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Effect of Farm Product Intrinsic Properties on Convective Drying: Case of Okra

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Abstract

In this study, the material is okra, a cucurbitaceous largely consumed in West Africa and South Asia. The influence of the external air parameters on food drying with different size, maturity, shape of the material is considered by convective drying. So, the okra was cut in several parts according to its three characteristic zones, the basis, the middle of the okra and the extremity because the three parts of the vegetable have not the same resistances in transfers by convective drying. The maturity of the okra also has an influence. The okra dries faster in its younger or older age. Okra dries slowly when its maturity is convenient to be consumed. The drying duration of okra with the age of 1, 2, 3, 4 and 5 days is respectively 580, 780, 990, 1200 and 850 min. When we consider the three (matters) constituent of the okra: the skin, the seeds and the central material, the central matter dries faster. The diffusion coefficient was identified in all cases in order to compare the influence of those intrinsic properties of that food.

Keywords

Convective Drying, Okra Intrinsic Properties, Food, Maturity, Size, Diffusion Coefficient

1. Introduction

Farm products' drying is a subject of a major importance. It is an adequate means of overproduction conservation [1] and economic development [2]. For that comes true, the dried product has to fit the consumer's expectations. Firstly, it is about the gustative appreciation [3] and after, we have the various applications as the dietetic and medical domains [4].

It is known that air parameters such as temperature, velocity and other considerations as the exposure time of the product have an important role on the dried product quality [5] [6]. Indeed, organic products have a fragile cellular structure with volatile elements component as aromas, as well as the thermo-sensitive elements and vitamins.

The drying proceeding has an important role on dried product quality in a sense that it allows drying time optimization. Also, it preserves volatiles and thermo-sensitive elements preservation.

Okra is one of the most significant fruit vegetables grown throughout the tropics and warmer parts of the temperate climatic zone [7]. It is well dried in tropical zone and very appreciated in nutrition, due in part to its content in nutritive elements [1]. Okra seeds have content in oil in order of 15% - 19% and its proteins are in good quality [2]. Also, okra has polysaccharide content giving a strong viscous and sticky solution appearance [4]. Moreover, it has medicinal use to fight against some cardiovascular and dental diseases and decreases gastric irritations. It is also used as diuretic agent. These properties of okra are due to its contain in oligomerics catechins, derived flavonol (respectively 2.5 mg/g and 3.4 mg/g per seeds) and polyphenol with hydroxycinnamic and quercetins (0.2 and 0.3 mg/g of it skins) [8]. Physically, okra has cylindrical shape and conical extremity, supported by a peduncle. It has a complex inside structure. The cut, from the outside to inward (**Figure 1**), shows a thick skin, then a spongy material in the center. Between the skin and the central material, there are alveoli, creating cavities which accommodate spherical seeds. These three materials have different structures [9].

In West Africa, Nigeria is the greatest producer (1,039,000 t) followed by Ivory Coast, Ghana and others [10] (FAOSTAT, 2008).

To preserve the high produced quantity, the producers, generally women in Africa, proceed to its drying. The product is then cut in various sizes [1] and

