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Effective Moisture Diffusivity and Activation Energy of Tannia Cormels: Influence of Temperature, Pre-Treatment and Slice Thickness

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Abstract

This study investigated the effects of temperature, pre-treatment and slice thickness on the effective moisture diffusivity and activation energy of tannia (Xanthosoma sagittifolium) cormels. White-fleshed and pink-fleshed varieties of the cormels were used for this study. The effective moisture diffusivity and activation energy of fresh and blanched cormels were determined by drying them at three temperature levels (60, 70 and 80℃) and three slice thicknesses (2, 3 and 4 mm). The effective moisture diffusivity and activation energy of the cormels ranged between 1.47×10^{-7} and 2.09×10^{-6} m^2s^{-1} and 49.02 and 63.23 $kJmol^{-1}$ respectively. The study established that the effective moisture diffusivity and activation energy are drying temperature dependent. The effects of pre-treatment and slice thickness were also found to be significant on the measured parameters. Drying of blanched thin slices of tannia cormels at relatively high temperature levels is recommended for faster and cost-effective drying of the cormels.

Keywords: tannia cormels, drying, effective moisture diffusivity, activation energy, heat treatments

1. INTRODUCTION

Tannia, *Xanthosoma sagittifolium*, is cultivated for the purpose of utilizing its corms (the vertical swollen underground stem used in its propagation) and cormels (developed at the base of the mature corm) for various applications such as food products for human consumption, animal feed and as raw material for industrial usage. It serves as main food items in many parts of the tropics including Nigeria. It is a member of root and tuber crops which constitute the main source of most of the daily carbohydrate intake for large populations [1, 2]. Its cormel is superior to cassava and yam in terms of the nutritional composition [3].

Tannia cormel can be used for various delicacies. It can be eaten boiled, baked, fried in oil or pounded into *fufu*. In Western Nigeria, it is used to prepare '*ebiripo*' which is made by grating its cormels, mixing with condiments, wrapping in leaves and then steaming for some minutes. The corms and cormels can also be made into flakes, chips and flour. Its flour is easily digested and can therefore, be recommended for infants and invalids [4–6].

Tannia cormel in its fresh state has been found to be highly susceptible to both pre-harvest and post-harvest diseases which reduce the storage stability and quality of the tannia cormels [7]. This necessitates prompt processing of the cormels after harvest into other products such as flour, flakes and chips with better storage stability. Tannia cormel processing involves various unit operations and the sequence of the processing operations depends on the desired final product. Some of these unit operations include cleaning (washing and peeling), size reduction (slicing, dicing or grating), heat treatments (blanching, drying, boiling), dry milling, separation (screening or sieving) and packaging [5, 6, 8].

Drying is an important operation involved in the conversion of fresh tannia cormels into products such as chips, flakes and flour with better storability and improved shelf life. It is the process of reducing the amount of moisture present in an agricultural material to a pre-determined level through the application of heat. It is the most widely used method of preservation probably due to its various applications in different fields. It makes the food products suitable for storage and protects them against attack of insects, molds and other micro-organisms during storage [9–11].

Drying is an energy-intensive process accompanied by heat and mass transfer and the knowledge of moisture diffusivity and activation energy required to achieve the reduction of the amount of moisture in a biomaterial to a safe level is useful in promoting a sound understanding of its drying characteristics [12]. Many researchers have investigated the effect of drying variables such as temperature, air velocity, sample geometry (dimen-

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sions and shapes) and pre-treatment on the effective moisture diffusivity (D_{eff}) and activation energy (E_a) of various biological materials such as apple slices [13], apricot [14], green bean [15], red chillies [16] and crain-crain leaves [17], cocoa beans [18], Ibadan-local tomato varieties [19], mango [20], star fruit [21], cocoyam corms [22], pre-osmosed fresh water frog [23] and yam tuber [24]. Temperature levels, air velocities and slice thicknesses considered in these studies were within the ranges of 40 – 80°C, 0.2 – 1.5 ms^{-1} and 3 – 12.5 mm respectively. Pre-treatment methods applied include blanching and dipping in sugar and salt solutions. [22] investigated the effect of temperature levels and their corresponding relative humidities on D_{eff} of fresh cocoyam corms of 0.3 cm thickness and the values reported ranged between 1.09 and 2.53 × 10^{-5} m^2s^{-1}. Activation energy of the corms was not investigated in the study and the effects of slice thickness and pre-treatment were also not considered. The knowledge of the moisture diffusivity and activation energy under different drying conditions is essential in optimizing the process of drying food and agricultural materials. This study therefore, investigated the effects of temperature, pre-treatment and slice thickness on the effective moisture diffusivity and activation energy during the drying of tannia (*X. sagittifolium*) cormels.

