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# Physical Transformations of Agri-Food Products during Their Convective Drying: Characterization of the Contraction and Isotropicity of Okra

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## Abstract

The physical transformations in terms of contraction of okra dimensions during convective drying were examined. During drying, the lateral and longitudinal dimensions of okra decrease over time. The lateral dimensions go from their initial value to around 53%, 65% and 66% of this value after 530 min. The length of the two samples used goes from 8.65 and 9.02 cm to 6.79 and 7.52 cm after 14,300 min, *i.e.* a variation of 78.50% and 83.37%. All the two directions give variations almost linear depending on the water content. These linear contractions result in a volume contraction of the okra. It considerably decreases in volume during the drying process. The volume goes from 831.32 $cm^3$ to 367.57 $cm^3$ in min, a variation of 44.22%. The isotropic index reveals that okra does not behave the same in the lateral and longitudinal directions. It contracts its diameter more than its length.

## Keywords

Physical Transformations, Contraction, Isotropicity, Okra

## 1. Introduction

Shrinkage during drying has usually been assumed negligible to facilitate solving heat and mass transfer equations; however, such an assumption is not valid for all substances in all moisture ranges [1]. It has been shown that both volumetric shrinkage [2] and dimensional shrinkage [3] are dependent on moisture content.

Mathematical models relating shrinkage to moisture content are required for future use. The theoretical basis for shrinkage should involve mechanical laws that take material stresses into account and deformations during dehydration [4]. However, analysis of agri-foods material physical behavior is extremely complicated because of the multiphase and cellular nature of the system. In order to model shrinkage of agri-foods from this point of view, a knowledge of the structural, mechanical and elastic properties of each phase of the system, and the variation of water content and temperature, is required. Therefore, a practical approach to the study of agri-food shrinkage is experimentally based.

The aim of this work is to examine the okra physical behavior during its convective drying. Linear dimensions variation and volumic shrinkage characteristics of whole okra during convective drying are evaluated. Okra isotropicity is examined to compare longitudinal and lateral directional behavior.

## 2. Material and Methods

### 2.1. Okra

We consider okra to be a structurally complex product. It has three constituents of different natures. As shown in **Figure 1**, the dark green skin constitutes an outer covering. It contains more or less spherical seeds which are attached to a spongy material constituting the central axis of the okra. Okra contains fibers that are oriented lengthwise [5]. It is therefore necessary to characterize the isotropicity of okra. For these experiments, fresh okra was purchased from a local market in Burkina Faso. They were kept in a refrigerator at 12˚C between 2 and 3 days, the time necessary to carry out these experiments.

### 2.2. Sample Processing

Convective drying of okra 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 okra, we mark with indelible ink three geometric locations where the diameter measurement will be carried out. Then, the diameter considered is the average of these three measurements. The samples are removed from the oven, at a time interval predefined by preliminary tests, for

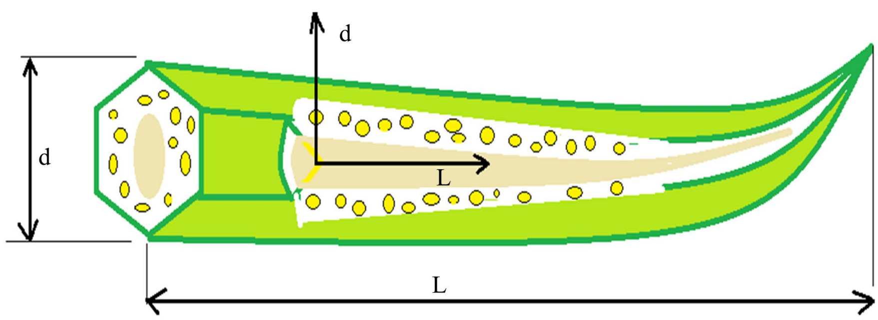


**Figure 1.** Anisotropicity of okra: $L$ = length or fibers direction, $d$ = lateral or direction perpendicular to fibers.

measurements to be taken. We minimize the measurement time so as not to disturb the thermal balance already established in the product. Geometric characterization of the samples is done by initially measuring the diameters of a few sections along the entire length of the okra as well as the length of the entire okra over the drying time. For some samples, we measure the length of the sections that have been marked during drying. To do this, we use the digital micrometer (MITUTOYO, Japan, precision $2 \times 10^{-5}$ m).

