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Validation of a Characteristics Dimensions for Transfers during Convective Drying of Sweet Potato Cubic, Cylindrical and Spherical Shapes

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Abstract

This present work solves the problem of initial shape influence on transfer during convective drying. A characteristic dimension is found for the cubic, cylindrical and spherical-shaped samples of the sweet potato. This characteristic dimension corresponds to the diameter D for the sphere, to the edge a for the cube and the diameter = height D = H for the cylinder. Unlike the sphere where this characteristic dimension is perfect, the cubic and cylindrical shapes have space factors which are, among other things, angles and borders. By fixing the same characteristic dimensions, we end up with overlapping curves, showing identical and uniform transfers.

Keywords

Drying, Initial Size, Characteristic Dimension, Forms

1. Introduction

The complexity of estimating transfers during convective drying of organic products no longer needs to be demonstrated. This is accentuated by the very nature of the material that is the biological product [1] [2]. Failure to control transfers during drying leads to dry products with non-uniform quality [1] [3]. The field of drying is thus slow to take off due to the lack of control of the drying parameters. To consider the industrialization of the field, it is more than necessary to understand the behavior of the biological environment during convective drying [4] [5] [6]. Indeed, multiple parameters come into play in the evaluation of transfers. One distinguishes the external parameters [7] [8], especially related to the environment of drying [9] [10], the nature of the product [11], the parameters intrinsically linked to the nature of the product [12] [13] [14], but also to the parameters related to the pretreatment of samples. Among these preprocessing parameters [15] [16] the cutout [17] [18] [19] plays an important role. In the field, in sub-Saharan Africa, we notice that the products are cut in bulk and spread out for drying. A heterogeneous mixture of different shapes and sizes is therefore obtained, which is exposed to drying. The studies of Ouoba 2013 [1], showed that the size and the shape play an important role in the evaluation of the convective drying of agri-food products. He clearly states that no study to his knowledge proposed a dimension that characterizes the drying beyond the shape and size of the samples, which was our observation by browsing the scientific literature. Ouoba (2013) [1], suggested the existence of a characteristic dimensions which could dictate the transfers during their convective drying, and which bypasses the effect of the form as indicated in **Figure 1**. It is defined as being the shortest path the heat will take to reach the water the farthest from the drying environment. In other words, it is also the path that the last water molecule will take, the one that is farther from the outside, to be evacuated to the outside. **Figure 1** describes the concept of the characteristic dimension Dc as the largest sphere containing in specimen of any shape. The center (C) of the characteristic sphere contains the humidity furthest from the exchange surface. The parts limiting transfers (A) constitute a brake on transfers in the characteristic sphere. Thus, the points of the border of the characteristic sphere are not directly exposed to drying environment, Ouoba, 2013.

We will devote ourselves in this work to determining this characteristic dimension for sweet potato samples of cubic, spherical and cylindrical shapes. We have fixed the characteristic dimension being the diameter for the sphere, the

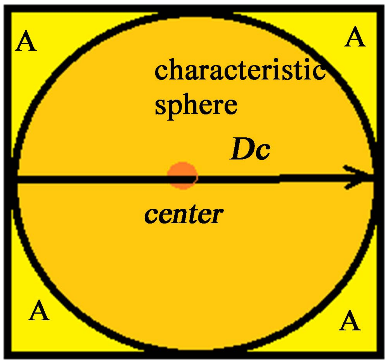

Figure 1. Concept of the characteristic dimension *Dc*: largest sphere cut from a specimen of any shape. The center (C) of the characteristic sphere contains the humidity furthest from the exchange surface. The parts limiting transfers (A) constitute a brake on transfers in the characteristic sphere. Thus, the points at the border of the characteristic sphere are not directly exposed to drying, Ouoba, 2013 for the cube or cylinder shape.

edge for the cube and diameter = height for the cylinder.

2. Material and Methods

2.1. Preparation of Samples

This present work requires a material with a homogeneous macrostructure. Indeed, if the material is not homogeneous, transfers can be favored from one direction compared to the other. Thus the sweet potato (*Ipomoea batatas*) is used to minimize the effects of the macrostructure and the influence of the multi-constituents [4], on the evaluation of transfers during convective drying. Thereby; the sweet potato tubers were used as an experiment for this present work.

The tubers which served as samples for our experiments, cultivated in Bobo-Dioulasso (Burkina Faso) were bought in a local market in the same heap in batches in order to reduce the differences in material properties [3]. The potato is therefore transported to the Polytechnic University of Bobo-Dioulasso. The tubers are washed, peeled and cut manually into the desired shape and size using a stainless steel knife. The use of the stainless steel knife avoids the oxidation of surfaces in contact with the oxygen in the air. The cut samples are quickly immersed in water to prevent oxidation and to evacuate excess starch from the surface which forms a film that slows down transfer.