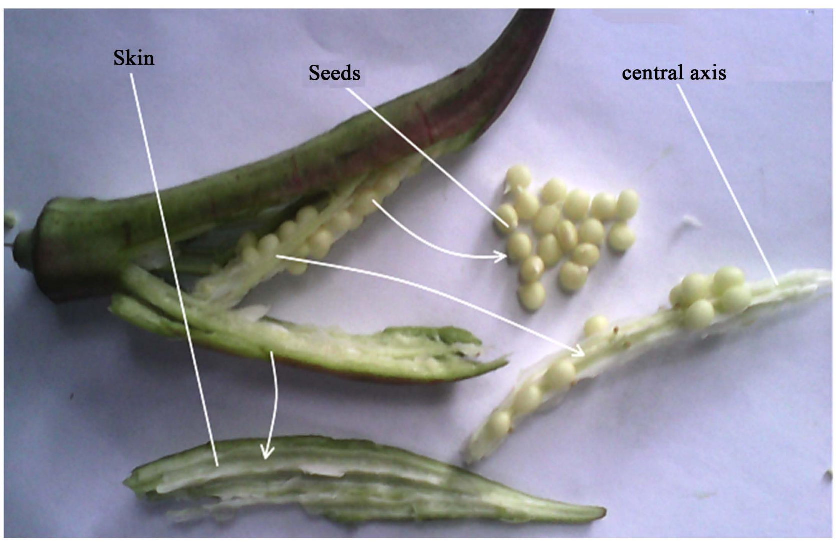

Figure 1. Okra physical external and internal constitution.

exposed directly to the sun or, more rarely, in solar-dryers. Most of dryings are achieved without control of the relative humidity, air temperature or drying air flow, above all, without distinction of age. The dried product has often doubtful and inhomogeneous quality, losing the initial organoleptic quality. However, it is not advisable, for mastering okra drying phenomena and its mechanical behavior, to study solely the whole okra behavior, without examining the effect of okra age on its convective drying. So, we can obtain an acceptable final quality, which takes into account its appreciation in the food domain and its therapeutic virtues.

The aim of this study is to look for processes which take into account, okra intrinsic properties that optimize the organic product drying. Then, the various parameters depending to the product nature were examined. Also, product constituents and maturity influence on foodstuff products convective drying were studied in this work. Mechanical difference which exists on the various zones of the okra is taken into account during its convective drying [10]. By reconciling all these processes, practices which optimize the convective drying of organic products with complex constitution as okra can be sorted out. In this work, we characterized also the convective drying of whole okra with regard to the influence of maturity using okra from 2 to 7 days old. Both fruits gathered on the same plant to avoid divergences due to okra variety, particular physical structure and the chemical composition [11].

2. Material and Method

2.1. Experimental Material and Samples Preparation

Freshly okras were obtained from various places such as local market and farm. Particularly, for the maturity influence studied, freshly okras were collected directly in a farm in Bobo-Dioulasso, which is located in the west of Burkina Faso. The samples for each experiment were collected on the same tree, to avoid divergences due to variety that can induce difference into physical structure and the chemical composition [11].

As soon as the plant of the okra is selected, it is marked. In the appearance of a flower, we mark and follow its advancement. When a fruit appears from the flower, that day is noted day 0. The first day will correspond to 24 h from initial time (0 h). Let us remind that the okra is appreciated in food at 2 - 5 days beyond of which, the fruit increases its content in fiber, becomes hardens and thus unfit for consumption. The okras were washed, and then were transported to Polytechnic University of Bobo-Dioulasso situated about 30min from the farm where okras were obtained.

The drying experiments were carried out using okra of day 1, day 2, day 3, day 4, day 5 and day 6. The samples presented average initial moisture content from 12.01 kg_w/kg_{dm} to 3.82 kg_w/kg_{dm} according to their age. The air drying temperature was settled at 60˚C. All the tests were repeated at least twice for repeatability.

Figure 1 shows the constitution of the okra, from the outside inward. A thick skin wraps seeds fixed to a spongy material constituting the central axis of the okra.

Figure 2(a) and Figure 2(b) show the existing differences between the various states of maturity of the okra. Young fruits which are generally short soft and breakable. Advanced in age fruits increase their content in fibers and become flexible and no more easily breakable.

2.2. Drying Equipment

Drying kinetics of okra samples were established using a natural convection oven-dryer (WTF BINDER). The samples were placed in the oven-dryer initially regulated to the drying temperature. During drying, the samples weight was regularly measured with a balance (Master Pro SARTORIUS, 0.001 g precision). These measurements were done every 10 - 15 min during the first 200 min. Then, due to the decrease of the drying rate, measurements were taken every 20 25 min until 300 min drying and finally every 30 - 35 min until the last stage of drying. At the end of each experiment, the dry mass m_s of the product is obtained by drying the sample in the oven dryer at 105˚C for 24 h [12] (AOAC, 1990). From the initial mass m_0 and dry mass m_s, the initial water content of each sample is determined by the following equation:

$$X_0 = \frac{m_w}{m_s} = \frac{m_0 - m_s}{m_s} \quad (1)$$

where m_w is the mass of water inside the product.

