STUDY OF SHRINKAGE PHENOMENON DURING CONVECTIVE DRYING OF PAPAYA (*Carica papaya L.*)

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Abstract. Shrinkage of foodstuffs is a common physical phenomenon observed during different dehydration processes. These changes affect the quality of the dehydrated material, producing large changes in its volume and its heat and mass exchange area because of spatial and time variable structure. Therefore, the shrinkage phenomenon should be taken into consideration when predicting moisture or temperature profiles in the dried product. The aim of this work was to study the material dimensions and bulk density changes during the convective drying of papaya (*Carica papaya L.*) slices and to model the shrinkage kinetics. A continuous flow fixed bed dryer was used and the tests were conducted at four different air temperatures (40, 50, 60 and 70^{0}C) and at constant air velocity. The results showed that the shrinkage degree was not influenced by the process conditions and that the sample dimensions changes were only function of its moisture content. A logarithmic behavior was observed between the product dimensions and its moisture content along the drying process; however, the relationship between the volume of removed water and volume of sample was linear. The sample thickness was the dimension with larger shrinkage compared to its air flow transversal area. During the early drying stages, samples bulk density increased sensibly until a certain moisture content of papaya samples, but, close to the equilibrium condition, its value decreased, indicating an increase on samples porosity.

Keywords: Papaya, Convective Drying and Shrinkage.

1. Introduction

Drying is a process of simultaneous heat and mass transfer which induces changes in the material undergoing dehydration. These mainly originate from temperature increase, prolonged contact with air and removal of water. It is one of the most common processes used to improve food stability, since it decreases considerably the water activity of the material, reduces microbiological activity and minimizes physical and chemical changes during its storage.

The present demand of high-quality products in the food market requires dehydrated foods that maintain at a very high level the nutritional and sensorial properties of the initial fresh product. A thorough understanding of the factors responsible for the decrease in the quality of the product during the dehydration process is thus of major relevance.

One of the most important physical changes that the food suffers during drying is the reduction of its external volume. Loss of water and heating cause stresses in the cellular structure of the food leading to change in shape and decrease in dimension. Shrinkage of food materials has a negative consequence on the quality of the dehydrated product. Changes in shape, loss of volume and increased hardness cause in most cases a negative impression in the consumer. There are, on the other hand, some dried products that have had traditionally a

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shrunken aspect, a requirement for the consumer of raisins, dried plums, peaches or dates (Mayor and Sereno, 2004).

It was found that, during drying process, the decrease of food surface under the influence of the contraction of tissues compensates partially for the loss of water. Consequently, all the parameters which depend on internal and external dimensions change, making the use of a complete model for drying simulation of these products difficult. The very low number of reliable data on this phenomenon makes the concept of the characteristic curve of drying one of the best adapted methods used by many authors (Belahmidi et al., 1993; Desmorieux, 1992; Fornell, 1979; Keey, 1977; Talla et al., 2001) to describe the behavior of the foodstuffs during drying.

The shrinkage phenomenon affects in particular the diffusion coefficient of the material, which is one of the main parameters governing the drying process; it also has an influence on the drying rate (Lima et al., 2002; Queiroz, 1994; Queiroz and Nebra, 1996). Besides, various characteristics of the material depend on its density so that the knowledge of the density variation with moisture content will be useful to characterize the behavior of this material. The determination of its variation is thus essential (Nadeau and Puiggali, 1995).

In food systems shrinkage is rarely negligible, and it is advisable to take it into account when predicting moisture content profiles in the material undergoing dehydration. For such purpose different types of models that predict volume change in the material are available and should be used. Several authors have successively reviewed the process of food dehydration both from an experimental and modelling viewpoint, pinpointing new approaches and methodologies. Some representative examples of such effort are the works of Bruin and Luiben (1980), Chirife (1983), Holdsworth (1971), Jayaraman and Das Gupta (1992), King (1971), Lozano et al. (1983), Rossen and Hayakawa (1977), Suzuki et al. (1976), Van Ardsel (1963), Waananen et al. (1993).

Therefore, the objective of this work was to study the material dimensions and bulk density changes during the convective drying of papaya (*Carica papaya L.*) slices and to model the shrinkage kinetics using the uniform model of Suzuki et al. (1976) and an empirical logarithmic model proposed in this work.

