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The effect of pulsed electric field pre-treatments prior to deep-fat frying on quality aspects of potato fries

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ABSTRACT

The effect of pulsed electric fields (PEF) on potatoes intended for deep-fat frying was investigated. Potato cubes were submitted to 18.9 kJ/kg PEF treatments by applying 9000 pulses at 0.75 kV/cm electric field or 810 pulses at 2.50 kV/cm electric field. Regardless of the process conditions applied, PEF treatments increased moisture and softened potato cubes with no modification on their fresh-like appearance. Potato cubes submitted to PEF also showed a lower oil uptake upon frying than blanched and water-dipped controls. These effects were attributed to the structural modification of potato tissue upon PEF-induced electroporation. The latter could also favour leaching of reducing sugar from potato cubes surface, accounting for a lower browning tendency during frying.

Industrial relevance: PEF technology could reduce chemical use, process time, water and energy consumption in potato fries production. It could also allow mass transfer to be controlled during frying, improving product colour and reducing oil uptake.

1. Introduction

Blanching is a particularly critical process in par-fried potato production. It is generally performed in water at 55–75 °C for at least 10 min to get a uniform colour of the product by inactivating polyphenoloxidase and to soften the tissues by the activity of pectin methyl esterase. The latter also promotes strengthening of potato cell walls by increasing the amount of free carboxyl groups of pectin, thus allowing networking by Ca^{2+} bridges (Andersoon, Gekas, Lind, Oliveira, & Oste, 1994; Bartolome & Hoff, 1972; Tajner-Czopek, Figiel, & Carbonell-Barrachina, 2008). Blanching has the drawback of being time-intensive and requiring high amounts of water. In addition, it has low energy efficiency, which further decreases when blanching water becomes saturated with sugars leached from the potato strips (Bingol, Wang, Zhang, Pan, & McHugh, 2014). Potato iron and chlorogenic acid may form a colourless complex upon blanching that, upon oxidation, creates ferridichlorogenic acid providing an undesirable dark colour of the blanched tissue (Wang-Pruski & Nowak, 2004). In order to prevent this defect, the blanching aqueous solution is generally added with chemicals as sulphites. However, the latter may leave a residue in the product, causing an allergic reaction in sensitive consumers (Peroni & Boner, 1995).

The minimisation of chemical additives and the excessive use of water and energy are thus major challenges for par-fried potato producers. This issue follows the general trend of the food industries which are nowadays required not only to provide the consumers with safe and healthy food but also to reach this goal by applying sustainable technologies (Ölmez & Kretzschmar, 2009). In recent years, growing attention has been given to novel non-thermal technologies which have great potential in terms of their ability to reduce both energy costs and also shorten treatment times. In this context, pulsed electric fields (PEF) are recognised as an appropriate technology for different applications in food processing with rather low power consumption (Boussetta, Grimi, Lebovka, & Vorobiev, 2013). PEF involves the application of short duration pulses (μs to ms) of high voltage electric fields to a sample located between two electrodes. The generation of transmembrane potential may cause temporary or permanent permeabilisation of cell membranes through a process known as electroporation (Zimmermann, 1986). Besides its well-known use to decontaminate food, PEF is also exploited to modify plant tissue structure. Compared to small bacterial cells (1–10 μm), which require high electric fields for membrane permeabilisation, plant cells need lower electric fields (1–2 kV/cm) due to the larger size (10–100 μm) (Janositz & Knorr, 2010).

A review of the literature shows that PEF promotes softening of plant tissue such as carrots, apples and potatoes (Boussetta et al., 2013; Lebovka, Praporscic, & Vorobiev, 2004). PEF have also been applied to enhance mass transfer processes such as extraction, drying and frying in different fruits and vegetables (Amami, Khezami, Vorobiev, & Kechaou, 2008; Donsì, Ferrari, & Pataro, 2010; Górgora-Nieto, Sepúlveda, Pedrow, Barbosa-Cánovas, & Swanson, 2002; Janositz,

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Noack, & Knorr, 2011a; López, Puértolas, Condón, Raso, & Alvarez, 2009; Palgan et al., 2012). However, little data is available on the possibility for PEF treatments to improve the quality of potatoes intended for deep-fat frying.

The aim of the present work was to investigate the potential of pulsed electric fields to modify raw potato structure and to influence the final quality of deep-fat fried potatoes. In particular, potato cubes were submitted to low electric field strength (0.75 and 2.50 kV/cm). The tissue modification was studied in comparison with water-dipped and blanched potato cubes considering the changes in drip loss, colour and texture. Following PEF pre-treatments, samples were par-fried, frozen, stored at −20 °C for 7 days to simulate industrial production of par-fried potatoes. Potato cubes were then finish-fried and analysed for texture, colour and oil content.

2. Materials and methods

2.1. Sample preparation

Raw potatoes (*Solanum tuberosum*, var. Rooster) were purchased at a local supermarket and stored in the dark at room temperature for a maximum of 7 days. Potatoes were manually peeled, washed in tap water, drained with paper and cut into 2 × 2 × 2 cm cubes (8.5 g). Potato cubes were immersed in tap water at 20 °C prior to PEF processing, which occurred within 20 min.

