FUOYE Journal of Engineering and Technology (FUOYEJET), Volume 6, Issue 2, June 2021 ISSN: 2579-0625 (Online), 2579-0617 (Paper)

Effect of Different Drying Methods on the Drying Kinetics of Fermented Cardaba Banana Peels

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Received: 13-JAN-2021; Reviewed: 13-MAR-2021; Accepted: 30-MAR-2021
http://dx.doi.org/10.46792/fuoyejet.v6i2.599

Abstract- Cardaba banana peels (*Musa acuminata*) were fermented for three days and dried using solar dryer, open sun and tunnel dryer. Nonlinear regression analysis was used to fit in the experimental data. Moisture drying was investigated using Fick's second law. Statistical tools such as coefficient of determination (R^2), reduced chi square (χ^2), Mean Bias Error (MBE) and Root Mean Square Error (RMSE) were used to test the reliability of the model. Sample dried in sun had single falling rate pattern whereas samples in solar and tunnel dryer exhibited a second falling rate pattern. The values of R^2 ranged from 0.872-0.989, χ^2(1.4E-34-0.0624), MBE (-0.0067-0.0491) and RMSE (1.1E-17-0.2247). Effective moisture diffusivity for samples dried in solar, tunnel and sun were 2.92 E-11m^2/s, 1.98 E-11m^2/s and 1.09 E-11m^2/s, respectively. The energy of activation in the process was 64.9kJ/mol. Page model best described drying behavior of the samples.

Keywords- Fermentation, banana peels, drying, models, diffusivity, activation energy

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1 INTRODUCTION

Banana is claimed to be world's second most important fruits crop after oil palm (Faturoti *et al.*, 2007). In 2017, the production and trading of banana stood at 22.47 million tonne (Vivek *et al.*, 2020). Cardaba banana is a type of banana with thick peels and Nigeria is a leading producer of this type of banana and plantain in Africa (Kainga and Seiyabo, 2012). The fully ripe ones can be eaten as fruit or processed into chips by frying in oil and packaged while unripe ones are processed into flour to be used in food formulation. The thick peels make this banana disadvantaged because the weight of peel is greater than the pulp. This makes the cost of this banana to be cheaper in the market because consumers do not know the usefulness of its peels and hence, they are discarded. The process of indiscriminate disposal of this peel waste constitutes environmental problem.

Recent development of converting agricultural waste to useful product such as organic fertilizers, citric and tartaric acids for industries is a privilege which is of interest to researchers. For example, starch contents of cassava peels were used to produce citric acid as reported by Ajala *et al.* (2020) and Ajala *et al.* (2019). Also, Jayabalan et al. (2019) reported the use of citrus peels for citric acid production. Cardaba banana could also be a good source of such product. However, for the banana peel to be preserved and useful for industrial use, it has to be preserved in dry form because it deteriorates and turns blackish quickly after the peel has been removed from the banana. During the course of drying, moisture is removed from the peels to the surrounding air, the amount of moisture kinetics from the peels is required to model and predict the moisture behavior of the sample in drying equipment. Therefore, the objective of this study was to determine the drying kinetics of fermented cardaba banana peels.

2 MATERIAL AND METHODS

2.1 DRYING EXPERIMENT

Cardaba banana bunches were procured at Aradaa Market in Ogbomoso, Oyo State, Nigeria. The bananas were removed from the bunch and peeled manually with a stainless knife. They were sorted so as to eliminate all form of dirt and physical contaminants that were likely to be present in the samples. About 2 kg of the peels were fermented in a hessian sack for three days at room temperature. The peels were cut into rectangular slab-like structure for the experiments with average dimensions of 3x2x0.1 cm for the length, breadth and thickness of the samples measured with a Veneer caliper. After that, the peels were dried. The drying experiment was performed using sun (average temperature of 37°C), solar dryer (average temperature of 40°C) and tunnel dryer (50°C) built in the Department of Food Engineering, Ladoke Akintola University of Technology, Ogbomoso Nigeria. The samples were weighed manually every 1 hour during drying to determine weight loss of the sample. The drying experiment was stopped when three consecutive sample weights remained constant at average moisture content of 0.4 (db) according to El-Amin *et al.* (2008) and Ali *et al.* (2010).

2.2 MATHEMATICAL MODEL

To understand the suitable model for the drying characteristics of the samples, the experimental data were fitted in six models described in Table 1.

