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Process conditions effect on the quality of banana osmotically dehydrated

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ABSTRACT

Banana is greatly perishable and does not resist freezing, hence dehydration is the preservation technique of choice. This paper deals with the effect of process conditions on both the dehydration kinetics and the final quality of banana osmotically dehydrated. Banana slices (5 mm thick, 23 mm diameter) were osmotically dehydrated for 4 h, following a 3^2 full factorial design (temperature (30, 40, and 50 °C), sucrose concentration (45, 55 and 65% w/w)) with experiments in triplicate. The kinetics of dehydration efficiency (DE) and mass loss (DM) and the quality of osmotic dehydrated banana, was analysed through the measurement of colour, final volume (V/V^0) and shape changes (SF).

Both temperature and sucrose concentration in the osmotic solution had a significant effect on DE but had no significant effect on DM. Peleg's equation fitted well the data for DM and DE during OD. Sucrose concentration and temperature, had no significant effect on DM after 4 h OD or at the equilibrium mass loss (DM^e) ($p > 0.05$), however, temperature had a significant effect on the initial rate of DM ($p < 0.05$). Sucrose concentration and temperature, had no significant effect on the colour parameters (*L*, Chroma and Hue), but showed a significant effect on V/V^0 and SF, with temperature having a more extensive negative impact on V/V^0 and SF than sucrose concentration. Process temperature (low temperature, e.g., 30 °C) has to be carefully selected in order to reach a compromise between OD rate and an appropriate final product quality. The reduction in the kinetics caused by low temperature could be compensated by using highly concentrated sucrose solutions (as much as 65%), which would favour the compositional changes with a lesser impact on the product quality.

1. Introduction

Banana is among the most produced and consumed fruits in the world, and has a high nutritional value. From the standpoint of production, it is extremely perishable, and high losses occur after cropping. Moreover, it does not resist freezing, and dehydration is the choice technique for its preservation (Fernandes et al., 2006). Fruit dehydration has been extensively studied in the last two decades. In the case of banana, a variety of works have been reported on several drying techniques, such as simple heating in a kiln (Baini and Langrish, 2009), convection air drying (Boudhrioua et al., 2002; Demirel and Turhan, 2003; Maskan, 2000; Nguyen and Price, 2007), microwave drying (Maskan, 2000) and osmotic dehydration (Rastogi et al., 1997), as well as combinations such as osmotic dehydration followed by air drying (Fernandes et al., 2006). Amongst all these methods, osmotic dehydration (OD) is especially interesting because, unlike others, does not require high temperature, allowing for quick water removal from the cells without the disturbance of phase change (Tregunno and Goff, 1996). Being applicable at low temperature, OD is more appropriate than other techniques to protect the colour of foodstuffs against enzymatic browning (Lerici and Mastrocola, 1988), which is believed to be one of the main causes of quality loss during post-harvest handling and processing (Quevedo et al., 2009).

The methodology for OD is very simple. It requires the immersion of the foodstuff in an osmotic solution, whose water activity is lower that that of the product. The cellular structure of the plant tissue allows for water loss whereas a simultaneous solute gain occurs (Rastogi et al., 1997). Both mass flows are affected by many factors, such as the temperature and solute concentration of the osmotic solution, amongst others (Lazarides, 1994; Torreggiani, 1993). Temperature is an important factor affecting the rate and extent to which OD processes occur. Generally, high temperatures promote mass transfer in accordance to Arrhenius law. However, a compromise has to be achieved between the rate of OD and the preservation of the product's quality, given that high temperatures may negatively affect product quality. In fact, if temperature reaches a critical value, the cellular membrane starts to loose its specialized permeability functions due to protein denaturation (Gekas, 2001).

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Nomenclature

A	slice cross-section area (m^2)
a	Hunter colour parameter representing redness (non-dimensional)
b	Hunter colour parameter representing yellowness (non-dimensional)
DE	dehydration efficiency (X_w^r/X_s^r) (non-dimensional)
ΔE	total colour difference (non-dimensional)
DM	mass loss (g/g fresh sample)
K_1	intercept value parameter of Peleg's model (see Fig. 2)
K_2	slope parameter of Peleg's model (see Fig. 2)
L	Hunter colour parameter representing lightness (non-dimensional)
m	mass of a banana slice (g)
P	slice perimeter (m)
r^2	coefficient of determination (non-dimensional)
SF	shape factor (non-dimensional)
t	time of osmotic dehydration (h)
V	volume of a banana slice (m^3)
V/V^0	final volume (non-dimensional)
X_i	mass fraction of component i: w: water, s: solids (g i/g banana)
z_s	solute concentration in the banana liquid phase (g solute/g banana liquid phase)
Superscripts	
0	fresh sample
e	equilibrium
r	reduced property (referred to that of fresh banana)
t	time of osmotic dehydration

