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STUDIES ON SHRINKAGE OF TURMERIC RHIZOMES DURING DRYING

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ABSTRACT

Shrinkage is one of the most important physical phenomena that occur during drying in most of the biological materials, especially in those which have high moisture content. Turmeric rhizomes are such kind of material. The turmeric finger rhizomes recorded 50.54 % reduction in thickness and 27.38 % reduction in length and an average volume reduction of 76.80 % when the moisture content was reduced from 411.25 to 7.81 % (db). These results clearly indicate that shrinkage is anisotropic and more shrinkage was appeared in the radial direction than in the axial direction. The moisture removed per unit surface area of turmeric finger rhizomes during drying at 50^{o}C was calculated with shrinkage and without shrinkage. When the shrinkage was not taken into account the moisture removed per unit surface area of rhizome showed around 15 to 62 % reduced values for the drying period of 16 to 48 hours as compared to the values with shrinkage. The values of effective moisture diffusivity obtained by considering the samples shrinkage were lower than those calculated without considering this phenomenon. From this study, it is clear that significant variation in the drying parameters is observed for the same material while considering and not considering the shrinkage effect. Therefore, it is suggested that shrinkage that occurs in turmeric during drying must be taken into account and this information will help the scientists while designing a dynamic type materials dryer, storage structures for known volume of fresh produce etc.

Keywords: drying, turmeric rhizomes, shrinkage, effective moisture diffusivity

INTRODUCTION

Turmeric (*Curcuma longa* L.) is grown widely throughout the tropics, and has a prominent role in the Indian economy as it ranks third among the spices with regard to foreign exchange earnings. Turmeric rhizomes are used for centuries as a natural colouring agent in food, as a flavouring and health compound in cosmetics, as an insect repellent in grain storage and also as an Indian medicine. Turmeric has been used as an antioxidant, digestive, antimicrobial, anti-inflammatory and anti-carcinogenic agent.

One of the most important physical changes that the food suffers during drying is the reduction of its external volume. Loss of water and heating cause stresses in the cellular structure of the food leading to change in shape and decrease in dimension (Mayor & Sereno, 2004). Turmeric rhizomes are a kind of material with high initial moisture content and a considerable shrinkage always happens during the drying process. The quantification of this phenomenon is important because, it allows the analysis of the drying kinetics and consequently the whole drying phenomenon correctly. This paper aims at comparing the diffusivity values calculated without and with the shrinkage and indicating importance of consideration of shrinkage for arriving correct results. Drying models cited in most of the literature are established assuming no shrinkage in the drying materials. However, this seems to be not true always.

MATERIALS AND METHODS

RAW MATERIALS

Freshly harvested turmeric finger rhizomes (Erode variety) were collected from farmer's field at Namakkal District of Tamil Nadu for the study.

BOILING AND DRYING OF TURMERIC FINGER RHIZOMES AT LABORATORY CONDITION

Open shallow metal (Mild Steel) pan was used for boiling turmeric. The pan was loaded with cleaned turmeric rhizomes and water was added just enough to soak them and covered by wet gunny bags. Then, the pan was kept over a stove and heated. The appearance of white fumes on the gunny bags surface and release of characteristic flavour indicates the completion of boiling. The completion of boiling was further tested using fresh soft stick taken from coconut leaves. If the stick penetrates into the rhizome without any resistance, it indicates that the boiling was completed. Then, the boiling pan was lifted from the stove using long wooden poles and the contents were poured over the ground (both rhizomes and water). After draining the excess water, the boiled rhizomes were dried in tray drier at a temperature of 50°C.

CHANGE IN VOLUME OF FINGER RHIZOME DURING DRYING

True volume of the turmeric rhizomes can be determined by water displacement method. However, to avoid errors due to absorption of water by turmeric rhizomes, instead of water, mercury was used. One kg of rhizomes was randomly drawn from the bulk and from this, three rhizomes of different sizes (large, medium and small) were selected, weighed individually in an electronic balance having a least count of 0.01 g and a small pin was inserted vertically immediately after boiling for easy identification. The rhizomes were weighed as whole and individually in case of identified rhizomes and subjected to drying. At every 2hours interval, the length and thickness of the selected rhizomes were measured using a vernier calliper having a least count of 0.1mm. Then, weight and volume reduction were calculated and recorded.

MODELLING OF DRYING CURVES

All the drying processes related to grains are explained using Fick's second law and the solution for this is given by Crank (1975) assuming that there is no change in the dimensions (volume) of the grain. However, there is a definite change in the volume of the finger rhizome during drying process. Hence, there is limitation to apply Crank's solution to describe the drying process for turmeric finger rhizomes.

