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Influence of osmotic pretreatment on the convective drying of guava

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Abstract

The effect of osmotic pretreatment on the air-drying kinetics of guava slices was studied. The pretreatment was carried out with different pressure regimes at 40ºC and 50ºC. Fresh and pretreated fruits were submitted to convective drying at 70ºC and air velocity of 1 m/s. Drying kinetics were described by three mathematical models of different nature. The pretreatment had a significant effect on air-drying process. However, drying kinetics of pretreated guavas were not statistically different to each other. Models provided a satisfactory prediction of the experimental moisture. The average values of the effective diffusion coefficient were of 5.40 x 10^{-10} m^2/s and 3.46 x 10^{-10} m^2/s for the first and second falling rate period of the pretreated fruit drying, respectively. Nevertheless, only one falling rate period was observed for the fresh fruit with a value of 3.18 x 10^{-10} m^2/s.

Introduction

Guava is a fruit from tropical and subtropical regions of America. It is an excellent source of vitamin C and is appreciated because of its pleasant flavour and aroma. Nevertheless, this fruit is a perishable food due to its high moisture content. Thus, processing techniques must be applied to reduce the water activity of this agricultural product in order to prolong its shelf life.

The use of combined methods in fruit drying allows stable products to be obtained while preserving the organoleptical and nutritional properties of the natural product. Osmotic dehydration followed by air-drying is widely applied to products such as mango (Maldonado *et al.*, 2010), pumpkin (Falade and Shogaolu, 2010), melon (Rodrigues and Fernandes, 2007) and pear (Chafer *et al.*, 2011). Osmotic pretreatment is used to reduce the initial water content, shortening total processing and air-drying time, and decreasing energy consumption (Ruiz-López *et al.*, 2010). This method also inhibits enzymatic activity, retains colour and volatile aromas of the natural fruits, and improves product quality after rehydration (Maldonado *et al.*, 2010).

There are many studies about guava osmotic dehydration in literature, covering aspects such as the effect of operating parameters on process kinetics (Panadés *et al.*, 2008; Correa *et al.*, 2010) and quality aspects of the resulting product (Duangmal and Khachonsakmetee, 2009; Pereira *et al.*, 2009). Nevertheless, few studies about the combination of osmotic pretreatment and the subsequent convective drying of this fruit have been found. These studies are mainly focused on quality aspects after guava processing (Sanjinez-Argandoña *et al.*, 2005; Duangmal and Khachonsakmetee, 2009) while drying kinetics is not studied.

The aim of this paper is to study the effect of different osmotic pretreatment conditions on the subsequent convective drying of guava. Experimental data were fitted to theoretical, semi-theoretical and empirical models in order to model the drying process and estimate the effective diffusivity of water.

Materials and Methods

Sample preparation

Guavas (*Psidium guajava* L) from Red Dwarf variety were used for the experiments. Ripe fruits free of mechanical damages with diameter and length of 72 ± 1 mm and 74 ± 1 mm, respectively, were selected to ensure the homogeneous size of samples. Fruits were washed with tap water and manually peeled. Subsequently, they were cut in eighth and then seeds were removed to obtain slices with an average thickness of 6.9 ± 0.5 mm (Panadés *et al.*, 2008). The average initial moisture content on wet basis (w.b.) was determined gravimetrically using a vacuum oven for drying to constant weight at 60ºC

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(AOAC, 1997).

Osmotic pretreatment

Processing was carried out in a vacuum rotary evaporator (Buchi Labortechnik AG, Switzerland) with 100 g of fruit sample for every 800 g of sucrose dissolution (65 ºBrix). Two temperatures (40 and 50ºC) and pressure regimes (continuous (C) and pulsed (P) vacuum) were applied for the osmotic pretreatment. A vacuum time of 5 min followed by atmospheric pressure was used for the pulsed vacuum regime. The absolute pressures of the system were those of the syrup vapor pressure at the studied temperatures: 40ºC - 5.2 kPa; 50ºC - 10.7 kPa. Rotation speed and processing time were of 100 rpm and 1.5 h, respectively. These operation parameters were selected from a previous study (Panadés *et al*., 2008). Each osmotic pretreatment was performed in triplicate.

