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Effect of vacuum impregnation with calcium lactate on the osmotic dehydration kinetics and quality of osmodehydrated grapefruit

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ABSTRACT

The effect of calcium lactate (2%) on osmotic dehydration kinetics and on the respiration rate, mechanical properties and shelf-life of fresh, vacuum impregnated (VI) and pulsed vacuum osmodehydrated (PVOD) grapefruit was evaluated. An isotonic solution was used for VI and a 55°Brix sucrose solution for PVOD treatments. Vacuum pulse was carried out at 50 mbar for 10 min and osmotic treatment was extended to 180 min. An increase from 5 to 8 days in the shelf-life of grapefruit was achieved due to sample dehydration and to 11 days if calcium is added to the osmotic solution, with no effect on the mechanical properties of the sample. This effect seems to be related with the decrease in the cellular respiration rate caused by dehydration and enhanced with the presence of this ion. Nevertheless, the water effective diffusion coefficient is reduced from 3.64×10^{-11} to 1.80×10^{-11} m^2/s when calcium lactate was added during the osmotic treatment.

1. Introduction

The fact that many fruits and vegetables possess antioxidant properties which are related to the prevention of degenerative diseases is widely recognized (Kaur and Kapoor, 2001). Grapefruit contains important micronutrients and phytochemical compounds, such as vitamin C, vitamin E, carotenoids, flavonoids such as hesperidin, narirutin and naringin, and other compounds with antioxidant capacity (Del Caro et al., 2004; Peiró et al., 2006) which are essential to remain healthy.

Consumer demand for fresh ready-to-use products has led, over the last 20 years, to an increasing interest in minimally processed fruits and vegetables, as these products combine freshness and convenience (Kim et al., 1993). Minimally processed fruits and vegetables are products that contain living tissues, which have suffered minor changes from their fresh state. Unfortunately, common processes undergone by fresh fruit, such as peeling, cutting and slicing, accelerate product deterioration since they provoke cell disruption with the subsequent decompartmentation of enzymes and substrates, thus resulting in an enhanced rate of physiological reactions. Quality loss occurs due to enzymatic browning, firmness reduction, off-flavour development, a decrease in nutritional value, physiological changes and microbiological growth (Brecht, 1995; Watada et al., 1996; Pretel et al., 1998), all of which depend not only on the storage time and temperature but also on the packaging used (Gunes and Chang Lee, 1997).

Osmotic dehydration (OD) is a process that may be used to increase the shelf-life of products, minimally decreasing the quality properties of the fresh fruit. In the last few years, the osmotic dehydration of fruits has become relevant as a technique to decrease water activity, thus increasing the product's stability (Raoult-Wack, 1994). During the osmotic dehydration process, a cellular tissue is dipped in a highly concentrated solution in order to promote water loss in the cells of the fruit. Nevertheless, due to the open structure of the tissue in the intercellular spaces, there also takes place a diffusion of external solutes and a hydrodynamic gain of external solution (Chiralt and Talens, 2005). Vacuum application for a short period of time at the beginning of the osmotic process (pulsed vacuum osmotic dehydration, PVOD) has beneficial effects on process kinetics and fruit quality in many fruits and also helps to reduce energy costs (Fito and Chiralt, 2000). Fruit impregnation with osmotic solution occurs in this case, which implies that the gas is exchanged in the pores for the external fluid (Fito, 1994). In this sense, solutes with a physiological function such as calcium can be incorporated into the cellular structure of the fruit, which could affect osmotic dehydration kinetics.

The kinetics of OD processes is usually evaluated in terms of water loss, weight loss and solid gain (Fito and Chiralt, 1997) and mainly depends on raw material characteristics (Raoult-Wack, 1994) and on operational conditions, such as solution

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Nomenclature

A	area under the force–deformation curve (N)
a_w	water activity
D_{eff}	effective diffusivity (m^2/s)
E	slope of the linear part of the force–deformation curve at low deformation
F_F	force at fracture point (N)
l	semi-thickness of the sample (m)
M	mass of the samples (g)
RQ	respiration quotient
RR_i	respiration rate, expressed as i: O_2 consumption or i: CO_2 production ($ml_i\ kg^{-1}\ h^{-1}$)
V	volume of headspace (ml) in Eq. (3)
x_i	mass fraction of the component i (w: water, s: soluble solid) in the sample (g i/g product)
Y	reduced driving force in the product liquid phase at time t of dehydration
y_i	concentration of the gas i in the head-space, i: CO_2 or O_2, (ml i/100 ml)
z_w	mass fraction of water in the sample liquid phase (g water/g liquid fraction)
ΔM_i	relative mass variation of the component i, w: water; s: solutes, (lost or gained g i/g fresh sample)
ΔM_T	total mass variation of samples (g/g fresh sample)
ε_F	deformation at fracture point (N)
Superscripts	
0	fresh sample
t	time t of dehydration
∞	equilibrium
t'	time t of measurement
t'_0	initial time of measurement

concentration and temperature (Barat et al., 2001), exposure time (Escriche et al., 2000) or pressure (Barat et al., 2001; Fito and Pastor, 1994).

