Food Chemistry 192 (2016) 842–848

Contents lists available at ScienceDirect

Food Chemistry

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

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

Oleksii Parniakov [a,b,*], Francisco J. Barba [b,c], Nabil Grimi [b], Nikolai Lebovka [a,b], Eugene Vorobiev [b]

[a] Institute of Biocolloidal Chemistry named after F. D. Ovcharenko, NAS of Ukraine, 42, blvr. Vernadskogo, Kyiv 03142, Ukraine
[b] Sorbonne Universités, Université de Technologie de Compiègne, Laboratoire Transformations Intégrées de la Matière Renouvelable (UTC/ESCOM, EA 4297 TIMR), Centre de Recherche Royallieu, CS 60319, 60203 Compiègne Cedex, France
[c] Universitat de València, Faculty of Pharmacy, Nutrition and Food Science Area, Avda. Vicent Andrés Estellés, s/n 46100 Burjassot, València, Spain

ARTICLE INFO

Article history:
Received 10 March 2015
Received in revised form 26 June 2015
Accepted 22 July 2015
Available online 23 July 2015

Keywords:
Mango peel
Pulsed electric fields
High voltage electrical discharges
Green extraction
Nutritionally valuable compounds
Antioxidant

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,

* Corresponding author at: Sorbonne Universités, Université de Technologie de Compiègne, Laboratoire Transformations Intégrées de la Matière Renouvelable (UTC/ESCOM, EA 4297 TIMR), Centre de Recherche Royallieu, CS 60319, 60203 Compiègne Cedex, France.
E-mail address: oleksii.parniakov@utc.fr (O. Parniakov).

http://dx.doi.org/10.1016/j.foodchem.2015.07.096
0308-8146/

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

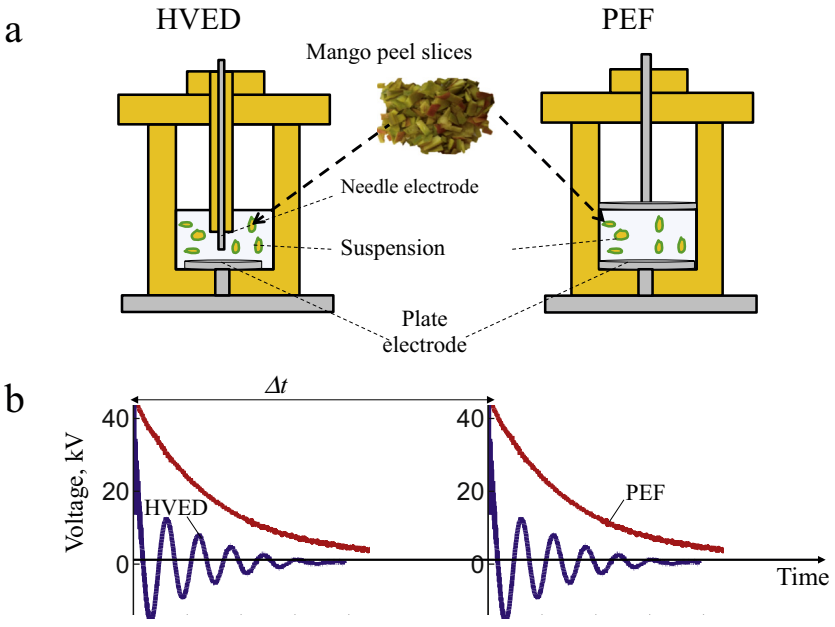

Fig. 1. PEF and HVED treatment chambers (a) and pulsed protocols (b).

K-type thermocouple (±0.1 K), connected to the data logger thermometer Center 305/306 (JDC Electronic SA, Yverdon-les-Bains, Switzerland) and a pause was made for 1 min after each 100 pulses to maintain the temperature below 35 °C.

The energy delivered to the product was defined in terms of voltage and current transients. For each PEF pulse the specific energy consumption was calculated as

$$W_k = \frac{1}{m}\int_o^{t_i+\Delta t} u(t)I(t)dt \quad (1)$$

and the total specific energy consumption was calculated as sum over all pulses

$$W = \sum_{k=1}^{n} W_k \quad (2)$$

where n is the number of pulses, m is the product mass (kg), U is the voltage (V) and I is the current strength (A), t_i is the time of one pulse (s).

The degree of extraction of ionic components Z after the PEF and HVED treatments was estimated monitoring the electrical conductivity of mango peel suspensions. The value Z was defined as (Vorobiev & Lebovka, 2008, 2010):

$$Z = (\sigma - \sigma_i)/(\sigma_f - \sigma_i) \quad (3)$$

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 mango peels was $\sigma_i = 56 \pm 3$ μS/cm. Value of the σ_f was estimated by measurement of the electrical conductivity of the suspension after applying HVED at the longest treatment time ($t_{PEF} \approx 20$ ms, $n = 2000$) and it was $\sigma_f = 1360 \pm 40$ μS/cm. The application of the above equation gives $Z = 0$ for the untreated suspension and $Z = 1$ for the maximally disintegrated mango peels. The electrical conductivity was measured using a conductivity meter InoLab pH/cond Level 1, WTW (Weilheim, Germany) at temperature of 20 °C.