Convective drying

Both pretreated and fresh guava samples were dried in a laboratory dryer equipped with a data recording system. A constant number of guava slices were hung 7 mm apart into the drying chamber of the convection direct dryer, exposing the entire surface of the slices to the air stream. Flow rate and air temperature were of 1 m/s and 70ºC, respectively, following the optimal drying temperature obtained for guava drying in an earlier study (Kek *et al*., 2013a). Samples weight was registered every 10 min and the drying process was accomplished for 5 h. Each experiment was performed in triplicate and the average values were used for the comparison.

Mathematical modeling

The analytical solution of Fick's second law for diffusion in an infinite planar slab was used to model the air-drying process (Doymaz and Pala, 2002; Ochoa and Ayala, 2005; Akpinar, 2006):

$$\Psi = \frac{W}{W_0} = \sum_{N=0}^{\infty} \frac{8}{(2N+1)^2 \pi^2} \exp\left[-(2N+1)^2 \pi^2 \frac{D_e}{4L^2} t\right] \quad (1)$$

where "Ψ" is the dimensionless moisture content, "W0" is the initial moisture content (kg water/kg dry mater), "W" is the moisture content at any drying time (kg water/kg dry matter), "N" is the number of terms taken into consideration, "t" is the drying time (s), "De" is the effective diffusion coefficient (m^2/s) and "L" is the half thickness of the fresh slice (m). Dimensionless moisture content, moisture content on dry basis (d.b.) and drying rate were calculated as was suggested by Akoy (2014).

Effective diffusion coefficient was calculated by minimizing the square differences between the experimental and predicted moisture content, considering fifty terms of the development series (Eq. 1). Newton's method available in SOLVER for EXCELTM spreadsheet was used with 10^{-12} accuracy and a convergence criterion of 10^{-10}.

Peleg's model (Eq. 2) and Page's model (Eq. 3) were also fitted by non-linear regression using the software Statgraphics Centurion XV. Peleg's model is an empirical model that has been widely applied to the dehydration of food products (Peleg, 1988). Page's model is a semi-theoretical model that has shown a close connection with the diffusional model of Fick's second law (da Rocha *et al*., 2012).

$$W = W_0 \pm \frac{t}{k_1 + k_2 t} \quad (2)$$

$$\Psi = \exp\left(-kt^n\right) \quad (3)$$

where "k_1" is a kinetic constant (s kg dry matter/kg water), "k_2" is a characteristic constant for each product (kg dry matter/kg water), "n" is the drying coefficient (dimensionless) and "k" is the drying constant (min^{-1}). The other terms have the same meaning exposed above. The goodness of fit was determined by using the regression coefficient (r^2), the standard error of the estimation (S_{yx}) and the mean relative error (MRE) (Wang and Brennan, 1991; Krokida *et al*., 2003).

The simple effect of each pretreatment factor (temperature and pressure regime) on the convective drying kinetics was examined through analysis of variance (ANOVA), looking at significant differences ($p<0.05$) between mean values of dimensionless moisture content for each drying time. The method applied to discriminate among means was the Fisher's least significant difference procedure (LSD), using the software Statgraphics Centurion XV. This statistical analysis was also conducted to look for significant differences between mean values of effective diffusion coefficient and drying coefficient.

Results and Discussion

Effects of osmotic pretreatment on convective drying of guava slices

The effects of temperature and pressure regimes on the convective drying kinetics of guava slices were analyzed. The drying curves are shown in Figures 1 and 2. As can be seen from Figure 1, the tendency of the drying curves was the same for all pretreated samples. The analysis of variance showed that there are no significant differences ($p>0.05$) between the drying kinetics of the guava slices submitted to the