2.2. Drying

After cutting, the samples are washed and wiped with blotting paper. This operation aims to clean the excess starch present on the surface. The samples are placed in the oven, the temperature of which is suitably adjusted for drying. We used an AIR concept, temperature varying from 40˚C to 250˚C, with PID regulation, with digital display from SIYB & TI, in Burkina Faso. The samples are regularly withdrawn for the determination of the mass during the drying time and reintroduced into the oven. The mass is determined by a balance (SARTORIUS, 0.001 g precision, France). The measurement time is fast so as not to disturb the thermodynamic equilibrium. Given the regular withdrawal of samples, we consider that the transfers take place on all sides. The samples are placed directly on the racks. We calculate the initial areas as the total area of the sample from the dimensions measured with a Mitutoyo (Japan) precision 2.10 - 5 mm micrometer. Note that we were unable to measure air speed and relative humidity which are important parameters in evaluating drying. To do this, we compare the results of experiments which were carried out simultaneously and in the same oven to circumvent the influence of these two parameters. The determination of the dry mass is made after a stay of 24 hours in an oven at 70˚C (AOAC, 1990) [20].

3. Data Processing

3.1. Water Content

The initial water content (Equation (1)) of the product is the quotient of the total mass of water contained in the freshly cut product m_e divided by the mass of solid matter m_s [2] [4] [5].

$$X(t) = \frac{m_e}{m_s} = \frac{m_0 - m_s}{m_s} \tag{1}$$

where m_0 is the initial mass of the sample and ms is the dry mass of the sample. The curves of the water contents as a function of the drying time were drawn from the experimental data. From the mass of the sample at time *t*, we deduce the water content according to [3] [5] [6] [10]:

$$X(t) = \frac{m(t) - m_s}{m_s} \tag{2}$$

where $m(t)$ the mass of the sample at time *t* of drying.

3.2. Drying Kinetics

From the value of the mass $m(t)$ and the dry mass ms of the sample we calculate the water content $X(t)$ according to Equation (2). The relation $X(t)—t$ gives us the kinetics of the variation of the water content of the product. To have the same basis of comparison, we normalize the water content at time t by the initial water content X_0 of the product determined according to Equation (1). This gives us the curves $X/X_0—t$.

4. Results and Discussions

4.1. Validation of Results

In order to clearly show the importance of taking into account the size and shape of the samples subjected to drying, and to highlight the role of a characteristic dimension which governs the drying, it is essential to verify the repeatability of our results. This is proof that not only are the experiments carried out correctly, but that the material used is reliable. Figure 2 groups the data of identical samples in three (3) copies, for data validation. Indeed, if these data are disparate, it would prove that the samples have different characteristics. Two dimensions for

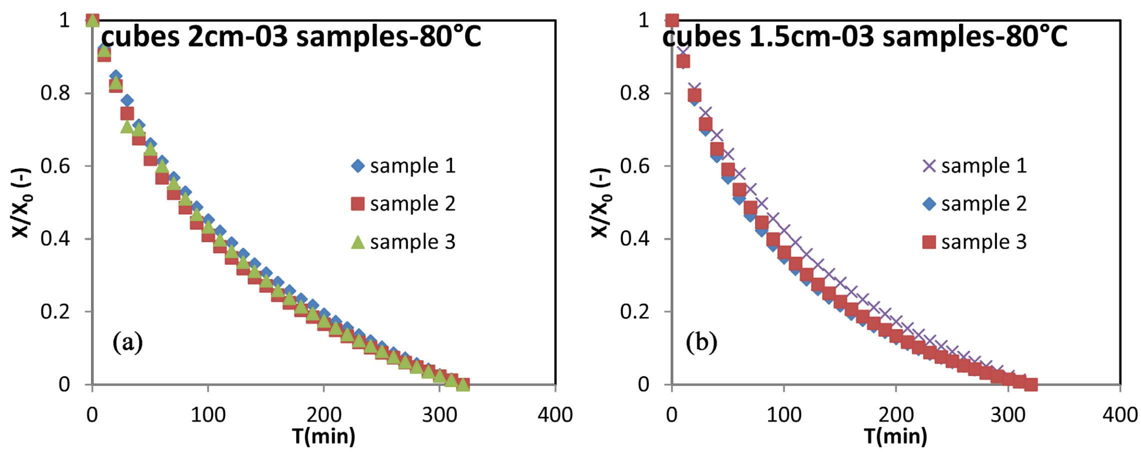

Figure 2. Validation of the results on cubic sweet potato samples: (a) cubes of edge a = 1.5 cm; (b) cubes of edges a = 2 cm.

the cubic shape, either 1.5 cm edge and 2 cm, have been shown. The other dimensions, also respecting the same trends, have not been represented with regard to the multiplicity of data.

