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THIN-LAYER DRYING CHARACTERISTICS OF CASTOR (*RICINUS COMMUNIS*) SEEDS

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ABSTRACT

The thin-layer drying behavior of gray small size and white big size varieties of castor seeds dried at 40, 50, 60 and 70C in a laboratory model tray dryer fitted with a temperature control system was investigated. Temperature was found to affect the drying characteristics with samples dried at higher temperature attaining equilibrium moisture content faster. From the five thin-layer drying equations fitted to the drying data, the modified Page model gave the best fit with highest correlation coefficients of 0.999, 0.990–0.999 and the least root mean square error of 0.010–0.013, 0.011–0.038, respectively, for the two varieties. The effective diffusivity coefficient of moisture transfer varied, respectively, from 8.24×10^{-9}–1.81×10^{-8}m^2/s and 3.72×10^{-8}–7.62×10^{-8}m^2/s, which are within the range for food materials. The activation energies are, respectively, 21.47 kJ/mol and 18.03 kJ/mol. This indicates that the diffusion process requires lower energy hence ease of drying of the castor seeds.

PRACTICAL APPLICATION

Whole castor seed is extremely poisonous; however, it becomes fit for human consumption when properly processed. Drying is a fundamental unit operation in the processing of this seed which influences the physicochemical and quality characteristic of the product, hence an evaluation of the drying characteristics as a function of drying conditions could help in predicting suitable drying conditions for good quality products.

INTRODUCTION

Castor plant (*Ricinus communis*) is a major source of raw material for the production of sebacic acid, a basic ingredient in production of synthetic resins and fibers, lubrication fluid, a constituent of embalming fluid, soap opal wax in polishes, cosmetics, hair dressing, brake fluids where a degree of compressibility is important and in printing ink. This array of uses is the main reason for continuing world demand for the oil (Ogunniyi and Njikang 2000).

Whole castor seeds are extremely poisonous, but when properly processed, they become fit for human consumption. There are several methods for processing castor into food products. Akpan *et al.* (2006) reported that castor beans undergo various processing with a number of unit operations such as cleaning by handpicking of dirts and foreign materials, drying by sun drying in the open, until the casing splits and sheds the seeds, winnowing, soaking, boiling and grinding. Locally, for one of the popular staple foods, the seeds are cracked open after drying, the testa removed and cotyledons wrapped in small banana leaf bundles, before boiling for 1 hour. They are then fermented for 2 days, removed and pounded into paste. The mass is scooped out, tied into banana leaves and dried again for a day. The finished product, which is used as food is called "*Ogili-isi*" in Onitsha or "*Ogili-ugba*" in Awka or generally *Ogiri* (Okorie and Anugwa 1987) in Igboland, Southeastern Nigeria. It is also used as food seasoning. In this case, the castor seed to be used to produce mash for seasoning are dried and cracked then soaked in water to soften for milling or further dried for other forms of processing.

The large scale production of castor in Borno State, in the North Eastern part of Nigeria and the wide range of possible products from it, will require that the traditional open-air sun-drying method be replaced with efficient drying systems. Open-air drying is slow; it exposes the product to environmental hazard and is difficult to control. To properly model and improve the efficiency of the drying process of this tropical crop and thus improve the efficiency of the drying systems, an insight into the drying characteristics of this crop becomes necessary.

Drying is a fundamental unit operation in the processing of castor. Drying influences physicochemical and quality characteristic of products (Gorling 1958), thus, evaluation of the drying characteristics as a function of drying conditions could help in predicting suitable drying conditions (Hamdami *et al.* 2006). In recent years, several studies on the drying characteristics of various fruits, vegetables and agricultural products have been carried out. Studies reported include hazel nut (Ozdemir and Devres 1999), bell pepper (Tunde-Akintunde *et al.* 2005) green pepper, green bean and squash (Yaldiz and Ertekin 2001), melon seed and wheat (Ajibola 1989; Sun and Woods 1994), apricot (Togrul and Pehlivan 2003), potato (Akpinar *et al.* 2003a), green chili (Hossain and Bala 2002), tomato (Akanbi *et al.* 2006), apple (Akpinar *et al.* 2003b), pumpkin (Akpinar *et al.* 2003c), red pepper (Akpinar *et al.* 2003d), egg plant (Ertekin and Yaldiz 2004), carrot (Doymaz 2004), cassava roots (Kajuna *et al.* 2001) and rosehip (Erenturk *et al.* 2004) and in each study the model that best fits the experimental data is chosen.

