the final temperature after electrical treatment T_f never exceeded 35 °C after 400 pulses. After each series of 400 pulses, a pause was made and the suspension was cooled down to 20 °C.

Suspension temperature was controlled by K-type thermocouple (±0.1 K), connected to the data logger thermometer Center 305/306 (JDC Electronic SA, Yverdon-les-Bains, Switzerland).

The degree of extraction of ionic components Z during electrical treatment was estimated by monitoring the electrical conductivity of papaya peel suspensions. The value of Z was defined as following (Vorobiev & Lebovka, 2008, 2010):

$$Z = (\sigma - \sigma_i)/\left(\sigma_f - \sigma_i\right) \quad (1)$$

where σ is the electrical conductivity and the subscripts i and f refer to the initial and final values, respectively.

The initial (before treatment) electrical conductivity of aqueous suspension of papaya peels was σ_i = 40 ± 4 μS/cm. The value of σ_f was estimated by measurement of electrical conductivity of the suspension that was HVED-treated during a long treatment time ($t_{PEF} \approx 20$ ms, n = 2000), and it was σ_f = 1400 ± 30 μS/cm. The above equation gives Z = 0 for the untreated suspension and Z = 1 for the maximally disintegrated papaya peels.

The kinetics of extraction was controlled by periodical chemical analysis and measurements of electrical conductivity. For this purpose the samples of suspension were centrifuged for 5 min at 4000 rpm MiniSpin Plus Rotor F-45-12-11 (Eppendorf, France) and the electrical

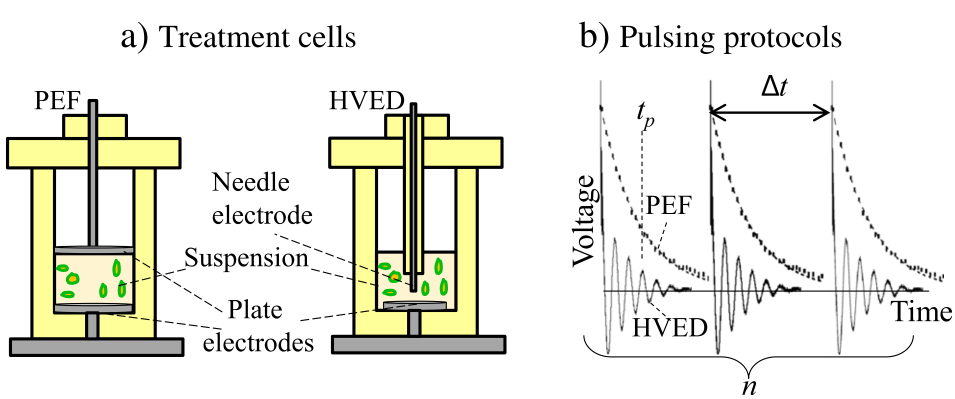

Fig. 1. Pulsed electric fields (PEF) and high voltage electrical discharges (HVED) treatment cells (a), pulsing protocols (b) and aqueous extraction procedures.