LWT - Food Science and Technology 74 (2016) 493–503

Contents lists available at ScienceDirect

LWT - Food Science and Technology

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

Effects of ohmic heating on extraction of food-grade phytochemicals from colored potato

Ricardo N. Pereira [a], [*], Rui M. Rodrigues [a], Zlatina Genisheva [a], Hélder Oliveira [b], Victor de Freitas [b], José A. Teixeira [a], António A. Vicente [a]

[a] *CEB - Centre of Biological Engineering, University of Minho, Campus de Gualtar, 4710-057, Braga, Portugal*
[b] *REQUIMTE/LAQV, Department of Chemistry and Biochemistry, Faculty of Sciences, University of Porto, 4169-007 Porto, Portugal*

ARTICLE INFO

Article history:
Received 14 January 2016
Received in revised form
30 June 2016
Accepted 31 July 2016
Available online 1 August 2016

Keywords:
Ohmic heating
Moderate electric field
Extraction
Anthocyanins
HPLC

ABSTRACT

The influence of ohmic heating (OH) through the application of moderate electric fields on phytochemical compounds recovery from colored potato (*Solanum tuberosum* L. var. Vitelotte) was studied. A Box–Behnken design was used to simultaneously assess the effects of operational parameters such as electric field strength, temperature and process time on the yields of anthocyanins and total phenolic recovery on pretreatment of potato samples. From the analysis of the model, electric field, temperature and time were shown to have independent and interactive effects on the values of extraction yields. Aqueous extraction of phytochemical compounds after pretreatments can be described by using a two-step model involving simultaneous washing and diffusion of the solutes from the samples. Results shows that electrical fields of low energy levels and thermal effects can be combined and optimized into a single step treatment on extraction of anthocyanins and phenolic compounds from vegetable tissues providing high recovery yields with a reduced treatment time, less energy consumption and with no utilization of organic solvents (green extraction).

1. Introduction

The growing concerns over environmental issues are driving a strong and sustainable demand for “green” processing technology solutions. Maximizing process efficiency, reducing waste or using byproducts and nonconventional sources of raw materials are interesting alternatives and are drawing attention form researchers both in academia and industry (Lin et al., 2013). Food-stuff is an interesting source of biomolecules as proteins, polysaccharides, lipids, as of lower amounts of high added-value substances such as polyphenols, pigments, vitamins, among others (Galanakis, 2012). During food processing significant amounts of this compounds are lost ether by the degradation during processing or discarded along the waste. Most of these compounds, when recovered, may be reintroduced in the food industry or valorized e.g. for energy production, use in pharmaceutical products, among others (Galanakis, 2012; Lin et al., 2013). Together with the increasing interest in this compounds, new recovery methods are being developed. The focus is to maintain the energy input low, reduce the use of chemicals and organic solvents and increase recovery efficiencies (Chemat, Vian, & Cravotto, 2012).

Recently, electro-technologies such as Pulsed Electric Fields (PEF) and Ohmic Heating (OH), also known as Moderate Electric Fields (MEF), gained considerable interest for the processing of foods and in bioprocesses. They have shown to be mild processing technologies preserving nutritional, functional, structural, and sensory properties of products better than conventional technologies (Knirsch, Alves dos Santos, Martins de Oliveira Soares Vicent, & Vessoni Penna, 2010; Vorobiev and Lebovka, 2009). These are also environmentally clean technologies (at least locally), be it by improving the overall energy efficiency of the process or by reducing the use of non-renewable resources, reducing environmental footprint, while reducing processing costs and improving the added-value of the products (Pereira & Vicente, 2010.). In both cases the presence of an electric field causes electroporation of cellular tissues allowing an enhanced extraction of bioactive compounds (El Darra, Grimi, Vorobiev, Louka, & Maroun, 2012; Sensoy & Sastry, 2004; Vorobiev & Lebovka, 2009). PEF is usually presented as an attractive alternative due to its high efficiency, low energy

---

* Corresponding author.
E-mail addresses: rpereira@deb.uminho.pt, rncpereira@hotmail.com (R.N. Pereira).

http://dx.doi.org/10.1016/j.lwt.2016.07.074

requirements and lower heat generation. However, this technology still presents some drawbacks related with electrodes oxidation and erosion, power generator costs and complexity, together with difficulties in controlling e.g. temperature as well as other processing consequences such as electrode fouling, bubbling, among others (Mohamed & Eissa, 2012; Ravishankar, Zhang, & Kempkes, 2008). OH is mostly known for its capacity to provide fast, homogeneous and precise heating wherever direct application of electrical energy to the food ensures a highly efficient energy transfer. For these reasons OH is currently being successfully implemented in food processing industry (Sakr & Liu, 2014; Sastry, 2008). MEF non-thermal effects (e.g. electroporation) were also reported in the literature, nevertheless they were not yet as studied as in PEF nor commercially exploited (Kusnadi & Sastry, 2012; Sastry, 2008). Despite electric effects in MEF being reported to be more effective at low frequencies (Nair et al., 2014; Shynkaryk, Ji, Alvarez, & Sastry, 2010), they have also been observed at high frequencies (i.e. kHz range) and proven effective in other applications such as cancer cell disruption (Kirson, 2004). From the process point of view, working at high frequencies (i.e. >17 kHz) is more advantageous since electrolysis, electrode erosion and leakage of metals to the heating medium are effectively eliminated, ensuring the reliability of the system and the safety of the processed products, even when a low-cost and electrochemically active electrode material like stainless steel is used (Pataro et al., 2014; Sastry, 2008; Shynkaryk et al., 2010).