2. Material and Methods

2.1. Raw Material

Papayas (Formosa variety) with similar maturity (10–12^{0}Brix) and weight (2.0–2.5kg) were purchased in a local market. The samples were hand-peeled and cut into slices (30 x 50 x 5 mm) using a cutter designed for this purpose.

2.2. Air-drying experiments with fresh papaya slices

A continuous flow fixed bed dryer was used and the tests were conducted at four different air temperatures (40, 50, 60 and 70ºC). The dryer system consisted of vertical air flow through trays and was arranged as a closed circuit. For the air heating, three electric resistances were used (two of 1600W and one of 800W), which could be worked independently, controlled by a digital thermostat. A thermal-hygrometer (TESTO 635) was used in order to measure the dry bulb temperature as well as the drying air humidity.

Samples had an average initial moisture content of 87.73% wet basis which was gravimetrically measured using a vacuum oven (635 mmHg) at 60ºC for 24h. Sample moisture content during the air-drying process was gravimetrically determined from the sample initial moisture content (before air-drying process). Sample weight was measured using a semi-analytical balance. The drying process was carried out until the dynamic equilibrium between the sample moisture content and drying air humidity was reached when the sample weight became constant.

2.3. Shrinkage analysis

The shrinkage kinetics was accomplished by attendance of samples total superficial area and apparent volume variations along the drying process.

Papaya samples were photographed, using a digital camera SONY *Cyber-shot*, in the same instant that they were weighed. Samples width and depth changes were obtained directly by the photos, through arithmetic average of the measurements done in five different points along the sample for each dimension, according to Figure 1.

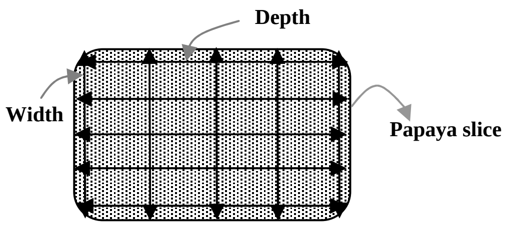

Fig. 1. Depth and width measurement of papaya slices.

The variation of samples thickness during drying was determined through an arithmetic average of the measurements done in five different points of the sample, using a digital micrometer MITUTOYO (Figure 2).

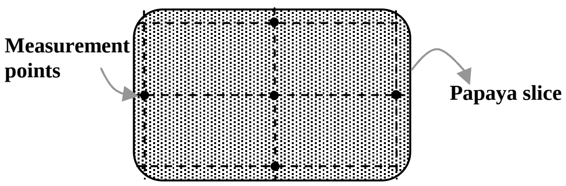

Fig. 2. Thickness measurement of papaya slices.

The samples superficial area was obtained by photography. All photographs were enlarged to the same size. The surface area was measured cutting out from the photographs the shapes of the samples and establishing a relationship between their weight and the weight of $1cm^2$ of the same paper used to print the photographs. Apparent volume of the samples was found multiplying the transversal area by the average thickness of the material. The samples density was obtained using weight and apparent volume data along the drying process. All the experimental determinations were made in triplicate.

2.4. Shrinkage modelling

The shrinkage modelling was accomplished using the uniform model of Suzuki et al. (1976) (Eq. (1)).

$$\frac{A}{A_0} = (aX + b)^n \tag{1}$$

Where:

A = Sample superficial area during the process, (m^2);

A_0 = Initial sample superficial area, (m^2);

X = Sample moisture content during the process, (kg water/kg dry matter);

X_0 = Initial sample moisture content, (kg water/kg dry matter);

ρ_0 = Initial sample density, (kg/dm^3);

$a = \rho_0/(X_0 + 1)$;

$b = 1 + a - \rho_0$.

The Eq. (1) try to relate the changes in samples superficial total area with the decrease in their moisture content, taking into account the samples bulk density data in initial condition. The *n* parameter is the shrinkage factor.

An empirical logarithmic model (Eq. (2)) was also used to describe the changes in samples superficial area with their moisture content during the whole drying curves.

$$\frac{A}{A_0} = c + d\ Ln\left(\frac{X}{X_0}\right) \tag{2}$$

Where:

c and d = Model parameters.

2.5. Modelling Evaluation

For model evaluation, a nonlinear regression procedure was used, for both models by the statistical package Statistica 5.0 (Statsoft, 1997). The modelling was characterized by the average relative error E (Eq. (3)) calculation and the correlation coefficient r^2.

$$E(\%) = \frac{1}{N}\sum_{i=1}^{N}\left|\frac{V_E - V_P}{V_E}\right| 100 \tag{3}$$

Where N is the number of experimental data, V_E is the experimental value and V_P is the calculated value.