There appears to be lack of information in the literature on the drying characteristics of castor especially as affected by temperature. There is therefore the need to study the drying characteristics of castor seed with a view to understand the drying process and recommend appropriate drying steps for the seeds. This study therefore aimed at establishing the drying characteristics of two varieties of castor over the range of drying temperatures commonly employed in the tropics and to fit the data obtained from thin-layer drying of this crop to some of the generally accepted thin-layer drying models. Some of the previous studies reported drying temperatures of 40–60C for candlenuts (Tarigan *et al.* 2006), 50–70C for green beans (Doymaz 2004) and 45–75C for tomatoes (Akanbi *et al.* 2006).

THEORY

The primary factor influencing the rate of drying when heated air is used as the drying medium is temperature (Yunfei and Morey 1987). Drying temperature has the greatest effect on thin-layer drying, followed by initial moisture content, air velocity and relative humidity. In thin-layer drying of agricultural crops, the Page equation has been used extensively (Kajuna *et al.* 2001). It was successfully used to describe drying characteristics of American ginseng (Yunfei and Morey 1987) and strawberry (Akpinar and Bicer 2006) among many others. This equation is empirical and is given as

$$MR = \frac{M - M_e}{M_o - M_e} = \exp\left(-\mathrm{k}t^{\mathrm{N}}\right) \tag{1}$$

where, MR is the moisture ratio, M_o, the initial moisture content (% dry basis [d.b.]), M_e, the equilibrium moisture content (% d.b.), M the moisture content at time t (% d.b.), t the drying time (h), k and N are drying constants.

Equation (1) is a modification of the theoretical model known as the exponential or the Newtonian model (Sun and Woods 1994). The model is further described (Nellist 1976; Patley *et al.* 1988; Colson and Young 1990; Crisp and Woods 1994) as

$$\frac{dM}{dt} = \mathrm{k}(M - M_e) \tag{2}$$

Integrating Eq. (2) gives

$$\frac{M - M_e}{M_o - M_e} = \exp(-\mathrm{k}t) \tag{3}$$

This equation (Eq. 3) assumes that resistance to moisture movement and consequently gradients within the material are negligible (Colson and Young 1990). At constant temperature, pressure and humidity, this equation is valid if drying is characterized by "falling-rate" regime (Nellist 1976), which is a characteristic of drying of low moisture content products such as grains. As reported by Kajuna *et al.* (2001), this model has been successfully used for barley, wheat, paddy and shelled corn. The drying constants in thin-layer drying equations vary with temperature (Yunfei and Morey 1987) while the initial moisture content was also found to affect the drying rate of yellow corn (Misra and Brooker 1980).

Other semi-theoretical models widely used are the Henderson and Pabis model, modified Page I and II models. These require short time compared to theoretical thin-layer drying models and do not need assumptions of geometry of a typical food, its mass diffusivity and conductivity (Parry 1985).

METHODOLOGY

The Drying Equipment

A laboratory model tray dryer fitted with a temperature control system designed and fabricated at the Department of Agricultural and Environmental Engineering, University of Ibadan, Nigeria was used for this study. The dryer consists of a drying chamber with perforated trays that are arranged vertically and placed horizontally in a plenum chamber. A 0.374 kW axial flow fan supplies drying air at a rate of 14.3 m^3/min over the elements into the drying chamber. The frame and lagged casing enclosing the functional units form the body of the dryer and gives it a compact look. When in operation, the axial fan blows air through the plenum chamber over the heating elements. The air gets heated and enters the drying chamber where it picks moisture from the product being dried and discharged through the air outlet. A door is provided in front of the drying chamber for loading and unloading the sample tray. The experiments were conducted at the Department of Agricultural and Environmental Engineering between March and May 2007 corresponding to the end of dry season and beginning of raining season when the relative humidity was about 65–85% and ambient temperature was between 23 and 37C.

