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THE EFFECTS OF SHRINKAGE ON DRYING CHARACTERISTICS OF SLICED ZEDOARY

PENGARUH PENYUSUTAN TERHADAP KARAKTERISTIK PENGERINGAN TEMU PUTIH

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ABSTRAK

Tujuan penelitian ini adalah untuk mempelajari fenomena penyusutan irisan temu putih selama proses pengeringan dengan menggunakan analisis citra dua dimensi serta pengaruh penyusutan terhadap karakteristik pengeringan temu putih. Pengeringan temu putih dilakukan pada tiga level suhu (50, 60 dan 70^{o}C) dengan tiga tingkat RH (20%, 30% dan 40%) dengan suhu tetap. Perubahan berat sampel diamati secara kontinu sedangkan perubahan area permukaan direkam dan dihitung setiap 5 menit. Data laju pengeringan menurun terhadap waktu digunakan untuk menentukan koefisien difusivitas efektif. Hasil studi menunjukkan bahwa pengeringan simplisia temu putih terjadi pada periode laju menurun dan penyusutannya dipengaruhi oleh kadar air bahan secara linier sedangkan suhu dan RH udara pengeringan berpengaruh tidak nyata terhadap penyusutan irisan temuputih. Temu putih yang dikeringkan pada suhu 70^{o}C terlihat mengalami pembengkokan yang lebih besar daripada suhu 50 dan 60^{o}C. Koefisen difusivitas efektif temu putih pada rentang suhu percobaan dengan mempertimbangkan adanya penyusutan berada pada interval 4.74-6.19×10^{-9} m^2/s.

Kata kunci **:** *difusivitas, pengeringan, penyusutan, pengolahan citra, kadar air, temu putih*

ABSTRACT

The effects of drying conditions on shrinkage of zedoary were studied. A thin-layer dryer with machine vision 2D system and image analysis software was used. Zedoary slices were dried at temperatures of 50, 60 and 70^{o}C (at constant RH) and relative humidities of 20%, 30% and 40% (at constant temperature). The falling drying rate data were used to calculate the effective diffusion coefficients from the Fick's equation. Changes in area of the slice were measured every 5 minute during drying. Shrinkage showed almost linear relation with moisture content. It was found that air temperature and relative humidity had no significant effect on shrinkage. Drying took place entirely in the falling rate period. Slices dried at 70^{o}C showed more bend than slices dried at 50 and 60^{o}C. Effective diffusivity values by considering the shrinkage were estimated in the range of 4.74-6.19×10^{-9} m^2/s for studied drying temperatures.

Keywords: drying, shrinkage, moisture, diffusivity, image analysis, zedoary

INTRODUCTION

Dehydration of foods is one of the most common processes used to improve food stability, since it decreases considerably the water activity of the material, reduces microbiological activity and minimizes physical and chemical changes during its storage. 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. Shrinkage of food materials has a negative consequence on the quality of the dehydrated product and should be taken into consideration when predicting moisture and temperature profiles in the dried material. Changes in shape, loss of volume and increased hardness cause in most cases as negative impression of the consumer (Mayor and Sereno, 2004).

Zedoary or *temu putih* (*Curcuma zedoaria* Rosc.) is one of the important medicinal plants in Indonesia. Its rhizome uses for food suplement material and traditional herbal medicine called *jamu*. Many small traditional medicine companies need *temu putih* in dried-slices also called *simplicia*. As one of the herbal producing countries in the world, Indonesia produce 518 million tones herbs and export 41.4 million tones or US$ 211.4 million in 2011. Recently, there has been an increasing demand for organic and natural vegetables due to human health benefits (Anonymous, 2013).

Shrinkage has been studied by direct measurements with a caliper or micrometer or by changes in related parameters such as porosity and density. Recently, there have been many studies to describe the shrinkage behavior of various fruits and

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vegetables in terms of prediction models. Lozano *et al*. (1983) found a general correlation for prediction of fruit and vegetable shrinkage with changing in moisture content. Shrinkage has been correlated linearly to moisture content (Al-Muhtaseb *et al*., 2004; Hernandez *et al*., 2000; McMinn and Magee, 1997; Park, 1998). Hatamipour and Mowla (2002) reporteda linear correlation for volume change and empirical relation for axial contraction of carrots during drying in a fluidized bed dryer with inert particles. Potato shrinkage has been reported as non-isotropic or irregular (Yang *et al*., 2001).

