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Thin Layer Drying Kinetics of Pineapple: Effect of Blanching Temperature – Time Combination

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ABSTRACT: Drying is an energy intensive unit operation and long drying periods tend to increase the energy requirements for the production of a unit dry product. In this study, the effect of blanching temperature - time combinations treatment conditions on the drying behavior of pineapple slices was investigated. Slices of pineapple were blanched at different temperature-time combinations before being dried in an oven dryer at a dry bulb temperature of 70°C. Four thin-layer drying models were fitted to the experimental drying data. The results show that drying rates and drying times were affected by the blanching temperature-time combinations. Drying times increased as blanching temperature-time combinations increased. The predominant drying regime of the blanched pineapple was observed to be in the falling rate period. The logarithmic model best describe the drying behaviour of blanched pineapple slices with goodness of fit ($R^2 > 0.99$). The effective moisture diffusivity of blanched samples decreased with increase in blanching temperature-time combinations. This implied enhanced mass transfer activities of blanched pineapple slices at decreasing blanching temperature-time combinations. Therefore, blanching pretreatment at lower temperature-time combinations in the drying of fruits and vegetables reduces the drying time and energy cost of drying.
Keywords: Blanching; drying; drying models; effective diffusivity; pineapple; temperature.

INTRODUCTION

Pineapple is a seasonal tropical fruit rich in proteins, vitamins and minerals (Barnell, 1974; Ihekoronye and Ngoddy, 1985). Being highly perishable, it requires preservation in some form. Drying is one of the methods commonly used for preserving pineapple (Ramallo and Mascheroni, 2012; Gujral *et al*., 2013); other methods may be freezing, canning, irradiation and controlled atmosphere storage. Drying refers to the removal of moisture from solid material upon the application of heat. It is a type of dehydration that is driven by a number of factors such as humidity, temperature and velocity. It lowers the mass and volume of materials and improves efficiency of storage and transportation. It also has a great effect on the sensory and nutritional characteristic of the end product (Kingsly *et al*., 2007). Drying is an energy intensive unit operation (Dandamrongrak *et al*., 2003) whose working media are mainly air and steam; long drying periods tend to increase the energy requirements for the production of a unit dry product as well as lead to final product of poor quality (Dandamrongrak *et al*., 2003; Agarry *et al*., 2005).

Application of physical pretreatment (such as blanching) prior to convective drying may be an option to obtain good quality dried fruit and vegetables as well as improved drying kinetics. Pretreatments reduce the drying period (Piga *et al*., 2004; kingsly *et al*., 2007) by increasing the drying rate (Dandamrongrak *et al*., 2003; Doymaz, 2004). Reported works on convective drying combined with blanching reported increased drying rate for food products such as red peppers, carrot, apples and peaches as recorded respectively by Mazza, (1983), Barbanti *et al*. (1991) and Turhan *et al*. (1997). However, blanching of some food materials such as potato and banana has not increased the rate of drying; rather it has caused starch gelatinization and reduced porosity (Saravacos and Charm, 1962; Alzamora and Chirife, 1980; Dandamrongrak *et al*., 2003; Agarry *et al*., 2005). Drying kinetics study refers to the fitting of measured drying properties such as drying rate, moisture content, temperature, diffusivity, drying time etc into empirical equations used for predicting the drying parameters and behaviours of materials at other conditions.

The drying kinetics of all food materials cannot be described by the same equation due to their difference in moisture content and transport phenomenon during dehydration. Recently, there are many studies on the effect of pretreatment on the drying kinetics of fruit and vegetables (Pala *et al*., 1996; Pangavhane *et al*., 1999; Doymaz and Pala, 2002; Doymaz, 2004). Although pineapples are one of the world's most traded fruit in both fresh and processed forms (such as pineapple juice, pineapple concentrate, and dried pineapple chips) there is a dearth of literature on the effect of blanching temperature and blanching time combinations on the drying of pineapple. Therefore, the main objective of this study was to investigate the effect of blanching temperature-time combinations on the drying kinetics of pineapples.

