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Effect of pulsed electric fields on mass transfer and quality of osmotically dehydrated kiwifruit

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ABSTRACT

The effects of pulsed electric fields (PEF) on mass transfer and quality during osmotic dehydration (OD) of kiwifruit were investigated. Whole peeled kiwifruit was subjected to different PEF (field strengths E, 0.7, 1.1 and 1.8 kV/cm) process conditions. PEF processed and non processed samples were cut into discs and treated by immersion in OD solution consisting of glycerol, trehalose, maltodextrin, ascorbic acid, sodium chloride, calcium chloride and citric acid ($w_{food}/w_{solution}$ = 1/5) for 240 min at different temperatures (T 25, 35 and 45 °C). Water loss (WL), solid gain (SG), water activity (a_w) as well as main quality indices (colour, texture, vitamin C) were estimated during processing. OD resulted in substantial WL and SG. Application of PEF significantly enhanced rates. Fick's 2nd law for diffusion was used for the calculation of the effective diffusivities of water with higher temperature and field strength showing higher values. The effect of temperature and PEF field strength on the effective diffusivity coefficient of water was mathematically modelled. Shorter OD times, when PEF pretreatment is applied, may be adequate to remarkably improve diffusion kinetics leading to a level of WL/SG that allows the product to retain optimum quality characteristics and adequate decrease of a_w. PEF OD processed kiwifruit presented high quality (acceptable level of colour change, increased firmness, high vitamin C content) suggesting that PEF and OD combination can be an effective processing step in the production of intermediate moisture products.

1. Introduction

Osmotic dehydration (OD) of fruits and vegetables is achieved by immersion in hypertonic sugar or salt solutions of high osmotic pressure/low water activity. Diffusion phenomena take place with two simultaneous countercurrent flows: a water flow from the food to the outer solution and a simultaneous flow of solute from the solution to the plant tissue. These mechanisms lead to water loss and solid gain in the food. OD process occurs at mild temperatures (up to 50 °C) and requires less energy compared to conventional drying while aiming to improve and maintain desirable quality characteristics such as colour and flavour retention. Cellular membranes exert a high resistance to mass transfer thus slowing down the OD rate. Various approaches have been reported in the literature (such as pretreatment of the material prior to osmosis, varying temperature and concentration of the osmotic solution and mass ratio of the solution to food material) to influence the rate of diffusion during OD (Ferrando and Spiess, 2001; Rastogi et al., 1999; Torreggiani and Bertolo, 2001). It is worth remarking the variables can only be manipulated over a limited range outside of which they adversely affect quality even though rate of transfers may be enhanced. It is therefore necessary to identify methods which enhance rate of transfers with minimal alteration in quality (Ade-Omowaye et al., 2003a,b).

Among the emerging nonthermal processes of interest pulsed electric field (PEF) show promising features of inducing cell membrane permeabilisation, called electroporation of food plants (such as apples, carrots, mangos, and red bell peppers). PEF processing is used to increase permeability of the cell membrane and, in the case of

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expression and extraction, enhances mass transport out of the cells leaving the product matrix largely unchanged (Fincan et al., 2004; Knorr et al., 1994; Knorr and Angersbach, 1998). Disruption of the cells can be achieved by applying PEF of different intensities (for particular products) across the cell medium or plant tissue (Ade-Omowaye et al., 2002, 2003a,b; Amami et al., 2005, 2006; Lebovka et al., 2001; Tedjo et al., 2002). The mechanism of electropermeabilisation of cell membranes induced by PEF is not yet well elucidated. However, different researchers indicate that the cell walls seem not to be seriously affected by this treatment and the product overall retains its quality (Amami et al., 2006; Jemai and Vorobiev, 2002; Lebovka et al., 2003; Taiwo et al., 2001).

Kiwifruit (*Actinidia deliciosa*) is an important source of vitamin C with high antioxidant capacity due to carotenoids, lutein, phenolics, flavonoids and chlorophylls (Du et al., 2009). However, the shelf life of kiwifruit is short and requires processing techniques to enhance its commercial life (Kaya et al., 2010; Orikasa et al., 2014). Main quality characteristics of kiwifruit such as colour, firmness and flavour are negatively affected by conventional processing techniques (Stanley et al., 2007). Drying, canning (thermal processing), freezing and modified atmosphere packaging are commonly used as processing/preservation techniques of processed/fresh kiwifruit. Raw kiwifruit used in the fresh-cut industry requires high firmness and low soluble content (Beaulieu, 2010). OD enables unripe kiwifruits to reach soluble solids content comparable with ripe fruit (Bressa et al., 1997; Panarese et al., 2012; Talens et al., 2003; Tylewicz et al., 2011). OD of kiwifruit has been reported in literature, mostly, to describe the structural and physicochemical changes occurred during the process (Bressa et al., 1997; Cao et al., 2006; Escriche et al., 2000; Gianotti et al., 2001; Tocci and Mascheroni, 2008; Tylewicz et al., 2011). PEF pretreatment of OD processed kiwifruit has not been studied.

