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The effect of pulsed electric field treatment on immersion freezing, thawing and selected properties of apple tissue

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ABSTRACT

The aim of this work was to investigate the effect of pulsed electric field on kinetics of immersion freezing and thawing, and quality of freeze–thawed apple. The time of each freezing and thawing stage was distinguished. The quality of freeze–thawed products was assessed by mass loss, textural properties and color change. PEF application resulted in 3.5–17.2% total freezing time reduction. The phase transition stage during freezing was up to 33% shorter in comparison with the untreated samples. The total thawing time was reduced by 71.5%. Maximal mass loss (8.9%) was noticed for apples treated by 50 pulses at 5 kV/cm. However, the samples treated by 10 pulses at 3 kV/cm were characterized by lower mass loss (1.6%) as compared to the untreated samples (2.3%). PEF treatment changed the color of samples (ΔE = 5.74–19.58). The results of the research indicate that it is possible to modify freeze–thawed products' texture by PEF application.

1. Introduction

Freezing is one of the most important food shelf life prolongation methods. It allows to retain most of valuable nutritional components, color and flavor for a long time, due to the chemical, enzyme reaction and microorganisms growth inhibition (Janiszewska and Sakowski, 2012). The advantages of this process are mostly linked with decrease of product temperature. However, freezing, next to drying, is being considered as one of the most energy consuming processes applied in the food industry. Generally, in the course of freezing three following stages can be distinguished: pre-cooling, phase transition (described also as the freezing effective time) and sub-cooling (Kamińska and Lewicki, 2006). Phase transition is the most important step, regarding both frozen food quality and processing costs. Therefore, a lot of effort has been taken to reduce the time of the process, especially the freezing effective time. This aim can be achieved by the freezing method alteration, for instance cryogenic freezing in a liquid nitrogen utilization or by application of specific treatment (e.g. ultrasound or osmotic dehydration) during freezing or before it (Li and Sun, 2002; Kamińska and Lewicki, 2006). Presently, non-thermal technologies are sought to modify the existing heat or mass, and heat transfer based processes in order to provide better quality product (Chun et al., 2013). The literature asserts that there are different non-thermal techniques, such as: high hydrostatic pressure (HHP) (Kalichevsky et al., 1995; Realini et al., 2011; Won Kim et al., 2014), ultrasound (US) (Li and Sun, 2002; Comandini et al., 2013) and pulsed electric field (PEF) (Jalté et al., 2009; Ben Ammar et al., 2010; Wiktor et al., 2012; Wiktor and Witrowa-Rajchert, 2012) to enhance the freezing rate and modify the properties of food. The latter technology depends on the electroporation (electropermeabilization) – a phenomenon that occurs as an electrically induced (application of external electrical field), reversible or irreversible perforation of the cell membrane. The character of electroporation depends on the processing parameters and features of the treated material. Irreversible electroporation is related to disruption of the cell membrane continuity and often causes cell death (Hjouj et al., 2012; Neu and Neu, 2010). In the reversible process, the development of membrane pores is not so advanced and the cell membrane can be resealed (Bazhal et al., 2003; Ngadi et al., 2003). Such PEF influence on the biological systems is often monitored by electrical properties changes (Wiktor et al., 2011). The benefits of pulsed electric fields are used in food preservation (Caminiti et al., 2011a,b; Xiang et al., 2013; Altuntas et al., 2010), extraction and pressing (Jaeger et al., 2012; El Darra et al., 2013; Grimi et al., 2011), dehydration (Ade-Omowaye et al., 2003; Wiktor et al., 2013; Amami et al., 2008), cutting (Kraus, 2003) or even in brandy aging (Zhang et al., 2012).

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The technology of pulsed electric field due to its mechanism and its influence on biological cells, as mentioned before, seems to be a promising one to enhance the freezing process despite of the fact that it is not widely discussed and the literature is not sufficient (Jalté et al., 2009; Ben Ammar et al., 2010; Wiktor et al., 2012).

Therefore, the aim of this study was to investigate the influence of pulsed electric field pretreatment on the immersion freezing and thawing kinetics of apple tissue. Moreover, the quality of freeze–thawed product was assessed by means of mass loss, color and mechanical properties measurement.

2. Material and methods

2.1. Material

Apples (*Malus domestica*, variety "Elstar") purchased in the local supermarket (Berlin, Germany) were used in the investigation. Material was stored at 4 °C until required. The apples were removed from the storage compartment, left to obtain a room temperature (20 ± 1 °C) and washed with tap water before each experiment. The samples were prepared in the cylindrical form (without the peel) with a diameter of $d = 15$ mm and height of $h = 10$ mm, cut parallel to the main axis of the fruit.