2.2. Pulsed electric field treatments

A lab scale pulsed electric fields (PEF) unit (ELCRACK HVP5, DIL, German Institute for Food Technologies, Quakenbrück, Germany) with a maximum output voltage of 25 kV was used. The system employed a bipolar rectangular-shaped pulse having pulse width of 20 μs and a repetition rate of 250 Hz. The system was connected to a digital oscilloscope (Model No. TDS 2012, Tektronix, Beaverton, OR, USA). The treatment module consisted of a batch chamber with 8 cm electrode gap and 37.5 cm^2 area for each electrode, resulting in a 300 cm^3 total volume, modified after Haughton et al. (2012). For each PEF treatment, 9 potato cubes (75 g) were placed on the Teflon base of the chamber in a 3 × 3 configuration. Tap water (225 g) was added to guarantee uniform distribution of the electric field. Samples were processed at room temperature and were subjected to PEF treatments characterised by a total energy (*Q*) of 18.9 kJ/kg. The latter was calculated according to Zhang, Barbosa-Cánovas, and Swanson (1995) based on:

$$Q = \frac{V^2 t}{R\, m} \tag{1}$$

where *V* is the voltage (kV), *t* is the treatment time (s), *R* is the resistance (ohm) and *m* is the sample mass (kg).

Two PEF treatments were performed: (i) 9000 pulses at 0.75 kV/cm electric field ("Low PEF") (ii) 810 pulses at 2.50 kV/cm electric field ("High PEF"). After the treatment, samples were taken from the PEF chamber, drained with paper and stored for further analysis.

Control samples were prepared by dipping just-cut potato cubes in tap water at 20 °C for 20 min (potato–water ratio 1:10, *w*/*w*). Additional control samples were prepared by blanching potato cubes in a 0.25% (*w*/*v*) sodium metabisulfite aqueous solution (Merck KGaA, Darmstadt, Germany) in a thermostated bath (Mod. JB5, Grant Instruments Ltd, Cambridge, UK) at 70 °C for 16 min (potato–water ratio 1:10, *w*/*w*) (Bingol et al., 2014). Potato cubes were then cooled in tap water at 20 °C for 2 min (potato–water ratio 1:20, *w*/*w*). After the treatments, control samples were drained with paper and used for further analysis.

The total energy (*Q*) of potato blanching was 209.3 kJ/kg. The latter was calculated based on:

$$Q = c_p \Delta T \tag{2}$$

where c_p is the specific heat capacity of liquid water (kJ/°C kg) and ΔT is the temperature increase from 20 to 70 °C.

2.3. French fries preparation

A commercial deep-fat fryer (Cookworks, Argos Ltd, Milton Keynes, United Kingdom) was used for the frying tests. Potato cubes were par-fried in sunflower oil at 190 °C for 1 min (potato–oil ratio 1:40, *w*/*w*). The frying sieve was shaken to remove the excess oil and the potato cubes were drained for few seconds on paper. After cooling at room temperature for 10 min, potato cubes were frozen in an air blast freezer (Mod. FT36, Armfield, Hampshire, United Kingdom) at −30 °C for 30 min. Samples were then packed in plastic bags (Mod. 021ODC681, Webomatic, Bochum, Germany) and stored at −18 °C in a thermostated cell for 7 days. Potato cubes were then finish-fried for up to 4 min adopting the same procedure previously described.

2.4. Temperature

A K-type thermocouple connected to a data logger (Mod. 8856, Eurolec Instrumentation Ltd, Dundalk, Ireland) was used.

2.5. Weight loss

Samples weight loss was calculated as the percentage weight difference between initial and final weight as a result of treatments.

2.6. Moisture

The moisture content was determined according to oven drying method at 105 °C for 18 h (AACC, 2000).

2.7. Drip loss

A potato cube was weighted, wrapped in cheesecloth and inserted into a 50 mL capacity plastic centrifuge tube half fitted with cotton wool. Following the centrifugation at 1000 rpm for 10 min (Rotina 380, Hettigh Instruments LP, Tuttlingen, Germany), the sample was removed from the tube and reweighed. Drip loss was calculated as the percentage ratio between initial and final weight of the potato cube.

2.8. Colour

Colour was analysed using a tristimulus colourimeter (Model No. CR-400, Minolta Ltd., Osaka, Japan). The instrument was standardised against a white tile before measurements. Colour was expressed in lightness (L^*), green to red (a^*) and blue to yellow (b^*) Hunter scale parameters. For each sample eight measurements were taken at different position on the surface.

2.9. Texture

An Instron Universal Testing machine (Mod. 5544, Instron Corporation, High Wycombe, UK) equipped with a 500 N load cell was fitted with a Warner Bratzler flat blade (1.0 mm thick). The test was performed at a cross head speed of 250 mm/min for the first 2.5 mm followed by a 50 mm/min speed for a total length of 20 mm. Data were analysed by Bluehill 2 software package (Version 2.5, Instron Corporation, High Wycombe, UK). The parameters measured from the force deformation curve were the maximum peak force (N) and total energy calculated as the area below the curve (J).

2.10. Oil content

Potato cubes were weighted and dried at 70 °C for 12 h in a convection oven (FD 115, Binder GmbH, Tuttlingen, Germany). The oil