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Physical Transformations on Organic Product during Its Convective Drying: Case of Sweet Potato

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Abstract

This study highlighted the physical transformation that agri-food products undergo during their drying. This transformation enormously affects the customer's choice and the profit margin of the dried product promoter. The example of the experimental study of the potato reveals that the product continually changes its dimensions during its drying. The more the product loses its water, the more the dimensions decrease. The results initially showed that the water parameters such as mass or water content decrease according to the drying principle. The dimensions length *L*., width *l* and thickness *e*. decrease following a linear trend whose mathematical equations which describe them are determined using the office tool, excel. This trend has repercussions on the surface and volume parameters which in turn decreases almost linearly with the product's water content. Note that the coefficient R^2 is not always acceptable, confirming the complex nature of the behavior of organic products.

Keywords

Dimensions Reduction, Shrinkage, Index I

1. Introduction

Food samples undergo volume changes, *i.e.*, shrinkage, on water loss. Such shrinkage affects the physical attributes and the transport properties of the solids. The volume change during drying is not theoretically an easily predictable function.

In this work, a visual examination of the samples throughout the drying process reveals that the shrinkage is not perfectly homogeneous (**Figure 1**). In the initial stage of drying, the samples keep the original geometry, *i.e.*, the cell structure appears to be intact. As drying proceeds, however, the shrinkage is accompanied by particle deformation.

Quantitative evaluation of the shrinkage was performed on the basis of a bulk shrinkage coefficient, *i.e.*, a ratio of the sample volume at time, *t*, to initial volume, V/V_0. The experimental data show a linear behavior [1] between bulk shrinkage coefficient and moisture content, which suggests that the shrinkage is predominantly due to the volume of water removed.

A linear relationship, bulk shrinkage coefficient versus water content, was fitted to the experimental data. Some researchers reported the linear shrinkage behavior of food materials, including [2]-[4].

For this work, the samples were considered to be homogeneous; however, some heterogeneity was present. We will examine both, the mechanical behavior of the samples in terms of their solid matrix contraction, and the directional behavior of the contractions in terms of isotropicity index. Mathematical models will be empirically developed using experimental data.

a) raw sweet potato b) Freshly cut samples c) Samples drying, undergoing deformation

Figure 1. From raw sweet potato to drying sample: a) Raw sweet potato, b) freshly cut samples, c) samples undergoing deformation during their drying process.

2. Materials and Methods

2.1. Sample Processing

Convective drying of the sweet potato was carried out in an oven. The temperature is set at 70°C. As soon as thermal equilibrium is reached, the samples are introduced into the oven enclosure. On each sweet potato sample, we mark with indelible ink three geometric locations where the measurements will be taken. Three measurements are taken to finally consider the average. Samples were removed at predetermined time intervals throughout the experimental run for lateral, longitudinal and thickness dimensions and mass measurements. We minimize the measurement time so as not to disturb the thermal balance already established in the product. The geometric characterization of the samples is done by initially measuring the dimensions as well as the final values. For this purpose, we use the digital micrometer (MITUTOYO, Japan, precision 2.10 - 5 m).

2.2. Data Processing

2.2.1. Contraction

During the sweet potato drying process, its material undergoes physical deformations. The loss of water during convective drying leads to cellular collapse and consequently, the contraction of the solid matrix of the product. The models in the literature are mainly empirical and cannot be transposed from one product to another or from one drying condition to another [5]-[12]. There are nevertheless basic theories in the literature [13]. The multiplicity and diversity of products and their physical properties (density, material concentration, contraction coefficient, collapse, porosity, change in dimensions, etc.) make comparisons very difficult [14]-[20]. From experimental data, contractions are represented by relations:

- Case of length and transposable for width and thickness:

$$\frac{L}{L_0} = a_L \frac{X}{X_0} + b_L \tag{1}$$

- Case of the volume and transposable for the surface:

$$\frac{V}{V_0} = a_v \frac{X}{X_0} + b_V \tag{2}$$

Where a and b are constants deduced graphically, the indices V, L and d are related respectively to the volume, length and diameter. These models have been used by certain authors for different products and applications: for spirilina [16], potato [21] [17], grapes [22], gelatin slabs [23], okra [24], mango [25] and tomato [26].

2.2.2. Shrinkage Isotropicity

The difficulty linked to the study of the drying of agri-food products comes from the great diversity in the field. Added to this is the structural factor. The heterogeneity and anisotropicity of the agri-food product give it, during its drying, very complex physical and mechanical characteristics. We can distinguish three main directions:

- The longitudinal direction (L), which is that of the fibers;
- The tangential direction (T), perpendicular to the plane containing the fibers;
- The radial direction (R), is perpendicular to the longitudinal and centripetal axis.