2. MATERIALS AND METHODS

2.1. Materials

Locally available white-fleshed and pink-fleshed tannia (*Xanthosoma sagittifolium*) cormels were obtained from Ogunmakin market, Ogunmakin town in Ogun State, South-Western part of Nigeria. The market is popularly known for fresh agricultural produce which are supplied in large quantities from the neighbouring farms. The cormels were then cleaned, peeled manually and prepared for use in carrying out the experiments.

2.2. Methods

2.2.1. Drying process

Thin layer drying of tannia cormels was carried out in a convective hot air laboratory oven. The drying characteristics such as changes in mass (moisture content), moisture ratio and drying rate during drying of the tannia cormels were measured at temperature levels of 60, 70 and 80°C. The temperature levels were chosen based on preliminary investigations and consideration of the high moisture content of the cormels. Drying of agricultural materials with high moisture content at very low temperature levels would result in prolonged retention period and subsequently, mould growth and spoilage of the samples could occur. Tannia cormels were blanched as a form of pre-treatment before drying and the drying curves of both fresh and blanched cormels were obtained. Blanching of the cormels is one of the processes involved in the production of flour among the women in the South Eastern Nigeria to enhance the drying process [8]. The pre-treatment involved soaking of the samples in hot water for 5 minutes, draining the water and allowing the samples to cool down before drying [25, 26]. Drying of fresh (unblanched) and blanched cormel slices were carried out at the three temperature levels with a view to determining the effect of pre-treatment on the effective moisture diffusivity and activation energy of the cormels. The cormels were sliced into 2, 3 and 4 mm slice thicknesses to investigate the effect of product slice thickness on the effective moisture diffusivity and activation energy of the cormels. The sample weights before, during and after drying were measured using a digital weighing balance (Kerro digital scale, Taiwan, 0.1g). Reductions in moisture levels were recorded at 60 minutes' intervals throughout the period of the experiment for the determination of the drying curves. The samples were retained in the drying chamber until there was no significant reduction in three consecutive weights of the cormels with increasing drying time [25]. Moisture ratio of the cormel was calculated using Eq. (1) [23, 24, 27].

$$MR = \frac{M_t - M_e}{M_i - M_e} \qquad (1)$$

where MR is the moisture ratio (dimensionless), M_t is the moisture content of the cormel at any given time, t (%, dry basis), M_i is the initial moisture content of the cormel (%, dry basis) and M_e is the equilibrium moisture content of the cormel (%, dry basis)

The rate of moisture removal from the cormel was calculated from Eq. (2) [28, 29].

$$DR = \frac{M_w}{M_d t} \qquad (2)$$

where DR is the drying rate (kg water/kg Dry Matter – h), M_w is the mass of moisture removed (kg), M_d is the mass of the dry matter (kg), and t is the drying time (h)

2.2.2. Effective diffusivity coefficient and activation energy

Fick's second law for products of slab geometry was used to determine the effective moisture diffusivity of the white-fleshed and pink-fleshed tannia cormels as shown in Eq. (3) [24, 25, 30]. The shape of the tannia cormel slices was assumed to be perfectly of slab geometry.

$$MR = \frac{8}{\pi^2} \sum_{n-1}^{\infty} \exp\left[-\frac{(2n-1)^2\pi^2}{4L^2} Dt\right] \qquad (3)$$

Where n is the number of terms taken into consideration, D is the moisture diffusivity (m^2/s) and L is the half of product slice thickness (m).