2.3. Aqueous extraction

The aqueous extraction (AE) experiments were done using mango peel suspensions in distilled water (1/10 w/w solid/liquid ratio) at three different temperatures, ambient $T = 20$ °C, and elevated, $T = 50$ °C and $T = 60$ °C. In diffusion experiments at ambient temperature, the data for electrically treated and untreated samples were compared.

In order to enhance the diffusion process and prevent the degradation of thermolabile compounds, a moderate temperature, $T = 50$ °C, was selected. At the highest temperature, $T = 60$ °C, the effects of diffusion are expected to be accelerated, however, the degradation effects cannot be excluded. The AE experiments were also done at different values of pH (2.5, 6, 11). The pH 6 corresponded to the natural value obtained for the mango peel suspensions in distilled water. The acidic, pH 2.5, and basic, pH 11, values were chosen for evaluating the impact of pH on the extractability of the investigated valuable compounds. Hydrochloric acid or sodium hydroxide were used for adjustment of pH values. pH was controlled using a pH meter Consort C931 (Bioblock Scientific, France) at temperature of 20 °C. In order to avoid any evaporation, the extraction was done under continuous magnetic stirring in 250 ml hermetically closed flasks. The kinetics of extraction was controlled by periodical chemical analysis. For this purpose, samples of suspension were centrifuged for 15 min at 4000 rpm MiniSpin Plus Rotor F-45-12-11 (Eppendorf, France) and supernatant (extract) was analyzed. The two-stage procedure PEF + supplementary aqueous extraction (+SE) included PEF-assisted extraction as the first step, followed by aqueous extraction ($T = 50$ °C, pH 6, $t = 3$ h) as the second step.

2.4. Chemical analyses of extracts

All chemical analyses were based on color reactions with chemical reagents that were measured using UV/vis spectrophotometer LibraS32 (Biochrom, Lagny-sur-Marne, France).

2.4.1. Content of proteins

The concentration of proteins, (mg of bovine serum albumin equivalent/ kg of dry weight, mg/kg), was determined by the Bradford method (Bradford, 1976). 0.2 ml of extract and 1.8 ml of threefold diluted Bradford Reagent (Sigma–Aldrich, France) were mixed. The sample was kept for 5 min at room temperature ($T = 20$ °C). The absorbance, A, was measured at the wavelength of 595 nm. Bovine serum albumin (Sigma–Aldrich, France) was used for the calibration.

2.4.2. Total phenolic compounds (TPC)

The concentration of total polyphenols, (mg of gallic acid equivalent/kg of dry weight, mg/kg), was determined by the Folin–Ciocalteu method. It was based on a colorimetric oxidation/reduction reaction of phenols (Singleton, Orthofer, & Lamuela-Raventos, 1999). In experiments, 0.2 ml of extract and 1 ml of Folin–Ciocalteu reagent (Sigma–Aldrich, France) (diluted 1:10 with water) were mixed. Then 0.8 ml of Na_2CO_3 (75 g/L) (VWR, France) was added to this mixture. The sample was incubated for 1 h at room temperature ($T = 20$ °C). The absorbance, A, was measured at the wavelength of 750 nm. Gallic acid (Sigma–Aldrich, France) was used for the calibration.

2.4.3. Carbohydrates

The concentration carbohydrates, (g of glucose equivalent/ kg of dry weight, g/kg), was determined by the phenol–sulfuric acid method (Du Bois, Gilles, Hamitton, Reders, & Smith, 1956) that was partially modified in order to reduce the consumption of reagents (Parniakov et al., 2014). The color reaction was initiated by mixing 2 ml of extract with 1 ml of 5% phenol solution and 5 ml of concentrated sulfuric acid (Sigma–Aldrich, France). The reaction mixture was kept at room temperature ($T = 20$ °C) for 30 min. The absorbance, A, was measured at the wavelength of 490 nm. D-glucose (Sigma–Aldrich, France) was used for the calibration.

2.4.4. Pectin identification

The method used for pectin identification was a visual test, which identifies the presence or the absence of pectin in a sample (Grimi, Mamouni, Lebovka, Vorobiev, & Vaxelaire, 2011). A sample volume of 5 ml was gently mixed with 10 ml of acidified ethanol (1 ml of chloride acid in 100 ml of ethanol) and kept 15 min at room temperature ($T = 20$ °C). Appearance of a gel confirms the presence of pectin in the sample.