Image processing technique can be easily applied to measure the shape of food. Yan *et al*. (2008) used image analysis to measure the dimensional change of pineapple, mangoand banana during drying. Changes of parameters such as area, perimeter, equilibrium diameter and shape factor were measured by image analysis and correlated with change in moisture content by second order polynomial trends. Non-isotropic shrinkage of potatoslabs during convective drying with two digital cameras for top and side view was measured by Mendiola *et al*. (2007). Cellular surface area of potato cells was recorded and related to moisture content by means of an empirical equation. Computer vision was used to analyze the effect of drying on shrinkage, color and image texture of apple discs (Fernandez *et al*., 2005). Yadollahinia *et al*. (2009) used machine vision system and image processing to measure changes in area, perimeter, major and minor diameters, diameters parallel and perpendicular to airflow, roundness and elongation of the potato slices during drying.

It is obvious that drying change physical properties of the product. Also, the change in physical dimension of product is specific and varies according to drying conditions. Moisture content of zedoary when harvested is about 80-90%, while the final moisture content of drying is less then 10%, thus changes in the volume of dried slices of zedoary quite large and can not be ignored. Meanwhile, the drying of zedoary takes place in the falling rate period where diffusion is the dominant physical mechanism governing moisture movement in the product (Manalu *et al*., 2009).

The aim of this work was to determine shrinkage of zedoary slices during drying using machine vision and image analysis and to study the effect of shrinkage on drying characteristics of zedoary slices during drying.

MATERIAL AND METHODS

Samples Preparation

Fresh zedoary rhizome obtained from test field of Centre for Medicinal and Aromatical Plant in Bogor, Indonesia. Moisture content was determined by drying the samples at 70^{o}C in a vacuum oven (Memmert, Germany) for 24 h. Samples of zedoaries were washed and sliced into chips of 3 mm thickness with a knife and then dipped into boiling water for 5 min.

Experimental Dryer

A thin-layer dryer was designed and made based on computer visionfor measuring the effects of drying on surface shrinkage andrelation between surface shrinkage and moisture content of fruitslices. The drying experiments were carried out using the laboratory dryer in the Department of Mechanical and Biosystem Engineering, Bogor Agricultural University of Indonesia, which could be regulated to any desired drying air temperature between 30 and 80^{o}C and relative humidity between 20 and 90%. The air temperature and the relative humidity are controlled by AVR Atmel microprocessor controller with temperature accuracy of ±1 ^{o}C and relative humidity accuracy of ±2%. The unit is equipped with a 2000 W steam injection humidifier, a 2000 W heating and heating control unit, an electrical fan, temperature and humidity measurement sensor by SHT15 Sensirion, camera digital and the drying chamber (Figure 1). The desired drying air temperature and relative humidity are maintained by PID control system. The air from the heating unit at the desired temperature entered the drying chamber.The lever manual-controller regulate the velocity of the drying air flowing through the drying chamber and it was measured by a hot wire digital Kanomax anemometer with the accuracy of ±0.1 m/s.

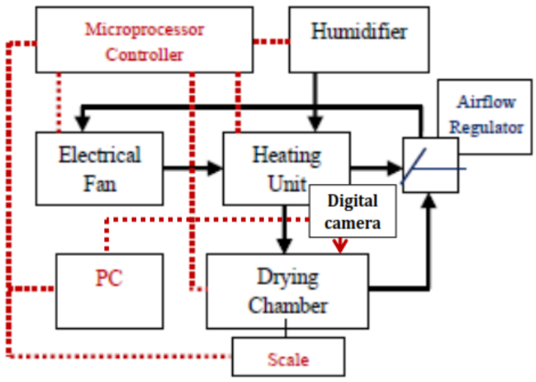

Figure 1. Schematic of the experimental dryer coupled to the digital image system

Animage acquisition system consisting of a digital web camera, illumination chamber, computer hardware andsoftware was developed to capture and process the images. All parameters related to shape (area, perimeter, majorand minor diameters) determined by the image processing software for all of the captured images. In each experiment one of the slices was placed on the top shelf of samples in the illumination drying chamber to record the surface shrinkage by capturing images. The other slices were placed on placed on the bottom shelfused to evaluate weight loss and moisture of samples during drying. Weighing of samples inside the drying chamber was done automatically at desired time interval using a digital balance (GF-3000 A & D with an accuracy of 0.01 g). The digital camera and digital balance were interfaced to a PC via USBand RS-232 port, respectively.

