

Study of Cassava Contraction during Its Convective Drying

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Abstract

During this study, a focus is placed on the physical transformations that cassava undergoes during convective drying. The product continually changes its size, shape, and even its texture and consistency. The more moisture a product loses, the smaller its size. Firstly, the results show that water parameters such as mass or moisture content are reduced according to the drying principle. The dimensions length L , width l and thickness e decrease following a linear trend. The mathematical equations describing them were determined using the Excel office tool. This trend impacts surface and volume parameters, which in turn decrease almost linearly with the water content of the product. Note that the R^2 coefficient is not always acceptable, confirming the complexity of the behavior of organic products.

Keywords

Dimensions Reduction, Shrinkage, Index I

1. Introduction

In Africa, Cassava (*Manihot esculenta*) is largely product and has a great potential to be used as an industrial base [1]. Its derivative products are very appreciated and even its peel is used for the treatment of mining wastewater [2]. For the wide

use of this product, its drying is necessary. During its drying process, the samples undergo volume changes, i.e., shrinkage. Such shrinkage (**Figure 1**) affects the physical attributes and the transport properties of the solids. The volume change during drying is not theoretically an easily predictable function [3]-[6].

The aim of this present work is to study the physical changes, particularly shrinkage, that occur during convective drying of cassava. A special attention will be focused on the directional behavior of the shrinkage in terms of isotropy.

Quantitative evaluation of the shrinkage will be performed on the basis of a bulk shrinkage coefficient, i.e., ratio of sample volume at time noted t to initial volume (V/V_0). From experimental data, we look for a linear behavior [4] [7] [8] between bulk shrinkage coefficient and moisture content, which suggests that the shrinkage is predominantly due to the volume of water removed.

A linear relationship between bulk shrinkage coefficient and water content is fitted to the experimental data. The linear shrinkage behavior of food materials was reported by a number of researchers including [4] [6] [8].

For the purpose of this work, the samples were considered to be homogeneous, however, some heterogeneity is in fact present. We will examine both the mechanical behavior of the samples in terms of contraction of its solid matrix, and the directional behavior of the contractions in terms of isotropicity index. Under experimental data, mathematical models will be empirically developed.

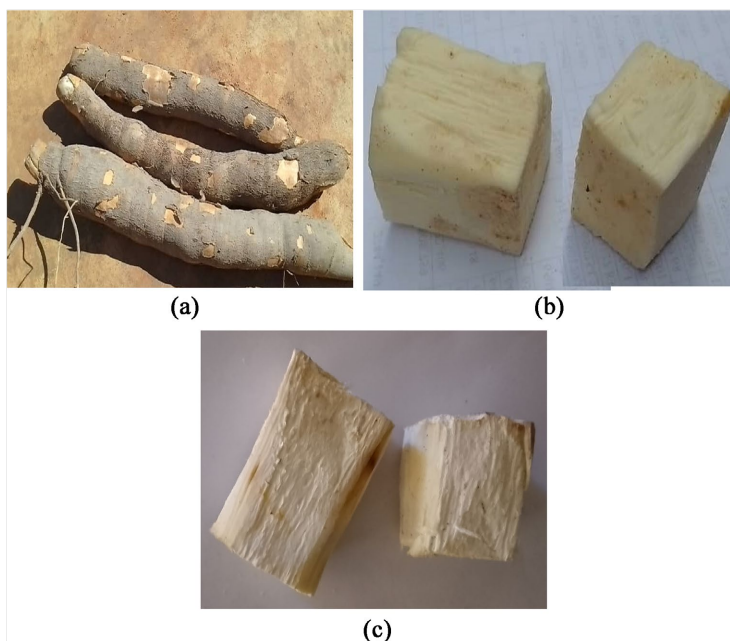


Figure 1. From raw to drying samples of cassava. (a) raw cassava; (b) freshly cut samples; (c) samples undergoing deformation during their drying process.

2. Materials and Methods

2.1. Obtaining Samples and Handling

Cassava is dried by convection in an oven. The temperature is set at 70°C. Once

thermal equilibrium is reached, the sample is introduced into the oven chamber. On each cassava, we have marked with indelible ink three geometric positions where the measurements will be taken. Finally, three measurements were taken to consider the average value. Samples were taken at predetermined intervals throughout the experiment for transverse, longitudinal, and thickness dimensions and mass measurements. We minimize the measurement time so as not to disturb the thermal balance established in the product. Geometric characterization of the sample is carried out by initially measuring dimensions and final values. For this, we use a digital micrometer (MITUTOYO, Japan, precision 2×10^{-5} m).