2.4.5. Antioxidant capacity

The method used was as described by Brand-Williams, Cuvelier, and Berset (1995). DPPH (2,2-diphenyl-1-picryl-hydrazyl-hydrate) free radical method is a popular antioxidant assay based on electron-transfer that produces a violet solution in methanol. The samples were diluted with methanol until an inhibition percentage of 20–80% was reached. The reaction was initiated by adding 50 μL of a suitable dilution of sample extract to 1.45 mL of DPPH colored radical solution (0.06 mM) (Sigma–Aldrich, Steinheim, Germany). The sample was incubated for 30 min at room temperature ($T = 20$ °C). Absorbance, A, was measured at the wavelength of

515 nm (Barba, Esteve, Tedeschi, Brandolini, & Frígola, 2013). Relative antioxidant capacity (R_{AC}) was evaluated as

$$R_{AC} = (A_o - A_f)/A_o \quad (4)$$

where A_o and A_f are the absorbances of the DPPH colored radical before and after adding the diluted methanolic sample extract, respectively.

At the same time, a trolox calibration curve was prepared for a concentration range of 0–1 mM for calculation of the antioxidant capacity AC in millimolar trolox equivalents (mM TE).

2.5. Colloidal stability

The sedimentation (colloid) stability of extracts obtained by different methods was investigated using analytical photocentrifuge LUMiSizer 610.0-135 (L.U.M. GmbH, Germany). The analysis used a centrifugal rotor, a light source (pulsed near-infrared light-emitting 880 nm diode) and a light sensor. 0.4 g of aqueous suspension (1 wt%) was subjected to centrifugation in rectangular polycarbonate optical cells, supplied by the photocentrifuge manufacturer. The operating principle of the analytical photocentrifuge is based on the measurement of light transmission though the cell, filled by the studied sample (Lerche & Sobisch, 2007). The radial distance of the centrifugal cell bottom from the axis of rotation R was equal to 0.13 m. Centrifugation experiments were carried out at the fixed rotor speed $\omega = 418.7$ rad/s (4000 rpm). The centrifugal acceleration at the bottom of the cell was $g = R * \omega^2 = 2324 g_0$. Mean light transmission, averaged over the height of the sample, $\langle T \rangle$, versus the time of centrifugation, t_c, was measured.

2.6. Statistical analysis

All experiments and measurements of characteristics were repeated using, at least, five replicates. One-way analysis of variance (ANOVA) was used for statistical analysis of the data using the Statgraphics plus (version 5.1, Statpoint Technologies Inc., Warrenton, VA). For each analysis, significance level of 5% was assumed. The error bars presented on the figures correspond to the standard deviations.

3. Results and discussion

The impact of PEF and HVED on the degree of extraction of ionic components (Z) from mango peel at equivalent energy input (W) was evaluated (Fig. 2). The parameter Z reflects the permeabilization of cells and is correlated with an increase in the extraction of the different valuable compounds. After the relatively long treatment and high energy input ($n = 2000$, $W \approx 1000$ kJ/kg), Z values were $Z \approx 1$ and $Z \approx 0.71$ for HVED- and PEF-assisted extractions, respectively (Fig. 2). HVED treatment was more efficient in terms of energy input than PEF in order to achieve a higher Z value. A possible explanation for this phenomenon is the ability of HVED to induce fragmentation of the particles due to the propagation of shock waves and explosion of cavitation bubbles, thus facilitating the extraction of soluble biomolecules (Boussetta & Vorobiev, 2014). Moreover, these effects can be also attributed to the hydrodynamic modifications that can occur after HVED treatments. Meanwhile, PEF is based on cell electroporation and can attain a better selective extraction process.

The concentration of total phenolic compounds and proteins of mango peels water extracts obtained after HVED and PEF treatments were compared to those found after aqueous extraction (20 °C, pH 6) at the same diffusion times (Fig. 3). One-way ANOVA analysis showed a significant increase in the concentration

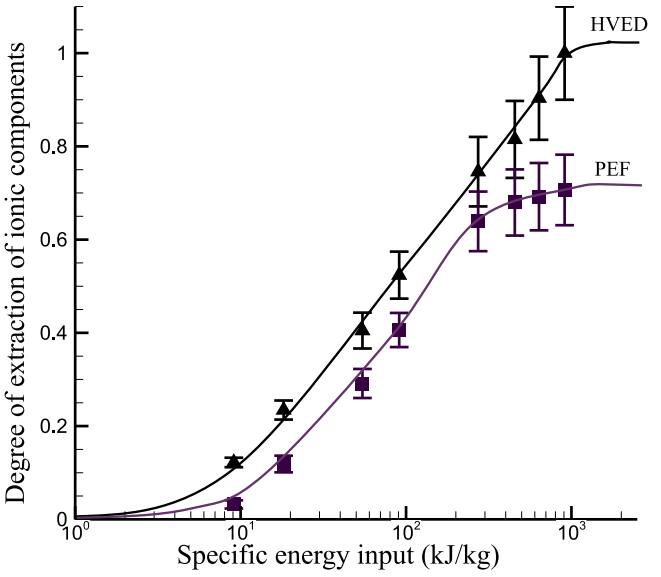

Fig. 2. The degree of extraction of ionic components versus energy input of pulsed electrical treatment for PEF- and HVED-assisted extractions.