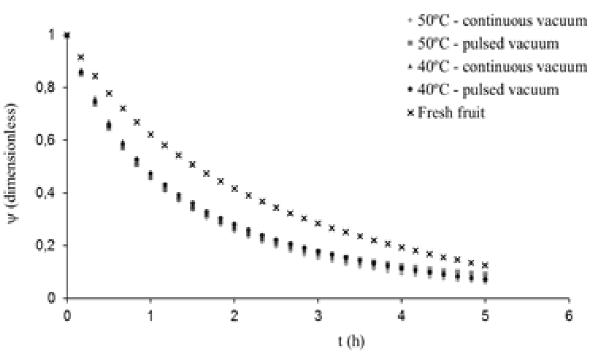

Figure 1. Effect of osmotic pretreatment on guava dimensionless moisture content during convective drying

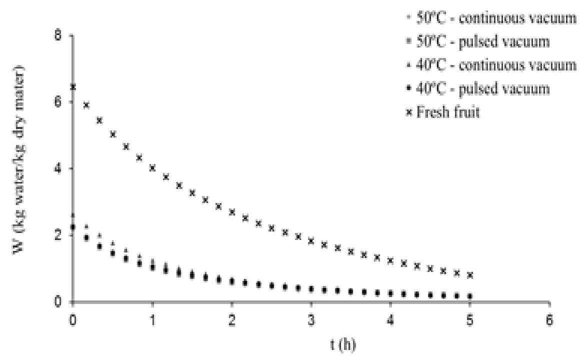

Figure 2. Effect of osmotic pretreatment on guava moisture content (d.b.) during convective drying

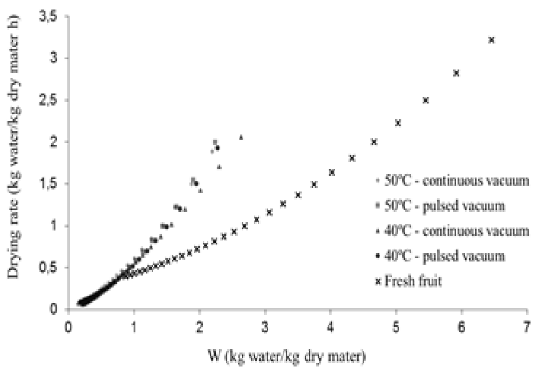

Figure 3. Effect of osmotic pretreatment on guava drying rate

osmotic conditions applied in this work. However, the analysis of variance also showed that there are significant differences ($p<0.05$) between the drying kinetics of untreated and pretreated fruits. The time required to reduce the moisture ratio to any given level was dependent on the pretreatment application, being lower for pretreated fruit. So, the pretreatment reduced the time required to attain the desired moisture content in the subsequent drying process.

As shown in Figure 2 for the convective drying, the initial moisture contents of pretreated guava slices (69.9 ± 2.8% w.b.) were lower than that of fresh slices (86.6 ± 1.7% w.b.). Thus, the pretreatment allowed the initial moisture content to be decreased about 17% (w.b.), which significantly reduces total moisture to be removed in the subsequent drying process.

On the other hand, more than 50% of the moisture in pretreated guava slices was removed during the first hour of air-drying, and the remaining water content was eliminated in a comparatively higher period. This probably was due to the shrinkage of fruit tissue with the corresponding pore reduction that increases water transport resistance during the drying process (Pereira *et al*., 2009). Nevertheless, untreated fruit required almost double drying time to reach the same moisture reduction.

In addition, the air-drying of untreated guava took about 4.5 h to reach the moisture attained (50%, w.b.) in the first hour of pretreated fruit drying. The average reduction of drying time was higher than that reported by Kek *et al.* (2013b) who applied ultrasound pre-osmotic treatments on this fruit. This fact indicates that the osmotic pretreatment pressure significantly influences the subsequent convective drying, since pretreatment temperatures were in the range tested by these researchers.

Figure 3 shows convective drying rate of guava slices plotted versus moisture content on dry basis. This figure reveals that there is no constant drying rate period for any material, and that all the drying process occurs in the falling rate period. These results are in agreement with those shown in earlier reports of fresh guava slices (Kek *et al*., 2013a) and other fruits (Rayaguru and Routray, 2012; Akoy, 2014) drying kinetics.