Heat generation is commonly faced as an issue in studies regarding electric effects, however technologically thermal effects may be advantageous (Allali, Marchal, & Vorobiev, 2008; Lebovka, Kupchik, Sereda, & Vorobiev, 2008) and the synergistic effects of temperature and electric field may bring new perspectives in the processing industry, as in the case of blanching or thermal stabilization of bio-materials.

Potato tissue is commonly used as a model for vegetable and foodstuff cellular material. Several studies report thermal and electric effects in this material, regarding for example stabilization or blanching (González-Martínez, Ahrné, Gekas, & Sjöholm, 2004; Zielinska, Błaszczak, & Devahastin, 2015) and permeabilization (Kulshrestha & Sastry, 2006; Lebovka, Praporscic, Ghnimi, & Vorobiev, 2006). *Solanum tuberosum* L. var. Vitelotte, is a colored potato variety with blue skin and violet flesh widely used for human consumption. The pigments responsible for its color are anthocyanins, which have reported antioxidant and antimicrobial activities (Bontempo et al., 2013). Anthocyanins belong to the class of phenolic compounds and are characterized by their color and stability, which are both affected by physical and (bio)chemical factors - i.e. temperature, light, pH and attacks by specific chemical groups or enzymes (Reyes & Cisneros-Zevallos, 2007). Other phenols are present in this potatoes, also with reported bioactivities and recognized value (Al-Saikhan, Howard, & Miller, 1995; Mulinacci et al., 2008; Nems et al., 2015).

The present study has the objective of evaluating the combined effects of the most relevant OH process parameters (i.e. electric field strength, temperature and time of process), in the pretreatment and further extraction of bioactive compounds from colored potatoes. A Box-Behnken design in Response Surface Methodology (RMS) was used to study the electric, thermal and time effects and to establish the most favorable pretreatment conditions and its influence on anthocyanin and total phenols extraction. The selection of treatment and extraction conditions aimed at achieving a feasible, low-cost and low-environmental impact process.

2. Material and methods

2.1. Sample material

Purple potatoes (*Solanum tuberosum* L. var. Vitelotte) were kindly supplied by a local producer. Potatoes with no apparent defects and approximately the same caliber (Ø 50 mm) were selected and stored (4 °C and ≈100% RH) in the dark without the addition of sprouting inhibitors. Before utilization potatoes were allowed to equilibrate at room temperature, then washed and peeled. A potato cylinder was obtained with a tubular cutter (Ø 20 mm) along with the tuber axis, obtaining a sample constituted by medulla and perimedulla tissue. This cylinder was then cut in 5 mm thick discs, from which the end pieces were discarded to ensure maximum homogeneity between samples. The obtained discs were washed with distilled water and gently dried with paper towels. For each individual potato, the samples were divided in two groups and immediately used; one group was used to perform the electro-heating treatments and the other group was used to determine maximum content of anthocyanins and total phenolic content (TPC) of that particular individual. This allowed to normalize all the results as a percentage of the maximum content of these compounds found in each individual potato thus overcoming its natural variability.

2.2. Experimental setup

The electro-heating treatments were performed in a jacketed static ohmic heater as described elsewhere (Pereira et al., 2015; Pereira, Souza, Cerqueira, Teixeira, & Vicente, 2010). The distance between electrodes was kept constant, and the voltage varied in the power source working with a sinusoidal wave at 25 kHz (1 Hz–25 MHz and 1–10 V; Agilent 33220A, Penang, Malaysia). A circulator water system (F25-ED, Julabo, Seelbach, Germany) was used to heat up in the case of conventional thermal treatment (0 V/cm) and to refrigerate when higher electric fields were applied, thus allowing to maintain similar heating rates in all types of treatments. A KCl iso-conductive solution was prepared according with Kulshrestha and Sastry (2006) to ensure a homogeneous current flow and poured to the processing chamber in a solid-liquid ratio of 1:1. Temperature was recorded with a type-K thermocouple (temperature precision of ±1 °C; Omega Engineering, Inc., Stamford, CT, USA), placed at the geometric center of the sample volume and connected to a data logger (USB-9161, National Instruments Corporation, Austin, TX, USA). Measurements of electrical frequency, voltage and current intensity during OH treatments were measured through portable oscilloscope (ScopeMeter® 125/S, Fluke, Everett, WA, USA).

2.3. OH treatments

Electro-heating treatments were performed through three-factor Box–Behnken experimental design in which the combined effect of three independent variables – electric field, holding temperature and treatment time were evaluated. During OH the MEF applied was of 0 V/cm (conventional heat exchange heating), 15 V/cm and 30 V/cm (OH); for each MEF level the temperatures selected were 30 °C (≈room temperature), 60 °C and 90 °C (corresponding to minimum and maximum blanching temperatures (Abu-Ghannam & Crowley, 2006). The holding time was of 0, 5 and 10 min. The response values were anthocyanins yield and TPC yield. The design consisted of 15 combinations including three replicates of the center point (Table 1). All experiments were made in a randomized order to avoid variability in the independent variables due to the eventual occurrence of systematic errors. The heating