Pinedo and Murr (2006) discussed the drying kinetics of pumpkin seeds and modelled the drying process taking into account the shrinkage that occurred during drying. The method consists of an analysis of the drying process considering a diffusion model. The differential equation based on Fick's second law for diffusion of water during drying is

$$\frac{\partial W}{\partial t} = \nabla.(D_{ef}\nabla W) \quad \text{---------------} \quad (1)$$

where W is moisture concentration (kg/m^3), t is the time (s) and D_{ef} is the moisture diffusivity (m^2/s).

For the drying process, the concentration may be converted to moisture content per unit of dry material. Considering shrinkage as negligible, Eq. (1) could be expressed (Sherwood, 1929) as

$$\frac{\partial X}{\partial t} = D_{efx}(\nabla^2 X) \quad \text{-----} \ (2)$$

With

$t = 0, X = X_0$

$t > 0, z = 0, \partial X/\partial z = 0$

$t > 0, z = L, X = X_e$

where D_{efx} is moisture diffusivity without shrinkage (m^2/s), L is diffusional path (m), X is moisture content (kg water/kg dry solid), X_e is equilibrium moisture content (kg water/kg dry solid) and X_0 is initial moisture content of rhizomes (kg water/kg dry solid).

For the unidirectional diffusion in a cylinder shaped material one may obtain (Crank, 1975):

$$\left(\frac{X - X_e}{X_o - X_e}\right) = \frac{4}{\Pi^2}\sum_{n=0}^{\infty}\frac{1}{(2n+1)^2} \times \exp\left[-(2n+1)^2\,\Pi^2\,\frac{D_{ef}.t}{L^2}\right] \quad ... (3)$$

Adding the density of dry solid (ρ_s) in Eq. (1) we obtain:

$$\frac{\partial(\rho_s X)}{\partial t} = \nabla.(D_{ef}\nabla(\rho_s X)) \quad ... (4)$$

or, for constant weight of dry solid (Park, 1998; Uddin *et al.*, 2004):

$$\frac{\partial X_s(X/V)}{\partial t} = \frac{X_s \partial(X/V)}{\partial t} = X_s D_{ef}\nabla^2(X/V) \quad .. (5)$$

Substituting Y = X/V and cancelling X_s on both sides, we have:

$$\frac{\partial Y}{\partial t} = D_{efy}(\nabla^2 Y) \quad \ldots (6)$$

With

$t = 0, Y = X_0/V_0$

$t > 0, z = 0, \partial Y/\partial z = 0$

$t > 0, z = L, Y = X_e/V_e$

$$\left(\frac{Y - Y_e}{Y_o - Y_e}\right) = \frac{4}{\Pi^2}\sum_{n=0}^{\infty}\frac{1}{(2n+1)^2} \times \exp\left[-(2n+1)^2\,\Pi^2\,\frac{D_{efy}.t}{L^2}\right] \quad \ldots (7)$$

When the drying time t is longer, the terms other than first approaches zero (Chakraverty, 1995). Then the equation (7) becomes

$$\left(\frac{Y - Y_e}{Y_o - Y_e}\right) = \frac{4}{\Pi^2} \times \exp\left[-\Pi^2\,\frac{D_{efy}.t}{L^2}\right] \quad ... (8)$$

where D_{efy} is the effective diffusivity (m^2/s) considering the shrinkage and V is sample volume (m^3).

RESULTS AND DISCUSSION

STUDIES ON SHRINKAGE OF TURMERIC FINGER RHIZOMES DURING DRYING

In general, drying resulted in decrease in size of drying material. This may be very small when compared to the whole volume of dried product in some cases like grains and appreciably higher in some other cases like turmeric rhizomes. Turmeric rhizomes are a kind of material with high initial moisture content and a considerable shrinkage always happen during the drying process.

DRYING CHARACTERISTICS

The initial average moisture content of the turmeric finger rhizomes was 411.25 % (db) and it attained an equilibrium moisture content of 7.81 % (db) after drying for a period of 48 hours. The drying curve and the drying rate curve are shown in Fig.1 and Fig. 2, respectively. From the figures, it could be seen that due to the high initial moisture content of rhizomes, drying rate was higher during the initial period of drying and as the drying progresses, the drying rate decreased because of the rate of diffusion of moisture from the centre to the surface. The following polynomial equations described the relationship between drying time and moisture content and between moisture content and drying rate of turmeric finger rhizomes.