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Section A- AGRICULTURAL ENGINEERING & BIOLOGICAL SCIENCES
Can be cited as:
Oni O.K., Ajala A.S. and Oloye A.O. (2021): Effect of Different Drying Methods on the Drying Kinetics of Fermented Cardaba Banana Peels, FUOYE Journal of Engineering and Technology (FUOYEJET), 6(2), 5-9. http://dx.doi.org/10.46792/fuoyejet.v6i2.599

Table 1. Mathematical drying models

Models	Equation	References
Henderson and Pabis	$MR=a_1\exp(-k_1t)$	Kuitche *et al.*, (2007)
Logarithms	$MR=a_2\exp(-k_2t)+c_2$	Togrul and Pehlivan (2003)
Newton	$MR=\exp(-k_3t)$	Kingly *et al.* (2007)
Page	$MR=\exp(-k_4t^n)$	Karathanos and Belessiotis (1999)
Two term	$MR=a_5\exp(k_5t)+b_5\exp(jt)$	Hodge and Taylor (1999)
Wang and Sing	$1+a_6t+b_6t^2$	Wang and Singh (1978)

These models show relationship between moisture ratio, drying constants and drying time. Moisture ratio (MR) during the thin layer drying was obtained using Equation 1

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

where MR= dimensionless moisture ratio, Mi = instantaneous moisture content (g water/g solid), Me = equilibrium moisture content (g water/ g solid), Mo = initial moisture content (g water/ g solid). However, due to continuous fluctuation of relative humidity of the drying air in the dryer, Equation 1 was simplified in Equation 2 according to Goyal *et al.* (2007)

$$MR=\frac{M_i}{M_O} \qquad (2)$$

2.3 DETERMINATION OF MOISTURE DIFFUSIVITY

Fick's equation was simplified to describe the drying characteristics of the banana peel samples. The simplified equation was used to determine the effective moisture diffusion from the samples during drying. The equation according to Ajala *et al.* (2012b) is represented thus:

$$MR=\frac{M-M_0}{M_0-M_e}=\frac{8}{\pi^2}\sum_{n=0}^{n=1}\frac{1}{(2n-1)^2}exp\frac{-(2n-1)^2\pi^2D_{eff}t}{4l^2} \qquad (3)$$

where D_{eff} is the moisture diffusivity (m^2/s), t is the drying time (s), *l* is the half of the slab thickness (m)

The effective moisture diffusivity (D_{eff}) was calculated from the slope of plot of ln MR against drying time (t) according to Doymas, (2004) and is represented in Equation 4

$$k=\frac{D_{eff}t}{4l^2} \qquad (4)$$

Where *k* is the slope.

2.4 DETERMINATION OF ACTIVATION ENERGY

Arhenius equation describes the relationship between moisture diffusion and temperature of drying. The relationship is given in Equation 5.

$$D_{eff}=D_0\ exp\frac{-E_a}{RT} \qquad (5)$$

Where D_0 is the pre-exponential factor of the Arrhenius equation in m^2/s, E_a is the activation energy in kJ/mol, R is the universal gas constant in kJ/mol K and T is the absolute air temperature in K. The activation energy was calculated by plotting the natural logarithm of D_{eff} against inverse of the absolute temperature.

2.5 STATISTICAL ANALYSIS

The drying model constants were estimated using a non-linear regression analysis. The analysis was performed using Statistical Package for Social Science (SPSS 16.0 versions) software. The reliability of the models was verified using statistical criteria such as coefficient of determination (R^2), reduced chi-square (χ^2), root mean square error (RMSE) and mean bias error (MBE). A good fit is said to occur between experimental and predicted values of a model when R^2 is high and χ^2, RMSE and MBE are lower (Ajala *et al.*, 2012a). The comparison criteria method can be determined as follows:

$$\chi^2=\frac{\sum_{i-1}^{n}(MR_{(exp,i)}-MR_{(pred,i)})^2}{N-z} \qquad (6)$$

$$MBE=\frac{1}{N}\sum_{i=1}^{n}(MR_{(pred,i)}-MR_{(exp,i)}) \qquad (7)$$

$$RMSE=\left[\frac{1}{N}\sum_{i=1}^{n}(MR_{(pred,i)}-MR_{(exp,i)})^2\right]^{1/2} \qquad (8)$$

3 RESULTS AND DISCUSSION

3.1 EFFECT OF DRYING METHODS ON MOISTURE CONTENT AND MOISTURE RATIO

Figures 1 and 2 respectively shows the moisture content and moisture ratio of the banana peels as drying progressed using sun drying, solar drying and tunnel drying. There was exhibition of second falling rate periods in the samples but prominent in the tunnel dried samples. This could be attributed to the higher moisture diffusion as a result of higher temperature regime (50°C) in the dryer. Although a second falling rate period is rare in agricultural products, but such had earlier been observed in cassava chips (Ajala *et al.*, 2018), Shrimp (Ajala and Ajala, 2014) and Granny Smith apple (Velic *et al.*, 2007).