One very serious problem with fresh-cut fruit products is that of tissue softening which can limit shelf-life. Fresh-cut fruit firmness is an important quality attribute that can be affected by cell-softening enzymes present in the fruit tissue (Varoquaux et al., 1990) and by a decrease in turgor due to water loss. The role calcium plays in increasing cell rigidity has been related to its ability to bind with mid lamella pectate (Rolle and Chism, 1987). In this way, the firmness of the flesh of fresh-cut fruit products may be improved if treated with calcium compounds. Dipping fresh-cut products in solutions of 0.5–1.0% calcium chloride is very effective at maintaining product firmness (Ponting et al., 1971, 1972). Calcium lactate has recently been shown to be as effective as the chloride form, without imparting a bitter flavor at higher concentrations (Luna-Guzmán and Barreto, 2000). On the other hand, a decrease in the respiration rate has been observed in samples treated with calcium. This effect may be related to the increase in the membrane rigidity which blocks the gas interchange (Saftner et al., 1999; Serrano et al., 2004), to a delay in the arrival of the senescence (Lester, 1996) or to the level of active water transport inhibition (Kinoshita et al., 1995).

Microbial decay of fresh-cut fruit may occur much more rapidly than in vegetable products due to the higher levels of sugars found in most fruit. However, the acidity of fruit tissue usually helps to delay bacterial growth, but not the growth of yeasts and moulds. The predominant microorganisms associated with spoilage of fresh-cut vegetables are bacteria (e.g. Pseudomonads spp.), whereas the predominant microorganisms associated with the spoilage of fresh-cut fruit products are yeasts and moulds (Gorny et al., 1998).

The objective of this work was to study the effect of osmotic dehydration and vacuum impregnation with calcium on the mechanical properties and on some aspects related to the shelf-life of the grapefruit, such as respiration rate and microbial counts. The effect of calcium on the osmotic dehydration kinetics was also studied.

2. Materials and methods

2.1. Raw material

Grapefruits (*Citrus paradisi*), of the cultivar Star Ruby, were purchased in local markets in Valencia (Spain). Grapefruit pieces were selected on the basis of a similar degree of ripeness (ratio °Brix/acidity = 5–7) and apparent fruit quality (color and firmness). They were stored in refrigerated chambers at 10 °C and at 85–90% relative humidity until they were used (less than 24 h). Before treatments, fruit pieces were manually washed and peeled and cut, perpendicularly to the fruit axis, into 1 cm thick half slices. Only the four central slices were used for treatments. Fig. 1 shows the process flow diagram explaining the different studies carried out, as detailed below.

2.2. Sample treatments

2.2.1. Pulsed vacuum osmotic dehydration (PVOD)

Grapefruit samples were submitted to osmotic dehydration processes in a temperature-controlled water bath at 30 °C (J.P. Selecta S.A., Precisterm S-141, Barcelona, Spain). Sucrose (food grade commercial sugar) mixed with heated (30 °C) distilled water until total dissolution, was used to prepare a 55°Brix osmotic solution (ratio solution/fruit 10:1). Calcium lactate 5-hydrated (Number CAS 5743-47-5, Panreac, Barcelona, Spain) was added to osmotic solution (0% and 2% (w/w) calcium lactate). A pressure of 50 mbar was applied to the system for the first 10 min of the osmotic process, afterwards restoring the atmospheric pressure for 10 min more in order to promote the previous sample impregnation with the osmotic solution. The impregnated grapefruit samples were immersed in a plastic tank filled with the osmotic solution and a plastic screen was placed on the basket to keep the slices totally immersed and separate from the stirrer working at 250 rpm (Heidolph Instruments, RZR 2102 control, Schwabach, Germany), used to homogenize the syrup continuously during the operation. For kinetic studies, samples were kept immersed in the osmotic solution for different times (t = 0, 15, 30, 45, 60, 90, 180, 300, 480 and 600 min) after which they were withdrawn from the solution and analyzed as described below (Section 2.3). Moreover, PVOD samples dehydrated for 180 min were analyzed as to the different aspects commented on in Section 2.4.

2.2.2. Vacuum impregnation (VI)

In order to separate the effect of the vacuum pulse and the osmotic dehydration in the study, the same calcium levels (0% and 2% (w/w) of calcium lactate) were added to an isotonic solution (≈18°Brix, a_w = 0.987 0.003) and vacuum impregnation of grapefruit samples was performed in the same conditions (10 min at 50 mbar and then atmospheric pressure was restored and maintained for 10 min more).