The isotropicity index allows us to characterize and compare the contraction of samples in two directions during drying.

For drying times different from the initial time, the shrinkage isotropicity between X and Y directions was defined as the ratio of the reduction in X divided by the ratio of the reduction in Y.

For these directions, we define the isotropicity index J_{XY} by the following relation:

$$I_{XY} = \frac{\left(\frac{X - X_0}{X_0}\right)}{\left(\frac{Y - Y_0}{Y_0}\right)} \tag{3}$$

Thus, the thickness-length isotropicity index is defined by the following relation [18] [20]:

$$I_{eL} = \frac{\frac{\mathrm{e} - \mathrm{e}_0}{\mathrm{e}_0}}{\frac{L - L_0}{L_0}} \tag{4}$$

Where e_0, e are respectively the initial and the current values of the sample thinness and L_0, L respectively the initial and the current values of the sample length.

3. Results and Discussions

3.1. Evolution of Mass and Water Content

The principle of drying is to lose the water contained in the product. With the drying time, the product sees its mass decrease as shown in **Figure 2**. This loss of water results in a decrease in the water content of the product with the drying time. The mass of the product decreases from its initial value to m_0. A final value m_f, which no longer varies with drying time. By pushing the drying according to the law [27] AOC, 1995 by putting the sample in an oven at 105°C for 24 hours, the mass m_f, decreases slightly and reaches the value m_S. The product has therefore lost all traces of water likely to promote biological action. m_s, is the mass of the solid skeleton. At the same time, its water content decreases from its initial value X_0, to a final value X_f, which can be calculated based on the value of m_f, so-called wet-based or value-based m_S, called dry base. The results in **Figure 2** shows that m_f/m_0 is 0.202 for the potato. The product X_f/X_0 value takes almost zero value.

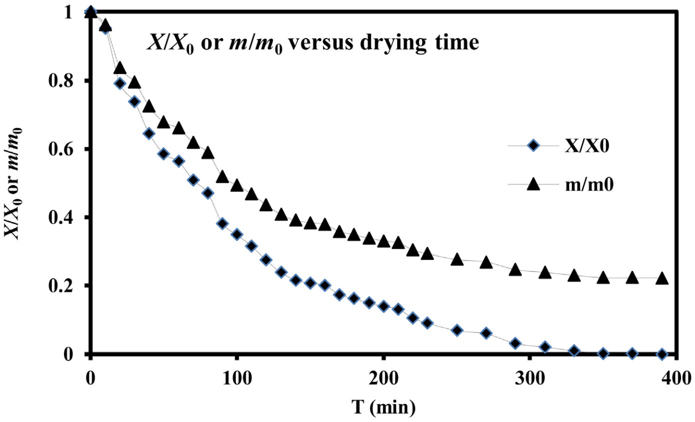

Figure 2. Evolution of water parameters during sweet potato drying.

3.2. Contraction of Linear Dimensions

During drying, the lateral dimensions of the sweet potato decrease with time. As the product loses its water it undergoes a collapse of the material which compensates for the loss of water. Consequently, its dimensions decrease. Figure 3 shows us that for the dimensions length L, width l and thickness e, they go from 100% to X/X_0 = 1 at around L/L_0 = 0.88, l/l_0 = 0.86 and e/e_0 = 0.83 for X/X_0 = 47%. A X/X_0 = 21%. These values are respectively 0.82, 0.77 and 0.75. At the end of drying, *i.e.* for X/X_0 = 0.09 they stabilize, respectively at a ratio of 0.72, 0.65 and 0.64. Let us note an anomaly which occurs at this moment with the appearance of a crack which affects certain measurements.

All variations of the rates L/L_0, l/l_0 and e/e_0 as a function of the rate X/X_0, are quasi-linear and can be put in the form of equation1.

We see that, the smaller dimension decreases more quickly. Thus the line relating to e/e_0 has a steeper slope than that of l/l_0. The curve of the largest dimension, which is the length L/L_0, has the smallest slope.