## 2.3. Sample Processing

**Contraction**

During the drying of okra, the product undergoes physical deformations, as shown in (**Figure 2**.). In the case of drying, contraction (shrinkage) is a consequence of the loss of water from the solid matrix of the product. The models in the literature are mainly empirical and cannot be transposed from one product to another or to other experimental conditions [6]-[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]-[19].

From experimental data, contractions are represented by the following relationships (Equations (1)-(3)):

- **Volume:**

$$\frac{V}{V_0} = a_v \frac{X}{X_0} + b_V \tag{1}$$

- **Length:**

$$\frac{L}{L_0} = a_L \frac{X}{X_0} + b_L \tag{2}$$

- **Diameter:**

$$\frac{d}{d_0} = a_d \frac{X}{X_0} + b_d \tag{3}$$


**Figure 2.** Physical change observing during okra convectif drying, 70˚C.

where $a$ and $b$ are constants deduced graphically, the indices $v$, $L$ and $d$ being related respectively to the volume, length and diameter. These models have been used by certain authors for different products and applications: for carrots [20] [21], potatoes [22], apples [23], grapes [24], hammered [25] potatoes and carrots (okra [21] [26] [27] [28] [29] [30]).

**Shrinkage isotropicity.**

The difficulty linked to agri-food product drying study comes from the great diversity in the field. Added to this is the structural factor, heterogeneity and anisotropicity of the agri-food product giving 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 makes the comparison of 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 $XY$ by the following relation:

$$I_{XY} = \frac{\frac{X - X_0}{X_0}}{\frac{Y - Y_0}{Y_0}} \tag{4}$$

Thus, the radial-axial isotropicity index is defined by the following relationship, in the case of a cylindrical sample where equation 4 becomes Equation (5) [19]:

$$I_{dL} = \frac{\frac{d - d_0}{d_0}}{\frac{L - L_0}{L_0}} \tag{5}$$

where $d_0$, $d$ are respectively the initial and the current values of the sample diameter and $L_0$, $L$ respectively the initial and the current values of the sample length.

## 3. Results and Discussions

### 3.1. Lateral Contractions

During drying, the lateral dimensions of okra decrease over time. As the product loses its water it undergoes a collapse of the material which compensates for the loss of water. Consequently, its diameter decreases. **Figure 3(a)** indicates that for diameters 1, 2 and 3 the lateral dimensions increase from their initial value to