MATERIALS AND METHODS

Sampling of materials

Fresh pineapples were purchased from the local market in Ogbomoso, Nigeria. The pineapples that were injured, unripe, overripe with flowing liquid were separated from moderate ripe pineapples. The selected pineapples to be used for the study were kept in a refrigerator prior to usage.

Sample Pretreatment

The moderately ripe pineapple fruits were washed with tap water and grouped. They were then peeled and their cores were removed. The samples did not contain the central axis, only the pulp material. The pineapple pulps were cut into rectangular slices of about 5mm diameter (thickness).

Blanching: Approximately 50g of the sliced samples were put in a beaker containing water and placed in a temperature controlled water bath (DK-420 Glufex Medical and Scientific, England). The beaker and its contents were heated to a temperature of 60 ^oC and maintained for 3 min after which the samples were removed from the water and blotted dry using tissue paper in order to remove the excess water. It was then re-weighed. This procedure was repeated on other 50g samples at 60 ^oC for 5 and 10 min; 70 ^oC and 80 ^oC each for 3, 5 and 10 min, respectively. All the experiments were done in duplicates. Also, approximately 50g of the sliced pineapple samples were set aside without blanching (or pretreatment), to serve as a control.

Oven drying

The drying experiments were performed in a laboratory model oven dryer (Uniscope SM 9053 A laboratory oven, Surgifriend Medicals, England). The dryer (0.693 × 0.470 × 0.486 m) consisted of a tray, electrical heater, fan and a temperature controller (50 – 200 ^oC, dry bulb temperature). Approximately 50g each of the unblanched and blanched pineapple slices were loaded on a metal tray and dried in the oven at a dry bulb temperature of 70 ^oC. Weights of the trays and pineapple slices were recorded at intervals of 1h during drying until the final moisture content of approximately 38% dry weight basis (db) was obtained. The moisture contents of both the fresh and dried samples were determined according to AOAC (1995).

Drying parameter estimation

Moisture content: The moisture content (MC) was calculated from equation 1.

$$MC = \frac{W_o - W_f}{W_o} \quad (1)$$

Where W_o and W_f is the initial and final weight of the food material (g)

Moisture ratio: In thin layer drying, the moisture ratio during drying was calculated from equation 2.

$$MR = \frac{M - M_e}{M_o - M_e} \quad (2)$$

Where MR is the dimensionless moisture ratio, M, the average moisture content at time t, M_o, the initial moisture content, and M_e, the equilibrium moisture content respectively, on dry weight basis.

During thin layer drying of pineapple, the equilibrium moisture content was not determined and since this is usually not high for food materials (Togrul and Pehlivan, 2004; Waewsak *et al.,* 2006), the equilibrium moisture content was assumed to be zero. Thus, the moisture ratio was simplified according to Pala *et al* (1996) and Kingsly *et al* (2007) to equation 3.

$$MR = M / M_o \quad (3)$$

The recorded moisture contents for each sample were then used to plot the drying curves.

Drying rate: The drying rates of the sample for each treatment were calculated based on weight of water removed per unit time per kilogram of dry matter, expressed in units of kg $kg^{-1}h^{-1}$ (Sankat *et al*., 1996; Dandamrongrak *et al*., 2003; Agarry *et al*., 2005).

Effective moisture diffusivity: For the determination of the effective moisture diffusivity (D_{eff}), a mathematical model was used based on Fick's second law of diffusion which expresses a relationship between the moisture ratio and the effective moisture diffusivity, the solution for which was given by Cranck (1975) for longer times and for a rectangular slab geometry is presented in equation 4. Linear regression analysis was used to fit the experimental data to equation (4) (Feng *et al.,* 2000).

$$MR = \frac{8}{\pi^2} \exp\left[\frac{-D_{eff}}{4l^2}\pi^2 t\right] \quad (4)$$

Where D_{eff} is effective moisture diffusivity (m^2/s), t, drying time and l, thickness (m).