During drying sample was monitored continuously and image of the slice was captured by machine vision system. After drying had finished parameter related to shape (surface area) was determined by the image processing software for all images.

Drying Experiments

The experiments were conducted in triplicate at three levels drying air temperatures at constant humidity of 40% RH (50, 60 and 70°C) and at three levels drying air humidities at constant temperature of 50°C (20%, 30% and 40%) while air velocity kept constant at 0.8-0.9 m/s. Drying experiments were continued until a constant mass was obtained. The moisture loss from the samples and surface shrinkage along drying were determined respectively by weighing the sample with the digital balance and capturing image from slice very 5 min.

Shrinkage Modelling

Shrinkage defined as the reduction of size of volume, area (surface area) or the thickness of the material. Volume shrinkage of dried material was formulated as follows:

$$S = \frac{V}{V_0} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

In this study, the material of shrinkage is assumed uniform (isotropic) so that the thickness shrinkage is proportional to the reduction in surface dimensions. For the slab-shaped material, relation between surface area and thickness and volume shrinkage ratio is:

$$\frac{L}{L_0} = \left(\frac{A}{A_0}\right)^{1/2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

$$\frac{V}{V_0} = \left(\frac{A}{A_0}\right)^{3/2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Reducing the volume of the dried material is proportional to the volume of water coming out so that the volume shrinkage model uses linear equations (Lozano *et al*., 1980) as follows:

$$\frac{V}{V_0} = a\frac{M}{M_0} + b \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

Combining Eqns. (2), (3) and (4) one may receive Eqn. (5), which was applied to calculate the length of a shrinking zedoary slab's edge.

$$L(M) = L_0\left(a\frac{M}{M_0} + b\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

Mathematical Modelling

Dehydration characteristics of many food products are often described using empirical thin layer equations. However, their parameters have no physical sense. In most situations, Fick's second law of diffusion has been used to describe moisture diffusion processes. The solution of Fick's equation can be applied for different solid geometry, e.g. slab, cylinder and sphere (Crank, 1975). For slab-shaped solids, with the assumptions of moisture migration by diffusion, uniform initial moisture distribution, negligible external resistance to heat and mass transfer, constant temperature, and constant effective diffusion coefficient, the solution of Fick's law for a slab can be written by a series type equation:

$$MR = \frac{M - M_e}{M_0 - M_e} = \frac{8}{\pi^2}\sum_{n=0}^{\infty}\frac{1}{(2n+1)^2}exp\left(\frac{-(2n+1)^2\pi^2 D \cdot t}{4L^2}\right) \ldots\ldots\ldots (6)$$

For long dehydration periods (MR<0.6), a limiting form is obtained for slab-shaped equation by considering only the first term in its series expansion (Babalis and Belessiotis, 2004). Then, Eqn. (6) can be written as follows,

$$M = \frac{8}{\pi^2}exp\left(-\frac{\pi^2 D_{eff} \cdot t}{4L^2}\right) \ldots\ldots\ldots\ldots\ldots\ldots (7)$$

The coefficient of determination (R^2) and standard error (SE) were used as the primary criterion for selecting the best equation to account for the validation of a curve when non-linear regression techniques are used (Madamba *et al*., 1996; Panchariya *et al*., 2002; Lee *et al*., 2004; Menges and Ertekin, 2006). The SE gives the deviation between the predicted and experimental values and it is required to reach zero. The R^2 gives the ability of the model and its highest value is 1. These statistical values can be calculated as follows:

$$R^2 = 1 - \frac{\sum_{i=1}^{N}\left(MR_{exp,i} - MR_{pre,i}\right)^2}{\sum_{i=1}^{N}\left(MR_{exp,i} - \overline{MR}_{exp}\right)^2} \ldots\ldots\ldots\ldots (8)$$

$$SE = \frac{\sqrt{\sum_{i=1}^{N}\left(MR_{exp,i} - MR_{pre,i}\right)^2}}{N - n} \ldots\ldots\ldots\ldots (9)$$

RESULTS AND DISCUSSION

Shrinkage Behavior during Drying

Figures 2 and 3 show a gallery of images of a zedoary slice during drying at different temperatures and relative humidities. Obvious visually changes can be seen in the size of the slice (shrinkage).