2.2. Data Processing

During the drying of cassava, 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 [9]-[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 type relationships:

- case of width and transposable for length and thickness (Equation (1)):

$$\frac{l}{l_0} = a_l \frac{X}{X_0} + b_l \quad (1)$$

- case of the surface and transposable for the volume (Equation (2)):

$$\frac{S}{S_0} = a_s \frac{X}{X_0} + b_s \quad (2)$$

where a and b are constants deduced graphically, the indices S , and l being reported respectively the surface and the width. These models have been used by certain authors for different products and applications: for grapes [21], potato [22], bananas [23], gelatin slabs [24], oca [25], mango [26], tomato [27].

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 anisotropy 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), perpendicular to the longitudinal and centripetal axis.

The isotropicity index makes it possible 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 XY index by the following relation:

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

Thus, for example, the thickness-length isotropicity index is defined by the following relationship [20]:

$$I_{eL} = \frac{\frac{e - e_0}{e_0}}{\frac{L - L_0}{L_0}} \quad (4)$$

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

3. Results and Discussions

3.1. Evolution of Cassava Water Parameters during Convective Drying

The principle of drying is to lose the water contained in the product, with the drying time, the product sees its mass decrease as indicated 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 over time. By pushing the drying according to the law [27] AOC, 1995 by staying 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 basis or value basis m_s called dry base [28]-[30]. The results in **Figure 2** show that

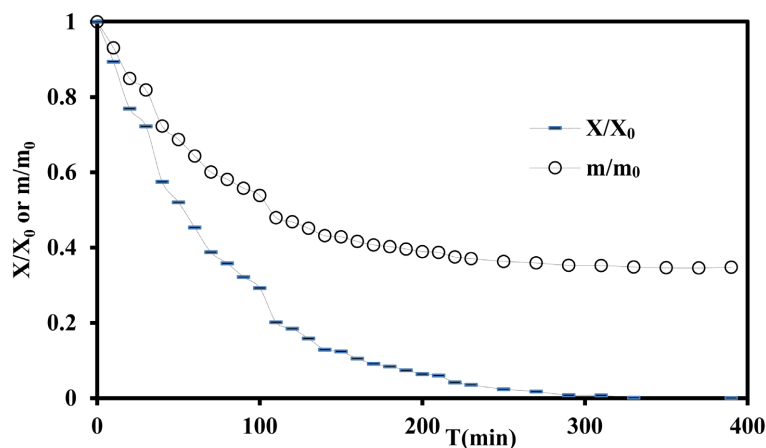


Figure 2. Evolution of water parameters during cassava drying.

m_d/m_0 is 0.347 for cassava. As for the value of X_d/X_0 , the product, it takes almost zero value.

3.2. Studies of Linear Contractions

During drying, the lateral dimensions of cassava decrease with time, in accordance to other agri-food products [31]. 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** tells us that for the dimensions length L , width l and thickness e , they go from 100% to $X_d/X_0 = 1$ at around $L/L_0 = 0.99$, $l/l_0 = 0.94$ and $e/e_0 = 0.93$ for $X_d/X_0 = 77\%$. At $X_d/X_0 = 27\%$ these values are respectively 0.89, 0.86 and 0.87. At the end of drying, i.e. for $X_d/X_0 = 0.07$, they all stabilize around 0.82. 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_d/X_0 are quasi-linear and can be put in the form of equation 1.

We see that the size of the dimension has little influence on contraction. Slightly, the smaller the dimension, the more quickly it decreases. Thus the line relating to e/e_0 has a relatively 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.