Model Prediction and Goodness of Fit: Thin-layer mathematical drying models describe the drying phenomenon in a unified way regardless of the controlling mechanisms (Karathanos and Belessiotis, 1999; Kingsly *et al.,* 2007). Four known mathematical drying models that express relationship between MR and the drying time, t as presented in Table1 were applied to the drying curves obtained for each sample at each process variables using the non-linear regression analysis in order to select the best model (based on the quality of fit) that describes the drying characteristics or behavior. Some of these models are recently used for determination of moisture ratio with drying time by Doymaz (2004), Friant *et al* (2004), Akpinar and Bicer (2005), Sacilik and Elicin (2006) and Vega *et al.* (2007).

Table1: Typical models for drying solids

Model Names	Model Equation
Page	$MR = \exp(-kt^n)$
Henderson and Pabis	$MR = a\exp(-kt^n)$
Logarithmic	$MR = a\exp(-kt) + c$
Two-term exponential	$MR = a\exp(-kt) + (1-a)\exp(-kt)$

a, c, n, empirical constants; k, drying constant; t, drying time; MR, moisture ratio

Adapted from Ertekin and Yaldiz, 2004

The regression analysis was performed using MATLAB software package (version 6.5). The correlation coefficient (R^2) and root mean square error (RMSE) were the major criteria used for selection of the best model equation that describes the drying curve. For quality fit, R^2 value should be high and RMSE should be low (Demir *et al.,* 2004; Erenturk *et al.,* 2004; Waewsak *et al.,* 2007). In order to evaluate the goodness of fit of the simulation provided by the proposed (best selected) model, different statistical parameters are usually used. In this study, the reduced chi-square (equation 5) (Doymaz, 2007; Vega *et al.,* 2007) was calculated.

$$\chi^2 = \sum_{i=1}^{N} (MR_{\exp i} - MR_{prei}) \Big/ N - Z \qquad (5)$$

Where N, total number of observations, Z, number of model parameters, $MR_{\exp i}$, experimental moisture ratio values and MR_{prei}, predicted moisture ratio values. These modules have been used in the literature to evaluate the goodness of fit of different mathematical models.

RESULTS AND DISCUSSION

Drying Parameters

The results of the effect of blanching pretreatment on the drying properties of pineapple are presented in Table 2. It was observed that the initial moisture content increased with increase in blanching time as a result of increase in moisture uptake, thus, the initial moisture content of the blanched samples were significantly higher than that of the unblanched (or control) sample. The blanching pretreatment affected the drying time of the sliced pineapple. The sliced pineapple samples blanched respectively at 60, 70 and 80 ^oC for 3 and 5 min, and those blanched at 60 ^oC for 10 min showed less time of drying than the unblanched sample. This indicate that blanching at 60 to 80 ^oC for lower period of time (3→5 min) prior to drying showed increased mass transfer activity during the oven-drying process of pineapple slices. Similar observations have been reported by Pala *et al*. (1996), Doymaz and Pala (2002), Dandamrongrak *et al*. (2003), and Kingsly *et al*. (2007) when apricots, banana, grapes and peach were blanched with chemicals and then dried. The oven drying of sliced pineapple samples blanched at 70 and 80 ^oC for 10 min, respectively, showed increased drying time when compared with the unblanched pineapple samples (control) (Table 2). This could be because of the effect of carbohydrate gelatinization and a high water uptake.

The moisture ratio (MR) of the blanched and unblanched pineapple decreased continuously with drying time (Figure 1). This continuous decrease in moisture ratio indicates a diffusion controlled internal mass transfer. This is in agreement with the observations of Mazza and Maguer (1980), Piga *et al*. (2004) and Kingsly *et al*. (2007) for the studies on the drying properties of blanched onion, figs and peach, respectively. The drying rates of unblanched and blanched pineapple samples were initially high because the moisture content was high, but decreased rapidly to almost the same rate in the course of drying.