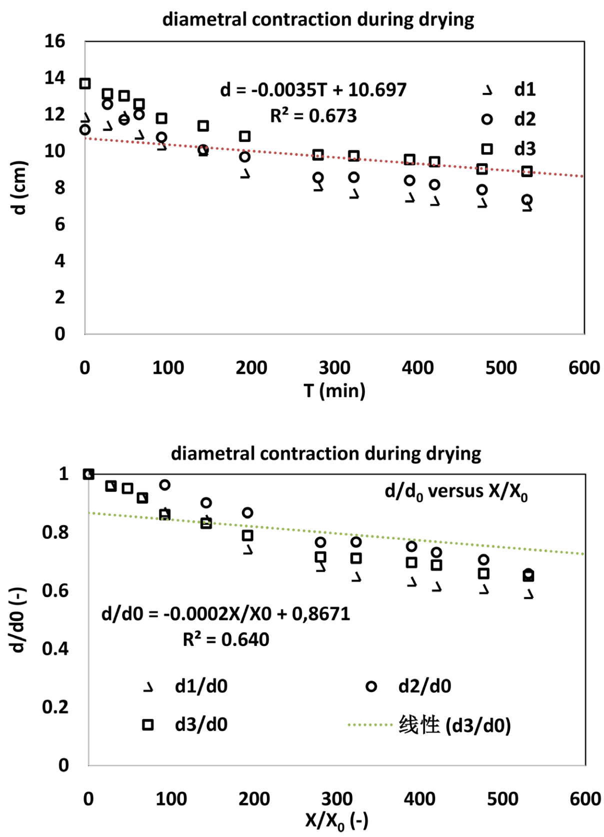


**Figure 3.** Anisotropicity of okra in lateral d direction during its convective drying, 70˚C.

around 53%, 65% and 66% of this value after 530 min. We nevertheless notice that at the first moments, before the first 100 minutes, the lateral dimensions increase and slightly exceed the initial values. This is certainly due to the increase in internal pressure. Indeed, the water from the seeds and the central material that evaporates remains trapped by the skin. The water vapor increases the pressure which swells the skin. This phenomenon increases the values of the lateral dimensions. A few moments later, this water vapor escapes and the pressure drops. In addition, the skin becomes rigid and no longer swells. The variation of $d/d_0$ as a function of $X/X_0$ is quasi-linear after the first 100 minutes. Considering the overall drying time, the linear modeling has a deviation of $R^2 = 0.640$, which is not satisfactory (**Figure 3(b)**). This poor correlation is linked to the complex structure of okra. Consequently, the lateral contraction curve which should be linear contains enormous irregularities. Lateral contraction can only be considered linear after a certain time necessary to establish a stationary transfer regime.

## 3.2. Longitudinal Contractions

The loss of water from okra during convective drying results in a contraction of the longitudinal dimension. As shown in **Figure 4(a)**, the length of these samples increases, on average, from 8.65 and 902 cm to 6.79 and 7.52 cm after 14,300 min, *i.e.* a variation of 78.50% and 83.37%.

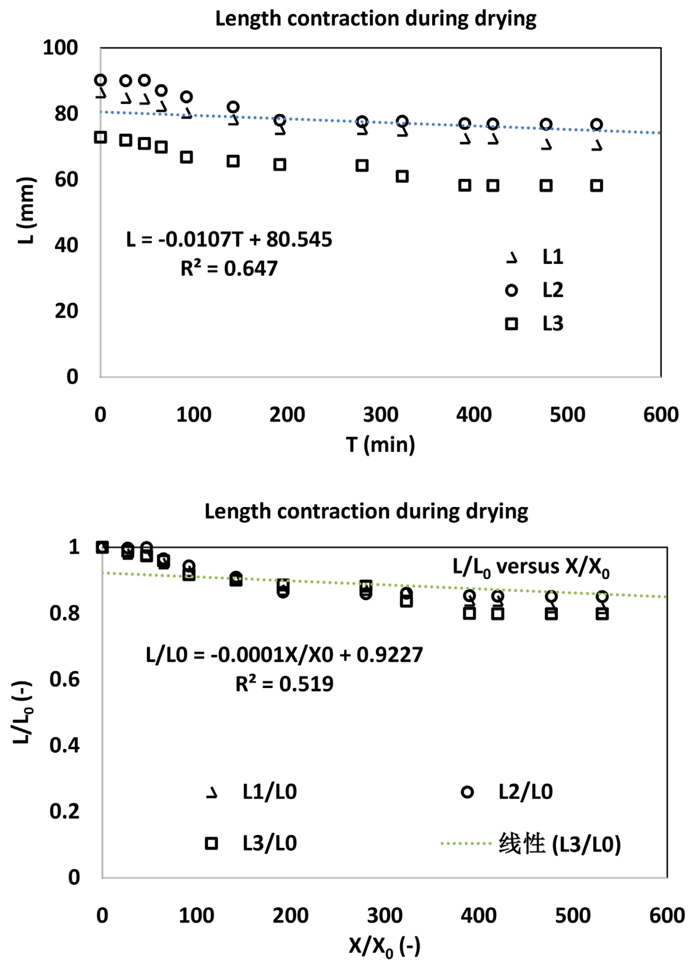


Figure 4. Anisotropicity of okra in L = length direction during its convective drying, 70˚C.

