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Recovery of colorants from red prickly pear peels and pulps enhanced by pulsed electric field and ultrasound

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ABSTRACT

The aim of this work was to evaluate the potential of the non-conventional pre-treatments; pulsed electric fields (PEFs) and ultrasounds (USNs), to enhance the extraction of red colorants from red prickly pear (*Opuntia stricta* Haw.) peels and pulps. The overall goal was to valorize the thick part of the fruit, being discarded for fruit's consumption. PEF and USN treatments were first optimized using fruit slices, followed by a supplementary aqueous extraction (+SAE) up to 1 h. The optimal conditions were then applied for peels and pulps, separately. Results showed that PEF + SAE and USN + SAE enhanced significantly the extraction of red colorants (betanin/isobetanin), compared to untreated tissues. Promising results for colorants recovery were obtained from fruit peels, using both pre-treatments, compared to that obtained from pulps, and without pre-treatment. Scanning electron microscopy revealed cell denaturation after PEF and USN pre-treatments, which can provide better recovery of the intracellular compounds with less impurity.

Industrial relevance: Wastes and by-products generated during fruit processing constitute a great source of high-added value compounds, which have the potential to be used as food additives and/or as nutraceuticals. *Opuntia* fruits constitute a great source of bioactive compounds. In particular, *Opuntia* fruit processing by-products are interesting as they contain a great amount of potential food additives, including food colorants (i.e. betanin/isobetanin), thus constituting an important alternative to replace synthetic colorants that have been restricted by governmental organizations. In this line, pulsed electric field and ultrasounds are proposed in this work as promising technologies for the enhancement of the extraction of colorants from red prickly pear peels and pulps.

1. Introduction

Waste and by-products generated during fruit processing constitute a great source of high-added value compounds, which have the potential to be used as food additives and/or as nutraceuticals. *Opuntia* fruit processing by-products are especially interesting as they contain a great amount of potential food additives, including food colorants (i.e. betanin/isobetanin), thus constituting an important alternative to replace synthetic colorants that have been restricted by governmental organizations, being the most affected are red colorants.

Red pigments present in *Opuntia* fruits (i.e. betacyanin) do not have any toxic effect on humans (Castellar, Solano, & Obón, 2012). Moreover, they have an important stability in aqueous solutions (Castellar, Obón, Alacid, & Fernandez-Lopez, 2003; Castellar, Obón, & Fernandez-Lopez, 2006; Fernandez-Lopez, Angosto, Gimenez, & Leon, 2013).

For instance, only conventional extraction methods have been used for the recovery of natural pigments from *Opuntia* fruits, showing the potential of this genus as a promising source of natural colorants (Castellar et al., 2006; Prakash Maran & Manikandan, 2012). Despite obtaining some interesting results, the applied methods required high amounts of solvent (usually water and/or ethanol), as well as several downstream purification steps, thus limiting the transfer of technology to industrial scales. Moreover, these conventional methods require generally long processing time in order to maximize the extraction yields, which increases the operational cost.

Finding new alternative technologies to reduce/eliminate the use of toxic solvents, along with reducing the operational time and energy, as well as the enhancement of the extraction yields, is of great importance. Therefore, many authors have been interested in emerging technologies, such as pulsed electric fields (PEFs), as alternative method for the recovery of biomolecules from plant matrices (i.e. pigments) (Barba, Grimi, & Vorobiev, 2015; Bobinaite et al., 2014; Corrales, Toepfl, Butz, Knorr, & Tauscher, 2008; Loginova, Lebovka, & Vorobiev, 2011; Puertolas, Cregenzan, Luengo, Alvarez, & Raso, 2013). It has been

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shown that PEF technology extracts selectively targeted molecules, without damaging the treated sample (Vorobiev & Lebovka, 2008; Barba, Parniakov et al., 2015). This finding is of great importance as it facilitates the downstream steps of separation and purification (Barba, Brianceau, Turk, Boussetta, & Vorobiev, 2015; Vorobiev & Lebovka, 2010). In addition, PEF technology allowed obtaining interesting results for the extraction of betanin from red beetroots (Fincan, DeVito, & Dejmek, 2004; Kannan, 2011; Neelwarne, 2012).

Another non-conventional technology consisting of ultrasound-assisted extraction has shown its potential to recover antioxidant and colorants from fruit by-products (Chemat, Zill-E-Huma, & Khan, 2011; Roselló-Soto et al., 2015). This technology is considered as a promising and alternative tool for conventional extraction procedure as in general it allows improving high-added value compounds yield, thus reducing the extraction time and the temperature as well as minimizing the solvent consumption. In this line, the potential of USN technology to extract colorants from red beetroots was previously discussed (Neelwarne, 2012).

However, at this stage of development there is a lack of information in the available literature regarding the effects of PEF- and ultrasound-assisted extraction for colorants recovery from red prickly pear (*Opuntia stricta* Haworth (Haw.)) by-products. Therefore, the main aim of this work is to show the potential of these technologies to be used for colorants recovery from *O. stricta* fruits. In this line, slices of red prickly pear were used for the optimization of the pre-treatment conditions using PEFs and USNs followed by a supplementary aqueous extraction (+SAE) up to 1 h. The best conditions were applied to the fruit's peels and pulps separately, and the recovery yield of colorants was compared to conventional aqueous extraction. The microstructure of the cells after 1 h extraction, PEF + SAE, and USN + SAE was also analyzed.