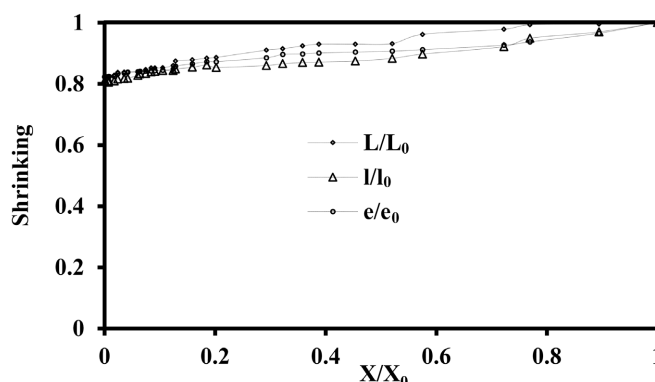


Figure 3. Change in linear dimensions of cassava samples during convective drying.

3.3. Evolution of the Surface Area and Volume of Cassava Samples during Convective Drying

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, players sell products in bags. 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 cassava 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_d/X_0 is quasi-linear. V/V_0 and S/S_0 go respectively from 100% for $X_d/X_0 = 1$, to respectively 0.85 and 0.89 when $X_d/X_0 = 0.72$. For a value of $X_d/X_0 = 0.29$, V/V_0 and S/S_0 reach 0.69 and 0.78 respectively. The end of drying is marked by $X_d/X_0 = 0.08$ or S/S_0 and V/V_0 stabilize at 0.67 and

0.55 respectively. The linearity of the linear dimensions leads to a linearity of the surface S and the volume V of the samples in their evolution with convective drying.

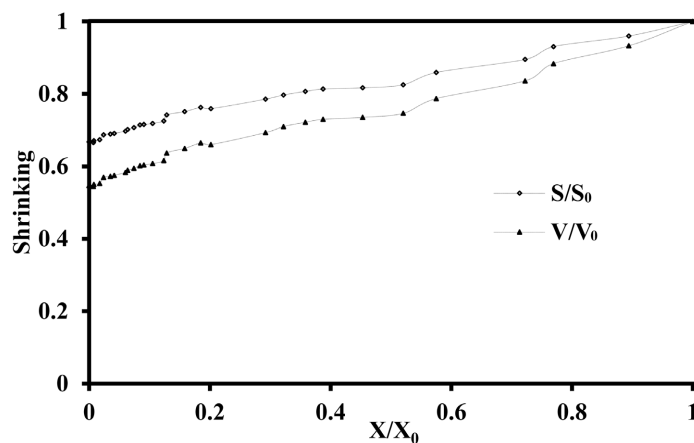


Figure 4. Evolution of spatial dimensions during cassava drying time.

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 3.21 cm at the start of drying to 2.32 cm at the end of drying, a reduction of 27.73% in its value. Likewise, the width and thickness increase respectively from 2.57 cm and 1.03 cm at the start of drying to 1.59 and 0.67 cm at the end of drying. They reach a reduction of 38.13% and 34.95%.

The surface S and the volume V increase respectively from 14.20 m² and 8.50 m³ at the initial instant to their final value of 6.31 m² and 2.47 m³. They therefore reach 44.41% and 29.08%.

Table 1. Initial and final characteristics of cassava samples having undergone convective drying.

cassava	Final and initial states				
	L (cm)	l (cm)	th (cm)	S (cm ²)	V (cm ³)
Start of drying	3.21	2.57	1.03	14.20	8.50
End of drying	2.32	1.59	0.67	6.31	2.47
Contraction (%)	72.27	61.87	65.05	44.41	29.08

3.5. Evolution of Cassava Density

Monitoring the contractions of the dimensions of the cassava during its convective drying seems to show a progressive evolution of its density. This situation has advantages because it allows easy transport of the product. **Figure 5** gives us an idea of the evolution of the density of a cassava sample as it loses its water during convective drying. This evolution is almost linear with $R^2 = 0.9599$ if the equation of the line describing the evolution of this density is $\rho = 375.58(X/X_0) + 790.57$.

This line does not take into account the start of drying which has thermal and water turbulence before reaching the steady state.

Thus, the density goes from $\rho = 1093.71 \text{ g/cm}^3$ at the initial instant, increases slightly because of the turbulence, and falls to 1063.33 for a standardized water content of 0.69. For $X/X_0 = 0.39$, the density falls to $\rho = 949.81 \text{ g/cm}^3$. At the end of drying, $X_f/X_0 = 0.39$ the density drops to $\rho_f = 949.81 \text{ g/cm}^3$.