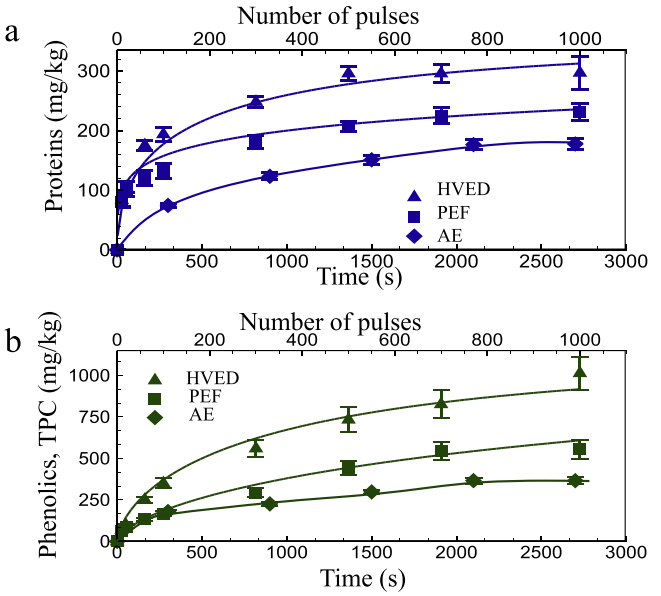

Fig. 3. Concentrations of proteins (a) and phenolics (b) versus extraction time of the extracts obtained after the application of PEF, HVED and conventional aqueous extraction (AE) at pH 6. The initial and final temperatures for PEF- and HVED-treatments were $T_i = 20$ °C and $T_f \approx 35$ °C. The aqueous extraction was done at $T = 20$ °C. The solid lines correspond to least square fitting by Eq. (5).

of TPC and proteins when the effective treatment time was increased for all the treatments (HVED, PEF and AE ($T = 20$ °C, pH 6). It should be noted that HVED-assisted extraction was demonstrated to be more effective than PEF-assisted and aqueous extractions to improve proteins and phenolic compounds recovery from mango peels. In addition, results confirmed the obtained data when Z parameter was studied. However, visual examination after applying the treatments showed that the extracts obtained by PEF were more clear and stable than the extracts obtained by AE and HVED assisted extraction, which can facilitate the subsequent separation and purification processes.

The analysis of the experimental data showed that the behavior of TPC and protein after HVED, PEF and AE followed different

kinetics. These dependences may be fitted well by the stretched exponential function (Eq. (5)).

$$C = C^{max}[1 - \exp((-t/\tau)^{\beta})] \quad (5)$$

where C is the concentration of protein or TPC, C^{max} is the maximal value of C at the longest extraction time, t is the time of extraction and τ and β are the parameters. The coefficient of determination R^2 was 0.997.

The stretching parameter β characterizes the broadness of the distribution of the extraction times. The case $\beta = 1$ corresponds to the single extraction time. The deviation of β from 1 reflects the presence of the distribution of the extraction times (Gradshteyn, Ryzhik, Jeffrey, & Zwillinger, 1980). The mean extraction time $\langle\tau\rangle$ was calculated as:

$$\langle\tau\rangle = (\tau\beta^{-1})\Gamma(\beta^{-1}) \quad (6)$$

where Γ is the Euler gamma function.

The stretching parameter, β, and the mean extraction time, $\langle\tau\rangle$, value for HVED and PEF extraction of proteins were 0.5 ± 0.03, 198.8 ± 5 s and 0.25 ± 0.04 and 1587.2 ± 10 s, respectively. Moreover, for TPC extraction assisted by HVED and PEF, the values of β were 0.64 ± 0.01 for both cases and, $\langle\tau\rangle$, values were 399.2 ± 3 s and 1399 ± 8 s, respectively. These data clearly demonstrate the different behavior of extraction kinetics after applying HVED and PEF treatments for the different valuable compounds.

Fig. 4 shows the experimental data for the two-stage procedure PEF + SE. In these experiments, PEF treatment ($n = 300$) was applied at the first stage and subsequently, a supplementary aqueous extraction (+SE) was done at $T = 50$ °C and pH 6. It was observed that the supplementary aqueous extraction after PEF pre-treatment had a significant positive effect on protein and TPC recovery. These results were in line with those reported by Boussetta, Lesaint, and Vorobiev (2013) and Luengo et al. (2013) when they studied the effects of PEF on polyphenol recovery from grape seeds and orange peels, respectively. The authors attributed the increase in TPC after PEF to cell permeabilization effect, which facilitated the release of polyphenols inside the cells. PEF + SE treatment allows extracting the highest amount of TPC (2169 mg/kg DM) after ≈3 h of extraction (Fig. 4). These results were in close agreement with those reported by Berardini, Knödler, Schieber, and Carle (2005) when they evaluated TPC content of mango peel extracts (1418.8 ± 22.1 mg/kg DM) after using an acidic extraction with sulfuric acid, combined with adsorber resins and subsequent precipitation with ethanol.