Sample Preparation and Drying Test Procedure

Castor is a crop that is only recently gaining popularity in Nigeria especially the North and Southeastern parts. There are no known scientific names for the varieties except the local names. The gray small size (GSS) variety is called *kwalikwali* in *Hausa* in the northeastern Nigeria and white big size (WBS) is called *Nkpuru Ukpa* in *Igbo* the southeastern part of Nigeria.

The GSS variety was obtained from a castor farm in Maiduguri, Northeastern part of Nigeria and the WBS variety was from a farm in Ihiala Local Government area in Anambra State, Southeastern part of Nigeria, the places where castor is mostly used in Nigeria.

Castor samples were cracked open, cleaned and then soaked in water, decanted to remove dirts, chaff and other foreign materials. The initial moisture content of the soaked and decanted castor varieties samples was determined using the ASAE standard method 352.1 (ASAE 1983) by placing 15 g samples (weighed using a top loading compact digital weighing balance EK-H6000i, A and D Company Ltd, Tokyo, Japan) in an air oven at 103 ± 2C and the weight monitored at interval until a constant weight was obtained.

The procedure employed for thin-layer drying of melon seeds by Ajibola (1989) was adopted with modifications to suit the laboratory and experimental conditions. The drying temperatures employed were 40, 50, 60 and 70C. For each experimental run, the dryer was allowed to run empty for 2 h to stabilize it at the specified air conditions before the tests began. Triplicate samples of specified castor varieties with known weights of 90–100 g were placed in drying trays. Change in sample weight was monitored throughout the experiment by weighing every 10 min for the first 1 h; every 30 min for the next 3 h; every 1 h for the next 3 h then every 2 h until the end of drying. The weighing continued until three consecutive readings gave identical weights. The test was then terminated as equilibrium with the drying environment was assumed to have been reached. The moisture content of the sample was then determined at this point and taken to be the dynamic equilibrium moisture content.

Based on the initial moisture content from oven drying, the weight loss was used to calculate the moisture content using the equation of Silayo (1995) and Kajuna *et al.* (2001) given as

$$Mt = \frac{M_i m_i - w_i}{m_i - w_i} \tag{4}$$

where, Mt is the moisture content at time t (% wet basis [w.b.]), M_i the initial moisture content (% w.b), m_i the initial weight (g) and w_i is the weight loss at time, t (g). The moisture content was converted to moisture ratio (MR) using the nonexponential part of the thin-layer equations being considered. As stated above, the last three readings of moisture content have the same value; however, in this study, the computation of the MR did not involve the last two, hence the last actual reading is the first of the last three. The drying curves will also stop on the "actual last reading," i.e., the first of the last three. This is important because while calculating the moisture ratio, if the last three are used, it will result in the last three MRs being zeros. Therefore, the last two readings for each experiment were taken as control for the drying process to ensure that equilibrium moisture has been attained. These were not used in any of the plots of parameters presented.

Determination of Drying Characteristics and Statistical Modeling Procedures

Moisture ratios of the castor samples during the thin-layer drying experiments were calculated by using the following relation from Eq. (1) (Akpinar *et al.* 2003a).

$$MR = \frac{M - M_e}{M_o - M_e} \tag{5}$$

The drying curve for each experiment was obtained by plotting the dimensionless moisture ratio of the sample against the drying time.

Five of the commonly used mathematical models (Jayas *et al.* 1991; Akpinar and Bicer 2006) for the thin-layer drying (Table 1) were tested to select the appropriate drying model for describing the drying of castor. Each of the model equations were converted to appropriate linear equation through logarithmic conversion and analysis was undertaken by regression on the five models to obtain the semi- or full-log form of predicted linear plot of MR against time from which the constants and coefficients were determined as slopes and intercepts. The models were then compared using the correlation coefficient (r) and the root mean square error analyses ($RMSE$) to determine the goodness of fit. The r and $RMSE$ were also obtained from the regression analysis procedure. The drying model with highest r and lowest $RMSE$ was selected as the best model describing the thin-layer drying characteristics of castor. The higher the values of r, and lower the values of $RMSE$, the better the goodness of fit (Akpinar *et al.* 2003a,b).

