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Physical and chemical changes induced by osmotic dehydration in plant tissues

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Abstract

The osmotic processes induce not only water and solute fluxes in the tissue but also changes in cellular structure, depending on the ratio in which different transport mechanisms act in the system: osmo-diffusional transport of water and solutes and hydrodynamic gains of external solution. The latter is more important in porous tissues, especially when submitted to vacuum impregnation process. In macroscopic samples, different compositional and structural profiles are induced depending on process variables and tissue microstructure; cells near the sample interface are practically perfectly equilibrated in composition with the osmotic solution, whereas the more internal cells may remain unaltered. Compositional–structural profiles developed in the tissue during the process has a great impact on physical (such as optical and mechanical) and chemical properties (such as volatile profile) of the final product, in part due to differences in the number of cells depth, altered and unaltered. The degree in which gas–liquid exchanges occur in the tissue also plays a relevant role.

Keywords: Osmotic dehydration; Structure; Physical properties; Chemical changes

1. Introduction

Different studies have been carried out into the use of osmotic processes to obtain several kinds of fruit products or food ingredients such as minimally processed or intermediate moisture fruits (Alzamora, Gerschenson, Vidales, & Nieto, 1997), or into their application as a pre-treatment in air drying (Alvarez et al., 1995; Nieto, Salvatori, Castro, & Alzamora, 1998) or freezing (Forni et al., 1987; Pinnavaia, DalIa Rosa, & Lerici, 1988; Giangiacomo, Torreggiani, Erba, & Messina, 1994; Sormani, Maffi, Bertolo, & Torreggiani, 1999; Maestrelli, Lo Scalzo, Lupi, Bertolo, & Torreggiani, 2001).

In osmotic dehydration a cellular tissue is immersed in a concentrated solution of sugars or salts in order to promote water loss in the cells due to the differences in water chemical potential established between the external solution and the internal liquid phase of the cells. Nevertheless, due to the open structure of the tissue in the intercellular spaces and cut external cells, diffusion of external solutes and hydrodynamic gain of external solution also occur. This contributes to a net opposite flux of water and solutes that allows the tissue to become concentrated with a determined ratio solute gain/water loss (SG/WL), depending on process conditions (Chiralt & Fito, 2003).

In addition to mass fluxes in the tissue, structural changes such as cell alteration due to deformation and break of cellular elements associated to dehydration and gas–liquid exchanges also occur. All these phenomena provoke changes not only in the macroscopic properties of the sample, such as optical and mechanical properties, which are related to the product appearance

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and texture, respectively (Torreggani, 1995; Torreggiani & Bertolo, 2001a, 2001b; Chiralt et al., 2001; Talens, Martínez-Navarrete, Fito, & Chiralt, 2002a), but also in cell physiology and biochemical reactions, which in turn can provoke several chemical modifications in the tissue such as changes in the volatile profiles (Escriche, Chiralt, Moreno, & Serra, 2000; Lo Scalzo, Papadimitriu, Bertolo, Maestrelli, & Torreggiani, 2001; Talens, Escriche, Martínez-Navarrete, & Chiralt, 2002b; Talens, Escriche, Martínez-Navarrete, & Chiralt, 2003), or development of chemicals (i.e. ethanol or acetaldehyde) associated with changes in respiration paths (Tovar, García, & Mata, 2001). All these changes greatly affect product quality.

Factors that affect properties of the final products depend on the product characteristics, such as cultivar, variety, ripeness degree and the tissue microstructure (cell packaging and porosity, membrane permeability, etc.), the surface/volume ratio (specific surface), pretreatments carried out on the piece (peeling, coating, blanching, freeze-thawing, etc.) and other process parameters such as osmotic solution composition (binary, ternary, molecular weight, etc.) and concentration, temperature, pressure (atmospheric, vacuum), product/solution contact (agitation, product/solution ratio) and simultaneous application of other techniques such as ultrasound (Simal, Benedito, Sámchez, & Roselló, 1998), high intensity electric field (Rastogi, Eshtiaghi, & Knorr, 1999) or high hydrostatic pressure (Rastogi & Niranjam, 1998) which alter cell membranes.

All the above-mentioned factors determine the extent to which the different mass transport mechanisms act in the tissue and their influence on the overall mass transfer rate, SG/WL ratio and structural changes. Modelling of osmotic processes is limited precisely by the complexity and diversity of structures in biological tissue as well as by its different structural response to the osmotic stress (Le Maguer, 1997).

The aim of this paper is to remark the relationship between plant tissue structure and mass transport phenomena and how this can affect physical (such as optical and mechanical) and chemical (such as volatile profiles) properties of the final products. The effect of the osmotic solution concentration on optical and mechanical properties and volatile profiles reached in kiwi and strawberry tissues concentrated at a determined level is analysed to illustrate these aspects.

2. Plant tissue structure and mass transport relationship

The complex microstructure of the plant tissue means that osmotic dehydration cannot simply be explained as a pure osmotic process in which cell membranes act as a semipermeable barrier allowing water to pass through, but as a process where many other mechanisms responsible for mass transport can act at different levels. At the cellular level, there are three accepted pathways for mass transfer: the apoplasmic transport (external to cell membranes) or movement of material within the extracellular volume, the symplasmic transport (internal to the plasma membrane), defined as the transport of material between neighbouring cells through plasmodesmata, and the transmembrane flux (Marcotte & Le Maguer, 1991). Nevertheless, the porous structure of the tissue favours the action of hydrodynamic mechanisms (HDM) in the pores due to capillary pressure and imposed or generated pressure gradients and diffusion in non-compartmented sample volumes such as intercellular spaces, or cells whose membranes became denatured as the tissue was being affected by osmotic treatment. Cell water loss provokes not only volume reduction, but also cell membrane alteration and separation from the cell wall that also becomes deformed, thus producing mechanical stress on the middle lamellae which are also altered (Alzamora, Castro, Vidales, Nieto, & Salvatori, 2000). When membranes loose their functionality, external solutes diffuse freely to all parts of the tissue, not only to the open intercellular spaces.

Hydrodynamic mechanisms (HDM) are responsible for the gain of external solution in the sample pores. Table 1 summarizes the actions of different HDMs as promoted by different pressure gradients, depending on the process time, which has been extensively discussed in previous works (Fito, Chiralt, Barat, & Martínez-Monzó, 2001; Fito, Chiralt, Barat, & Martínez-Monzó, 2002; Chiralt & Fito, 2003). First, after the sample immersion in the external solution, the content of the outer broken cells is washed and solution penetrates into the open pores due to capillary pressure (Fito, 1994).

In porous tissues, when sample cells deform in line with water loss, the volume of intercellular spaces, available for gas phase, is affected and so, the internal pressure in the tissue varies thus promoting HDM action. This aspect, together with the gas compressibility, contributes to the progressive impregnation of the sample as the osmotic process advances (Barat, Chiralt, & Fito, 1998; Cháfer, González-Martínez, Ortolá, & Chiralt, 2001a; Chiralt & Fito, 2003).

In long term osmotic processes (or in short processes in cells near the sample interface) cell wall relaxation, which occurs after the shrinkage provoked by water loss, is coupled with the suction of the external solution while cell cavities recover roundness and volume (Barat et al., 1998; Barat, Albors, Chiralt, & Fito, 1999). This hydrodynamic effect, extended to all the tissue, implies mass and volume recovery of the samples after the compositional equilibrium is reached. The extension of this phenomenon or sample gain of mass and volume is greatly affected by the tissue structure and especially by force of cell bonding that defines the mechanical