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Effect of electric field and osmotic pre-treatments on quality of apples after freezing–thawing

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ABSTRACT

This work discusses the effects of pulsed electric field (PEF), ohmic heating (OH), and osmotic (O) treatments on the structure of apple tissue and its freezing/thawing behaviour. Apple discs were treated at electric field strength $E = 800$ V/cm (PEF, isothermal regime) and $E = 40$ V/cm (OH, non-isothermal regime) to a high level of tissue disintegration (conductivity disintegration index Z was ≈0.98) and then were subjected to osmotic (O) treatment in the aqueous solution of glycerol (20 wt.%). The distribution of osmotic solution was practically homogeneous inside the disc of PEF-treated tissue and highly inhomogeneous in untreated and OH-treated samples. The freezing–thawing (FT) experiments (+20 °C → −40 °C → +20 °C) were done in order to reveal the effects of combined modes of treatment on the structure of apple tissue. The most pronounced reducing of both freezing and thawing times and strengthening of the apple texture were observed for PEF treatment.

Industrial relevance: Freezing-assisted preservation of plant materials in the most natural-looking state with near-original texture and colours requires thorough optimization of freezing operation. In this study, the research of the impact of pulsed electrotechnologies combined with osmotic pre-treatment on the structure of apple tissue, its freezing/thawing behaviour and texture quality, is provided.

1. Introduction

Freezing is widely used as an important unit operation in preservation of food tissues (Li & Sun, 2002). Its benefits are mainly attributed to the fact that food tissues subjected to freezing retain their initial quality, such as nutritive value, organoleptic properties, texture, colour, etc. The existing freezing-assisted preservation technologies try to avoid formation of large ice crystals inside the tissue by regulation of heat removal (Delgado & Sun, 2001). Water expands when frozen, and formation of large ice crystals causes membrane damage and cell shrinkage. The process of freezing the partially dehydrated foods is known as dehydrofreezing (James, Purnell, & James, 2014). It is claimed that dehydrofrozen fruits and vegetables have better quality than conventionally frozen products (Li & Sun, 2002). The air drying (Mujumdar, 2006) or osmodehydration (Akbarian, Ghasemkhani, & Moayedi, 2014) is the most commonly used techniques for removal of water from fruit and vegetable tissues prior to freezing. The sugars (sucrose, glucose, fructose), alcohols (sorbitol, glycerol) and salts (sodium chloride) are widely used as osmotic agents. In some cases, osmotic dehydration is more advantageous than air dehydration. High concentration of osmotic agent in the osmotic medium allowed the enhancement of firmness and preservation of colour. However it also resulted in high uptake of osmotic agent inside the tissue. The level of dehydration required prior to freezing can depend on the food tissue variety, the type of dehydration pre-treatment, and the applied method of freezing. That's why the reported levels of dehydration (i.e., % of water losses), required to improve the tissue texture after freezing and thawing, were rather different, e.g., they varied from 30% to 50% (Pham, 2008; Ramallo & Mascheroni, 2010; Rincon & Kerr, 2010; Spiazzi, Raggio, Bignone, & Mascheroni, 1998) or 2 to 10% (Dermesonlouoglou, Giannakourou, & Taoukis, 2007).

Nowadays, the application of pulsed electric field (PEF) pre-treatment was demonstrated to be an effective tool for enhancement of dehydration of different fruit and vegetable tissues (Donsi, Ferrari, & Pataro, 2010; Vorobiev & Lebovka, 2008, 2011). Under the effect of PEF with electric field strength E of 0.5–5 kV/cm and pulse duration from several microseconds to several milliseconds, the cell membranes become electroporated and permeable for small molecules or even some macromolecules (Pakhomov, Miklavčič, & Markov, 2010). Processing, assisted by PEF, has

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Nomenclature

F	force (N)
F^*	texture index
E	electric field strength (V/cm)
m	mass of sample (g)
n	number of pulses
N	number of series
s	mass of solids in the sample (g)
σ	electrical conductivity (S/cm)
t	time (s)
t_f	effective freezing time (s)
t_i	pulse duration (μs)
t_m	effective melting time (s)
Δt	pulse repetition time (μs)
Δt_t	pause between trains (s)
T	temperature (°C)
ΔT	temperature increase (°C)
x	distance from the centre of the apple disc (cm)
Y_h	moisture content in apple
Z	electrical conductivity disintegration index

Subscripts

d	damaged
i	initial
f	freezing
m	maximum
u	untreated (intact)

Abbreviations

U	untreated
PEF	pulsed electric field
O	osmotic
OH	ohmic heating
FT	freezing/thawing
H	thermal treatment at 60 °C
SG	solid gain
WL	water loss
WR	weight reduction
W	water
G	glycerol

also a good potential for microbial killing, preservation and it allows avoidance of undesirable changes in materials that are typical for other techniques, such as thermal, chemical and enzymatic ones (Barbosa-Canovas & Altunakar, 2006; Donsì, Ferrari, Maresca, & Pataro, 2011; Jaeger, Reineke, Schoessler, & Knorr, 2012; Knorr et al., 2011; Odriozola-Serrano, Aguiló-Aguayo, Soliva-Fortuny, & Martín-Belloso, 2013; Raso & Heinz, 2006).