This was due to the free moisture near the surface of the unblanched and blanched pineapple slices being removed early in the process (Figures 2 and 3). The effect of blanching time on the drying rates of oven-dried sliced pineapple can be seen in Figures 2a - c. At each blanching temperatures (60, 70, 80 ^oC), the initial drying rate increased as the blanching time increased from 3 to 10 min. The high initial drying rate probably occurred because the blanched pineapple samples gained more moisture during the blanching and cooling process that gave rise to increased initial moisture content (Table 2). However, there was a progressive drop in the drying rate at a higher blanching time than at a lower blanching time, thereby resulting in a longer drying time. The reason for this drop in drying rate at a higher blanching time may probably be due to gelatinization of carbohydrate which increased as blanching time increased, thus leading to decreased rate of moisture transport from inside the blanched pineapple samples to the surface during oven drying. It has been reported that blanching can cause gelatinization of carbohydrate (Ling *et al*., 1982; Dandamrongrak *et al*., 2003).

Also, it was observed that at each blanching time (3, 5, 10 min), the initial drying rates increased as the blanching temperature increased from 60 to 80 °C (Figure. 3a – c). However, the rate of oven drying of sliced pineapple samples blanched at a higher temperature gradually decreased than that blanched at a lower temperature. This gradual decrease in drying rate may probably have occurred because of gelatinization of carbohydrate which increased with increase in blanching temperature. The oven drying of unblanched and blanched pineapple slices was predominantly in the falling rate period only as shown in Figures 2 to 3. There was no constant rate period in the drying curves for the unblanched and blanched pineapple samples.

Table 2: Moisture content and drying times of sliced pineapple samples blanched at different temperature-time combination

Blanching Time	Blanching Temperature (°C)	Moisture content % (dry basis)	Drying Time (hr)
3	60	5.61 ± 0.02	5
	70	5.6 8± 0.01	6
	80	5.75 ± 0.03	7
5	60	5.6 3± 0.02	6
	70	5.75 ± 0.01	7
	80	5.80 ± 0.02	8
10	60	5.78 ± 0.01	9
	70	5.85 ± 0.03	10
	80	5.89 ± 0.03	11
Control (unblanched)	-	5.25 ± 0.02	10

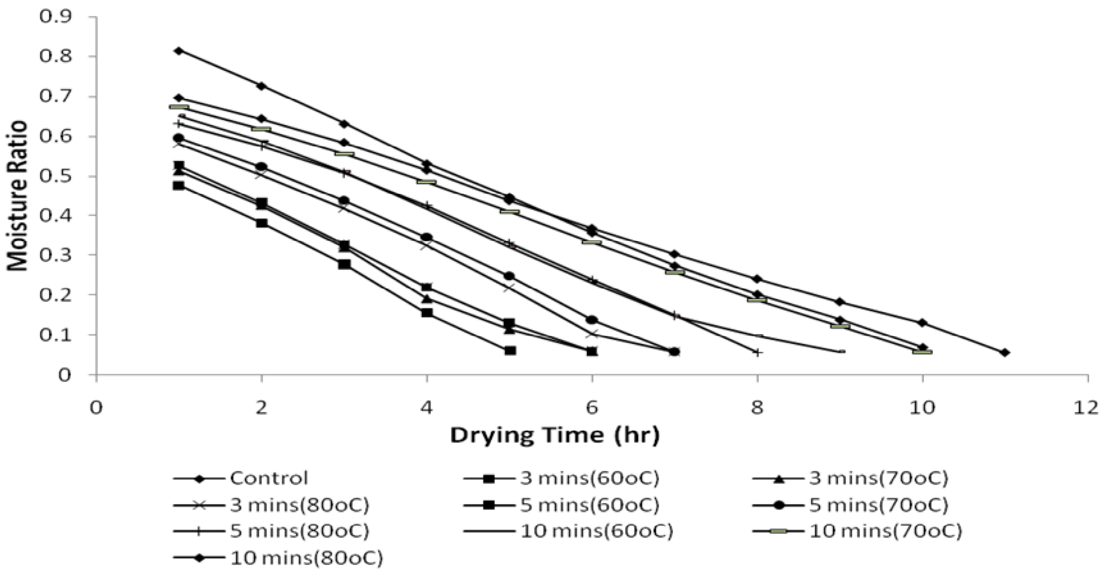

Figure 1: Plot of moisture ratio against drying time for sliced pineapple samples blanched at different temperature-time combination