The variation of $L/L_0$ as a function of $X/X_0$ is quasi-linear (Figure 4(b)). Linear modeling gives the equation:

$$\frac{L}{L_0} = -0.0001\frac{X}{X_0} + 0.9227 \tag{6}$$

With $R^2 = 0.5192$.

This correlation can be considered unsatisfied and highlights the complex nature of okra.

## 3.3. Volume Change

The shrinkage data obtained during convective drying were also analyzed in terms of the bulk shrinkage coefficient. Figure 5(a) shows the volume change as a function of moisture content. As shown, sampling again exhibits a linear shrink relationship with moisture content.

Considering the okra as having a cylindrical shape, the volume is calculated at each moment of drying. The results in Figure 5(a) shows that okra significantly decreases in volume during the drying process. The volume goes from 831.32 cm³

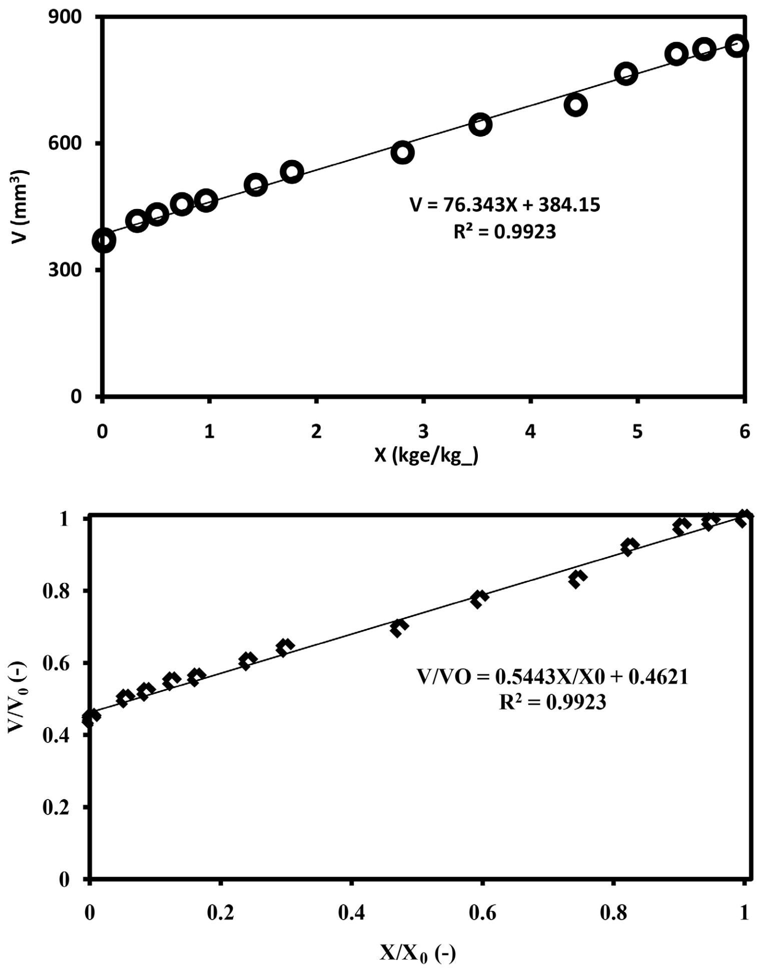


**Figure 5.** Okra bulk shrinkage during convective drying, 70˚C. (a) volume reduction at any water content value; (b) bulk shrinkage coefficient $V/V_0$ versus $X/X_0$.

to 367.57 cm$^3$ in min, a variation of 44.22%. Considering the relationship between $V/V_0$ and $X/X_0$ **Figure 5(b)** gives us a quasi-linear relationship. This linearity follows the equation:

$$\frac{V}{V_0} = 0.5443\frac{X}{X_0} + 0.4621 \quad (7)$$

with $R^2 = 0.9923$, the linear relationship will be considered acceptable.