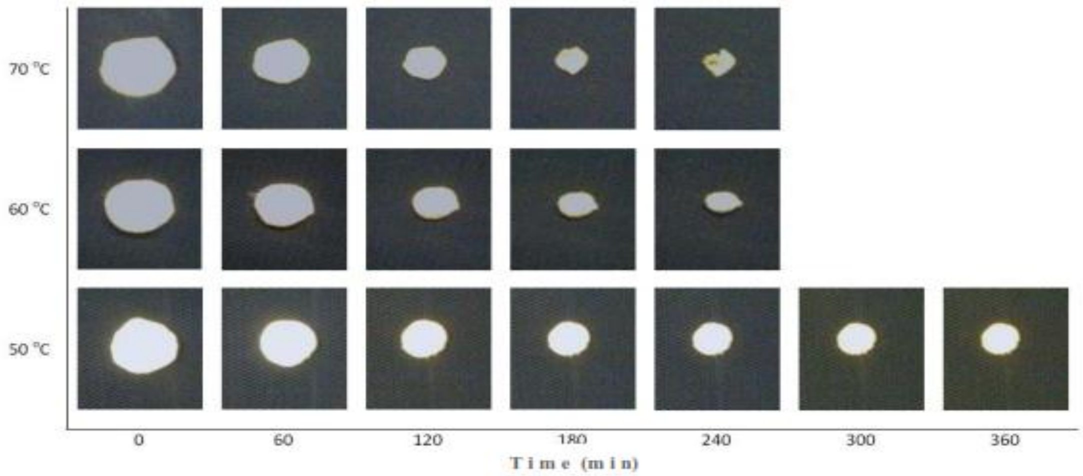

Figure 2. Gallery of images of a zedoary slice as a function of drying time at temperatures of 50, 60 and 70°C.

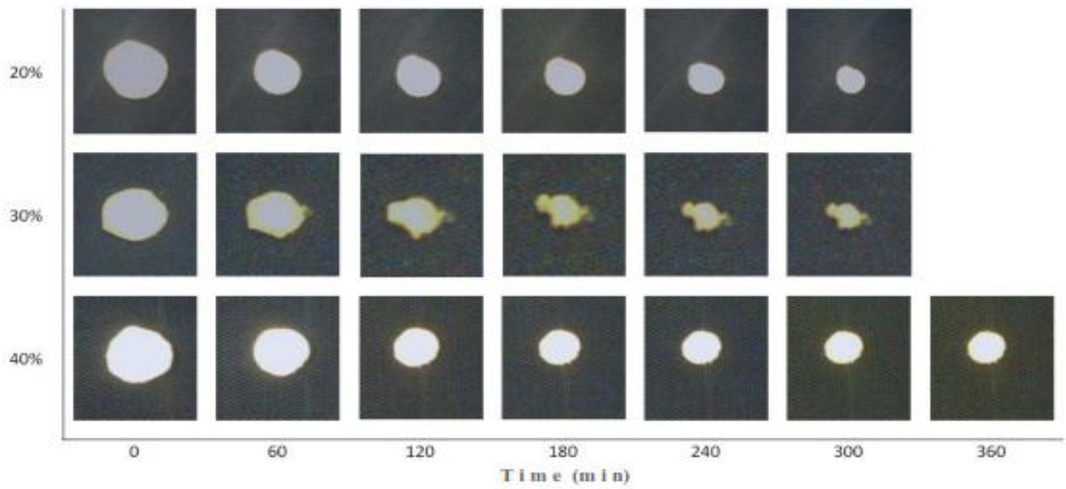

Figure 3. Gallery of images of a zedoary slice as a function of drying time at 20%, 30% and 40% RHs

The plot of dimensionless area changes (A/A_0) versus drying time for the samples dried at the different air temperatures and relative humidities is shown in Figures 4 and 5. These image shown that surface area of samples decreased rapidly in the beginning until a half-drying time and then more slowly at the end of drying.