Moreover, in the present study, the higher antioxidant activities (9.47 mM TE) were also obtained after applying the combined treatment PEF + SE.

Fig. 5 shows a comparison of the effects of temperature (20–60 °C) and pH on the concentration of proteins (a), total phenolic compounds (TPC) (b), antioxidant capacity values (AC) (c), and carbohydrates (d), of the extracts obtained after applying aqueous extraction (AE). The data for HVED and PEF methods ($n = 300$) alone and after applying PEF pre-treatment + SE (+SE, $T = 50$ °C, 3 h) are also shown. The results did not show any significant influence of temperature on the recovery of proteins and carbohydrates

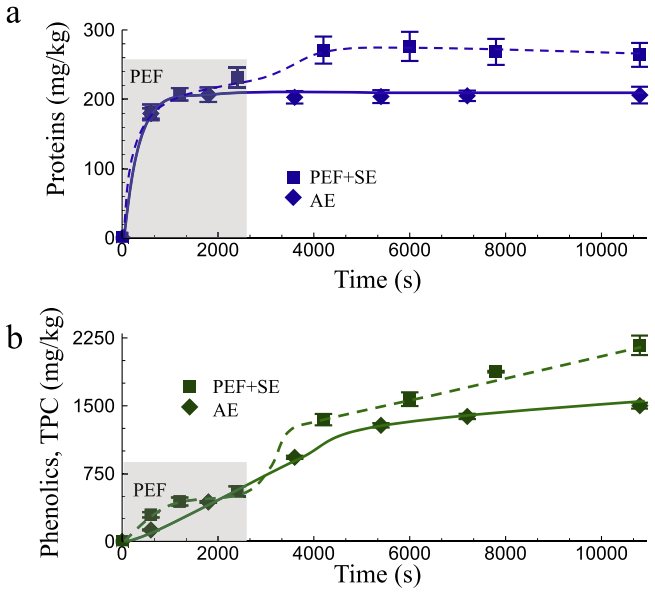

Fig. 4. Concentrations of proteins (a) and phenolics (TCP) (b) versus extraction time obtained after applying aqueous extraction AE and the two-stage procedure consisting on pulsed electric fields (PEF) + supplementary aqueous extraction (+SE) at $T = 50$ °C and pH 6. The dashed areas indicate the time periods where PEF was applied ($n = 1$–300) was stopped at $t = t_e \approx 3/4$ h. Then, the medium temperature was increased up to 50 °C and conventional extraction was continued.

