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Journal of Food Engineering 69 (2005) 307–316

JOURNAL OF FOOD ENGINEERING

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Influence of osmotic dehydration conditions on apple air-drying kinetics and their quality characteristics

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Received 24 May 2004; accepted 13 August 2004

Abstract

The influence of different osmotic pre-treatments on apple air-drying kinetics and their physical characteristics during drying were investigated. Apple samples were immersed in glucose or sucrose solutions of 30%, 45% (w/w) at different times. Sugar gain (SG) and water loss (WL) were calculated and an immersion time of 12 h was selected. Samples were further air-dried and the experimental data were fitted successfully using the Page model: MR = $\exp(-kt^n)$. Porosity, compressive fracture stress and colour were measured. Apples osmosed in glucose showed a large moisture decline in the early drying periods and similar drying rates to untreated samples for the same moisture change. Osmosed apples in sucrose showed lower drying rates ascribed to sugars concentration on the outer layers of apple tissue and their crystallization during drying. Samples pre-treated in 45% sugar solutions had greater porosity and better colour retention during drying. In glucose osmosed samples a greater texture hardening rate was observed, in sucrose just the opposite occurred.
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Keywords: Apple; Osmosis; Sugar solutions; Air-drying; Physical properties

1. Introduction

Dried fruits are widely used as components in many food formulations such as pastry, confectionery products, ice cream, frozen desserts and yogurt. Among them, dried apples are a significant raw material for many food products.

A widely used unit operation in the dried food process industry is hot air-drying, which could be considered as a simultaneous heat and mass transfer process, accompanied by phase change (Barbanti, Mastrocola, & Severini, 1994).

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doi:10.1016/j.jfoodeng.2004.08.021

Fruit drying is a well-known preservation method, mainly because water removal and water activity lowering reduce the risk of microbial development. Moreover, dried fruit can be stored and transported at a relatively low cost. However, water removal using high temperatures and long drying times may cause serious decreases in the nutritive and sensorial values, damaging mainly the flavour, the colour and the nutrients of dried products (Lenart, 1996; Lin, Durance, & Scaman, 1998).

One way of producing dried fruits of good quality is to use a pre-drying treatment, such as osmotic dehydration, able to reduce energy consumption and improve food quality (Torreggiani, 1993; Sereno, Moreira, & Martinez, 2001). Osmotic dehydration, also termed as 'Dewatering and Impregnation Soaking Process' (DISP), is a useful technique for the concentration of fruit and vegetables, realized by placing the solid food, whole or in pieces, in aqueous solutions of sugars or

Nomenclature

a	redness (CIELab tristimulus colour values)
b	yellowness (CIELab tristimulus colour values)
L	lightness (CIELab tristimulus colour values)
ΔC	colour change during drying time
ΔL	lightness change during drying time
Δa	redness change during drying time
Δb	yellowness change during time
A_0	original area of apple sample (cm^2)
A_t	circular area of apple cylinder at drying time t (cm^2)
F_f	force under compression at fracture point (N)
σ_f	stress at fracture (Pa)
H_0	initial height of the apple tube (mm)
H_t	height of the tube after compression at time t (mm)
M	moisture content at time t (g H_2O/g dry solids)
M_0	initial moisture content (g H_2O/g dry solids)
M_∞	equilibrium moisture content (g H_2O/g dry solids)
MR	moisture ratio
$\Delta M/\Delta T$	drying rate, moisture change versus respective time change (g H_2O/g dry solids · min)
k	drying constant of Page's model $(min^{-1})^n$
n	drying constant of Page's model
t	time (min)
V_b	bulk volume of apples (cm^3)
V_S	solids volume of apples (cm^3)
ε	porosity
SG	sugar gain (g/g fresh product)
WL	water loss (g/g fresh product)
ws_0	weight of solids initially present in the fruit (g/g fresh product in dry basis)
ws_t	weight of the solids in the fruit at the end of the treatment (g/g fresh product in dry basis)
w_t	weight of the fruit at the end of the treatment (g/g fresh product in dry basis)
ww_0	weight of water (g/g fresh product in dry basis)

salts of high osmotic pressure. It gives rise to, at least, two major simultaneous counter-current flows: an important water flow out of the food into the solution and a simultaneous transfer of solute from the solution into the food, that both occur due to the water and solute activity gradients across the cell's membrane (Rault-Wack, 1994; Torreggiani, 1993).

In addition osmotic dehydration is effective at ambient temperature with minimal damaging effect on food quality, achieving product stability, retention of nutrients and improvement of food flavour and texture. It results also in less discoloration of fruits by enzymatic oxidative browning, it satisfies consumers' demand for minimally processed products while additionally facilitates the industrial processes requiring reduced drying times (Kim & Toledo, 1987; Lerici, Pinnavaia, Dalla Rosa, & Bartolucci, 1985; Rault-Wack, 1994; Torreggiani, 1993; Velić, Planinić, Tomas, & Bilić, 2004). However, because it is a time consuming process, supplementary ways to increase the mass transfer are needed without affecting the product quality (Rastogi, Raghavarao, Niranjan, & Knorr, 2002).

Air-drying following osmotic dehydration was proposed for fruits and vegetables by many authors (Ertekin & Cakaloz, 1996; Kim & Toledo, 1987; Lenart & Lewicki, 1988b, 1988a; Lerici, Mastrocolla, & Nicoli, 1988; Lerici, Pinnavaia, Dalla Rosa, & Mastrocola, 1983; Torreggiani, 1993). Especially for apples the use of air-drying after osmotic pre-treatment is referred to Lenart (1996), Monsalve-Gonzalez, Gustavo, Barbosa-Cánovas, and Cavalieri (1993), Nieto, Salvatori, Castro, and Alzamora (1998), Reppa, Mandala, Kostaropoulos, and Saravacos (1999), Sereno et al. (2001) and Simal, Deyá, and Roselló (1997).

Mass transfer during osmosis depends on operating variables such as concentration and solute type of the dehydration solution. Therefore, the solute molecular weight can be a determinant factor influencing solute uptake during osmosis (Monsalve-Gonzalez et al., 1993; Rault-Wack, 1994; Rastogi & Raghavarao, 1995; Rastogi et al., 2002; Saurel, Raoult-Wack, Rios, & Guilbert, 1994).

In recent years there has been increased interest in the investigation of the physical characteristics of fruits, and especially of apples, after osmotic pre-treatment and drying.

Osmotic pre-treatment had a beneficial effect on the firmness of the rehydrated apples that had been air-dried at 50 °C. In addition osmotic dehydration before microwave-assisted air-drying increased the final overall quality of the product, but a negative correlation between apple texture and sugar diffusion was observed by Monsalve-Gonzalez et al. (1993) and Prothon et al. (2001).

Porosity can be related to the degree of water loss and solid gain in osmotic dehydration, to the immersion time during osmosis, to the fruit moisture content or to the microstructure changes of the tissue during drying. Moreover, changes in fruit porosity result in changes of its texture, influencing its firmness (Andrés, Bilbao,

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