Moreover, the drying rate of pretreated fruit was higher than that observed for the fresh fruit with the same moisture content. This result disagrees with those reported by Andrés *et al*. (2007) and Sanjinez-Argandoña *et al.* (2005), since they found out that the presence of sucrose molecules in pretreated tissue of mango and guava, respectively, increased the internal resistance to water diffusion. One possible reason might be that other factors, such as the increase of the cellular membrane permeability because of the pretreatment, begin to be more influential on the diffusion transport.

Modeling of drying kinetics

The nonlinear relationship between ln Ψ and drying time for pretreated materials indicated that there was more than one period of diffusion (Chirife and Cachero, 1970). This phenomenon has been attributed to variations of the diffusive mechanism, which are caused by the structural changes of the

Table 1. Quality of model fit for both falling rate periods

Rate period	Osmosis	Diffusive model			Peleg's model			Page's model		
	T (°C), Vacuum	r^2 (%)	S_{yx}	MRE (%)	r^2 (%)	S_{yx}	MRE (%)	r^2 (%)	S_{yx}	MRE (%)
First	40, P	85.91	0.083	6.11	100	0.000	0.01	99.95	0.004	0.55
	50, P	87.10	0.077	7.61	99.99	0.001	0.07	99.94	0.006	0.76
	40, C	88.95	0.076	7.67	99.99	0.005	0.32	99.96	0.005	0.77
	50, C	86.94	0.079	7.31	99.99	0.001	0.09	99.96	0.004	0.57
Second	40, P	91.09	0.052	10.70	99.99	0.000	0.11	99.98	0.003	0.69
	50, P	90.01	0.068	9.78	99.99	0.001	0.19	99.95	0.005	0.77
	40, C	88.93	0.072	8.40	99.99	0.001	0.28	99.96	0.004	0.66
	50,C	91.33	0.071	7.17	99.99	0.001	0.40	99.99	0.001	0.62
Fresh guava		93.84	0.062	14.39	99.99	0.005	0.23	99.98	0.003	1.11

Table 2. Drying constants and coefficients of the proposed models for each falling rate period

Rate period	T (°C), Vacuum	D_e x 10^{10}*	k_1 x 10^{-3}*	k_2*	k*	n
First	40, P	5.43 (0.09)	1.63 (0.05)	0.39 (0.01)	0.02 (0.02)	0.85 (0.02)
	50, P	5.32 (0.03)	1.59 (0.09)	0.39 (0.02)	0.03 (0.00)	0.84 (0.02)
	40, C	5.29 (0.06)	1.56 (0.02)	0.36 (0.00)	0.02 (0.01)	0.88 (0.03)
	50,C	5.55 (0.03)	1.65 (0.05)	0.37 (0.01)	0.02 (0.01)	0.87 (0.03)
Second	40, P	3.49 (0.07)	9.45 (0.07)	1.06 (0.03)	0.01 (0.00)	0.97 (0.04)
	50, P	3.38 (0.06)	9.90 (0.06)	1.15 (0.04)	0.01 (0.02)	0.94 (0.03)
	40, C	3.35 (0.02)	9.56 (0.07)	1.10 (0.00)	0.01 (0.01)	0.94 (0.02)
	50, C	3.60 (0.03)	9.50 (0.03)	1.09 (0.01)	0.01 (0.00)	0.95 (0.02)
Fresh guava		3.18 (0.08)	1.06 (0.02)	0.12 (0.01)	0.01 (0.01)	0.91 (0.01)

Numbers in brackets represent standard deviation
*De (m^2/s); k1 (s kg dry matter/kg water); k^2 (kg dry matter/kg water); k (min^{-1})

fruit during the drying process (Chirife and Cachero, 1970). In fact, two falling rate periods were identified for each pretreated material. The first period was shorter than the second one. The transition between these periods took place at a moisture content of about 0.8 kg water/kg dry matter. Nevertheless, the fresh fruit showed a linear relationship, which denotes that the relative influence of the different diffusive mechanisms was the same during the drying. The modification on the drying kinetics of pretreated samples in comparison with untreated ones indicates the marked influence of the applied osmotic pretreatment.