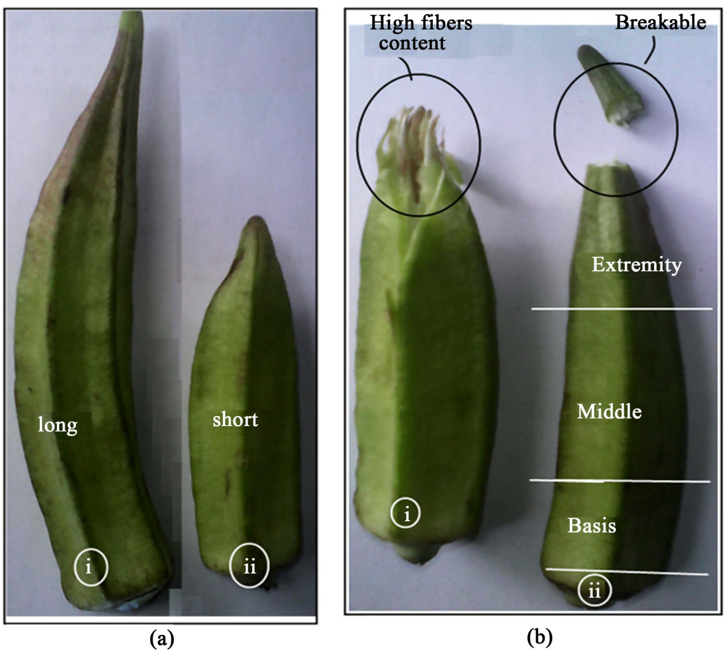

Figure 2. Okra different initial size (A), states of maturity (B) and length zoning. (A): Initial size, (i): long okra, (ii): short okra; (B) Maturity test, different zones, (i): beyond maturity with high fibers content; (ii): consumable, breakable without fibers.

2.3. Okra Convective Drying Characterization

The kinetics curves were established by measuring the mass $m(t)$ of okra at any time. The mass value decreases in proportion as drying time increase. At the end, the product's mass reaches constant value. Then the dry mass m_s is deduced.

From mass loss curves and dry mass, the water content at each instant of drying and the drying kinetics were determined.

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

Drying kinetics of okra samples were established by fitting $X(t)$ versus drying time.

2.4. Calculation of Moisture Diffusivity

The moisture ratio (MR) of samples was calculated using the following equation:

$$MR = \frac{X_t - X_{eq}}{X_o - X_{eq}} \tag{3}$$

where, X_t is the moisture content at any time, X_0 is the initial moisture content and X_e is the equilibrium moisture content. The unit of these parameters is kg_w/kg_{dm}.

The experimental drying data for the determination of diffusivity coefficient were interpreted using Fick's second diffusion model. The solution of Fick's second law for diffusion out of cylindrical form may be used to fit the experimental drying data [13]:

$$MR = \frac{X_t - X_{eq}}{X_o - X_{eq}} = \frac{4}{\beta^2} \exp\left(-\frac{\beta^2 D_{eff} t}{r_c^2}\right) \tag{4}$$

Equation (4) assumes that the effective diffusivity (D_{eff}) is constant, shrinkage of the sample is negligible for long drying times and okra was considered having cylindrical form. Several researchers demonstrated that Equation (4) could be further simplified to a straight-line equation as [14] [15] [16]:

$$\ln(MR) = \ln\left(\frac{4}{\beta^2}\right) - \left(\frac{\beta^2 D_{eff}}{r_c^2}\right) \cdot t \tag{5}$$

The effective diffusivities were determined using the method of slopes. Effective diffusivities are typically determined by plotting experimental drying data in terms of $\ln(MR)$ versus time. From Equation (5), a plot of $\ln(MR)$ versus time gives a straight line with a slope k containing D_{eff}:

$$k = \frac{\beta^2 D_{eff}}{r_c^2} \tag{6}$$

3. Results and Discussion

3.1. Okra Length Direction Behaviour during Convective Drying

The perceptible mechanical difference when touched comes with its seeds content distribution along the whole okra and influences okra drying characterization (**Figure 3**). This study examines the behavioral difference of the various parts of the okra cut on three zones. **Figure 3** shows that samples taken at the base, the middle and the extremity of the okra have not the same resistance to transfers during its convective drying. These three zones have respectively 400 min, 520 min and 600 min of drying time.