TABLE 1. MATHEMATICAL MODELS USED TO DESCRIBE DRYING CHARACTERISTICS

Model no.	Model	Equation	Reference
1.	Exponential (Newton)	$MR = \exp(-kt)$	Ajibola (1989)
2.	Henderson and Pabis	$MR = a.\exp(-kt)$	Westerman *et al.* (1973)
3.	Page	$MR = \exp(-kt^n)$	Agrawal and Singh (1977)
4.	Modified Page	$MR = \exp(-[kt]^n)$	Lahsasni *et al.* (2004)
5.	Logarithmic	$MR = a.\exp(-kt) + c$	Yagcioglu *et al.* (1999)

In order to confirm the selected appropriate drying model between the five different models tested, parameters of thin-layer drying models were determined by fitting experimental data to the model equations having obtained the model constants and coefficients. The resulting data were plotted with the experimental plots to determine the best fitted model through graphical method.

Effective Diffusivity Coefficients

The experimental drying data for the determination of diffusivity coefficient (D_{eff}) were interpreted using Fick's second law for spherical bodies according to Geankoplis (1983) and Doymaz (2004). This is because the shape of the seeds are closer to being spherical than the commonly used flat object (slab assumption). The diffusivity coefficient (D_{eff}) was obtained from the equation for spherical bodies

$$MR = \frac{6}{\pi^2}\exp\left(\frac{-\pi^2 D_{eff}}{R^2}t\right) \tag{6}$$

To obtain effective radius (R), the radius at initial moisture content when drying commenced was used. This was calculated using the equation given by Asoegwu *et al.* (2006) with equivalent diameter D_e given by

$$D_e = \frac{D1 + D2 + D3}{3} \text{ with } R \text{ being } \frac{D_e}{2}$$

$$\text{where } D1 = \text{Arithmetic mean diameter} = \frac{L_1 + L_2 + L_3}{3}$$

$$D2 = \text{Geometric mean diameter} = (L_1 L_2 L_3)^{\frac{1}{3}}$$

$$D3 = \text{Square mean diameter} = \left(\frac{L_1L_2 + L_2L_3 + L_3L_1}{3}\right)^{\frac{1}{2}}$$

L_1, L_2 and L_3 are the dimensions in the three perpendicular axes.

Therefore,

$$\ln(MR) = \frac{-\pi^2 D_{eff}}{R^2}t + \ln\frac{6}{\pi^2} \tag{7}$$

Moisture diffusivity coefficient (D_{eff}) was calculated from the slope derived from the linear regression of $\ln(MR)$ against time at different temperatures using Eq. (7).

Activation Energy

The diffusivity coefficient at different temperatures is often found to be well predicted by the Arrhenius equation given by

$$D_{eff} = D_o e^{-\frac{Ea}{R_g(T+273.15)}} \tag{8}$$

Where, D_{eff} is the moisture diffusivity coefficient (m^2/s), D_o is the maximum diffusion coefficient (at infinite temperature), E_a is the activation energy for diffusion (kJ/mol), T is the temperature (C) and R_g is the gas constant (kJ/mol K).

Linearizing the equation gives

$$\ln D_{eff} = \left(-\frac{1}{R_g(T + 273.15)}\right)E_a + \ln D_o \tag{9}$$

D_o and E_a were obtained by plotting $\ln D_{eff}$ against $\left(-\frac{1}{R_g(T+273.15)}\right)$

RESULTS AND DISCUSSION

The drying air flow rate was 14.3 m^3/min and this was kept constant throughout the drying process.

Drying Curves

The drying curve for the variations of moisture content with drying time based on drying air temperature for the two varieties of castor are as presented in Figs. 1 and 2. The times to reach dynamic moisture equilibrium from initial moisture content at the various drying air temperature were found to be between 210–360 min for GSS castor variety, and 180–300 min for WBS variety. Temperature had marked effect in both cases as the drying curves were steeper with increasing temperature showing that drying was faster at higher temperatures. The time to attain equilibrium was also shorter with increasing temperature as evident from near horizontal nature of the curves from 150 min for higher temperatures. This is evident in the drying of GSS while that of the WBS indicates that the drying was only in the falling rate phase. The drying times in both decreased with the temperature.