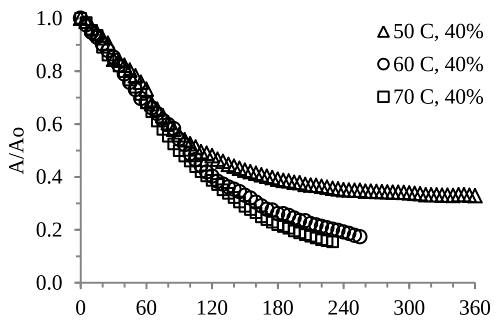

Figure 4. Area changes with drying time at the different temperatures

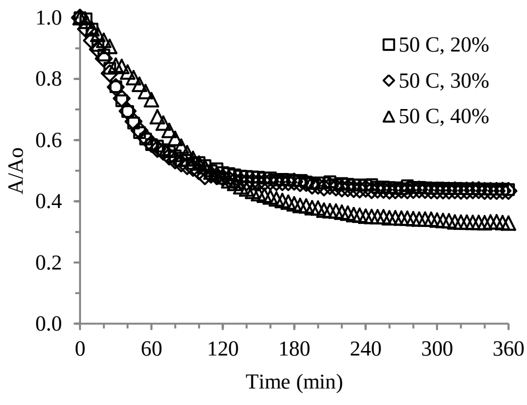

Figure 5. Area changes with drying time at the different relative humidities

Area shrinkage of zedoary slice versus its dimensionless moisture content at studied air temperatures and relative humidities are shown in Figures 6 and 7. Both of figures show area shrinkage decreased at lower moisture content. The slope of curve in the Figure 6 is higher than Figure 7, nevertheless the Anova test results indicate that both air temperature and RH had no significant effect on the shrinkage. This is indicated by the *P-values* of 0.89 and 0.61 at significance level of 0.99. Similar results were obtained by several authors like for air temperature by Mcminn and Magee (1997) with potato and for relative humidity of air by Ratti (1994) with potato, apple and carrot; Lang and Sokhansanj (1993) with wheat and canola kernels. Zogzas and Maroulis (1996) and Marinos-Kouris and Maroulis (1995) also reported independence of shrinkage characteristics on both the temperature and humidity of drying air.

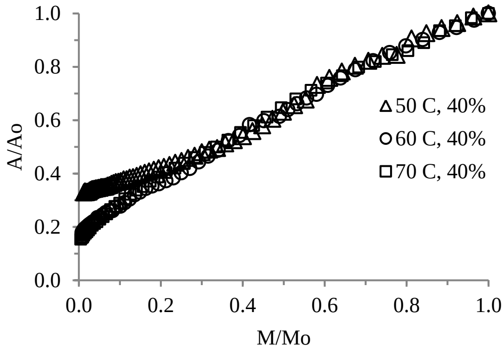

Figure 6. Dimensionless area changes (A/A_0) versus moisture content (M/M_0) at the different temperatures

The extent of area shrinkage, volume shrinkage and the amount of moisture evaporated during drying at the studied temperatures are given in Table 1. It presents that the percentage reduction in moisture content of the material is greater than the shrinkage volume of materials at all levels of drying temperature. The same result was reported by Wang and Brennan (1995) on the drying of potatoes and by Krokida and Maroulis (1997) on sweet potatoes and apples. Shrinkage of volume and surface area of zedoary slices at the studied temperatures ranges from 81.2%-93.9% and 67.1%-84.6% respectively with an average (89.3±7.1)% and (78.1± 9.6)% respectively, whereas removal moisture content varied 98.7-99.6%.