Eq. (3) was then reduced to Eq. (4) for relatively long drying periods [19, 20].

$$MR = \frac{8}{\pi^2} \exp\left[-\frac{\pi^2 Dt}{4L^2}\right] \qquad (4)$$

Table 1: Effective moisture diffusivity and activation energy for fresh cormels

Temperature		Effective moisture diffusivity ($\times 10^{-8}$ m^{2}s^{-1}) 60℃	70℃	80℃	Activation Energy (kJmol^{-1})
White	2 mm	2.15	2.87	7.24	58.80
	3 mm	3.39	4.41	14.88	62.46
	4 mm	4.34	5.64	16.93	66.02
Pink	2 mm	1.80	2.92	9.04	78.46
	3 mm	2.84	3.90	10.22	71.88
	4 mm	3.69	5.64	14.10	65.06

Table 2: Effective moisture diffusivity and activation energy for blanched cormels

Temperature		Effective moisture diffusivity ($\times 10^{-8}$ m^{2}s^{-1}) 60℃	70℃	80℃	Activation Energy (kJmol^{-1})
White	2 mm	1.47	2.51	7.00	69.26
	3 mm	2.70	4.67	14.69	57.66
	4 mm	4.86	5.96	17.30	42.80
Pink	2 mm	1.60	2.25	8.76	63.75
	3 mm	2.84	4.23	10.79	58.48
	4 mm	4.34	6.80	14.71	51.75

Linearization of Eq. (4) resulted in Eq. (5).

$$\ln(MR) = -\left[\frac{\pi^2 D}{4L^2}t\right] + \ln\frac{8}{\pi^2} \tag{5}$$

A straight line was obtained by plotting $\ln(MR)$ against drying time, t. The plot was characterised with intercept, $\ln\frac{8}{\pi^2}$, and the effective moisture diffusivity was obtained from Eq. (6).

$$\text{Slope} = -\left[\frac{\pi^2 D}{4L^2}\right] \tag{6}$$

The effect of temperature on effective moisture diffusivity (D_{eff}) of the tannia cormels was investigated using Arrhenius equation as shown in Eq. (7) [24, 31, 32].

$$D_{eff} = D_0 \exp\left[-\frac{E_a}{R_g(T+273.15)}\right] \tag{7}$$

Where D_0 is the effective moisture diffusivity at reference temperature (m^{2}s^{-1}), E_a is the activation energy (J mol^{-1}), R_g is the universal gas constant (8.314 J mol^{-1}K^{-1}), and T is the temperature (°C). Logarithmic linearization of Eq. (7) resulted in Eq. (8).

$$\ln D_{eff} = \left[-\frac{1}{R_g(T+273.15)}\right]E_a + \ln D_0 \tag{8}$$

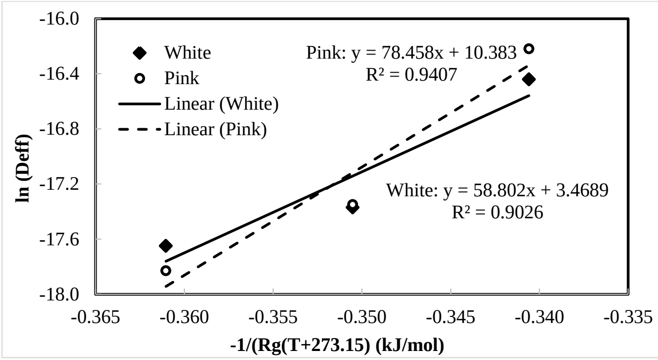

Figure 1: Activation energy for fresh 2 mm thick cormel

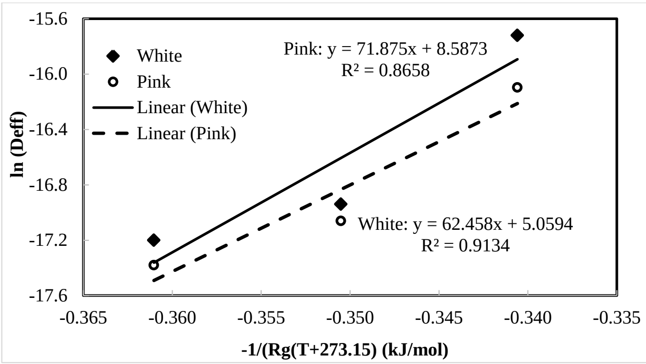

Figure 2: Activation energy for fresh 3 mm thick cormel

Plotting the values of ($\ln D_{eff}$) against the corresponding values of $\left[-\frac{1}{R_g(T+273.15)}\right]$ gave a straight line with intercept of ($\ln D_0$) and slope which is equivalent to the activation energy, E_a.