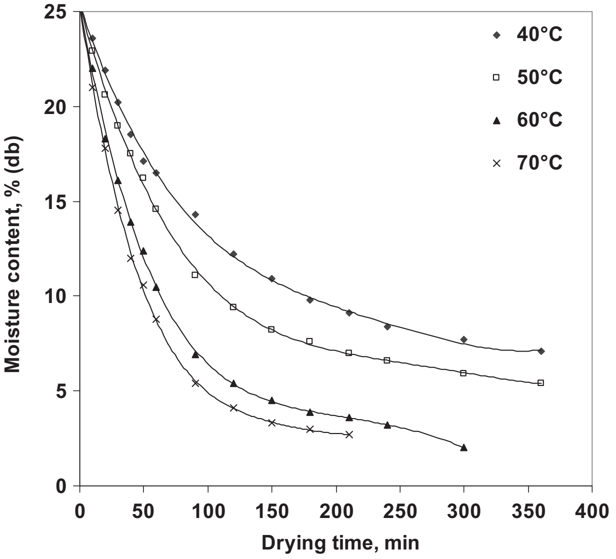

FIG. 1. THE DRYING CURVE FOR GSS VARIETY OF CASTOR

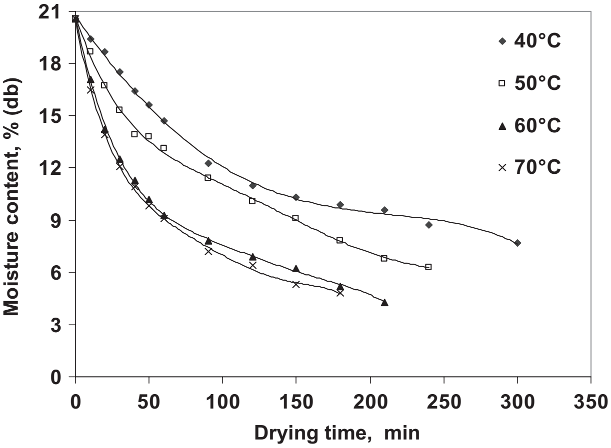

FIG. 2. THE DRYING CURVE FOR WBS VARIETY OF CASTOR

Modeling and Model Fitting of the Thin-Layer Drying Characteristics

The model constants, coefficients, correlation coefficients (*r*) and *RMSE* calculated from the curve fitting computations for the moisture ratio with the drying time and temperature on the five drying models are shown in Table 2. The correlation coefficient (R^2) in all the cases were greater than 0.98 (not presented in the Table), indicating a good fit (Madamba *et al.* 1996). The values of *r* and *RMSE* for these models vary between 0.997–0.999, 0.979–0.999 and $1.05–2.00 \times 10^{-2}$, $1.40–4.71 \times 10^{-2}$, respectively. From the table, the modified Page model gave the best prediction with the highest *r* and lowest *RMSE* compared to the other models and satisfactorily describe the drying characteristics of the castor seeds. The others also have very close values but the modified Page was followed very closely by the Page model.

The plots of *MR* against time at different temperatures for both castor varieties are as presented in Figs. 3 and 4 with the