3.2. Constituents' Contribution on Whole Okra Draying

Due to the fact that okra is constituted by three (03) different constituents, it is necessary to characterize the behaviour of every component during convective drying. The results presented in **Figure 4** show that okra' three (03) constituents have not the same behaviour to transfers. The drying time of the central material, the seeds and the skin is about 70 min, 150 min and 190 min respectively, instead of 400 min for the whole okra. Among these three constituents namely the skin, seeds and the central material, the skin is the constituent which slows down considerably the drying. So, it would be important to take into account the multi-constituent character of the okra during its drying. In so doing, obviously, to open at the most the skin of okra before drying is the best way.

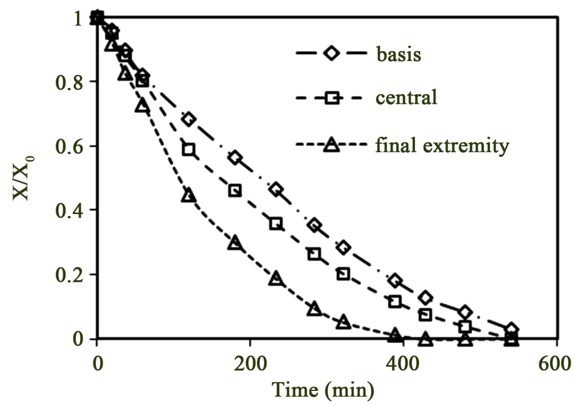

Figure 3. Okra different longitudinal zones behaviour during convective drying, 70˚C.

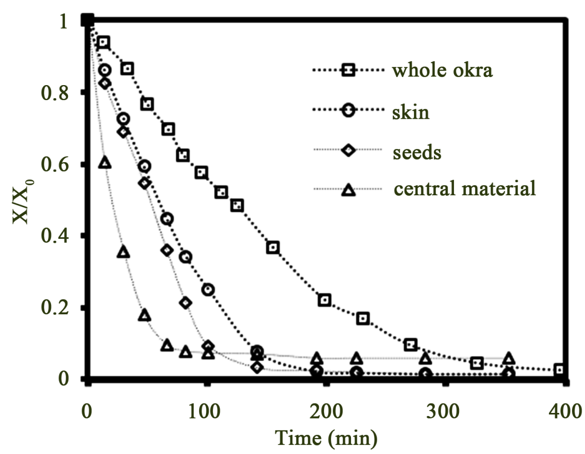

Figure 4. Constituents' contribution in whole okra drying process.

Opening the skin indeed, avoids the accumulation of the steam in the okra which increases the pressure and also to renew the air inside the okra. On the other hand, the opening allows exposing the constituents to the real conditions of drying environment and so increases the exchange air-product surface.

3.3. Influence of Maturity on Drying Curves

The effect of the age of okra fruit on the variation of the global moisture content of the whole okra during the drying process was evaluated. **Figure 5**, below, presents the initial moisture content for the different maturity degree. It can be seen from the results that the initial moisture content values decreases as the maturity degree is growing up. It was found that it is the fact that the fruit becomes more consistent which decreases the proportion of water in the sample. The experiment were carried out on whole okras collected from two different plants noted "Plant1" and "Plant 2". All of them gave similar results. The younger okra generally had the highest initial water content while the older okra had the least initial one. Whole okra of day 1, day 2, day 3, day 4 and day 5 have respectively 12.27, 9.00, 7.53, 5.97 and 4.92 kg_w/kg_{dm} of initial water contain. This suggests that at the first days, okra is affluent in water while mater becomes more and more abundant when age increases.