3. RESULTS AND DISCUSSION

Effective moisture diffusivity and activation energy obtained for fresh and blanched cormels are presented in Tables 1 and 2, respectively. Graphs of activation energy for fresh cormels of 2, 3 and 4 mm thicknesses are presented in Fig. 1 to 3 respectively while those for blanched cormels of 2, 3 and 4 mm thicknesses are presented in Fig. 4 to 6 respectively.

The effective moisture diffusivity, D_{eff}, obtained for the blanched tannia cormels ranged between 1.48×10^{-8} and 1.26×10^{-7} m^{2}s^{-1} while for the fresh (unblanched) cormels, it ranged between 1.81×10^{-8} and 1.75×10^{-7} m^{2}s^{-1}. The values obtained are within the general range of effective moisture diffusivity published for agricultural and food materials by other researchers such as 5.79×10^{11} – 17.15×10^{11} m^{2}s^{-1} for rough rice [33], 1.2×10^{-7} – 4.55×10^{-7} m^{2}s^{-1} for plum [34], 8.24×10^{-9} – 7.62×10^{-8} m^{2}s^{-1} for castor seeds [35], 3.89×10^{-10} – 6.99×10^{-10} m^{2}s^{-1} for mango [20], 1.46×10^{-8} to 4.25×10^{-8} m^{2}s^{-1} for unripe Cardaba banana [36], 6.75×10^{-9} and 9.57×10^{-9} for plantain [27] and 6.38×10^{-9} – 1.64×10^{-7} m^{2}s^{-1} for yam [24]. However, the D_{eff} obtained