2.2. Pulsed electric field treatment

Pulsed electric field (PEF) treatment was carried out in a prototype PEF reactor (Technische Universiät Berlin, Germany) with output voltage up to $U = 30$ kV and capacitance of $C = 1$ μF equipped with a high voltage generator (a.l.e. systems Inc., model 802L, LAMBDA) and oscilloscope (Tektronix TDS220, USA). The apparatus provided monopolar, exponential shaped pulses monitored by the oscilloscope. The capacitor was discharged through the sample immersed in the tap water at the frequency $f = 1$ Hz in order to minimize temperature increase during electric field application. Certain mass of material (0.135–0.140 g depending on process parameters) at room temperature (20 ± 1 °C) was placed in the treatment chamber parallel to the fruit main axis and inundated with tap water (0.725 mS/cm at 23 °C). After the PEF application the samples were prepared as described above. The distance between parallel, stainless-steel electrodes was $l = 30$ mm and the surface of electrodes was $A = 140\ \text{cm}^2$ each. The parameters of electric field applied in the experiment is presented in Table 1. Specific energy intake W_{spec}, in kJ/kg, was calculated according to the following equation (Zhang et al., 2012): $W_{spec} = (V^2Cn)/2m$, where V (V), C (F), n, and m (kg) are the voltage, capacitance of the energy storage capacitor, number of pulses and mass of the sample in the treatment chamber, respectively. The temperature increase of the sample after PEF application was not higher than 7.1 °C. The PEF pretreatment was conducted at least in a duplicate for each investigated treatment protocol.

2.3. The cell disintegration index (CDI) calculation

The cell disintegration index (CDI) was determined on the basis of electrical conductivity measurements (Angersbach et al., 1999) performed by an impedance analyzer (Biotronix, Henningsdorf, German). The cylindrical samples (10 mm diameter and 10 mm length) were cut from the PEF treated material and placed within a stainless steel electrodes (10 mm gap; 10 mm diameter) system. CDI was calculated according to the following equation:

$$CDI = 1 - b\frac{(K'_h - K'_l)}{K_h - K_l} \quad b = \frac{K_h}{K'_h} \tag{1}$$

where K_l and K_l' – electrical conductivity of samples in low frequency range (2.75 kHz), for intact and PEF treated samples, respectively. K_h and K_h' – electrical conductivities of samples in high frequency range (2.8 MHz), for intact and PEF treated samples, respectively.

The CDI varies between 0 and 1: where 0 indicates intact cells and 1 – totally disintegrated ones. Each measurement was done in triplicate.

2.4. Immersion freezing and thawing

Immersion freezing was carried out in the cryostat (Lauda, RUK 50-P, Germany) filled (tank volume $V = 27$ l) with the ethanol as a coolant. Apple samples were immersed in the coolant immediately after pulsed electric field treatment. A specially designed plastic frame with apertures for wires was used to locate the samples always in the same position. During freezing the temperature changes in the geometric center of the samples were recorded by the thermocouples connected to the data logger system until they reached −15 °C. The coolant temperature was set at −20 °C. Time of each stage of freezing was determined according to Kamińska and Lewicki (2006) method. Each experiment was carried out in quadruple.

2.5. Thawing

Thawing was performed at the room temperature (20 ± 1 °C) in the air (free convection). The temperature changes in the geometric center of the sample were recorded by the same set as in the case of immersion freezing, starting from −15 °C. Following steps of thawing were distinguished: pre-heating, phase transition, sub-heating, which were determined as time necessary by the sample to change the temperature from −15 to −4, from −4 to 0 and from 0 to 10 °C, respectively. Total time was calculated as the sum of each steps. Each experiment was carried out four times.

Table 1

Parameters of PEF treatment and the energy delivered to the sample.

Sample code	Electric field intensity E (kV/cm)	Pulse number n (–)	Pulse width t_i [a] (μs)	Specific energy intake W_{spec} (kJ/kg)	CDI
0p0	0	0	0	0	0.000 ± 0.000
1.85p10	1.85	10	15	1.13	0.038 ± 0.002
1.85p50	1.85	50	15	5.63	0.375 ± 0.001
1.85p100	1.85	100	15	11.25	0.379 ± 0.002
3p10	3	10	20	3	0.487 ± 0.005
3p50	3	50	20	15	0.508 ± 0.000
3p100	3	100	20	30	0.500 ± 0.000
5p10	5	10	24	8	0.446 ± 0.008
5p50	5	50	24	40	0.570 ± 0.001
5p100	5	100	24	80	0.679 ± 0.001

[a] Pulse width at 37% of maximal height.