Figure 6 presents the drying time from drying curves for samples at 60˚C with maturity of 1, 2, 3, 4, 5 and 6 days old both from the same plant to reduce variety or other genetic aspect influences on the result. Each drying kinetics experiment was carried out at least twice to check the reproducibility of the drying curves. All the drying, in case of okra, takes place in the falling rate period. This shows that diffusion is the dominant physical mechanism governing moisture movement in the samples. Similar results were obtained by Rosello *et al.* (1997) for green bean [17] and Gupta *et al.* (2002) for red chilli [18]. It is obvious from **Figure 6** that okra age causes an important impact on its drying curves.

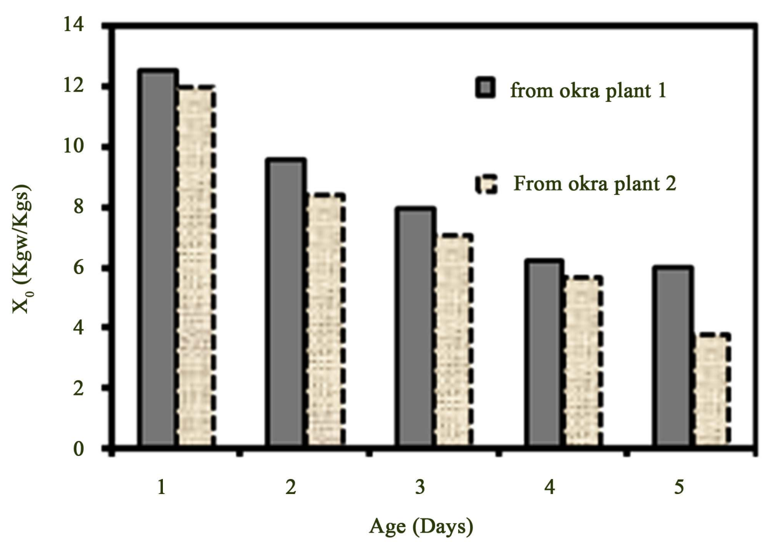

Figure 5. Okra initial water content evolution during it maturity.

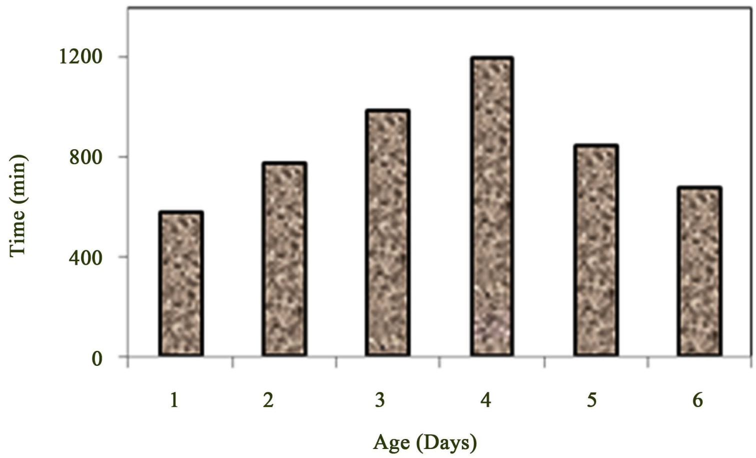

Figure 6. Influence of okra age on its convective drying.

The time required to reduce the moisture ratio to any given level was dependent on the sample age. At 1, 2, 3, 4, 5 and 6 days old, the drying effective time was respectively 780, 990, 1200, 850 and 750 min. One can divide okra maturity in two periods. The first one corresponding to the youngest age or raw fruits which goes from 1 day old to 4 days old; and, the second one, the older age or ripe fruit, which goes from 4 days old to 6 days old. The results indicated that age is an important parameter governing moisture movement in the okra samples during its convective drying. From these results, one can deduce that more okra's age is high, low is it water content. One has to notice that okra dries faster at extreme ages, youngest or older. Initial water content is not the parameter that governed the drying process. The reason of such result can proceed from the structure of the product, which changes according to okra ages as we can see in **Figure 4**. This means that the moisture transport is also controlled by inherent internal factors of maturity.