2. Materials and methods

2.1. Chemicals and reagents

Folin–Ciocalteu reagent, DPPH (2,2-diphenyl-1-picrylhydrazyl), gallic acid, formic acid and betanin/isobetanin standard were purchased from Sigma-Aldrich (Saint-Quentin Fallavier, France). Sodium bicarbonate was obtained from VWR (France). Acetonitrile (HPLC grade) was obtained from Fisher Scientific (France). Deionized water for both colorant extracts and HPLC analysis was obtained using Elix advantage water purification system E-POD (Merck Millipore, France) with an electrical conductivity of 0.18 μs/cm.

2.2. Plant material

O. stricta Haw. fruits were collected in the suburb of Sfax city (Tunisia) in January 2015. Moisture content, determined using a "Scaltec" infrared desiccator, was 78.7 ± 0.7%. Prior to extraction, the fruits were cut manually forming slices of 5 mm thickness and ≈25 mm diameter (Fig. 1), and were used for PEF and USN optimization process. Peels and pulps were then manually separated from the fruits using a scalpel. Pulps were cut forming 5 mm (thickness) slices, whereas peels were cut as presented in Fig. 1.

2.3. Conventional diffusion procedure

For control extractions, 30 g of *Opuntia* fruit slices, peels, and pulps was introduced separately in a beaker with 300 mL water (pH 7). The extraction was performed for 60 min under magnetic stirring (250 rpm), at room temperature (Fig. 1). Total colorant content was determined by grinding 30 g of fruits using a kitchen mixer and

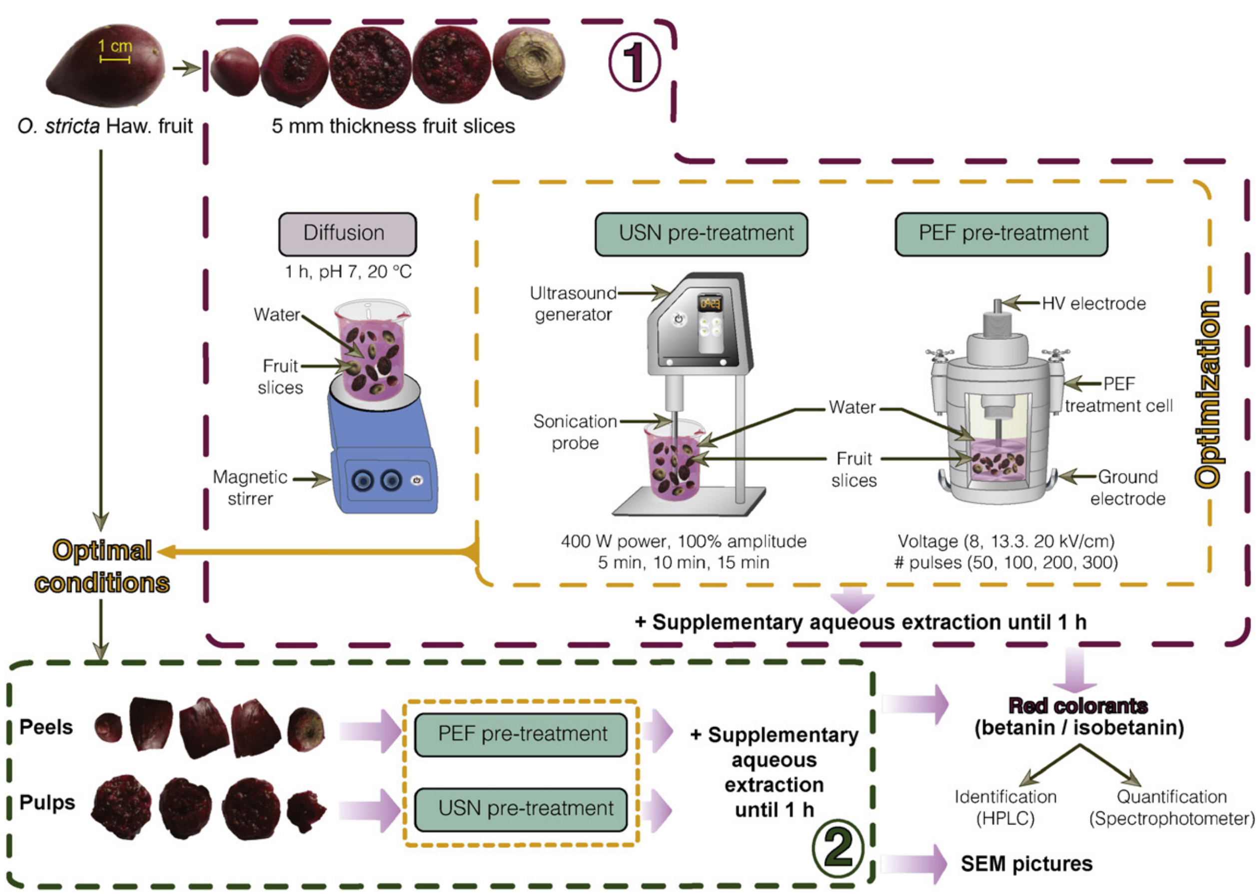

Fig. 1. Experimental set-up. HV: high voltage, PEFs: pulsed electric fields, USN: ultrasounds, SEM: scanning electron microscopy.