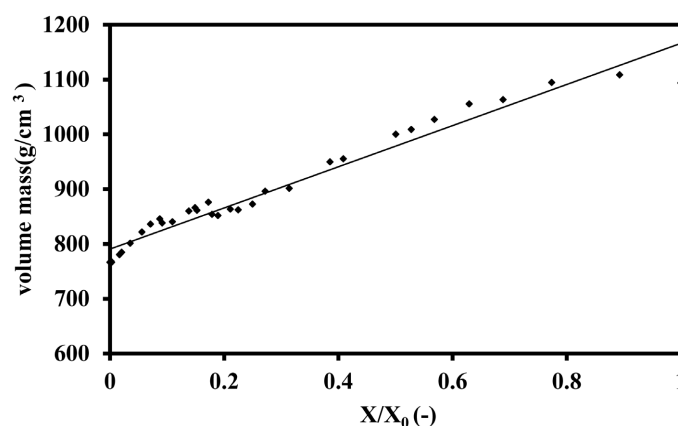


Figure 5. Variation in the density of cassava samples during convective drying.

3.6. Isotropicity of Cassava

The examination of the contractions of the dimensions of the cassava 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_{eI} 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 6**). Ouoba *et al.* [26] show in the case of okra that the direction of the fibers slows down its contraction compared to the direction

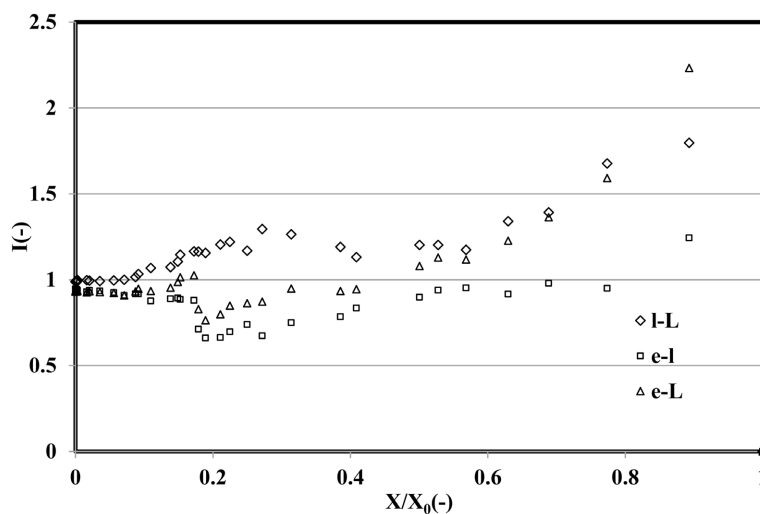


Figure 6. Isotropicity index of different directions of cassava samples.

orthogonal to the x fibers. This is also to intervene in the case of cassava when we know that all the directions are not visibly isotropic. In addition to other Ouoba studies [27] [28] have shown that sizes play a considerable role in the behavior of drying samples. This can also be a cause of the anisotropy of the samples, when we notice that the behavioral difference is linked to the size of the dimensions considered.

3.7. Mathematical Modeling of Dimensional Contractions of Cassava

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 allowing 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. These different models give acceptable satisfaction, seen from R^2 is quite close to unity.

Table 2. Mathematical models of contraction of cassava samples.

	Cassava	
	Equation	R^2
Length	$\frac{L}{L_0} = 0.20 \left(\frac{X}{X_0} \right) + 0.83$	0.9532
Width	$\frac{l}{l_0} = 0.17 \left(\frac{X}{X_0} \right) + 0.81$	0.9592
Thickness	$\frac{e}{e_0} = 0.19 \left(\frac{X}{X_0} \right) + 0.83$	0.9532
Surface	$\frac{S}{S_0} = 0.32 \left(\frac{X}{X_0} \right) + 0.68$	0.9833
Volume	$\frac{V}{V_0} = 0.42 \left(\frac{X}{X_0} \right) + 0.56$	0.9854
Volumic mass	$\rho = 375.58 \left(\frac{X}{X_0} \right) + 790.57$	0.9599

4. Conclusions

This work aimed to characterize the physical changes that occur in cassava during convective drying. In terms of shrinkage, or isotropy, the product is highly affected by water loss during convective drying.

The results highlighted the physical transformation that cassava undergoes

during its convective drying. It was revealed 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. m/m_0 passes from unity and stabilizes at 0.202 X/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 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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