The drying data of turmeric finger rhizomes dried at 50^oC is well explained by a regression equation				
y	=	$0.1477\,x^2 – 15.109x + 395.82$	$R^2 = 0.9979$	... (9)
where y = moisture content, % (db), x = drying time, h				
Drying rate curve of turmeric finger rhizomes followed				
y	=	$-1E\text{-}05x^2 + 0.0333x + 8.2927$	$R^2 = 0.9950$	(10)
where y = drying rate (g of water/h/100 g of bone dry material), x = moisture content, % (db)				

SHRINKAGE

The moisture removed per unit surface area of turmeric finger rhizomes during drying at 50^oC was calculated with shrinkage and without shrinkage. Fig. 3 shows the relationship between drying time and cumulative moisture removed per unit surface area for both cases. From the figure, it is seen that as the drying time increases, cumulative moisture removed per unit surface area increases in both the cases in the same rate up to a drying time of 14 hours of initial period of drying at 50^oC. Beyond that there is a deviation between two cumulative moisture removal curves. That is, the moisture removed per unit surface area was more in the rhizomes while considering the shrinkage, as the drying time increases. When shrinkage was not taken into account the cumulative moisture removed per unit surface area of rhizome recorded around 15 to 62 % reduced values for the remaining drying period of 16 to 48 hours as compared to the values with shrinkage. The cumulative moisture removed per unit surface area of turmeric finger rhizome, calculated with and without shrinkage was found to have a polynomial relationship with drying time and followed the regression equation of the form

y	=	$0.0002x^2 + 0.0084x + 0.0363$	$R^2 = 0.9913$	... (11)
Considering the shrinkage effect and				
y	=	$-0.0001x^2 + 0.0137x + 0.0135$	$R^2 = 0.9977$	... (12)
Without shrinkage effect				
where y = moisture removed/unit surface area, g/cm^2 x = drying time, h				

The relationship between moisture content and volume of turmeric finger rhizome as drying progress is depicted in Fig. 4. From the figure, it is seen that as the moisture content decreases, volume of the rhizome also got decreased gradually. This may be due to the fact that when moisture is removed from the material, a pressure unbalance is developed between the inner part of the material and the external pressure, generating contracting stresses that lead to material shrinkage as stated by Mayor and Sereno (2004), which in turn reduced the volume of the rhizome. When the moisture was reduced from 411.25 to 7.81 % (db), an average volume reduction of 76.80 % was observed in turmeric rhizomes. The rate of volume reduction was more in the initial stage since more water was removed which resulted in more contraction stresses in the material and at the later stage, it was less since the moisture available for transfer was less and finally it attained an equilibrium. The reduction in volume with moisture content was found to follow a linear relationship with moisture content and represented by a regression equation of the form

y	=	$0.0596x + 6.4259$	$R^2 = 0.9935$	... (13)
where y = volume of turmeric finger rhizome, cm^3, x = moisture content, % (db)				

The relationship between moisture content and length and thickness of turmeric finger rhizomes during drying at 50^oC is shown in Fig. 5. From the figure, it is seen that turmeric finger rhizomes recorded 50.54 % reduction in thickness and 27.38 % reduction in length when the moisture content was reduced from 411.25 to 7.81 % (db). These results clearly indicate that shrinkage is anisotropic and more shrinkage was appeared in the radial direction of the turmeric finger rhizome than in the axial direction. This may be due to the fact that as more and more water molecules moved in the radial direction during drying, more void space is formed between solid particles and this caused contraction of cell wall. Hence radial direction recorded more shrinkage. The starch particles swelled during boiling contracts during drying also contributes for shrinkage.

Similar results were reported by Xiaoxi Yang *et al*. (2006) for ginger rhizomes. The only difference is that in the case of turmeric finger rhizome, more shrinkage occurred in the radial (thickness) direction than in the axial(length) direction. This may be due to the movement of moisture in the radial direction during drying. In the case of ginger, Xiaoxi Yang *et al*. (2006) sliced and dried the rhizomes. Hence, more shrinkage was observed in the axial direction since the thickness of slice is less than radius of rhizomes. The relationship between shrinkage in longitudinal and radial direction and moisture content can be represented by the following logarithmic and power equations of the form

For shrinkage in longitudinal direction				
y	=	$0.5335\ln(x) + 4.7813$	$R^2 = 0.9926$	... (14)
For shrinkage in radial direction				
y	=	$0.8362x^{0.1774}$	$R^2 = 0.9878$	... (15)
Where y = shrinkage, x = moisture content, % (db)				