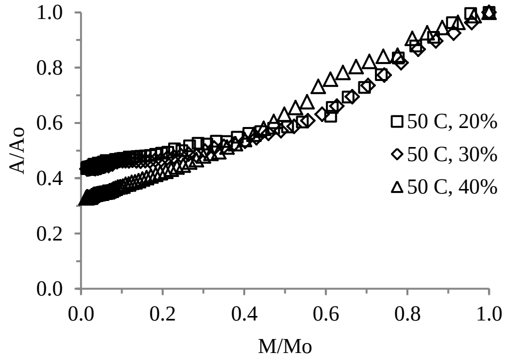

Figure 7. Dimensionless area changes (A/A_0) versus moisture content (M/M_0) at the different relative humidities

The extent of area shrinkage, volume shrinkage and the amount of moisture evaporated during drying at the studied RHs are given in Table 2. It presents that the percentage reduction in moisture content of the material is also greater than the shrinkage volume of materials at all levels of studied RHs. Shrinkage of volume and surface area of zedoary slices at the studied RH ranges from 71.3%-81.2% and 56.5-67.1% respectively with an average (74.6±5.6)% and (60.1±6.1)% respectively, whereas removal moisture content varied 98.5-98.7%. Both of Tables 1 and 2 show that zedoary shrinkage increased with increasing moisture loss.

Table1. Zedoary shrinkage at different studied temperatures (constant humidity)

Temp.	Area (mm^2)		A_{shrink} (%)	Volume (mm^3)		V_{shrink} (%)	Moisture loss (%)
	A_0	A_{end}		V_0	V_{end}		
50°C	310	102	67.1	931	176	81.2	98.7
60°C	325	56	82.7	976	70	92.8	99.2
70°C	496	77	84.6	1488	90	93.9	99.6

Table 2. Zedoary shrinkage at different studied RHs (constant temperature)

RH	Area (mm^2)		A_{shrink} (%)	Volume (mm^3)		V_{shrink} (%)	Moisture loss (%)
	A_0	A_{end}		V_0	V_{end}		
20%	318	138	56.5	954	274	71.3	98.6
30%	406	176	56.7	1217	347	71.5	98.5
40%	310	102	67.1	931	176	81.2	98.7

Shrinkage Model of Zedoary

Total volume shrinkage of zedoary slice versus its dimensionless moisture content is shown in Figure 8. It presents that the curves are almost linear. The value of constants *a* and *b*in equations (4) at each drying temperatures varied within the ranges of 0.8152 to 0.9434 and 0.0531 to 0.1435, respectively, as shown in Table 3.The model of linear equations that describes the shrinkage of zedoary obtained using all the drying data as presented in Eqn. (10) where the value of $R^2$and SE are 0.9757 and 0.0414, respectively.

$$\frac{V}{V_0} = 0.8826\frac{M}{M_0} + 0.0955 \ldots\ldots\ldots\ldots\ldots\ldots\ldots....(10)$$

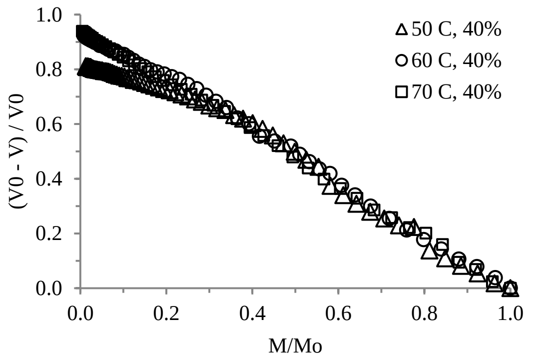

Figure 8. Total volume shrinkage $((V_0\text{-}V)/V_0)$ versus moisture content (M/M_0)

Table 3. Constants a and b of shrinkage model (Eqn.4)

Temp.	*a*	*b*	R^2	*SE*
70°C	0.9434	0.0571	0.9991	0.0091
60°C	0.9352	0.0531	0.9959	0.0182
50°C	0.8152	0.1435	0.9747	0.0375

Several authors also described the shrinkage behavior as a function of moisture content during conventional drying with a linear model, i.e. Lozano *et al*. (1980) on apples, Hatamipour and Mowla (2002) and Zielinska and Markowski (2010) on carrots. Plot of Eqn. (10) is given in Figure 9.