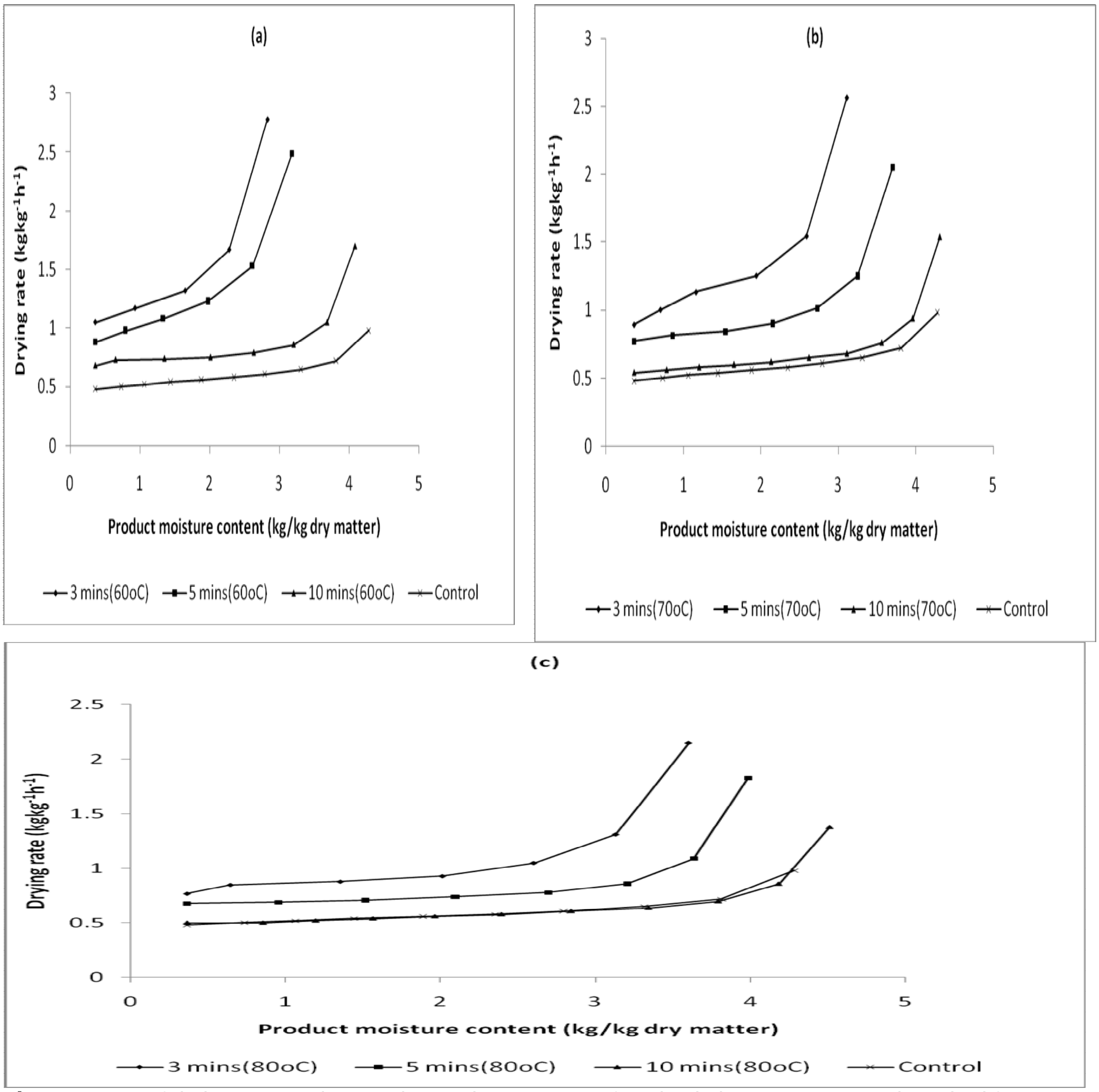

Figure 2: Plot of drying rate against product moisture content for sliced pineapple samples blanched for 3, 5 and 10 minutes at: (a) 60°C, (b) 70°C, and (c) 80°C