TABLE 2. PARAMETERS OF THE FIVE DRYING MODELS FOR DRYING KINETICS OF TWO VARIETIES OF CASTOR

Air temperature		40C		50C		60C		70C	
Model		GSS	WBS	GSS	WBS	GSS	WBS	GSS	WBS
Exponential	k	0.011	0.010	0.013	0.014	0.017	0.020	0.022	0.024
	r	0.999	0.997	0.999	0.990	0.998	0.979	0.999	0.989
	RMSE	0.013	0.025	0.013	0.038	0.02	0.047	0.010	0.033
Henderson and Pabis	a	0.988	1.033	0.996	0.967	0.979	0.866	1.006	0.882
	k	0.011	0.011	0.013	0.013	0.016	0.016	0.002	0.020
	R	0.998	0.997	0.999	0.990	0.997	0.991	0.999	0.998
	RMSE	0.013	0.021	0.013	0.036	0.020	0.029	0.010	0.015
Page	k	0.013	0.008	0.013	0.016	0.021	0.047	0.021	0.045
	n	0.966	1.049	0.992	0.963	0.940	0.778	1.018	0.829
	R	0.999	0.997	0.999	0.990	0.998	0.997	0.999	0.999
	RMSE	0.013	0.023	0.013	0.038	0.017	0.014	0.010	0.011
Modified Page	k	0.011	0.010	0.013	0.014	0.016	0.020	0.022	0.024
	n	0.966	1.049	0.992	0.963	0.940	0.778	1.018	0.829
	R	0.999	0.997	0.999	0.990	0.999	0.998	0.999	0.999
	RMSE	0.013	0.023	0.013	0.038	0.010	0.014	0.010	0.011
Logarithmic	a	0.985	1.015	0.901	1.075	0.969	0.855	1.009	0.877
	c	0.006	0.035	0.013	–0.155	0.045	0.074	–0.014	0.019
	n	0.011	0.012	0.013	0.009	0.019	0.022	0.021	0.022
	R	0.999	0.997	0.999	0.993	0.999	0.996	0.999	0.996
	RMSE	0.013	0.019	0.013	0.029	0.010	0.015	0.010	0.015

GSS = gray small size, WBS = white big size, RMSE = root mean square error.

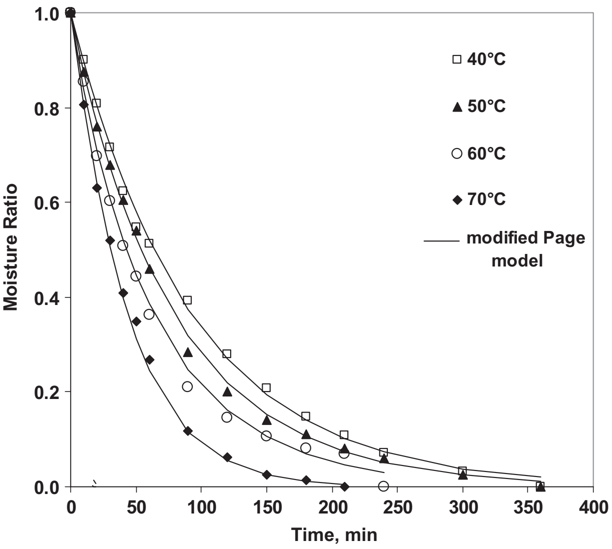

FIG. 3. EXPERIMENTAL AND MODIFIED PAGE PREDICTED MOISTURE RATIO FOR GSS CASTOR VARIETY

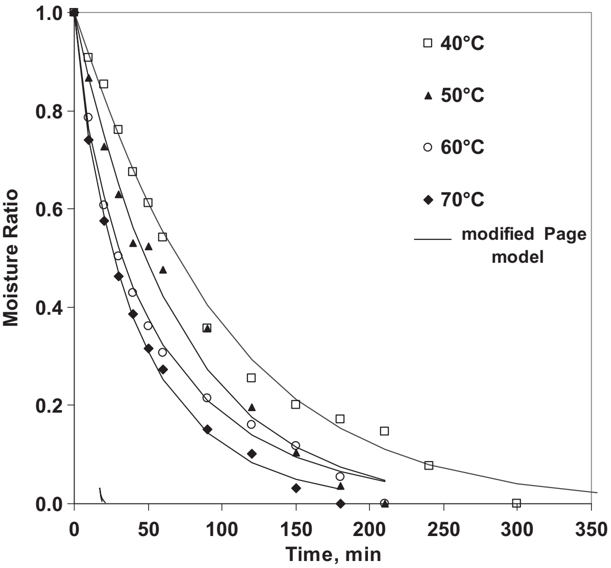

FIG. 4. EXPERIMENTAL AND MODIFIED PAGE PREDICTED MOISTURE RATIO FOR WBS CASTOR VARIETY

predicted curves for the modified Page model. The predictive curves for modified Page and Page models were found to follow the same path for all the temperatures. However, the predictive curves for only the modified Page are presented to show the level of fitness. The Page model is an empirical modification of the Lewis model, which is a special case of the Henderson and Pabis model where intercept is unity. Henderson and Pabis is the first term of a general series solution of Fick's second law. Therefore, the Page model is an empirical modification and a special case of Henderson and Pabis and has corrected its shortcomings (Yaldiz and Ertekin 2001; Doymaz 2005). It has been used to fit the experimental data of crops similar to castor such as soybean, white bean, green bean and corn (Yaldiz and Ertekin 2001). This study has therefore confirmed its appropriateness in the modified form for these two varieties castor seeds.