3. Results and Discussion

Figure 3 shows the relationship between the volume of removed water and the changes in samples volume during the drying process.

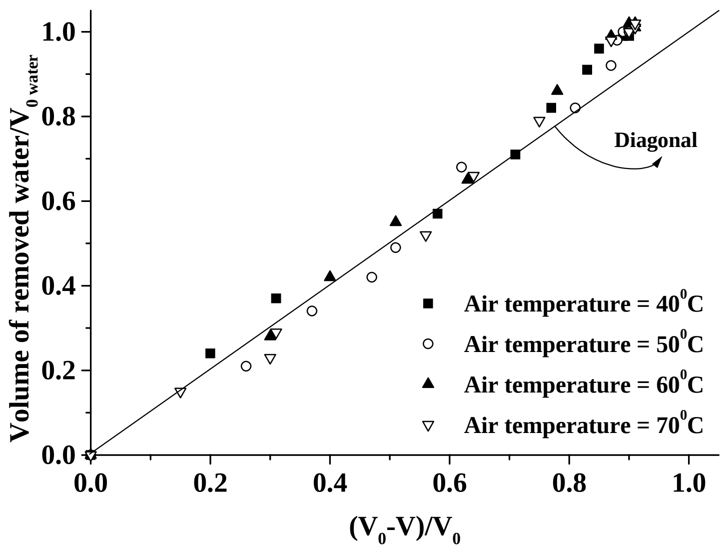

Fig. 3. Volume of removed water as a function of samples volume.

According to Figure 3, the relationship between the volume of removed water and the changes in papaya slices volume is linear, practically, and it was not observed a clear influence of process temperature on the samples shrinkage. However, close examination make us to notice that there is a smooth curvature at the end of the process (from a dimensionless sample volume of 0.7). It indicates that, close to the equilibrium condition, the volume of removed water was greater than the samples volume.

Shrinkage of food materials increases with the volume of water removed, since the more the water removed the more contraction stresses are originated in the material. In some cases the mechanical equilibrium is reached when shrinkage of the material equals volume of removed water. In shrinkage data for carrot drying presented by Krokida and Maroulis (1997) and Lozano et al. (1983), this behavior is observed during the whole drying process. In other cases, however, the volume of removed water during the final stages of drying is larger than the reduction in sample volume; this was observed during the drying of squid flesh (Rahman and Potluri, 1990; Rahman et al., 1996), potato and sweet potato (Lozano et al., 1983; Wang and Brennan, 1995), and apple (Krokida and Maroulis, 1997; Lozano et al., 1980). This behavior can be explained by the decrease in the mobility of the solid matrix of the material at low moisture contents.

Figure 4 shows the variation in sample bulk density as a function of its moisture content during the whole drying process.

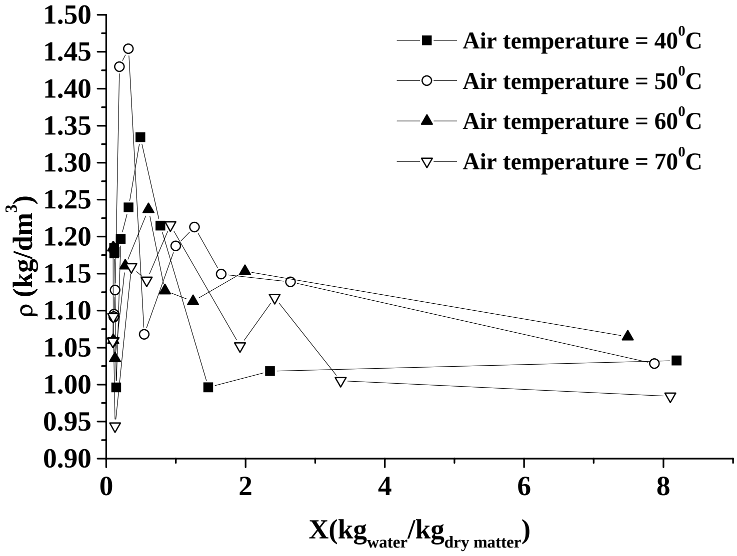

Fig. 4. Samples bulk density as a function of their moisture content at several air temperatures.