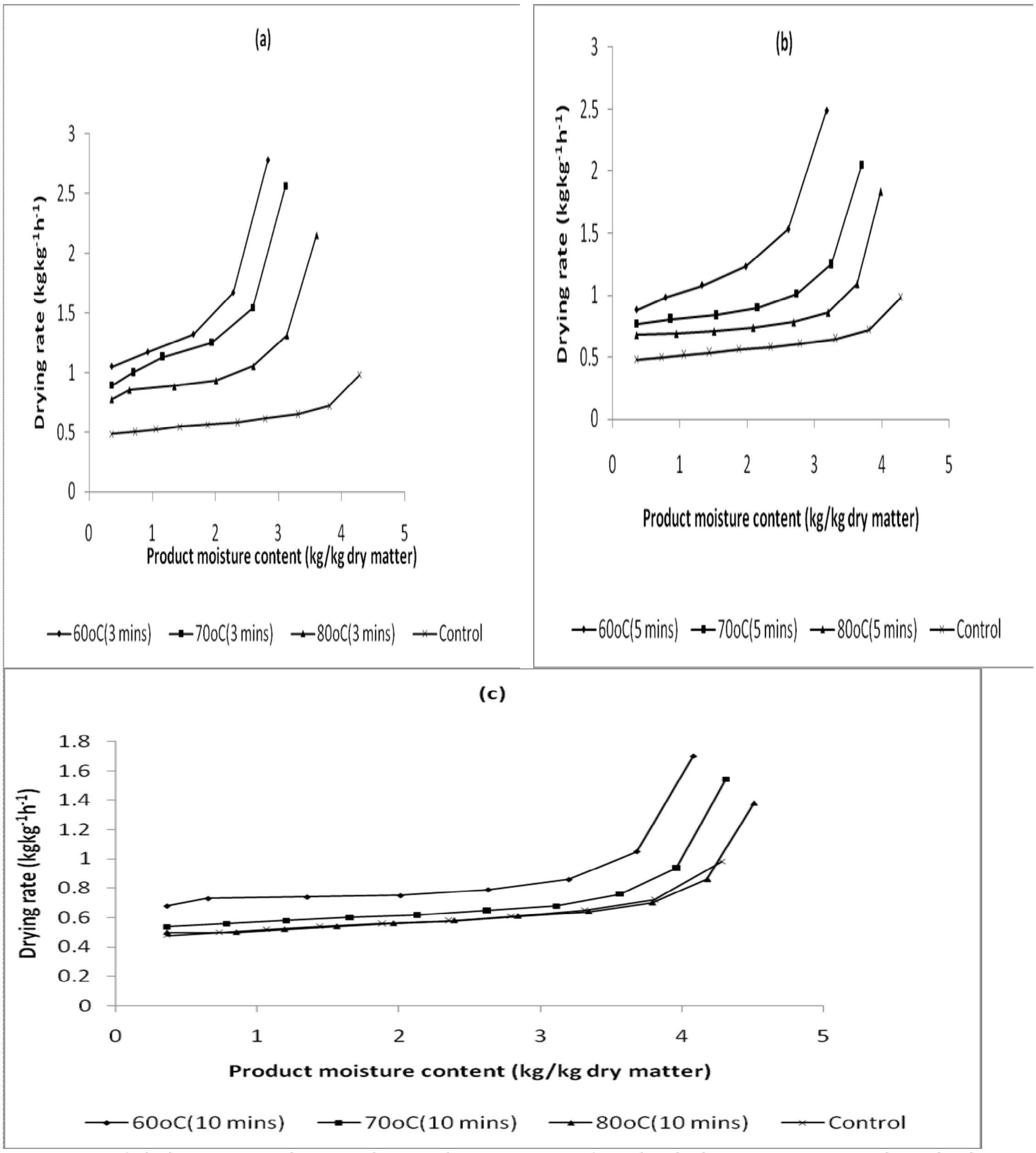

Figure 3: Plot of drying rate against product moisture content for sliced pineapple samples blanched at 60°C, 70°C and 80°C for: (a) 3 min, (b) 5 min, and (c) 10 min