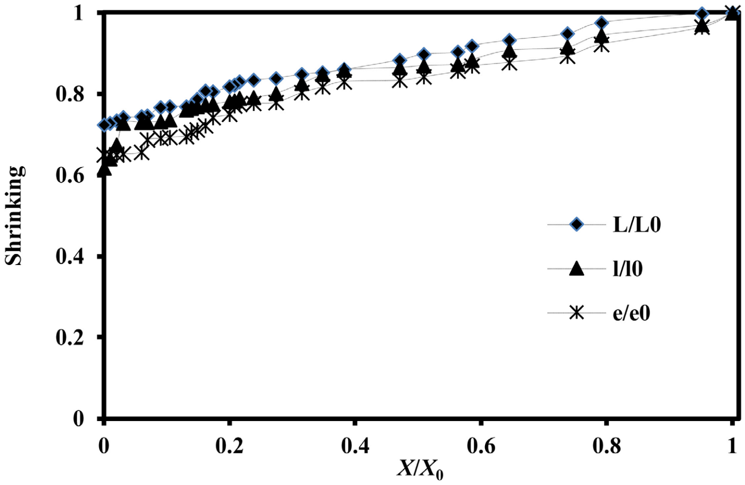

Figure 3. Change in linear dimensions of sweet potato samples during convective drying.

3.3. Surface and Volume Contraction

The change in dimensions during drying results in variations in the volumes and surfaces of the samples. However, in the assessment of the finished product, the state of these parameters affects its quality. In the local market, buyers visually choose by volume and not mass.

This study shows us, in Figure 4, the trends in the surface areas and volumes of the sweet potato samples submitted to our study. As shown in Figure 4, the variation of S/S_0 and V/V_0. as a function of X/X_0 is quasi-linear. V/V_0 and S/S_0 go respectively from 100% for X/X_0 = 1, to respectively 0.83 and 0.74 when X/X_0 = 0.64. For a value of X/X_0 = 0.38, S/S_0 and V/V_0 reach 0.72 and 0.61 respectively. The end of drying is marked by X_f/X_0 = 0.09 or S_f/S_0 and V_f/V_0 stabilize at 0.45 and 0.30 respectively. The linearity of the dimensions variation leads to a linearity of the surface S and the volume V of the samples in their evolution with convective drying.

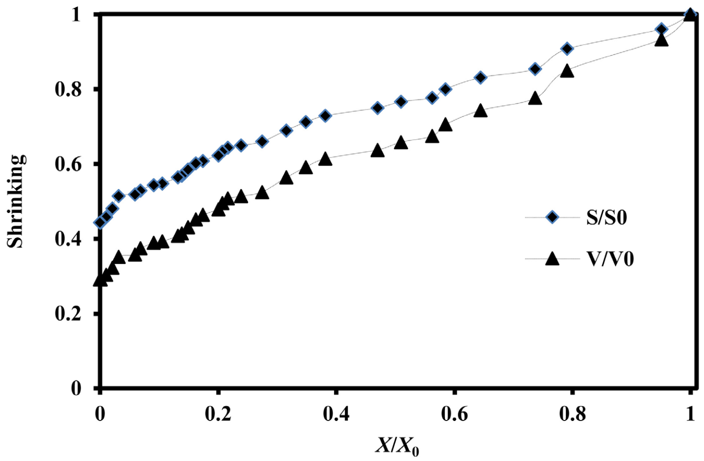

Figure 4. Evolution of spatial dimensions during sweet potato drying time.

3.4. Comparison of Initial and Final States

We examine the change experienced by the samples from the start of drying to its end. We can see, from **Table 1**, that the largest dimension goes from 4.21 cm at the start of drying to 3.61 cm at the end of drying, a reduction of 14.26% in its value. Likewise, the width and thickness increase respectively from 2.62 cm and 1.02 cm at the start of drying to 2.07 and 0.84 cm at the end of drying. They reach a reduction of 21% and 17.65%.

Table 1. Initial and final characteristics of the samples.

Sweet Potato	Final and Initial States				
	l (cm)	L (cm)	th (cm)	s (cm^2)	V (cm^3)
Start of Drying	4.21	2.62	1.02	35.99	11.25
End of Drying	3.61	2.07	0.84	24.60	6.28
Contraction (%)	85.74	79.00	82.35	68.03	55.79

3.5. Isotropicity

Examination of the contractions of the dimensions of the sweet potato during its convective drying seems to show a difference in behavior depending on its directions. Generally speaking, smaller sizes have a higher contraction rate compared to larger sizes. We obtain for I_{eL}, I_{el} and I_{lL} index curves above unity. We notice a large difference at the start of drying where the index I is clearly above 1. Towards the end of drying, the index approaches unity, showing a slowdown in contraction on all dimensions (**Figure 5**).