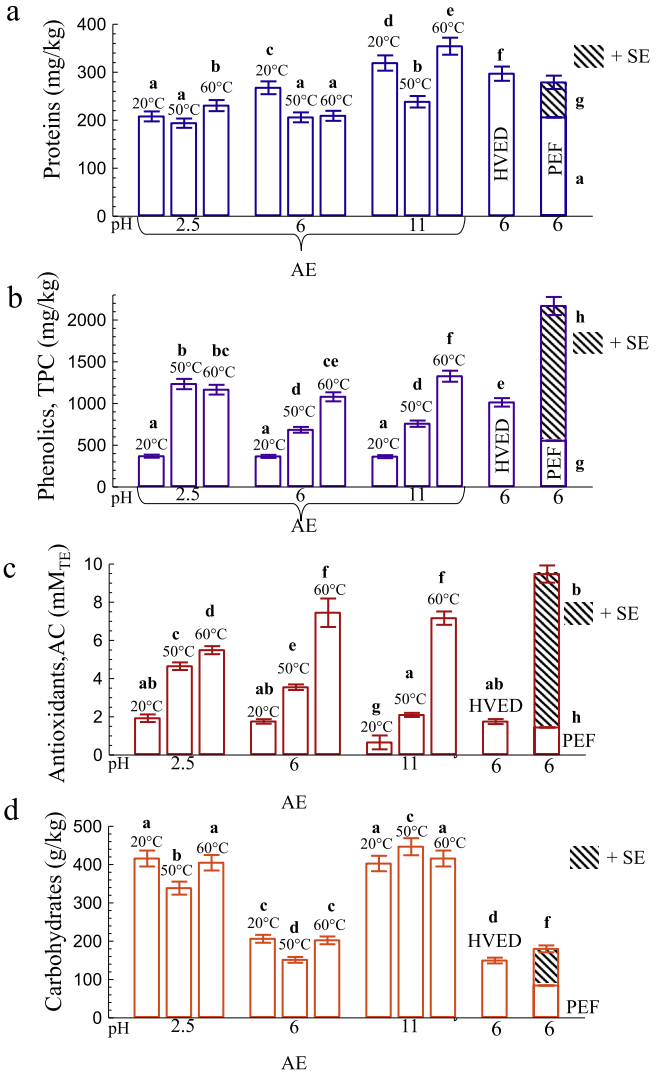

Fig. 5. Concentrations of proteins (a), phenolics (TPC) (b), antioxidants (AC) (c), and carbohydrates (d) of the extracts obtained after applying aqueous extraction (E), ($T = 20$, 50, 60 °C, $t = 3$ h, pH 2.5, 6, 11) and extraction assisted by HVED and PEF methods. The effects of the supplementary water extraction (+SE, $T = 50$ °C) of PEF pre-treated samples on the extracted compounds are also presented. Groups with the same letter are considered to be not statistically significantly different from each other.

when aqueous extraction was used. However, temperature had a significant influence on TPC recovery.

The highest level of proteins was observed in the extracts obtained after conventional AE method (60 °C, pH 11) (Fig. 5a). In this line, some previous studies showed that thermal treatment is a very important technique for the extraction of total proteins. However, high temperatures may result in protein denaturation (Tolman, 1995). For instance, visual observation showed that during 2 h of hot water extraction at 60 °C, the obtained extracts became turbid. This fact can be attributed to protein denaturation of the samples. Moreover, it should be noted that proteins extracted by alkali are not very suitable as food ingredients, probably due to irreversible denaturation during the isolation process. As solubility is often considered to be a prerequisite for the performance of proteins in food applications (Tan, Mailer, Blanchard, & Agboola, 2011), it is significant that proteins isolates from alkaline extraction of mango peels have poor solubility at neutral pH and poor technological functionalities.

Moreover, the obtained data evidenced that the extraction of polyphenols as well as antioxidant capacity (AC) were improved significantly when hot water extraction at 60 °C and pH 11 was used (Fig. 5b and c). In addition, the highest amount of carbohydrates, with an important amount of pectin, was found after using hot water extraction (Fig. 5d), confirming the total destruction of mango peel tissue. As suggested by Grimi et al. (2011), pectin may be responsible for sedimentation phenomena. Likewise, for PEF treatment, extraction of carbohydrates was more difficult. Moreover, extracts obtained after PEF were clearer (Fig. 6). This fact is related to the feasibility of PEF to permeabilize cell membrane without destructing tissue compared to hot water extraction.

In order to confirm this, the colloidal stability of the extracts obtained after PEF treatment and hot water aqueous extraction was studied. The extracts obtained after PEF treatment were relatively clear and practically stable. In addition, their light transmissions averaged over the height of the sample, $\langle T_r \rangle$, did not change during 3 h of centrifugation at 4000 rpm (Fig. 6). However, the extracts obtained by hot water extraction ($T = 60$ °C, pH 11, $t = 3$ h) and HVED methods were unstable. Moreover, a significant increase in $\langle T_r \rangle$ values of these extracts was found, which evidenced the presence of relatively large particles in them.

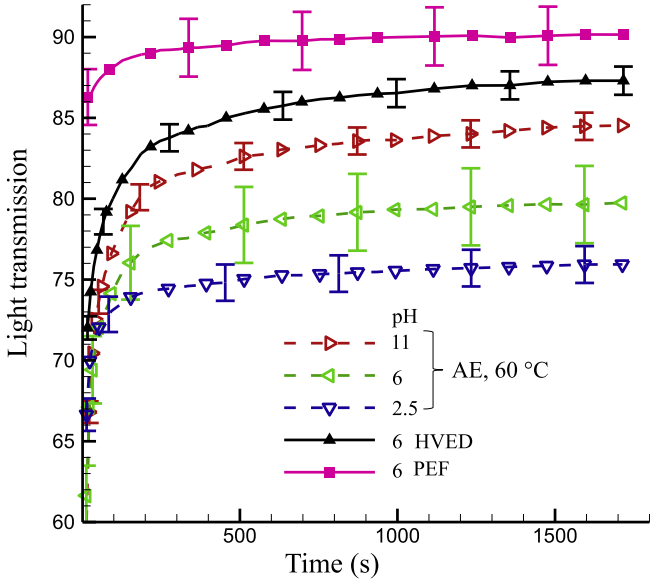

Fig. 6. Light transmission, averaged over the height of the sample versus time of centrifugation for mango peel suspensions.

All these findings confirmed the possibility to attain a selective extraction of valuable compounds from mango peels tissue when PEF is used.

4. Conclusions

The results obtained in the present work demonstrated the feasibility of PEF and HVED treatment combined with hot water extraction at mild temperatures to recover antioxidant compounds, especially total phenolic compounds, and protein from mango peels. These promising results can improve the recovery of nutritionally valuable compounds avoiding the use of solvents, reducing the temperature and using neutral pH conditions. It is of high importance to preserve the functional properties of high-added value components.