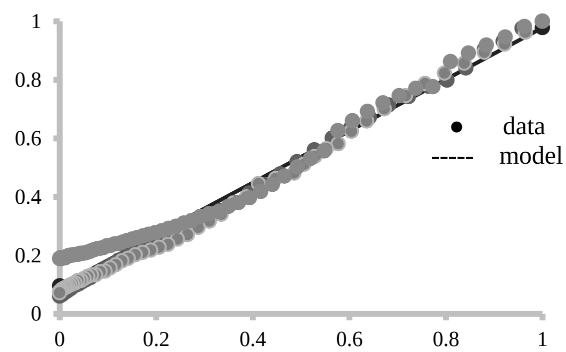

Figure 9. Linear model of zedoary shrinkage during drying

Effective Diffusivityof Zedoary

By using equation (7) and (5) then the value of the effective diffusivity by considering shrinkage (Sh) and without shrinkage (No-Sh) at each drying conditions can be determined (see Table 4 and 5). Effective diffusivity value by considering the shrinkage in the range of 4.74-6.19×10^{-9} m^2/s is smaller than without shrinkage in the range of 9.51-11.7 × 10^{-9} m^2/s. The same results was reported by Zielinska and Markowski (2010) for other rhizome slices (carrot) which are between 2.58×10^{-10} - 1.72×10^{-9} m^2/s and between 1.25-2.04 × 10^{-9} m^2/s, respectively for shrinkage and without shrinkage.

Table 4. Effective diffusivity of zedoary at constant RH of 40%

Temp.	Model	*D-eff*(m^2/s)	R^2	*SE*
50°C	Sh	4.74E-09	0.9937	0.0250
	No-Sh	9.51E-09	0.9976	0.0129
60°C	Sh	5.04E-09	0.9907	0.0330
	No-Sh	1.06E-08	0.9918	0.0244
70°C	Sh	5.68E-09	0.9947	0.0249
	No-Sh	1.17E-08	0.9900	0.0270

Table 5. Effective diffusivity of zedoary at constant temperature of 50°C

RH	Model	*D-eff* (m^2/s)	R^2	*SE*
20%	Sh	6.19E-09	0.9991	0.0083
	No-Sh	1.16E-08	0.9970	0.0137
30%	Sh	5.81E-09	0.9985	0.0111
	No-Sh	1.13E-08	0.9975	0.0130
40%	Sh	4.74E-09	0.9937	0.0250
	No-Sh	9.51E-09	0.9976	0.0129

The average values of determination coefficient of the model by considering shrinkage and without shrinkage are the same 99.5% while the average values of standard error by considering shrinkage and without shrinkage are 0.021 and 0018, respectively. Thus it is possible that zedoary shrinkage is not isotropic or not uniform.

The value of the effective diffusivity increased with increasing temperature but it decreased with increasing RH. The correlation between the drying temperatures and the effective diffusivity by considering shrinkage can be obtained in the Arrhenius type equation (Madamba *et al*., 1996) as follows:

$$D = 1.05 \times 10^{-7} exp\left(-\frac{8.343}{R \cdot T_{abs}}\right) \ldots\ldots\ldots\ldots\ldots\ (11)$$

where the value of Arrheniuspre-exponential factor (D_0) and activation energy for moisture diffusion

(*Ea*) are 1.05 x10^{-7} m^2/s and 8.343 kJ/mol, respectively, while the value of $R^2$is 0.96.

CONCLUSIONS AND RECOMMENDATION

Conclusions

The dryer with digital image processing system was used for measuring shrinkage of zedoary slice during drying. It was resulted that shrinkage of sliced zedoary influenced by its moisture content, whereas the drying air temperatures and humidities did not significantly affect to zedoary shrinkage. Shrinkage of volume and surface area of zedoary slices at the studied air drying temperatures ranges from 81.2%-93.9% and 67.1%-84.6% respectively. The linear equation model is fit and able to represent the shrinkage of sliced zedoary with high coefficient of determination. Shrinkage affects on zedoary drying diffusivity. Effective diffusivity values by considering the shrinkage (in the range of 4.74-6.19 ×10-9 m2/s) are smaller than those without considering the shrinkage (in the range of 9.51-11.7 × 10-9 m2/s).

Recommendation

Due to possibility that zedoary shrinkage was not isotropic or not uniform, therefore, in the future study, the machine vision and image analysis should be performed using 3D.

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