In agreement with Figure 4, at the beginning of drying process, samples density increases with their moisture content decrease until a certain moisture content of 0.50 kg_{water} / $kg_{dry\ matter}$, approximately. However, from this moisture content to the end of drying, samples density decreases until a certain value slightly higher than the initial samples density one.

This behavior was also observed by Wang and Brennan (1995), working with potato. Further reduction in moisture content resulted in a decrease in density of the samples. Marousis and Saravacos (1990) investigated the change in density of starch materials during drying and found similar results. Shrinkage may be responsible for the increased apparent density at low moisture contents. During the final stage of the drying the volume of the sample does not change with the further loss of water. Therefore, the density of the sample decreases with decreasing moisture content at low moisture contents. This fact confirms what was discussed in Figure 3.

The variation in papaya slices dimensions along the whole drying can be seen in Figure 5. In agreement with Figure 5, the thickness was the dimension that more varied due the process, followed by the width and the depth. Therefore, according to Figure 5, the drying of papaya slices could be considered a unidirectional mass transfer process.

Figure 6 shows the modelling using the Suzuki et al. (1976) uniform model (Eq. (1)) and the logarithmic model proposed in this work (Eq. (2)) for the drying of papaya slices at several air temperatures.

The Tables 1 and 2 show the model parameters obtained from a nonlinear regression procedure of the Eqs. (1) and (2).

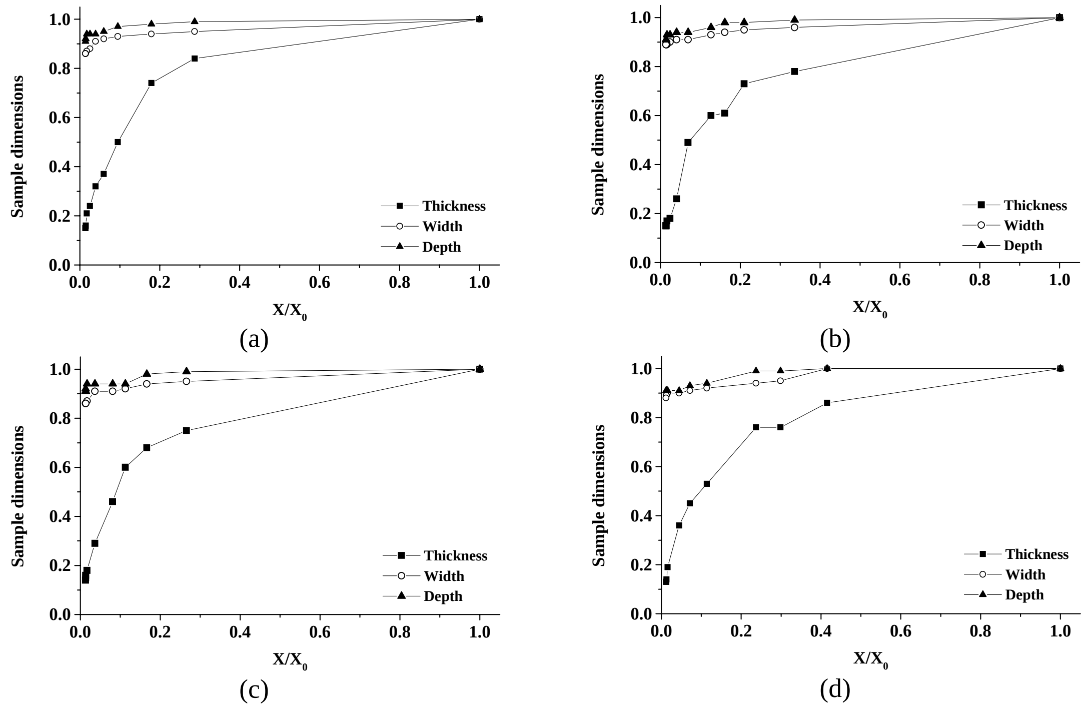

Fig. 5. Variation in samples dimension as a function of their moisture content at (a) 40^{0}C, (b) 50^{0}C, (c) 60^{0}C and (d) 70^{0}C.