Moisture diffusivity coefficient (D_{eff}) was calculated at different temperatures using Eq. (7) as the slope derived from the linear regression of ln(*MR*) against time. The plot of the ln(*MR*) against time for both varieties are as presented in Figs. 5 and 6. Similarly the activation energy was obtained as

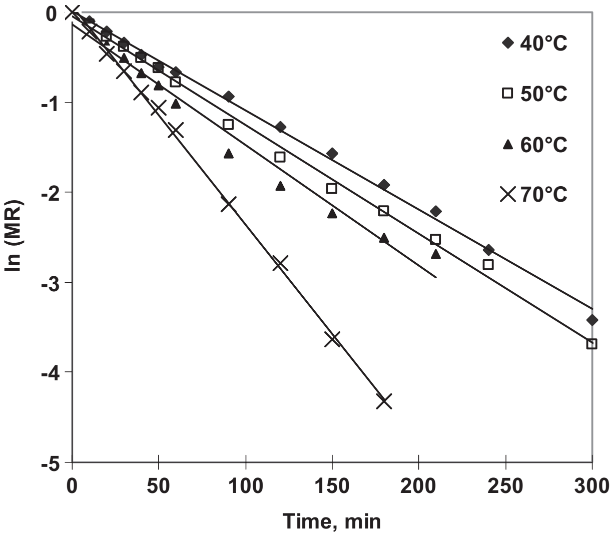

FIG. 5. SEMI-LOG PLOT OF MOSITURE RATIO FOR ESTIMATION OF DIFFUSIVITY COEFFICIENT FOR GSS CASTOR VARIETY

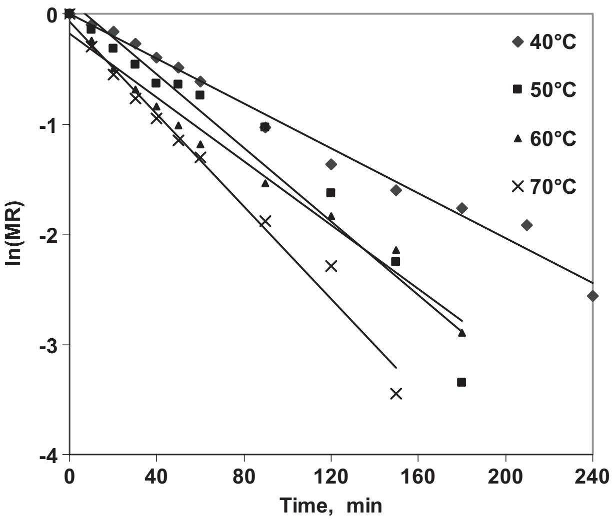

FIG. 6. SEMI-LOG PLOT OF MOSITURE RATIO FOR ESTIMATION OF DIFFUSIVITY COEFFICIENT FOR GSS CASTOR VARIETY

TABLE 3. EFFECTIVE MOISTURE DIFFUSIVITY (D_{eff}) AND ACTIVATION ENERGY (E_a) DURING DRYING OF CASTOR SEEDS

Temperature (C)	Effective diffusivity ($\times 10^{-9}$) m^2/s 40	50	60	70	Activation energy (E_a, kJ/mol)
GSS	8.24	9.07	9.74	18.1	21.47
WBS	37.19	60.89	52.87	76.21	18.03

GSS = gray small size, WBS = white big size.

the slope of the semi-log plot between moisture diffusivity coefficient and the inverse of the product of the gas constant and absolute air drying temperature as presented in Eq. (9). The moisture diffusivity coefficients and the resulting activation energy are as presented in Table 3.