The aim is to study the osmotic dehydration (OD) of kiwifruit treated by pulsed electric fields (PEF). The effect of processing time, temperature and electric field strength on (a) mass transfer kinetics (water loss, solid gain and water activity) and (b) quality characteristics (colour, firmness, vitamin C) of osmo dehydrated kiwifruit was investigated. The scope is to assess an optimized method of minimally processing kiwifruit that combines the novel nonthermal technologies of OD and PEF.

2. Materials & methods

2.1. Pulsed electric fields

Whole peeled kiwifruit "Hayward" was subjected to different PEF process conditions (field strength intensities). PEF treatment was conducted in a versatile pilot scale system for food processing (Elcrack-5kW, DIL, Quakenbruck, Germany). It comprises a pulse generator module and liquid handling system and can also be operated as a stand-alone research equipment. Kiwifruits were treated in a 80 × 100 × 50 mm (gap × length × depth), 400 ml volume stainless steel batch chamber for cell disintegration in tap water. The inlet temperature of the PEF treatment chamber was around 20 °C and the outlet temperature rise due to the PEF treatment did not exceed 5 °C. Experimental set consisted in applying 250 pulses at field strength intensities of 0.7, 1.1 and 1.8 kV/cm (with 15 μs pulse width at a frequency of 300 Hz). The employed field strengths had the following average specific energy input 8.0, 16.6 and 42.3 kJ/kg, respectively.

2.2. Osmotic dehydration

PEF treated and fresh, non treated samples were cut into flat discs (43.5 ± 0.8 mm diameter, 6.83 ± 0.03 mm thickness), and then partially dehydrated by immersion in a hypertonic solution of glycerol (30% w/w), trehalose (10% w/w), high DE maltodextrin (20% w/w), ascorbic acid (2.0% w/w), calcium chloride (1.5% w/w), sodium chloride (1.0% w/w) and citric acid (0.2% w/w) (OD). Glycerol, high DE maltodextrin and trehalose were used as low molecular weight a_w lowering agents reported to improve the texture o of foods and contribute to microbiological stability (Ferrando and Spiess, 2001; Clubbs et al., 2005). Calcium chloride was used to minimize tissue damage during processing by interaction with pectins and other cellular wall components reinforcing mechanical properties of the cellular matrix (Gras et al., 2003). Citric acid and ascorbic acid were applied to reduce the pH and hinder extended surface discolouration. To enhance mass transfer kinetics as well as to improve the sensory characteristics (particularly to balance the sweet taste) of the final osmodehydrated kiwifruit product, sodium chloride was added in the osmotic solution (Lerici et al., 1985).

OD treatment was conducted at temperatures 25, 35 and 45 °C (T) for time duration up to time 240 min (t). The solution to sample ratio was 5:1 (w/w) to avoid significant dilution of the medium by water removal, which would lead to local reduction of the osmotic driving force during process (Dermesonlouoglou et al., 2007a,b, 2008). Preweighted disks were kept submerged in the osmotic solution by means of a grid in beakers thermostated in waterbaths. At the selected times triplicate samples were removed from the osmotic solution, blotted gently to remove the excess coating solution and weighed. The experimental OD procedure was the same for non treated and PEF treated samples.

Water content (X_w) and soluble solids (X_s) were measured in fresh and PEF treated samples to determine the compositional changes promoted by OD. Moisture content was determined by drying at 105 °C for 24 h (WTB BINDER 7200, Type E53, Tuttlingen, Germany). Water activity (a_w) was monitored (Aqua LAB 4TEV, Decagon Devices, Inc., USA). Non treated kiwifruit samples showed average values of 0.8581 g water/g initial fresh matter (x_w), 0.1419 g total solids/g initial fresh matter (X_s) and a_w value of 0.9589. During OD processing, water loss and solid gain as well as main quality indices of kiwifruit (colour, firmness, vitamin C) were measured. All measurements were made in triplicate, and the mean values were reported.

2.3. Mass transfer calculations

Water loss (WL: g water/g initial dry matter) and solid gain (SG: g total solids/g initial dry matter) during osmotic dehydration were calculated according to the following equations (Eqs. (1) and (2)):

$$WL = \frac{(M_o - m_o) - (M - m)}{m_o} \quad (1)$$

$$SG = \frac{m - m_o}{m_o} \quad (2)$$

where M_o is the initial mass of kiwifruit disks before osmotic treatment, M is the mass of samples after time t of osmotic treatment, m is the dry mass of samples after time t of osmotic treatment and m_o is the dry mass of samples before osmotic treatment.

The effective coefficients of water and solute diffusivity were calculated by fitting the experimental measurements to the following analytical solutions based on Fick's 2nd law for diffusion from an infinite slab being dehydrated from both