The determined values of D_{eff} for different states of maturity were 1.38×10^{-10}, 6.09×10^{-11}, 1.23×10^{-11}, 8.98×10^{-11}, and 1.05×10^{-10} m^s/s respectively for1, 2, 3, 4, 5 and 6 days old. The values are in the general range of 10^{-11} m^2/s to 10^{-9} m^2/s for food materials [19]. Results show that okra's age can be divided on two parts. For the first period, (1 - 4 days old) okra effective diffusion coefficient decrease with its age. At the second period (4 - 7 days old) okra effective diffusion coefficient increases when okra age increases. A minimum is reached at 4 days old in this study.

4. Conclusions

In this work, whole okra drying was studied by taking into account the state of maturity of the fruit. The origin of dates correspond is the days when flower appears on the tree. The age of the okra is found to be an important parameter during the evaluation of okra's convective drying. The drying effective time of the okras of 1, 2, 3, 4, 5 and 6 days old, was respectively 780, 990, 1200, 850 and 750 min. From these results it is clear that okra dries faster when it is too young or when it is advanced in age.

By examining the behaviour of samples taken at different zones on okra length direction, it was found that the various parts of the okra cut on three zones have not the same behaviour during its convective drying. The results show that samples taken at the base, the middle and the extremity of the okra have respectively 400 min, 520 min and 600 min of drying time.

With this work, it appears clearly that okra three constituents have not the same behaviour to transfers' process. The drying time of the central material, the seeds and the skin was about 70 min, 150 min and 190 min respectively, against 400 min for the whole okra. Among these three constituents, the skin is the constituent which slows down considerably the drying. Then it is better to dry the okra by opening at most its skin. Indeed, the opening of the skin avoids the accumulation of the steam in the okra which increases the pressure and secondly allows renewing the air inside the okra. Also, it allows exposing constituents in the conditions of drying and increases the air-product exchange surface area.

The influence of maturity of okra in the range of 1 - 6 days old at 60˚C of drying air temperature for okra was studied.

The result allows predicting drying behavior of okra according to its age. Contrary to all expectations, okra drying time do not increase or decrease versus its age. It was found from the experimental results that okra maturity has important influence on it behavior during convective drying. At 2, 3, 4, 5 and 7 days old, the drying effective time was respectively 780, 1000, 1155, 850 and 750 min. The youngest and the oldest fruit dried fast while the middle one (4 days old) retained more moisture. The raison that can explain this situation is to consider the consistency of the matter inside the product. In fact, the younger okras generally had high initial water content while the older okras decrease their initial water content. Whole okra at 1, 2, 3, 4, 5 and 6 days old has respectively 12.27, 9.00, 7.53, 5.97 and 4.92 kg_w/kg_{dm} of initial water contain. The youngest fruit with high water content is revealed soft and breakable. This physical characteristic make transfers easy. The oldest one has low water content and high fibers content. It weak withstands to transfers.

Conflicts of Interest

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

References

[1] Kordylas, J.M. (1991) Processing and Preservation of Tropical and Subtropical Foods. Macmillan Education Ltd, London.

[2] Camciuc, M., Deplagne, M., Vilarem, G. and Gaset, A. (1998) Ocra (*Abelmoschus esculentus* L. Moench.), a Crop with Economic Potential for Set Aside Acreage in France. *Industrial Crops and Products*, **7**, 257-264.