### 3.4. Insitropicity Index Id-L of Okra

Examination of the lateral and longitudinal contractions of the okra during its convective drying seems to show a difference in behavior according to these directions. The samples give, on average, final lateral contractions of 53.65% and 66%, which are clearly different from the longitudinal contractions of 78.5% and 83.37%. These remarks lead us to examine the isotropicity of okra. The isotropicity index at the diametric direction versus the longitudinal one is significantly above 1 which is the isotropicity index of an isotropic product (**Figure 6**). However, from the first moments of drying, there is an inversion where the length

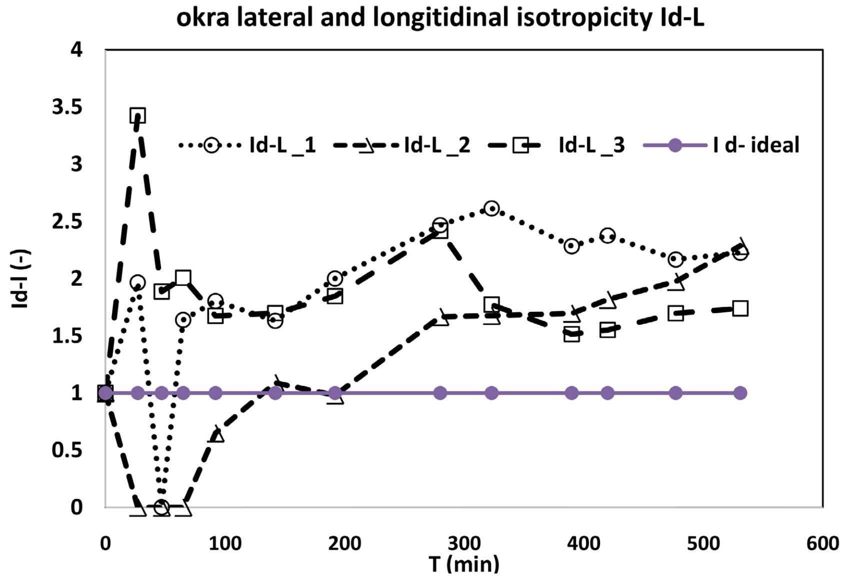


**Figure 6.** Lateral-longitudinal isotropicity index of okra during convective drying, 70˚C.

seems to contract more than the diameter. Which is characterized by a curve below the ideal Id-L = 1

Thus, the okra contracts more in diameter than in length. As can be seen in **Figure 6**, this isotropicity is not linear. We can explain these results by taking into account the difference in structure between the directions. Indeed, the fibers of okra are oriented in the longitudinal direction. These fibers can withstand more contraction stress, thereby reducing the decrease in length. On the other hand, these fibers parallel to each other can collapse and do not prevent the reduction in diameter.

## 4. Conclusion

During drying, the lateral dimensions of okra decrease over time. As the product loses its water it undergoes a collapse of the material which compensates for the loss of water. Consequently, its diameter decreases. The lateral dimensions go from their initial value to around 53%, 65% and 66% of this value after 530 min. During the first 100 minutes of drying, the lateral dimensions increase and slightly exceed the initial values. This is explained by the increase in internal pressure. This is because the water vapor coming from inside the okra is trapped by the skin. After these moments of turbulence, the variation of tau $d/d_0$ as a function of tau $X/X_0$ is quasi-linear. During convective drying, okra also contracts its longitudinal dimensions. The length of the two samples used goes from 8.65 and 9.02 cm to 6.79 and 7.52 cm after 14,300 min, *i.e.* a variation of 78.50% and 83.37%. The variation of tau as a function $L/L_0$ of tau $X/X_0$ can be modeled linearly. These linear contractions result in a volume contraction of the okra. It considerably decreases in volume during the drying process. The volume goes from 831.32 cm$^3$ to 367.57 cm$^3$ in min, a variation of 44.22%. The relation between $V/V_0$ and $X/X_0$ gives approximately a straight line. Examination of the results in terms of isotropicity index reveals that okra does not behave the same in the lateral and longitudinal directions. It contracts its diameter more than its length. These results may be related to the direction of the fibers. Indeed, the fibers of okra are oriented in the longitudinal direction. These fibers can withstand more contraction stress, thereby reducing the decrease in length. On the other hand, these fibers parallel to each other can collapse and do not prevent the reduction in diameter.

## Conflicts of Interest

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

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