Most of the papers dealing with OD of foodstuffs have been mainly focused on the modelling of the dehydration step in order to optimise the process conditions and ultimately expedite dehydration, but fewer studies have quantified the impact of such process conditions on the quality of the final product. In the case of banana, some studies have tackled the impact of temperature on the quality parameters of slices subjected to simple heating (Baini and Langrish, 2009), hot air and/or microwave drying (Maskan, 2000) and simple convective air drying (Boudhrioua et al., 2002). However, no studies have been found on the impact of OD process conditions on the quality of banana osmotically dehydrated. The aim of this work was to study the influence of sucrose concentration and temperature on (i) the OD process of banana and the kinetics of dehydration efficiency and mass loss and (ii) the quality of osmotically dehydrated banana, through the measurement of colour alterations, volume loss and shape changes.

2. Materials and methods

2.1. Raw materials, osmotic dehydration and compositional analyses

Yellow–green bananas (*Musa acuminata* species, *Cavendish* group) were purchased from a local market. Their degree of ripeness was 5, according to the Chiquita colour index (Boudhrioua et al., 2003). Slices (5 mm thick, 23 mm diameter) were cut and trimmed with a plastic cork borer, immersed in a citric acid solution at 1% (w/w) for 3 min to reduce enzymatic browning, and gently dried with blotting tissue. A 3^2 full factorial design was followed, considering 2 factors at 3 levels, i.e., temperature (30, 40 and 50 °C) and sucrose concentration of the osmotic solution (45, 55 and 65% w/w). For all 9 combinations, OD experiments were carried out in triplicate. Solution to samples mass ratio was higher than 20:1 to avoid significant dilution of the osmotic solution, samples were kept immersed by means of a net and mechanical stirring was applied. Total mass, moisture and solids content were measured throughout the process (0, 20, 40, 60, 120, 180 and 240 min).

Moisture content (X_w) was gravimetrically determined at 60 °C in a vacuum oven (10 kPa) to constant weight (method 20.013, AOAC, 1980). Soluble solids concentration in the liquid phase of the banana (z_s) was determined with a refractometer (Refracto 30P, Mettler Toledo, Japan), and the soluble solids mass fraction in the banana (X_s) was determined with Eq. (1).

$$X_s = \frac{X_w \cdot z_s}{1 - z_s} \tag{1}$$

The moisture content (X_w) of fresh banana was 0.77 (±0.01) g water/g banana, and its soluble solids content (X_s) was 0.18 (±0.03) g solute/g banana. Therefore, only 0.05 g per g of fresh banana corresponded to the solid phase (insoluble solids). The composition of slices dehydrated osmotically was reported as reduced variables (X_w^r and X_s^r), i.e., the ratio X_i of the dehydrated sample to that of the corresponding fresh fruit (Eq. (2)):

$$X_i^r = \frac{X_i}{X_i^0} \tag{2}$$

2.2. Kinetic model

Modelling the kinetics of a mass transfer processes such as OD should be approached from a double standpoint. Since dehydration, apart from extended shelf life, provides lighter weight for transportation (Sousa et al., 2003), the bulk mass loss obtained throughout OD is an important variable and should be subjected to the model. Additionally, the shelf life of the final product greatly depends on its composition (moisture and soluble solids contents), which is why some variable related to it should be modelled as well. For these reasons, the kinetics of bulk mass loss (DM) and dehydration efficiency (DE), respectively defined by Eqs. (3) and (4), were subjected to the model.

$$\text{DM} = \frac{m^t - m^0}{m^0} \tag{3}$$

$$\text{DE} = \frac{X_w^r}{X_s^r} = \frac{X_w^t/X_w^0}{X_s^t/X_s^0} \tag{4}$$

where m^0 is the mass of the fresh sample, m^t is the mass at time t of OD, X_w^0 is the moisture content of the fresh sample and X_w^t is the moisture content at time t of OD (same for X_s). In the definition of DE (Eq. (4)), the moisture and soluble solids content were referred to those at the beginning of the experiment, to reduce the impact of the raw material variability. As OD progresses, water removal and solids uptake occur through different mechanisms. These two simultaneous mass flows cause both the decrease of X_w^t and the increase of X_s^t. For this reason, DE was selected to illustrate the compositional changes throughout OD, as a single parameter which comprehends both water loss and solids gain.

A number of equations have been used to model the kinetics of OD processes. Amongst them, the equation proposed by Peleg (1979) has repeatedly shown a close fit to the experimental data, as reported by diverse authors (Atarés et al., 2008; Khin et al.,