Typically, application of PEF does not provoke the damage of the cell walls in plant materials (Fincan & Dejmek, 2002; Grimi, Mamouni, Lebovka, Vorobiev, & Vaxelaire, 2010). The positive effects of PEF pretreatment on the freezing and freeze-drying processes in different biomaterials were demonstrated (Ben Ammar, Lanoiselle, Lebovka, Van Hecke, & Vorobiev, 2010; Jalte, Lanoiselle, Lebovka, & Vorobiev, 2009; Wiktor, Witrowa-rajchert, & Chudoba, 2012). The freezing and freeze-drying processes are very important for the preservation of many bioactive compounds, phytochemicals and predominant phenolics in biological tissues (Lee, Kim, Kim, Lee, & Lee, 2003). Combination of PEF with vacuum infusion was applied to impregnate the cells of spinach leaves with cryoprotectant (trehalose) (Phoon, Galindo, Vicente, & Dejmek, 2008). It allowed substantial improvement of the freezing tolerance of spinach leaves. Effects of combination of PEF with cryoprotectant and texturizing agents (different salts, glycerol, trehalose and sucrose) on quality retention of tissues (carrot, potato) was recently studied (Shayanfar, Chauhan, Toepfl, & Heinz, 2013, 2014) The results have shown that combined treatment allowed prevention of tissue softening after defrosting.

This manuscript studies the effects of electric (pulsed electric field (PEF), ohmic heating (OH)), and osmotic (O) treatments on the structure of apple tissue and its freezing/thawing behaviour. All treatments were applied to the apple discs, O-treatment was done in an aqueous glycerol solution. Glycerol acts as a cryoprotectant and texturing agent. The data on kinetics and spatial distribution of osmotic solution inside the apple discs after combine PEF-, OH- and O treatments are discussed. The freezing–thawing (FT) experiments with apple discs treated using different combined methods were also done.

2. Materials and methods

2.1. Plant material

Commercial apples (*Jonagold*) of good and uniform quality were purchased in the local supermarket (Compiegne, France) and were used as a model tissue in this work. Apples were stored in a plastic bag in a laboratory refrigerator at 4 °C until required (but no more than one week). The moisture content, measured by drying 20 g of the fresh apple tissue at 105 °C to constant weight, was about 80 wt.%. The apple disc-shaped samples (29 mm in diameter and 10 mm in thickness) were manually prepared immediately before experiments using the special cylindrical knife.

2.2. Electric field treatment

Pulsed electric field (PEF) treatment was applied using a monopolar PEF generator (5 kV–1 kA, Hazemeyer, Saint-Quentin, France). The PEF generator provided pulses of a near-rectangular shape, and N series of pulses were applied. Each separate series consisted of n pulses with pulse duration t_i, time interval between pulses Δt and pause Δt_t after each train (Fig. 1). The total time of PEF treatment was regulated by variation of the number of series N and was calculated as $t = N \cdot n \cdot t_i$. The current and voltage values were measured during the period between two consecutive series of pulses. The following protocol was used in PEF experiments: $E = 800$ V/cm, $n = 10$, $t_i = 100$ μs, $\Delta t = 100$ ms, $\Delta t_t = 10$ s, and the value of N was varied in order to obtain the desirable total time of PEF treatment t, e.g., $N = 100$ corresponded to $t = 0.1$ s. The chosen protocol of successive trains with long pause after each train allowed fine control of the plant tissue permeabilization without any significant temperature elevation ($\Delta T \leq 3$ °C) during PEF treatment. The temperature inside the geometrical centre of the central sample was recorded in the online mode by a teflon-coated thermocouple Thermocoax type 2 (AB 25 NN) (Fig. 1).

Ohmic heating (OH) treatment was applied using an AC sinusoidal generator (400 V, 38 A, service operated at 50 Hz and electric field strength E of 40 V/cm). As far as significant temperature elevation inside the sample is observed during OH treatment, it was done in the interrupting mode using N series of heating until reaching the maximum temperature $T_m = 55$ °C with subsequent cooling to 20 °C (Fig. 1). Such mode of OH treatment allowed avoiding of undesirable over-heating and excluded possible effects of the thermally induced damage of apple tissue. The total time of OH treatment t_t was calculated as the time of direct application of AC power.

Electrical treatment cell consisted of a Teflon cylindrical tube (Atelier Genie des procédés industriels, UTC, Compiegne, France) with ≈110-mm inner diameter and an electrode at the bottom (Fig. 1). The seven apple disc-shaped samples were placed inside the cell on the bottom electrode and covered with fresh apple juice. After that the second electrode was put on the top of the samples (Fig. 1). The distance between the electrodes, 10 mm, was determined by the