For Figure 2(a) The results show that the differences between the curves X/X_0 $(kg_e/kg_{ms})/(kg_e/kg_{ms})$ are minimal, going close to zero (0) for the most repetitive to 0.357 − 0.332 = 0.025 obtained, as the most unfavorable case, for samples 1 and 2 of the cubic samples of 1.5 cm edges at the 120^{th} minutes of drying.

For Figure 2(b) the curves of the normalized water contents X/X_0 (−) of the cubic samples of 2 cm edges are practically the same. The maximum deviation is observed at the 130^{th} minute and is equal to 0.347 − 0.336 = 0.011.

These small differences can be attributed to measurement imperfections, but also to the complex nature of agri-food products.

4.2. Highlighting the Importance of the Search for a Characteristic Dimension

Controlling the drying of agri-food products is proving difficult. Although the influence of external parameters to drying such as temperature, hot air velocity, relative humidity seems to be under control, the contribution of parameters intrinsically linked to the nature of the product remains poorly understood.

This paragraph shows us how the size of the samples strongly influences the transfers in the product during convective drying.

Indeed, for the same cubic shape, several dimensions were used. Specifically, the cubic samples of edges 1, 1.5 cm, 2 cm and 3 cm were used for convective drying at 80˚C.

Figure 3 contains the results from the convective drying of these different samples. The average of the normalized water contents X/X_0 (−) of the four dimensions of the same geometric shape, namely the cube.

From the 100^{th} minute, a significant difference in behavior in the face of transfers widened. The cubic samples of 1 cm, 1.5 cm, 2 cm and 3 cm edges have

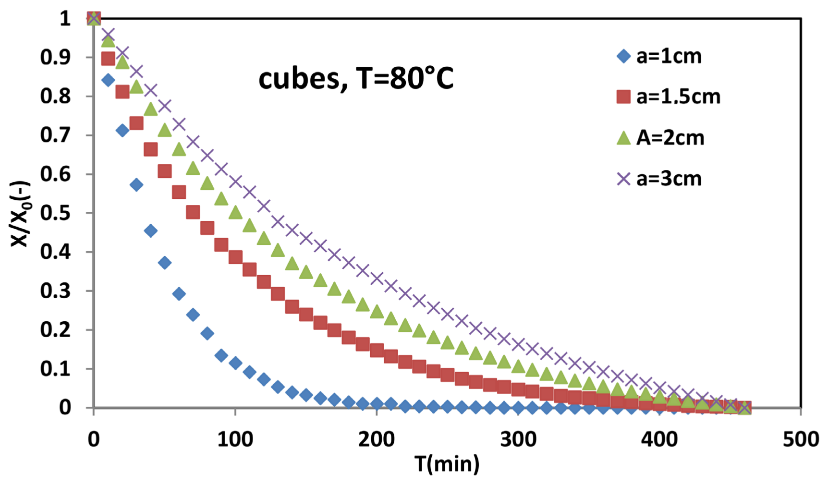

Figure 3. Demonstration of the importance of size and the need to research a dimension characteristic of transfers during convective drying of the sweet potato.

normalized water contents X/X_0, respectively 0.580, 0.502, 0.387 and 0.115. The biggest difference is therefore 0.580 − 0.115 = 0.465. This difference shows that the samples of different dimensions do not have the same behavior with regard to drying.

At the 160th minute, the small sample, a = 1 cm has its curve with zero asymptote, that is to say almost dry, while the largest sample, a = 3 cm is only about half of its drying time, or $X/X_0 = 0.451$.

It therefore appears that size plays an important role in the evaluation of the convective drying of the sweet potato. The search for a characteristic dimension is then necessary in order to better control the transfers during their convective drying.

4.3. Emphasis the Characteristic Dimension for Different Geometric Shapes: Cube, Cylinder, Sphere

Family-type drying in West Africa encounters many problems, especially with regard to the uniformity of the quality of the finished product. From batch to batch, the quality varies, Ouoba, 2013 [1], showed that if this situation is due to the external drying conditions, it is also strongly linked to the cutting of the samples. We find in a drying batch all kinds of shapes and sizes that affect the state of drying as shown in the previous paragraph.

We are looking here for parameters which can override the shape and which would best dictate the transfers during convective drying.