[3] Avallonea, S., Tiemtorea, T.W.E., Rivierb, C. and Trècheb, S. (2008) Nutritional Value of Six Multi-Ingredient Sauces from Burkina Faso. *Journal of Food Composition and Analysis*, **21**, 553-558. https://doi.org/10.1016/j.jfca.2008.04.012

[4] Sengkhamparn, N., Sagis, L.M.C., Renko de Vries, A., HenkSchols, H.A., Sajjaanantakul, T., Alphons, G.J. and Voragen, A.G.J. (2008) Physicochemical Properties of Pectins from Ocra (*Abelmoschus esculentus* (L.) Moench). *Food Hydrocolloids*, **24**, 35-41. https://doi.org/10.1016/j.foodhyd.2009.07.007

[5] Doymaz, I. (2007) Air-Drying Characteristics of Tomato. *Journal of Food Engineering*, **78**, 1291-1297. https://doi.org/10.1016/j.jfoodeng.2005.12.047

[6] Hassini, L., Azzouz, S., Peczalski, R. and Belghith, A. (2007) Estimation of Potato Moisture Diffusivity from Convective Drying Kinetics with Correction for Shrinkage. *Journal of Food Engineering*, **79**, 47-56. https://doi.org/10.1016/j.jfoodeng.2006.01.025

[7] Sankar, B., Abdul, J.C., Manivannan, P., Kishorekumar, A., Somasundaram, R. and Panneerselvam, R. (2008) Relative Efficacy of Water Use in Five Varieties of *Abelmoschus esculentus* (L.) Moench. under Water-Limited Conditions. *Colloids Biointerfaces*, **62**, 125-129. https://doi.org/10.1016/j.colsurfb.2007.09.025

[8] Adelakun, O.E., Oyelade, O.J., Ade-Omowaye, B.I.O., Adeyemi, I.A. and Van de Venter, M. (2009) Chemical Composition and the Antioxidative Properties of Nigerian Okra Seed (*Abelmoschus esculentus* Moench) Flour. *Food and Chemical Toxicology*, **47**, 1123-1126. https://doi.org/10.1016/j.fct.2009.01.036

[9] Ouoba, K.H. (2013) Séchage des produits agroalimentaires: Influence de la taille, de la forme et de la découpe. Thèse de Doctorat. Université de Ouagadougou, Burkina Faso.

[10] Ouoba, K.H., Desmorieux, H., Zougmoré, F. and Naon, B. (2010) Caractérisation du séchage convectif du gombo, influence de la découpe et de ses constituants, *Afrique Science*, **6**, 37-48.

[11] Corzo, O., Bracho, N. and Alvarez, C. (2008) Water Effective Diffusion Coefficient of Mango Slices at Different Maturity Stages during Air Drying. *Journal of Food Engineering*, **87**, 479-484. https://doi.org/10.1016/j.jfoodeng.2007.12.025

[12] AOAC (1990) Official Methods of Analysis. Washington DC.

[13] Crank, J. (1975) The Mathematics of Diffusion. 2nd Edition, Oxford University Press, London.

[14] Nuh, D.N. and Brinkworth, B.J. (1997) A Novel Thin-Layer Model for Crop Drying. *Transactions of the American Society of Agricultural Engineers*, **40**, 659-669. https://doi.org/10.13031/2013.21284

[15] Pala, M., Mahmutoglu, T. and Saygi, B. (1996) Effects of Pretreatments on Quality of Open-Air and Solar Dried Apricots. *Nahrung/Food*, **40**, 137-141.

[16] Riva, M. and Peri, C. (1986) Kinetics of Sun and Air Drying of Different Varieties of Seedless Grape. Journal of Food Technology, **21**, 199-208. https://doi.org/10.1111/j.1365-2621.1986.tb00441.x

[17] Roselló, C., Simal S., SanJuan, N. and Mulet A. (1997) Nonisotropic Mass Transfer Model for Green Bean Drying. *Journal of Agriculture and Food Chemistry*, **45**, 337-342. https://doi.org/10.1021/jf960534c

[18] Gupta, P., Ahmed, J., Shivhare, U.S. and Raghavan, G.S.V. (2002) Drying Characteristics of Red Chilli. *Drying Technology*, **20**, 1975-1987. https://doi.org/10.1081/DRT-120015579

[19] Madamba, P.S., Driscoll, R.H. and Buckle, K.A. (1996) The Thin-Layer Drying Characteristic of Garlic Slices. *Journal of Food Engineering*, **29**, 75-97. https://doi.org/10.1016/0260-8774(95)00062-3