Effective Moisture Diffusivity

The moisture transport during drying can be described by Fick's diffusion model (equation 4). The drying process of blanched pineapple slices obtained at different temperature- time combination (60, 70, 80°C for 3, 5, and 10 min) were adapted to the Fick's diffusion equation. The linearization of Equation (4) allowed for the estimation of the effective moisture diffusivity (D_{eff}) for both the unblanched and blanched treated samples, respectively. The results show that the effective moisture diffusivity ranged from 2.10 x 10^{-10} to 2.92 x 10^{-10} m^2/s for blanched treated pineapple and 1.93 x 10^{-10} m^2/s for unblanched pineapple slices (Table 3). These values are within the normal range 10^{-11}- 10^{-9} m^2/s for drying of food materials (Dandamrongrak *et al*., 2002; Madamba, 2003; Salicik and Elicin, 2006; Kaleemullah and Kailappan, 2006; Doymaz, 2004, 2006, 2007; Jain and Pathare, 2007). Karim (2010) reported an effective moisture diffusivity of 9.10 × 10^{-10} m^2/s and 4.91× 10^{-10} m^2/s for sulphite and osmotically pretreated pineapple slices dried at 70°C, respectively. The results also show that effective moisture diffusivity of the blanched pineapple slices decreased with increase in the blanching temperature-time combinations and that blanching pretreatment prior to drying improves the effective moisture diffusivity.

Table 3: Effective moisture diffusivity of blanched pineapple slices dried at 70 °C

Blanching Time (min)	Blanching Temperature (°C)	D_{eff} x10^{-10} m^2/s	R^2
3	60	2.92	0.8683
	70	2.59	0.8948
	80	2.46	0.9476
5	60	2.65	0.9255
	70	2.49	0.9521
	80	2.38	0.9731
10	60	2.23	0.9742
	70	2.18	0.9859
	80	2.10	0.9968
Control (unblanched)	-	1.93	0.9685

Model Prediction and Goodness of Fit

Experimental results of moisture ratio with corresponding drying time of the different blanched pineapple slices (Figure.1) were fitted into different drying models as listed in Table 1. The model constants a, c, n and k were then estimated. The values of R^2 and RMSE obtained by non-linear regression analysis (Table 4) were used to select the best model that describes the drying behaviour on the basis of high R^2 and low RMSE values. In all the cases, the logarithmic model had the highest R^2 and lowest RMSE values for each sliced pineapple blanched at different temperature- time combination. Thus, the logarithmic model may be proposed to best describe the oven drying behaviour of unblanched and blanched pineapple slices. The logarithmic model has been reported in the works of Sacilik and Elicin (2006), Xanthopoulos *et al*. (2007), Vengaiah and Pandey (2007), and Kingsly *et al*. (2007) to best describe the drying behaviour of organic apple, whole figs, sweet pepper and peach, respectively.

The values for the logarithmic model parameters are presented in Table 4. The influence of the blanching temperature-time combination on the model constant parameters can be seen such that 'k' and 'c' increased linearly, while the constant 'a' decreased, as the blanching temperature-time combinations increased. The model constant parameters dependence on the blanching temperature-time combinations can be represented by a linear regression relationship as given in equations 6 – 8:

$$k = 0.0342 + 0.0089x_1 + 0.0026x_2 \quad (6)$$

$$c = -0.9127 + 0.0305x_1 + 0.0086x_2 \quad (7)$$

$$a = 1.8784 - 0.0308x_1 - 0.0095x_2 \quad (8)$$

Where, x_1 and x_2 are the blanching time (minutes) and blanching temperature (°C), respectively. The accuracy of the logarithmic model (based on Equations (6) to (8) to simulate the drying curves of sliced pineapple blanched at different temperature-time combinations was evaluated.