The effective mean radii of castor varieties were obtained as 2.72×10^{-3} and 6.00×10^{-3} m for GSS and WBS, respectively. The D_{eff} of castor samples GSS and WBS changed between 8.24×10^{-9}–1.81×10^{-8} m^2/s and 3.72×10^{-8}–7.62×10^{-8} m^2/s as shown in Table 3. The correlation coefficients at all the temperatures for the straight lines obtained by linear regression for the D_{eff} were higher than 0.99 for GSS while those of WBS ranged between 0.95–0.98. These D_{eff} lie within the general range of 10^{-12}–10^{-8} m^2/s reported for food materials (Madamba *et al.* 1996; Zogzas *et al.* 1996; Babalis and Belessiotis 2004) such as date palm with 7.48×10^{-10}–1.10×10^{-8} m^2/s (Falade and Abbo 2007) and fresh lentils $2{:}89 \times 10^{-9}$–$3{:}81 \times 10^{-9}$ m^2/s (Karatas 1997).It can be seen that the values of D_{eff} increased with increasing temperature with a marked high value at 70C for both GSS and WBS. This could be as a result of the fact that water diffusion was mainly due to mass transport mechanism during the first phase of drying. The moisture from the inner core of the product migrates and replaces the surface and capillary moisture as they evaporated and eventually diffusion of moisture became the predominant mechanism. The surface water removal was faster at higher temperature especially at 70C with most of the drying mechanism being vapor diffusion hence the higher values. This has been reported in many research works such as Ramesh *et al.* (2001) and Falade and Abbo (2007).

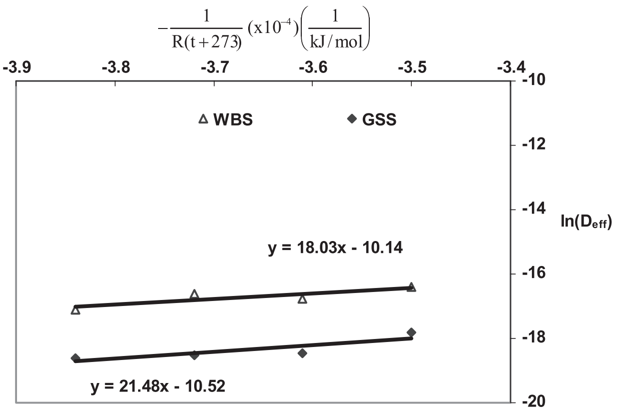

FIG. 7. ACTIVATION ENERGY FOR THE TWO VARIETIES

The plots for the two varieties as presented in Fig. 7 for the activation energy were found to be essentially straight lines in the range of temperatures investigated indicating Arrhenius dependence. Activation energy is a measure of the temperature sensitivity of D_{eff} and it is the energy needed to initiate the moisture diffusion within the seed. From the slope of the straight lines, the activation energies were found to be, respectively, 21.47 and 18.03 kJ/mol for GSS and WBS.

The activation energy obtained for each variety is within the general range of 12.7–110 kJ/mol (Zogzas *et al.* 1996) for most agricultural and food materials as presented by several other reports; 27.61 kJ/mol for corn (Tolaba and Suarez 1988), green bean 35.43–39.47 kJ/mol (Senadeera *et al.* 2003), soybean 28.80 kJ/mol (Kitic and Viollaz 1984) and pistachio nut 30.79 kJ/mol (Kashaninejad *et al.* 2007) and mints 82.93 kJ/mol (Park *et al.* 2002). The activation energy for the GSS is higher than that of the WBS, which indicates that more energy is needed to trigger the diffusion process and for drying to be accomplished in GSS castor variety.

CONCLUSIONS

The effect of drying air temperature in the range of 40–70C and 14.3 m^3/min air flow rate for two castor varieties studied indicated that the drying is entirely in the falling rate period. The drying rate and effective diffusivity are temperature dependent with drying increasing with increase in temperature and consequently faster drying. Temperature dependence of the diffusion coefficients was described by Arrhenius-type relationship. Lower activation energy for moisture diffusion compared to most agricultural and food materials indicates that drying of castor though mostly by diffusion requires less energy, hence it is a cost-and energy-saving method compared to the drying of other products. This is an advantage considering the level of poverty among the majority of the populace processing the castor seed to food seasoning and other products. Modified Page model gave the best fit for both castor varieties.

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