Figure 4 gathers the results of the samples of different shapes while fixing a dimension: the diameter D for the sphere, the edge a for the cube, the diameter = height D = H for the cylinder. For the two values of this characteristic dimension, namely 1 cm and 1.5 cm, the results show that we can consider the characteristic dimension rather the shape. Indeed, the curves are almost identical, showing uniform drying.

By examining Figure 4(a), for the characteristic dimension D = a = H = 1.5

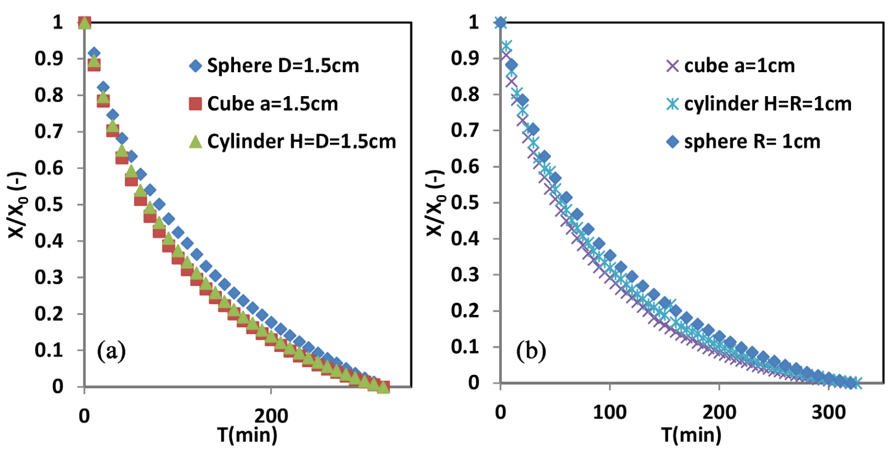

Figure 4. Validation of the characteristic dimension of the transfers during the convective drying of the sweet potato: the diameter D for the sphere, the edge a of the cube, the height and the diameter D = H of the cylinder.

cm, the curves of the cubic and cylindrical samples are exactly the same. Only the drying curves of the sphere shows a slight difference. The maximum of which is observed at the 140^{th} minute and odor of 0.331 − 0.245 = 0.086.

When the characteristic dimension D = a = H = 1 cm in **Figure 4(b)**, all the curves can be considered to be combined. The maximum deviation at the 110^{th} 0.322 − 0.285 = 0.037. Once again, for this characteristic dimension, the notion of form can be bypassed.

4.4. Characteristic Dimension of Drying Cubic, Cylindrical and Spherical Shapes

Examining the foregoing results enables us to resolve a crucial question. Although size is an important factor, and as shown in work by Ouoba, 2013 [1], that shape is also a factor influencing transfers during convective drying, the preceding results show us that can however overcome these two parameters by introducing the notion of the characteristic dimension. The conformity of the results, for samples of various shapes and of the same characteristic dimension, clearly indicates to us that the drying is dictated by said dimension.

The difference effects between the curves of the spherical samples and the others, namely cubic and cylindrical, can be attributed to what Ouoba 2013 [1], qualified as a congestion factor or part limiting the transfers, as indicated by the **Figure 1** B. Indeed, for the sphere, the transfers are directly radial. The diameter is exactly the characteristic dimension. unlike other shapes such as the cube and the cylinder which have edges and edges at an angle which blur the accuracy of the characteristic dimension.

Note, that these deviations are also observed at periods of drying dictated by upheavals of the structure, such as collapse, contraction, cracks, changes of structures, which in one way or another, changes the behavior, see the nature of matter. Dissa *et al.* have shown that by taking these factors into account, the assessment of drying changes.

5. Conclusions

This work highlighted the importance of taking into account the characteristic dimension when evaluating transfers during convective drying of cubic, spherical and cylindrical samples of sweet potato.

It appears that for various values of this characteristic dimension, as regards the cubic samples the transfers are slow as the characteristic dimension increases. This fact is already remarkable from the 100^{th} minute, where the cubic samples of 1 cm, 1.5 cm, 2 cm and 3 cm edges have different normalized water contents X/X_0 (−), respectively 0.580, 0.502; 0.387 and 0.115. The biggest difference is therefore 0.580 − 0.115 = 0.465.

By fixing the characteristic dimension for various geometric shapes, the results show that transfers are established almost uniformly in all samples.

The characteristic dimensions D = a = H = 1 cm and D = a = H = 1.5 cm, cu-bique and cylindrical samples have almost identical curves. Only small deviations ranging from 0.037 to 0.086 are observed and can be attributed to the size factors or to the change in the structure of the material.

Future work on a wide range of shapes and sizes should be considered in order to better understand the efficiency and the limits of the characteristic dimension of convective drying.

Conflicts of Interest

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

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