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Effect of ultrasound treatment on the water state in kiwifruit during osmotic dehydration

M. Nowacka [a,*], U. Tylewicz [b], L. Laghi [b,c], M. Dalla Rosa [b,c], D. Witrowa-Rajchert [a]

[a] Faculty of Food Sciences, Department of Food Engineering and Process Management, Warsaw University of Life Sciences (WULS-SGGW), Warsaw, Poland
[b] Interdepartmental Centre for Agri-Food Industrial Research, Alma Mater Studiorum, University of Bologna, Campus of Food Science, Cesena, Italy
[c] Department of Agri-Food Science and Technology, Alma Mater Studiorum, University of Bologna, Campus of Food Science, Cesena, Italy

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ABSTRACT

The present work investigates how ultrasound pretreatment modulates the effects of osmotic dehydration (OD) on the water state and microstructure of kiwifruit. Kiwifruit slices (10 mm thick) were subjected to ultrasonic waves in a water bath at a frequency of 35 kHz for 10, 20 and 30 min. OD process was then carried out by immersing the samples in 61.5% sucrose solution equilibrated at 25 °C for a contact period of 0, 10, 20, 30, 60 and 120 min. The partition of water into the cellular tissue structures (vacuole, cytoplasm, extracellular spaces and cell wall) was investigated by Time Domain Nuclear Magnetic Resonance (TD-NMR). In parallel, the microstructure of kiwifruits slices was examined using a Scanning Electron Microscope. The results showed that US pretreatment performed for more than 10 min had a positive effect on the mass exchange caused by osmotic dehydration. A creation of microchannels and an increase of the average cross-section area of cells were observed when the samples were pretreated with US before OD. TD-NMR showed a slight redistribution of water through the substructures of the cells, as a function of the length of the US pretreatment applied.

1. Introduction

Osmotic dehydration (OD) is a widely used method to partially remove water from fruits by immersion of cellular tissue in hypertonic aqueous sugar solutions. This process is particularly common as a pre-treatment before air-drying or to obtain minimally processed fruit and vegetables products. During the osmotic process a pressure difference is generated across the cellular surface, which acts as an effective semi-permeable membrane (Simal, Benedito, Sanchez, & Rossello, 1998), so that the solution of different sugars such as sucrose, glucose or fructose moves into free space of the tissue while water comes out of the cells (Deng & Zhao, 2008; Fernandes, Gallão, & Rodrigues, 2009; Vial, Guilbert, & Cuq, 1991). In order to accelerate mass transfer during the osmotic process several methods have been described, mainly based on agitation or rotation of the samples during dehydration process (Simal et al., 1998). Recently new treatments suitable for the application during or before OD process have been proposed to further enhance mass transfer, for instance application of pulsed-vacuum (Deng & Zhao, 2008), high and low pressure (Gabaldón-Leyvaa et al., 2007) and power ultrasound (Fernandes & Rodrigues, 2008a, 2008b).

Ultrasound (US) is a mechanical wave with frequency ranging from 20 kHz to 100 MHz that can propagate through a material medium, solid, liquid or gaseous. The high intensity ultrasound (power ultrasound) operates at the frequency range of kHz, promoting the alteration of physical and chemical properties of food products (McClements, 1995; Zheng & Sun, 2006). In solid–liquid systems power ultrasound induces compression and expansion of the material, usually referred as sponge effect (Fernandes & Rodrigues, 2007; Knorr, Zenker, Heinz, & Lee, 2004; Rastogi, 2010). This is believed to have a double effect on moisture removal and solid gain. On one side microscopic channels are created in fruits tissue. On the other side, expansion and escape of the gas trapped in the pores are eased, so that the empty pores are filled by the osmotic solution. This mechanism may explain the increase in mass diffusion when ultrasonic treatment is used (Simal et al., 1998).

To minimize food degradation possibly related to high temperatures, the combination of OD and ultrasound can be carried out at ambient temperature (Fernandes & Rodrigues, 2007). Indeed, experience gained on apples (Simal et al., 1998), melon (Fernandes, Gallão, & Rodrigues, 2008) or pineapples (Fernandes et al., 2009) shows that such combination gives high speeds of water removal and solid gain even at low temperatures, thus leading to better maintenance of a natural aroma, colour and nutrients content.

* Corresponding author. Address: Warsaw University of Life Sciences, Faculty of Food Science, Department of Food Engineering and Process Management, Nowoursynowska 159c, 02-776 Warsaw, Poland. Tel.: +48 22 593 75 79; fax: +48 22 593 75 76.
E-mail address: malgorzata_nowacka@sggw.pl (M. Nowacka).

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However even at ambient temperature tissue subjected to ultrasonic wave can undergo local heating due to cavitation effect, which could depend on the ultrasound sequence applied (pulsed or continuous), duration, strength and frequency of the pulses (Deng & Zhao, 2008; Fernandes, Gallão et al., 2008; Fernandes, Linhares, & Rodrigues, 2008; Fernandes & Rodrigues, 2007; Fernandes et al., 2009; Knorr et al., 2004; Leighton, 1998; Nowacka, Wiktor, Śledź, Jurek, & Witrowa-Rajchert, 2012; Rastogi, 2010; Simal et al., 1998). Unfortunately between these parameters and cavitation there is not a linear correlation (Knorr et al., 2004; Rastogi, 2010), so that the optimal combination between OD process and ultrasound treatment can be conveniently looked for by following a trial and error approach.