The origin of this anisotropicity remains to be sought. Ouoba [18] shows in the case of okra that the direction of the fibers slows down its contraction compared to the direction orthogonal to the fibers. This is also to intervene in the case of the potato when we know that all the directions are not visibly isotropic. In addition to, other Ouoba studies [18] have shown that sizes play a considerable role in the behavior of drying samples. This can also be a cause of the anisotropicity of the samples when we notice that the behavioral difference is linked to the size of the dimensions considered.

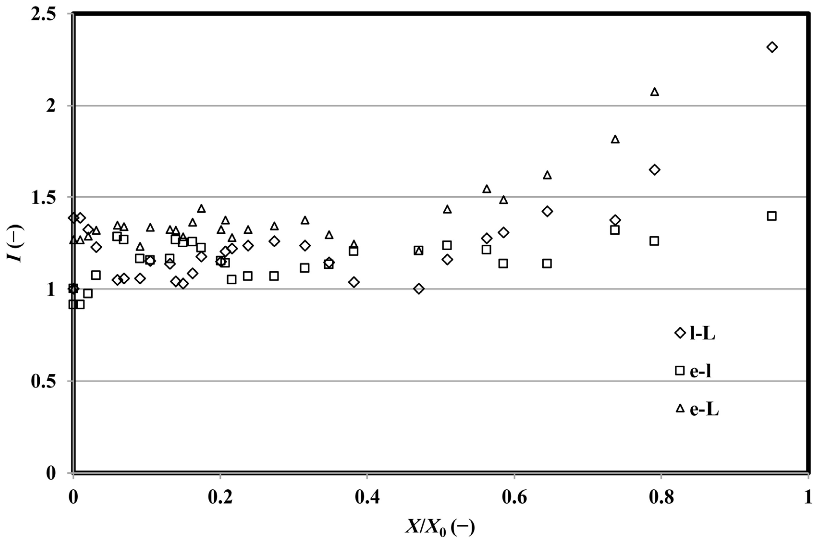

Figure 5. Isotropicity index of different directions of sweet potato samples.

3.6. Mathematical Modeling

Table 2. Mathematical models of contraction of sweet potato samples.

	Potato	
	Equation	R^2
Length	$\frac{L}{L_0} = 0.29\left(\frac{X}{X_0}\right) + 0.74$	0.9682
Width	$\frac{l}{l_0} = 0.33\left(\frac{X}{X_0}\right) + 0.69$	0.8887
Thickness	$\frac{\mathrm{e}}{\mathrm{e}_0} = 0.34\left(\frac{X}{X_0}\right) + 0.66$	0.9592
Surface	$\frac{S}{S_0} = 0.53\left(\frac{X}{X_0}\right) + 0.49$	0.9709
Volume	$\frac{V}{V_0} = 0.66\left(\frac{X}{X_0}\right) + 0.32$	0.9857

As we saw in paragraphs 3.2 and 3.3, the loss of water from the product leads to a proportional collapse both in its linear dimensions which are the length L, the width l and the thickness e, but also in its dimensions surface S and volume V.

This linearity leads us to find mathematical models that will allow actors to predict the behavior of samples. Equation 1 adapted to the width and thickness, as well as equation 2 applied to the surface allows us to braid **Table 2.**

If these models are practical for prediction, note that an error given by the value of R^2 is committed. For these different models, that linked to the width does not give acceptable satisfaction, as seen from R^2 is 0.8887, not close to unity.

4. Conclusions

This study highlighted the physical transformation that agri-food products undergo during their drying. The example of the experimental study of the potato reveals that the product continually changes its dimensions during its drying. The more the product loses its water, the more its dimensions decrease.

The results initially showed that the water parameters such as mass or water content decrease according to the drying principle. m_f / m_0 starts from unity and stabilizes at 0.202 X_f / X_0, decreasing towards zero asymptote at the end of drying.

Examining the contraction of dimensions reveals length L, width l and thickness e, which reduce their value linearly with the water content. They go from 100% at the start of drying to their final standardized values of 0.72, 0.65 and 0.64 respectively**.**

Thus L, l and e go from 4.21 cm, 2.62 cm and 1.02 cm at the start of drying to 3.61 cm, 2.07 cm and 0.84 cm at the end of drying. They achieve a reduction in its values of 14.26%, 21% and 17.65% at the end of drying.

The observed linearity was modeled mathematically with more or less acceptable R^2 coefficients.

A slight difference in contraction is observed depending on the dimension through the isotropicity indices I_{eL}, I_{el} and I_{lL} whose index curves are above unity, with an advantage of standardized contraction for the most small dimensions.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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