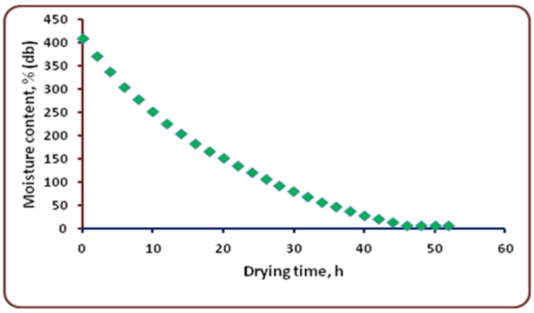

Fig. 1. Drying curve for turmeric finger rhizomes dried at 50 °C

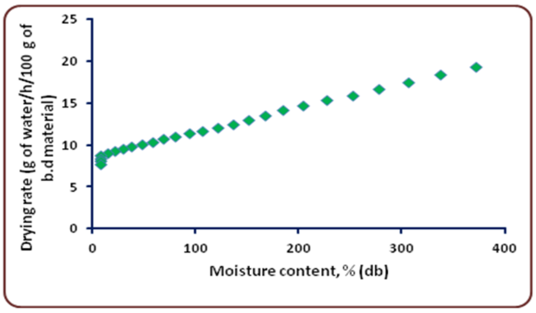

Fig. 2. Drying rate curve for turmeric finger rhizomes dried at 50 °C

From the above discussions, it is clear that significant variation in the drying parameters is observed for the same material when considering and not considering the shrinkage effect. Since there is a considerable shrinkage i.e. around 77 % of volume reduction was observed during drying of turmeric finger rhizomes, it is suggested that shrinkage that occurs in turmeric during drying is important and must be taken into account while discussing about the process of drying of turmeric rhizomes and similar materials. This type of correct information will help the scientists while designing dynamic type materials dryer, storage structures for known volume of fresh produce etc.

EFFECTIVE MOISTURE DIFFUSIVITY

Effective moisture diffusivity of turmeric finger rhizomes with and without considering the shrinkage (m^2/s) was calculated by using the Equations 3 and 8. The average moisture diffusivity of turmeric finger rhizomes considering the shrinkage was found to be 8.43×10^{-11} and 3.49×10^{-11} m^2/s during the first and second falling rate period of drying, respectively. Moisture diffusivity calculated without considering the shrinkage recorded 4.14×10^{-10} and 2.51×10^{-10} m^2/s during the first and second falling rate period of drying, respectively. From the results it is clear that considerable differences were noticed in the effective moisture diffusivity calculated with and without shrinkage. That is, the values of effective moisture diffusivity obtained by considering the samples shrinkage were lower than those calculated without considering this phenomenon. This indicates that the diffusivity calculated without considering the shrinkage phenomenon overestimates the transference of mass (moisture) by diffusion.

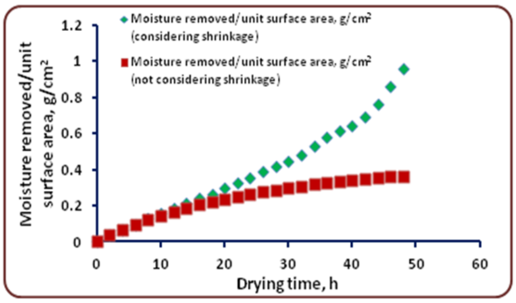

Fig. 3. Relationship between drying time and moisture removed per unit surface of turmeric finger rhizome during drying at 50 °C

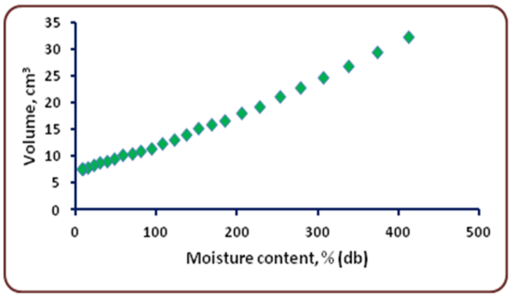

Fig. 4. Relationship between moisture content and volume of turmeric finger rhizome during drying at 50 °C

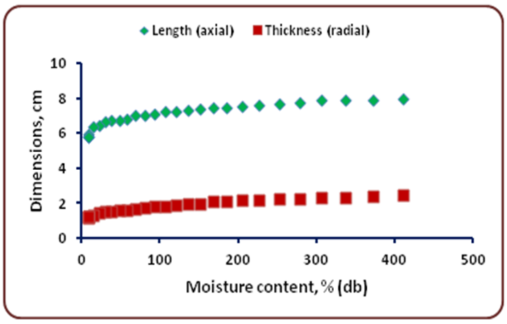

Fig. 5. Relationship between moisture content and length and thickness of turmeric finger rhizomes during drying at 50 °C

Pinedo and Murr (2006) reported that during drying the pre-treated pumpkin by freezing in a vacuum dryer at 70°C and a pressure of 5 kPa, the effective moisture diffusivity value calculated without considering the shrinkage was found to be 5.70×10^{-09} m^2/s. At the same operating condition the values of effective moisture diffusivity obtained by considering the shrinkage was found to be 3.90×10^{-09} m^2/s. The results of the present study followed similar trend and confirmed findings of the present study. So, the effective moisture diffusivity considering shrinkage helps for an accurate estimation of the drying phenomena.

CONCLUSION

The values of effective moisture diffusivity obtained by considering the samples shrinkage were found to be lower than those calculated without considering the shrinkage. This indicates that the diffusivity calculated without considering the shrinkage phenomenon overestimates the transference of moisture by diffusion. Therefore, the effective moisture diffusivity considering shrinkage allows an accurate estimation of the drying phenomena.

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