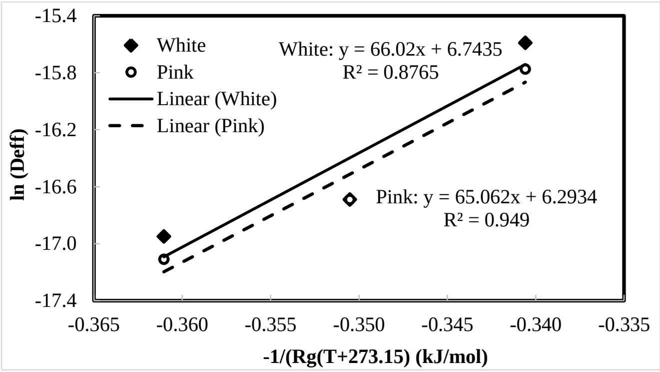

Figure 3: Activation energy for fresh 4 mm thick cormel

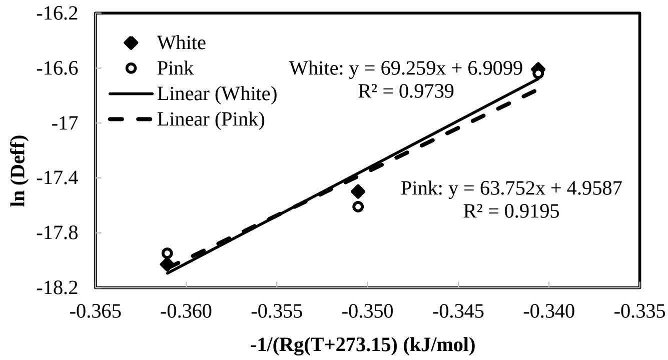

Figure 4: Activation energy for blanched 2 mm thick cormel

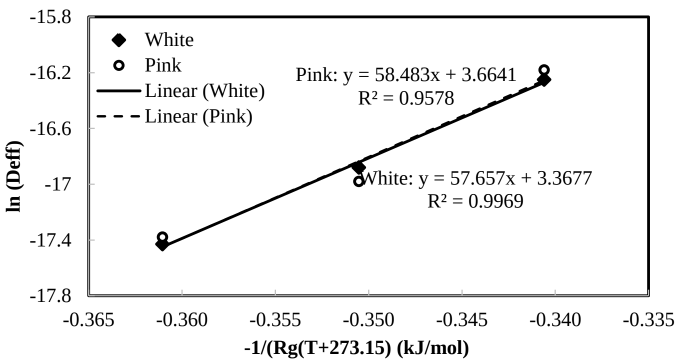

Figure 5: Activation energy for blanched 3 mm thick cormel

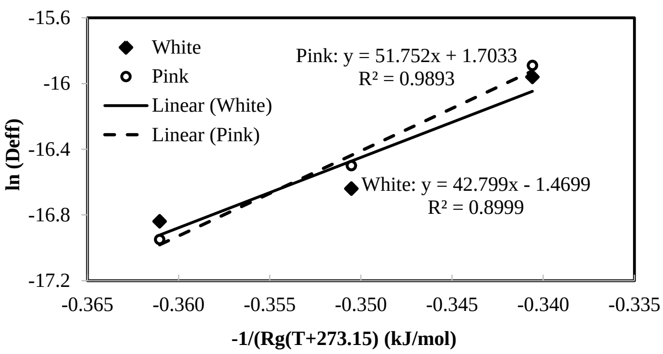

Figure 6: Activation energy for blanched 4 mm thick cormel

for fresh 3 mm thick cormel was far lower than those reported by [22] for cocoyam corms. The minimum D_{eff} for all the cases considered was obtained at 2 mm thickness and 60°C while the maximum D_{eff} was obtained at 4 mm thickness and 80°C for all cases.

This clearly showed that D_{eff}, which depicts the ease of migrating moisture from the core of the material to its surface for immediate removal by the drying air, increased as the temperature and slice thickness increased. This could be attributed to mass transport mechanism being the main determinant of moisture diffusion in the first phase of drying [35, 37, 38].

The minimum and maximum activation energies obtained for all the cases considered were 42.80 and 78.46 kJmol^{-1} respectively. Activation energies obtained for the blanched cormel for all the temperature levels and thicknesses considered ranged between 42.80 and 69.26 kJmol^{-1} while for the fresh tannia cormels, E_a ranged between 58.80 and 78.46 kJmol^{-1}. These values are within the general range of 12.7 – 110 kJ mol^{-1} for agricultural and food materials [35, 37]. The coefficients of determination (R^2) obtained from the regression lines for determining the activation energy for all the cases considered were in excess of 0.90 except for the fresh pink cormel of 3 mm thickness (R^2 = 0.87) and fresh white cormel of 4 mm thickness (R^2 = 0.88). This confirmed the suitability of the Arrhenius equation in predicting the activation energy of the white-fleshed and pink-fleshed tannia cormels within the temperature range considered.

The E_a obtained for the fresh (unblanched) cormels fluctuated without a specific trend, with 2 mm thick pink-fleshed cormel having the highest value (78.46 kJmol^{-1}). This is similar to the findings of [24] for drying yam slices in a convective hot air dryer.

The E_a obtained for blanched white-fleshed and pink-fleshed cormels reduced with increasing thickness. This indicated that the energy required to initiate moisture diffusion from the core of the cormel to the surface of the thinner slices was higher than the thicker ones since the thicker slices had more moisture present within the core of the samples. This can be attributed to the dependence of the activation energy on the moisture content of the samples. However, this result contradicts the findings of [32] for pumpkin slices.

The fresh tannia cormels had higher activation energy than the blanched samples in all the cases considered which clearly indicated that blanching as a form of pre-treatment helped to reduce the energy required to initiate moisture diffusion from the core of the material to the surface from where it could be easily evaporated for subsequent drying of the tannia cormels to the desired level. This showed that pre-treatment would result in faster drying and some energy savings and thereby, reduce the overall cost of drying the tannia cormels.

4. CONCLUSION

The effects of pre-treatment and slice thickness on the effective moisture diffusivity and activation energy of tannia (*Xanthosoma sagittifolium*) cormels have been investigated in this study. Variations in slice thicknesses and pre-treatment levels had significant effect on the effective moisture diffusivity and activation energy of the white-fleshed and pink-fleshed cormels. Blanching as a form of pre-treatment tannia cormels is recommended for faster drying, reduced drying period and some energy savings. The dependence of the moisture diffusivities of tannia cormels on temperature has been established to be clearly described by the Arrhenius equation in this study.

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