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Freezing of potato tissue pre-treated by pulsed electric fields

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ABSTRACT

The effects of pulsed electric fields (PEF) pre-treatment on the freezing, freeze-drying and rehydration behavior of potato were studied. Potato samples (26 mm diameter, 10 mm high) were treated by PEF (400 V/cm) for various durations between 10^{-4} and 0.3 s. The degree of tissue damage was quantified by the change in electrical conductivity. PEF treated and untreated samples were either frozen in an air-blast freezer with air at −35 °C and 2 m/s velocity or freeze-dried at 0 °C and 0.04 mbar pressure and then rehydrated in water at 25 °C. The freezing times for PEF pre-treated samples reduced as the PEF-induced tissue damage increased. Scanning electron microscope images of the air-blast frozen and then freeze-dried samples showed increased deformation of cells and larger intercellular spaces (frozen samples only) for the PEF pre-treated samples. However, PEF pre-treatment improved the rate of freeze-drying and improved the quality and rehydration of the samples.

1. Introduction

Freezing is widely used to preserve food products because it results in minimal deterioration of original color, flavour, texture or nutritional values. The quality of frozen food is considered inversely related to the extent of freezing-induced cellular dehydration, the size of the ice crystals and their location inside the foods (Delgado & Sun, 2001; Li & Sun, 2002a). The existing freezing preservation technologies try to avoid formation of large ice crystals inside the food by regulation of heat removal. Water expands when frozen, and large ice crystals formed cause membrane damage and cell shrinkage (Reid, 1997). A rapid freezing rate results in the formation of smaller and more numerous ice crystals, which is preferable for avoiding damage to the cellular structure. Different techniques, such as air-blast freezing, immersion freezing, contact freezing, their combination with dehydrofreezing, addition of antifreeze or ice nucleation proteins, and high-pressure- or ultrasound wave-assisted freezing, are discussed in the literature (Kalichevsky, Knorr, & Lillford, 1995; LeBail, Chevalier, Mussa, & Ghoul, 2002; Li & Sun, 2002b; Luscher, Schlüter, & Knorr, 2005; Martino, Otero, Sanz, & Zaritzky, 1998; Sun & Li, 2003).

This work investigates the effects of pulsed electric field (PEF) pre-treatment on the responses of potato tissue to freezing. It is known that PEF treatment at electric field strength, *E*, of 0.5–1 kV/cm and treatment times between 10^{-4} and 10^{-2} s causes electroporation and membrane damage (Weaver & Chizmadzhev, 1996), but has no serious effect on the semi-rigid structure of cell walls in soft cellular tissues (Fincan & Dejmek, 2002; Vorobiev, Jemai, Bouzrara, Lebovka, & Bazhal, 2005; Vorobiev & Lebovka, 2006). Moderate electric field treatment was also shown to be sufficient for electroporation of plant cells (Kulshrestha & Sastry, 2003, 2006).

The release of cytoplasm in the PEF pre-treated tissues is expected to influence the freezing process, but may result also in change of the spatial gradients (concentration and/or temperature) inside the sample. However, the freezing response of PEF pre-treated tissues was not studied previously.

The main objective of this study is to find the relationships between the PEF-induced damage and air-blast freezing or freeze-drying and rehydration behavior and structural changes in potato tissue.

2. Materials and methods

Commercial potatoes (Agata) of good and uniform quality were purchased at the local supermarket (Compiegne, France) and stored at 4 °C until required. The moisture content was 83–85%. Samples were prepared in the form of cylinders having diameter, *d*, of 26 mm and height, *h*, of 10 mm. In order to reduce the degradation processes and to avoid visible browning at the sample surface, the cylinders were soaked after cutting in fresh clarified juice prepared from the same plant tissue.

The PEF treatment cell consisted of a polypropylene cylindrical tube (Atelier Genie Chimique, UTC, Compiegne, France) with inner

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diameter, d, of 26 mm and an electrode at the bottom. Initially, bottom electrode was coved with fresh potato juice. Fresh juice was chosen as a natural medium in order to reduce the sample degradation and to improve electrical contact between the electrodes and the sample. Then a sample was placed inside the cell, coved with fresh potato juice and then a second electrode was installed at the top of the sample. The distance between electrodes was determined by the sample height ($h = 10$ mm).

The treatment cell was placed inside a thermostat (Haake N3, Berlin, Germany). The temperature control (±0.1 °C) was provided by a Teflon-coated thermocouple Thermocoax type 2- AB 25 NN (Thermocoax, Suresnes, France).

The electric field treatment was applied using a PEF generator, 400 V/38 A (Service Electronique UTC, Compiegne, France). It provided bipolar pulses of near-rectangular shape, which avoided asymmetric electroporation at the poles of the cells (Kotnik, Puciha r, Rebersek, Miklavcic, & Mir, 2003). N series of pulses were used for the PEF treatment. An individual series consisted of $n = 2$ pulses with pulse duration $t_i = 100$ μs and pulse repetition time of $\Delta t = 200$ μs. There was a pause of $\Delta t_t = 10$ s after each series (Fig. 1). The total time of PEF treatment was $t_t = nNt_i$.

In some PEF experiments the ohmic temperature elevation inside geometrical centre of a sample was checked. Due to the long inter-series pause Δt_t, the observed ohmic temperature elevation, ΔT, during each series application with a field strength, E, less than 400 V/cm was approximately 0.1 °C. Therefore, the system cooled to the initial temperature during the inter-series period, so that the PEF treatment was effectively isothermal and thermally induced effects were avoided (Lebovka, Shynkaryk, El-Belghiti, Benjelloun, & Vorobiev, 2007).