After verifying the superiority of the internal resistance to mass transport over the external (Mulet, 1994), the data of each falling rate period was fitted to the proposed models. Statistical analyses of the model fits are presented in Table 1. Statistical parameters indicate that the models could satisfactorily describe the drying of guava slices for practical purposes. Nevertheless, results revealed that Peleg's and Page's models attained the highest values of regression coefficient and the lowest values of standard error of the estimation and mean relative error. So, these models showed better suitability for describing the drying of guava slices.

Moreover, the applied diffusion model provides a good description of the experimental data in spite of the adopted simplifying assumptions (Doymaz and Pala, 2002). A more detailed description of the physical phenomenon would require using a more complex theoretical model to consider aspects such as sample shrinkage and heat transfer. However, it may be that model complexity does not compensate the advantages of simple models for common applications.

Drying constants and coefficients of different models

Table 2 shows values obtained for the effective diffusion coefficient. These are close to those obtained by other researchers for convective drying of fruits submitted to osmotic pretreatment (Barrera *et al.*, 2004; Gaspareto *et al.*, 2004). They are also consistent with the reported values of 2.27 to 4.97 x 10^{-10} m^2/s for the drying of apple in the temperature range of 40-60ºC (Sacilik *et al.*, 2006), 3.32 to 90.00 x 10^{-10} m^2/s for berberis fruit at 50-70ºC (Aghbashlo *et al.*, 2008) and 4.97 to 10.83 x 10^{-10} m^2/s for raw mango slices at 60-80ºC (Akoy, 2014). Nevertheless, they are higher than the informed values of 1.6 to 2.1 x 10^{-9} m^2/s for guava slices submitted to pre-osmotic dehydration with and without ultrasound application, at atmospheric pressure (Kek *et al.*, 2013b).

The fact that no significant differences ($p > 0.05$) were observed between mean values of effective diffusion coefficient for the pretreated samples (Table 2) supports the likeness found between their drying kinetics. The values obtained for this physic property in the first falling rate period were higher than those of the second period. This result corresponds with the shorter drying time required to remove more than 50% of moisture at the beginning of the drying process. As was stated before, it might be due to the restructuring of cell walls and the change of porosity related to the shrinkage of fruit tissue.

Nevertheless, both falling rate periods achieved higher effective diffusion coefficients than that of the fresh guava. This result is in agreement with the drying rate differences observed among these materials for the same moisture content. These results may be attributed to the severe structural damage of the cell walls that decreases water transport resistance after the pretreatment. Furthermore, a decrease in total amount of pectin substances might have occurred during the osmotic process. This allows explaining the reduction observed in the slices firmness and thereby the improvement in water diffusion (Karim, 2010).

Kinetic parameters of Peleg's and Page's models are also presented in Table 2. The coefficient "n" of Page's model has been considered as a constant in other studies since it does not depend on the temperature, but it depends on the kind of product to be dehydrated (Karathanos and Belessiotis, 1999; Senadeera *et al*., 2003). Results obtained in the current study show that drying coefficient values (n) for the pretreated slices are very similar in each drying rate period, which proves that these products have similar structures. Moreover, the two drying rate periods have different values of this parameter and differ from that of the fresh guava, what sustains the structural changes attributed to the air-drying and the osmotic process, respectively.

Conclusions

Convective drying kinetics of fresh guava was modified and two falling rate periods appeared by the application of the osmotic pretreatment. This additional stage reduces the convective drying time in comparison with the fresh fruit drying and therefore allows saving energy in the drying process. Peleg's and Page's models were found to be the most suitable models for describing the thin-layer drying kinetics of pretreated and fresh guava slices. Furthermore, the osmotic conditions tested allowed to obtain materials with similar drying kinetics. Thus, the less harsh conditions (40ºC, pulsed vacuum) are the best to pretreat guavas due to the smaller pretreatment cost.

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