Acknowledgements

The authors appreciate the support from the COST Action TD1104 (EP4Bio2Med – European network for development of electroporation-based technologies and treatments). F.J. Barba thanks the Valencian Autonomous Government (Conselleria d'Educació, Cultura i Esport. Generalitat Valenciana) for the postdoctoral fellowship of the VALi+d program "Programa VALi+d per a investigadors en fase postdoctoral 2013" (APOSTD/2013/092).

References

Ajila, C. M., Naidu, K. A., Bhat, S. G., & Rao, U. J. S. P. (2007). Bioactive compounds and antioxidant potential of mango peel extract. *Food Chemistry, 105*(3), 982–988.

Barba, F. J., Esteve, M. J., & Frigola, A. (2013). Gallic acid as a useful indicator of the antioxidant capacity of liquid foods? In *Handbook on gallic acid: Natural occurrences, antioxidant properties and health implications* (pp. 247–263). Nova Science Publishers Inc..

Barba, F. J., Esteve, M. J., Tedeschi, P., Brandolini, V., & Frígola, A. (2013). A comparative study of the analysis of antioxidant activities of liquid foods employing spectrophotometric, fluorometric, and chemiluminescent methods. *Food Analytical Methods, 6*(1), 317–327.

Barba, F. J., Jäger, H., Meneses, N., Esteve, M. J., Frígola, A., & Knorr, D. (2012). Evaluation of quality changes of blueberry juice during refrigerated storage after high-pressure and pulsed electric fields processing. *Innovative Food Science and Emerging Technologies, 14*, 18–24.

Berardini, N., Knödler, M., Schieber, A., & Carle, R. (2005). Utilization of mango peels as a source of pectin and polyphenolics. *Innovative Food Science & Emerging Technologies, 6*(4), 442–452.

Bluhm, H., & Sack, M. (2008). Industrial-scale treatment of biological tissues with pulsed electric fields. In E. Vorobiev & N. Lebovka (Eds.), *Electrotechnologies for extraction from food plants and biomaterials* (pp. 39–81). Springer.

Boussetta, N., Lesaint, O., & Vorobiev, E. (2013). A study of mechanisms involved during the extraction of polyphenols from grape seeds by pulsed electrical discharges. *Innovative Food Science and Emerging Technologies, 19*, 124–132.

Boussetta, N., & Vorobiev, E. (2014). Extraction of valuable biocompounds assisted by high voltage electrical discharges: A review. *Comptes Rendus Chimie, 17*(3), 197–203.

Bradford, M. M. (1976). A refined and sensitive method for the quantitation of microgram quantities of protein using the principle of protein-dye binding. *Analytical Biochemistry, 72*, 248–255.

Brand-Williams, W., Cuvelier, M. E., & Berset, C. (1995). Use of a free radical method to evaluate antioxidant activity. *LWT – Food Science and Technology, 28*(1), 25–30.

Du Bois, M., Gilles, K. A., Hamitton, J. K., Reders, P. A., & Smith, F. (1956). Colorimetric method for determination of sugars and related substances. *Analytical Chemistry, 28*, 350–356.

Evans, E. A., & Ballen, F. H. (2012). An overview of global papaya production, trade, and consumption. Retrieved from <http://edis.ifas.ufl.edu>.

Fincan, M., DeVito, F., & Dejmek, P. (2004). Pulsed electric field treatment for solid-liquid extraction of red beetroot pigment. *Journal of Food Engineering, 64*(3), 381–388.

Garcia-Magana, M. L., Garcia, H. S., Bello-Perez, L. A., Sayago-Ayerdi, S. G., & de Oca, M. M.-M. (2013). Functional properties and dietary fiber characterization of mango processing by-products (*Mangifera indica* L., cv Ataulfo and Tommy Atkins). *Plant Foods for Human Nutrition, 68*(3), 254–258.

Gardner, P. T., White, T. A. C., McPhail, D. B., & Duthie, G. G. (2000). The relative contributions of vitamin C, carotenoids and phenolics to the antioxidant potential of fruit juices. *Food Chemistry, 68*(4), 471–474.

Gorinstein, S., Poovarodom, S., Leontowicz, H., Leontowicz, M., Namiesnik, J., Vearasilp, S., et al. (2011). Antioxidant properties and bioactive constituents of