In order to mathematically evaluate the simulation, the correlation coefficient (R^2), reduced chi-square and root mean square error (RMSE) were calculated from comparing the experimental moisture ratio and those given by the proposed model for the whole range of sliced pineapple samples blanched at different temperature-time combination and oven dried at 70 °C. These results are shown in Table 5. It is observed that the correlation coefficient (R^2) values are high, the reduced chi-square (χ^2) and root mean square error (RMSE) values are low for all the blanched pineapple slices. The logarithmic model allowed an accurate simulation of the drying curves of blanched pineapple slices dried at 70 °C and therefore exhibiting a high concordance between experimental and predicted (estimated) moisture ratio.

Table 4: Goodness of fit of the different drying models for blanched pineapple slices

Model	Blanching time	Blanching Temperature	R^2	RMSE
Page	3	60	0.9865	0.0327
		70	0.9890	0.0277
		80	0.9921	0.0205
	5	60	0.9931	0.0211
		70	0.9913	0.0229
		80	0.9966	0.0136
	10	60	0.9974	0.0119
		70	0.9961	0.0140
		80	0.9994	0.0054
	Control	Control	0.9971	0.0146
Logarithmic	3	60	0.9999	0.0039
		70	0.9999	0.0033
		80	0.9957	0.0169
	5	60	0.9998	0.0040
		70	0.9994	0.0068
		80	0.9999	0.0028
	10	60	0.9996	0.0052
		70	0.9993	0.0062
		80	0.9995	0.0051
	Control	Control	0.9971	0.0146
Henderson and Pabis	3	60	0.9804	0.0393
		70	0.9860	0.0313
		80	0.9933	0.0189
	5	60	0.9924	0.0221
		70	0.9920	0.0219
		80	0.9978	0.0110
	10	60	0.9985	0.0091
		70	0.9982	0.0094
		80	0.9992	0.0062
	Control	Control	0.9964	0.0161
Two-term exponential	3	60	0.9736	0.0457
		70	0.9847	0.0327
		80	0.9877	0.0256
	5	60	0.9923	0.0222
		70	0.9913	0.0229
		80	0.9954	0.0159
	10	60	0.9955	0.0156
		70	0.9888	0.0236
		80	0.9917	0.0199
	Control	Control	0.9884	0.0289

Table 5. Logarithmic model constant parameters and goodness of fit for blanched pineapple slices

Blanching Time (min)	Blanching Temperature (°C)	Model a	Constants c	k	R^2	RMSE	χ^2
3	60	1.358	-0.4319	0.201	0.9998	0.0241	0.00145
	70	1.181	-0.2641	0.2169	0.9995	0.0260	0.00155
	80	0.9423	-0.0637	0.29	0.9699	0.0387	0.00263
5	60	1. 066	-0.1488	0.2704	0.9992	0.0121	0.00029
	70	1.016	-0.1221	0.258	0.9995	0.0245	0.00105
	80	0.9547	-0.0464	0.2983	0.9998	0.0118	0.00022
10	60	0.9507	-0.0355	0.2954	0.9994	0.0255	0.00104
	70	0.9074	-0.0311	0.2797	0.9987	0.0074	0.00008
	80	0.9107	+0.0117	0.3363	0.9995	0.0521	0.00388

CONCLUSION

Drying rates and drying time of pineapple slices are affected by the blanching temperature-time combinations. Increasing the blanching temperature-time combinations resulted in increased drying times. The logarithmic model sufficiently describes the drying behaviour of blanched pineapple slices. The Fick's diffusion model adapted adequately with the experimental results which enabled the determination of the effective moisture diffusivity. In general, blanching of pineapple slices improved the drying and effective diffusivity.

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