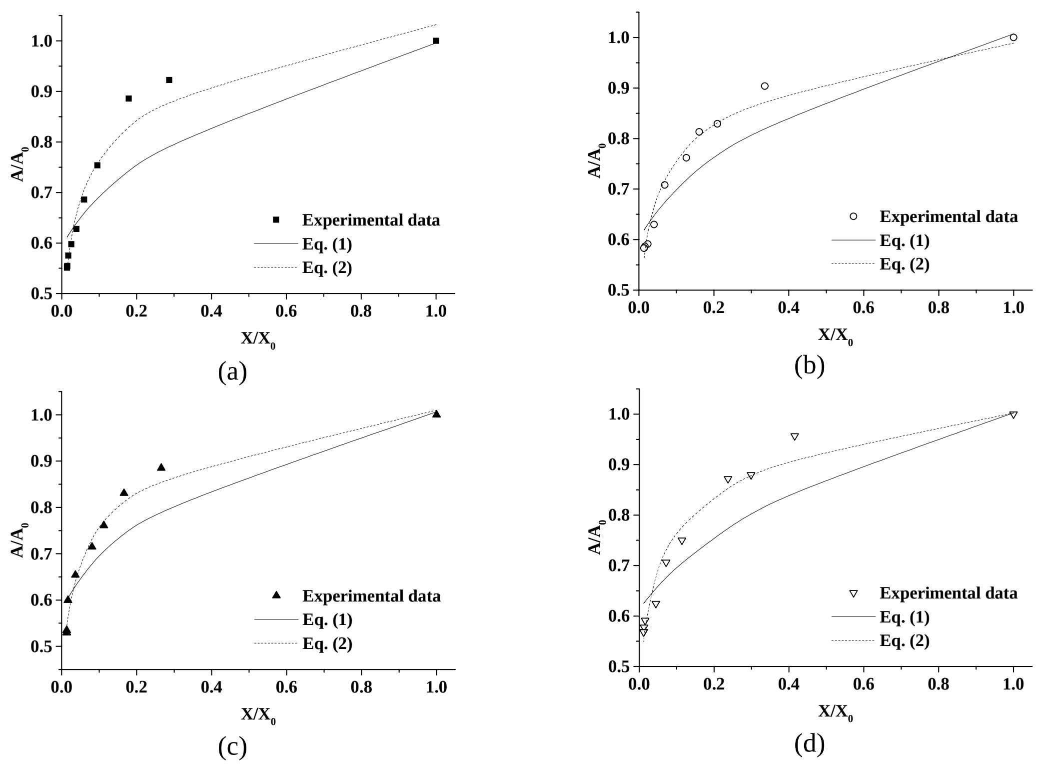

Fig. 6. Modelling of shrinkage kinetics, during drying process of papaya slices, using Eqs. (1) and (2) at (a) 40^{0}C, (b) 50^{0}C, (c) 60^{0}C and (d) 70^{0}C.

According to Table 1, the Eq. (1) did not fit very well to the experimental data presenting values of r^2 between 0.81 and 0.89, although it has presented low values of average relative error (inferior to 8%). The shrinkage factor *n* was not influenced by the air temperature, practically. Its average value was 0.21 and it indicates the quantitative relationship between the changes in samples superficial area and their apparent volume.

Table 1. Shrinkage modelling using the Suzuki et al. (1976) uniform model.

Air temperature (^{0}C)	n	r^2	E(%)
40	0.21	0.8073	7.94
50	0.21	0.8941	5.81
60	0.20	0.8629	7.53
70	0.23	0.8497	7.37

In agreement with Table 2, the logarithmic model satisfactorily fitted to the experimental data presenting low values of average relative error (inferior to 3.5%) and values of r^2 close to the unity (superior to 0.97).

Table 2. Shrinkage modelling using the logarithmic model.

Air temperature (^{0}C)	c	d	r^2	E(%)
40	1.03	0.11	0.9748	2.73
50	0.99	0.10	0.9793	2.65
60	1.01	0.11	0.9885	2.13
70	0.96	0.21	0.9762	3.20

4. Conclusions

The relationship between the volume of removed water and the samples volume was linear. During the early drying stages, samples bulk density increased sensibly until a certain moisture content of papaya samples, however, close to the equilibrium condition, its value decreased, indicating an increase on samples porosity.

Samples dimensions changes were only function of their moisture content once the shrinkage kinetics was not influenced by the air temperature. The sample thickness was the dimension with larger shrinkage compared to the other dimensions.

The logarithmic model satisfactorily described the shrinkage kinetics of papaya slices presenting low values of average relative error and values of r^2 close to the unity.

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