The work described in the present paper was designed to evaluate the performances of OD combined with ultrasound treatment on kiwifruit tissue, together with their consequences on the fruit microstructure. The ultrasound was applied at a frequency of 35 kHz for 10, 20 and 30 min. The physico-chemical and structural changes were studied through a combination of Scanning Electron Microscopy (SEM) and Time Domain Nuclear Magnetic Resonance (TD-NMR) spetroscopy. Fernandes et al. (2009) and Nowacka et al. (2012) demonstrated the effectiveness of SEM in giving precious information about the cells structures modifications by studying the microstrure changes and microchannels creation caused by ultrasound treatment applied before OD or convective drying. TD-NMR was found nicely suitable for obtaining a closer look to the distribution of the water inside the osmo-dehydrated kiwifruit tissues and its interactions with the biopolymers (Panarese et al., 2012; Santagapita et al., 2012; Tylewicz et al., 2011).

2. Materials and methods

2.1. Raw material

Kiwifruits (*Actinidia deliciosa* var *deliciosa* cv Hayward) with homogeneous size and refractometric index of 12 ± 1 °Brix were bought at a local market. Kiwifruits were sorted to eliminate damaged or defective fruit and stored at 4 ± 1 °C and with 90–95% of relative humidity (RH) in air until processing. The ultrasonic treatment and osmotic dehydration treatment was applied on fruit hand peeled and cut into 10 mm thick slices.

2.2. Ultrasound pretreatment (US)

The kiwifruit slices were subjected to ultrasonic waves in a water bath at a frequency of 35 kHz for 10, 20 and 30 min. The instrument used to generate the ultrasound (TransSonic TP 690-A Elma, Germany) had internal dimensions of 135 × 100 × 520 mm. Acoustic intensity applied during sonication was determined calorimetrically by recording the temperature increase against the time of ultrasound application (Cárcel, Garcia Perez, Riera, & Mulet, 2007; Raso, Manas, Pagan, & Sala, 1999).

$$P = MC_p \frac{dT}{dt}, \quad (1)$$

where P is the ultrasonic power, M is the mass of the solution, dT/dt is the increase of temperature, C_p is the heat capacity of the solution. Acoustic intensity (W/g) was determined by dividing the ultrasonic power by the mass of the ultrasonic treated samples.

The intensity of ultrasound was different for diverse time and was equal to 8.4×10^{-2}; 9.7×10^{-2}; 10.2×10^{-2} W/g for time 10, 20 and 30 min, respectively.

To avoid any flow out of the samples, the slices were placed next to each other and covered with the metal net (Fig. 1). The pre-treatment was carried out at room temperature (25 °C). The ratio of raw material to water was set to 1:4 (w/w), as recommended by Fernandes and Rodrigues (2008a, 2008b). After the treatment the plant materials were blotted with filter paper and subjected to osmotic dehydration. Before and after ultrasound treatment mass of the samples, dry matter content and water temperature were measured. The treatment applied for 10, 20 and 30 min caused a temperature increase of 3, 5 and 10 °C respectively. Such changes were caused by the work applied by ultrasonic waves flowing through the tissue, as observed also by Jambrak, Mason, Paniwnyk, and Lelas (2007), who registered temperature increases caused by the application of ultrasound on mushrooms, cauliflower and brussel sprout. The experiments were conducted in duplicate for each osmotic dehydration process.

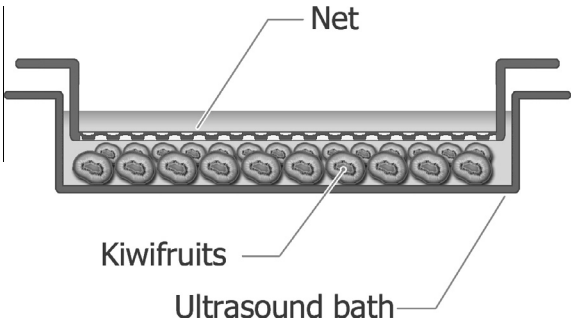

Fig. 1. Scheme of placing and maintaining samples in ultrasonic bath.

As US treatment was carried out in water, each US pretreatment experiment was flanked by a treatment in identical conditions but without US. For the sake of clarity in the remaining part of the text such treatment will be simply called "dipping in pure water" (DIP).

2.3. Osmotic dehydration treatment

Osmotic dehydration treatment (OD) was carried out by immersing the samples in 61.5% (w/w) sucrose solution for a contact period of 0, 10, 20, 30, 60 and 120 min. The osmotic solution-to kiwifruit ratio was maintained at 4:1 (w/w), to avoid changes in the solution concentration during the treatment. The process temperature was controlled using a thermocouple and a water bath set at 25 °C. Slices from the central part of each kiwifruit were placed in mesh baskets and immersed in osmotic solution. The baskets were continuously stirred with a propeller. The rotational speed, set to 88 rpm, was experimentally determined to assure negligible resistance to mass transfer. After removal from the solution, the dehydrated samples from each group were rinsed with 2000 ml of distilled water for 10 s and blotted with absorbent paper to remove excess solution. The osmotic dehydration processes were conducted in duplicate.

Osmotic dehydration kinetics of kiwifruit were evaluated by calculating net change (Δ) of kiwifruit slices total mass (M°), water mass (M^{w}) and solids mass (M^{ST}) adopting the following equations:

$$\Delta M_t^o = M_t^o - M_0^o = \frac{m_t - m_0}{m_0} \quad (2)$$

$$\Delta M_t^o = M_t^W - M_0^W = \frac{m_t x_{wt} - m_o x_{w0}}{m_0} \quad (3)$$

$$\Delta M_t^{ST} = M_t^{ST} - M_0^{ST} = \frac{m_t x_{wt} - m_o x_{ST0}}{m_0} \quad (4)$$

where m_0 is the initial weight before osmotic treatment (kg), m_t is the weight after a time t (kg), x_w is the water mass fraction (kg kg^{-1}) and x_{ST} is the total solids mass fraction (kg kg^{-1}).