some rare exotic Thai fruits and comparison with conventional fruits. In vitro and in vivo studies. *Food Research International, 44*(7), 2222–2232.
Gradshteyn, I. S., Ryzhik, I. M., Jeffrey, A., & Zwillinger, D. (1980). *Table of integrals, series, and products*. Academic Press.
Grimi, N., Dubois, A., Marchal, L., Jubeau, S., Lebovka, N. I., & Vorobiev, E. (2014). Selective extraction from microalgae *Nannochloropsis* sp. using different methods of cell disruption. *Bioresource Technology, 153*, 254–259.
Grimi, N., Mamouni, F., Lebovka, N., Vorobiev, E., & Vaxelaire, J. (2011). Impact of apple processing modes on extracted juice quality: Pressing assisted by pulsed electric fields. *Journal of Food Engineering, 103*(1), 52–61.
Hansen, S. L., Purup, S., & Christensen, L. P. (2003). Bioactivity of falcarinol and the influence of processing and storage on its content in carrots (*Daucus carota* L). *Journal of the Science of Food and Agriculture, 83*(10), 1010–1017.
Kim, H., Moon, J. Y., Lee, D.-S., Cho, M., Choi, H.-K., Kim, Y. S., et al. (2010). Antioxidant and antiproliferative activities of mango (*Mangifera indica* L.) flesh and peel. *Food Chemistry, 121*(2), 429–436.
Lebovka, N., Vorobiev, E., & Chemat, F. (2011). *Enhancing extraction processes in the food industry*. CRC Press, Taylor & Francis LLC.
Lerche, D., & Sobisch, T. (2007). Consolidation of concentrated dispersions of nano- and microparticles determined by analytical centrifugation. *Powder Technology, 174*(1–2), 46–49.
Luengo, E., Alvarez, I., & Raso, J. (2013). Improving the pressing extraction of polyphenols of orange peel by pulsed electric fields. *Innovative Food Science and Emerging Technologies, 17*, 79–84.
Malviya, R., & Kulkarni, G. T. (2012). Extraction and characterization of mango peel pectin as pharmaceutical excipient. *Polimery W Medycynie, 42*(3–4), 185–190.
Manas, P., & Vercet, A. (2006). Effect of pulsed electric fields on enzymes and food constituents. In J. Raso & H. Heinz (Eds.), *Pulsed electric field technology for the food industry. Fundamentals and applications* (pp. 131–153). Springer.
Parniakov, O., Lebovka, N. I., Van Hecke, E., & Vorobiev, E. (2014). Pulsed electric field assisted pressure extraction and solvent extraction from mushroom (*Agaricus bisporus*). *Food and Bioprocess Technology, 7*(1), 174–183.
Peschel, W., Sánchez-Rabaneda, F., Diekmann, W., Plescher, A., Gartzía, I., Jiménez, D., et al. (2006). An industrial approach in the search of natural antioxidants from vegetable and fruit wastes. *Food Chemistry, 97*(1), 137–150.
Rajha, H. N., Boussetta, N., Louka, N., Maroun, R. G., & Vorobiev, E. (2014). A comparative study of physical pretreatments for the extraction of polyphenols and proteins from vine shoots. *Food Research International, 65*, 462–468.
Singleton, V. L., Orthofer, R., & Lamuela-Raventos, R. M. (1999). Analysis of total phenols and other oxidation substrates and antioxidants by means of Folin–Ciocalteau reagent. *Methods in Enzymology, 299*, 152–178.
Soliva-Fortuny, R., Balasa, A., Knorr, D., & Martín-Belloso, O. (2009). Effects of pulsed electric fields on bioactive compounds in foods: A review. *Trends in Food Science and Technology, 20*(11–12), 544–556.
Tan, S. H., Mailer, R. J., Blanchard, C. L., & Agboola, S. O. (2011). Canola proteins for human consumption: Extraction, profile, and functional properties. *Journal of Food Science, 76*(1), 16–28.
Toepfl, S., Heinz, V., & Knorr, D. (2007). High intensity pulsed electric fields applied for food preservation. *Chemical Engineering and Processing: Process Intensification, 46*(6), 537–546.
Tolman, G. H. (1995). Effect of hot aqueous ethanol treatment on anti-nutritional factors, protein denaturation and functional properties in raw pea and pea protein isolate. *Animal Feed Science and Technology, 56*(1), 159–168.
Vorobiev, E., & Lebovka, N. (2008). Pulsed-electric-fields-induced effects in plant tissues: Fundamental aspects and perspectives of applications. In E. Vorobiev & N. Lebovka (Eds.), *Electrotechnologies for extraction from food plants and biomaterials* (pp. 39–81). Springer.
Vorobiev, E., & Lebovka, N. (2010). Enhanced extraction from solid foods and biosuspensions by pulsed electrical energy. *Food Engineering Reviews, 2*(2), 95–108.
Vorobiev, E., & Lebovka, N. I. (2006). Extraction of intercellular components by pulsed electric fields. In J. Raso & V. Heinz (Eds.), *Pulsed electric field technology for the food industry. Fundamentals and applications* (pp. 153–194). Springer.
Wang, L., & Weller, C. L. (2006). Recent advances in extraction of nutraceuticals from plants. *Trends in Food Science and Technology, 17*(6), 300–312.
Zulueta, A., Barba, F. J., Esteve, M. J., & Frígola, A. (2013). Changes in quality and nutritional parameters during refrigerated storage of an orange juice-milk beverage treated by equivalent thermal and non-thermal processes for mild pasteurization. *Food and Bioprocess Technology, 6*(8), 2018–2030.