The electrodes were connected to the PEF generator and the electrical conductivity of the sample was measured during the inter-series period at a frequency, f, of 0.5 kHz. This frequency was selected to minimise the polarizing effects on the electrodes and tissue sample. All the output data (current, voltage, electrical conductivity, and temperature) were collected using a data logger and special software, developed by Service Electronique UTC, Compiegne, France.

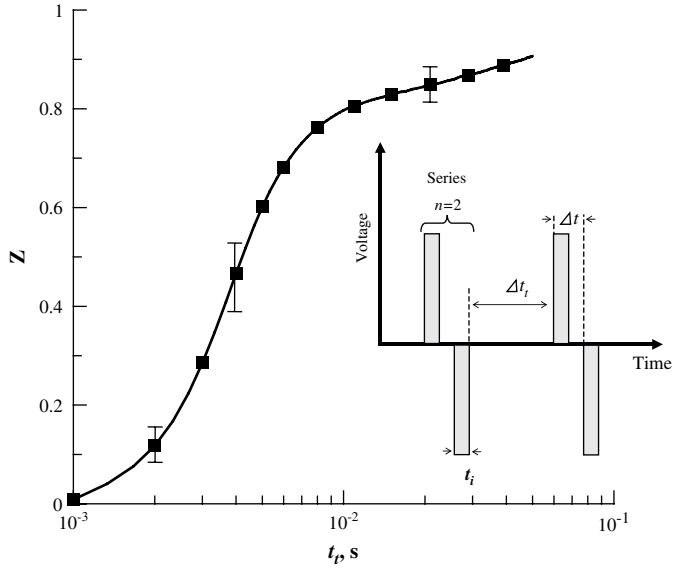

Fig. 1. The electrical conductivity disintegration index Z versus a total time of PEF treatment t_t at electric field strength of $E = 400$ V/cm. Insert shows the PEF pulse protocol. An individual series consisted of $n = 2$ pulses with a pulse duration $t_i = 100$ μs, pulse repetition time of $\Delta t = 200$ μs and there was a pause of $\Delta t_t = 10$ s after each series. The error bars represent the standard deviations of the data.

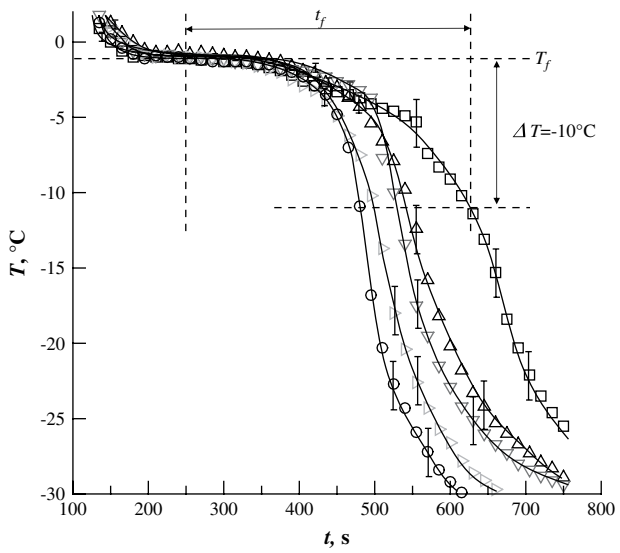

Fig. 2. The temperature inside the geometrical centre of sample T versus cooling time t during the air-blast freezing for the PEF pre-treated samples with different damage degree $Z = 0$ (□), 0.5 (△), 0.7 (▽), 0.8(▷), 0.98(○). Here, the definitions of effective freezing time, t_f, and of freezing temperature, T_f, were shown (Bøgh-Sørensen, 2006). The error bars represent the standard deviations of the data.

The degree of tissue damage was estimated from the electrical conductivity disintegration index, Z (Lebovka, Bazhal, & Vorobiev, 2002):

$$Z = (\sigma - \sigma_u)/(\sigma_d - \sigma_u) \quad (1)$$

where σ (S/m) is the measured electrical conductivity value and the subscripts u and d refer to the conductivities of untreated (intact) and completely damaged tissue, respectively.

The value of σ_d was determined from the measurements of electrical conductivity of a tissue slowly frozen in a cold store and then thawed. It was approximately the same as for the tissue that was subjected to PEF treatment at $E = 1000$ V/cm during 0.1 s in total. Fig. 1 presents an example of electrical conductivity

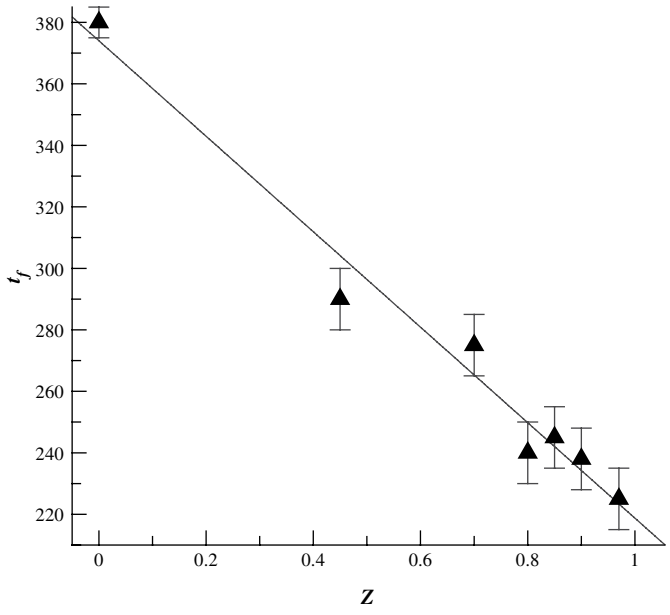

Fig. 3. The effective freezing time t_f versus the damage degree Z. The error bars represent the standard deviations of the data.