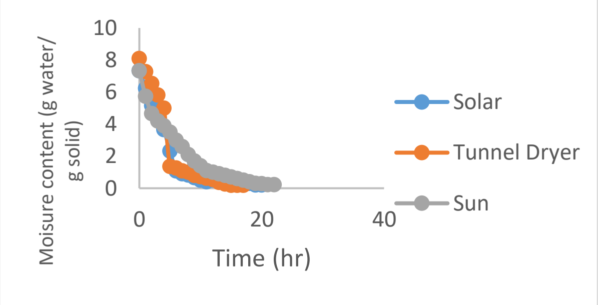

Fig. 1: Graph showing moisture content against time

http://dx.doi.org/10.46792/fuoyejet.v6i2.599

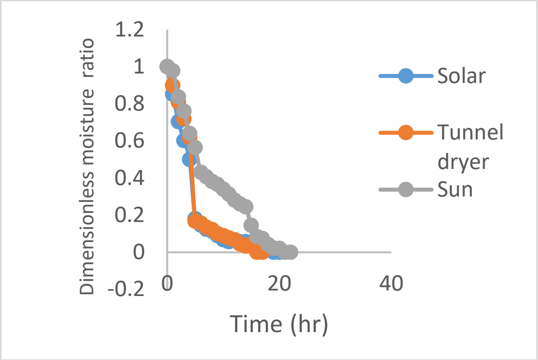

Fig. 2: Graph showing moisture ratio against time

3.2 STATISTICAL RESULTS AND CONSTANTS OF THE MODELS

Coefficient of determination (R^2), reduced chi square (χ^2), Mean Bias Error (MBE) and Root Mean Square Error (RMSE) were the statistical tools to test the reliability of the models. Table 2 presents the values of these statistical tools. The lowest and highest values of R^2 in Henderson and Pabis were 0.935 and 0.972 respectively while the lowest and highest values of R^2 for Logarithms, Newton, Page, Two terms, and Wang and Sing models, were 0.936 and 0.972; 0.924 and 0.985; 0.970 and 0.989; 0.935 and 0.973; 0.872 and 0.922 respectively. The values of R^2 in this study are in the same trend with that of Ajala *et al.* (2012a) for cassava chips and Gürlek *et al.* (2009) for tomato. The lowest and highest values of χ^2 for Henderson and Pabis Logarithms, Newton, Page, Two terms, and Wang and Sing models are: 8.0E-05 and 0.0010; 1.4E-34 and 2.0E-05; 5.0E-06 and0.0011; 0.0053 and 0.0088; 0.0004 and 0.0624; 0.0189 and 0.0485, respectively. The values of χ^2 in this study are lower than those reported by Ng *et al.* (2015) with range of values 1.2-417 for technical specified rubber. The lowest and highest values of MBE for Henderson and Pabis Logarithms, Newton, Page, Two terms, and Wang and Sing models are: -0.0067 and 0.0043; -0.0005 and 0.0009; 0.0005 and 0.0071; 0.0152 and 0.0195; -0.0067 and 0.0491; 0.0285 and 0.0457 respectively. These values are close to the values reported by Ahmad et al. (2014) for drying of red seaweed Likewise, the lowest and highest values of RMSE for Henderson and Pabis Logarithms, Newton, Page, Two terms and Wang and Sing models are: 0.0085 and 0.0305; 1.1E-17 and 0.0041; 0.0022 and 0.0327; 0.0696 and 0.0895; 0.0172 and 0.2247; 0.1309 and 0.2095 respectively. These values also are in the range of values got for drying of tomato (GÜRLEK et al 2008). According to (Yadollahinia *et al.* 2008), a model is said to have a good fit when R^2 is high as 0.7. As a result, Page model is adjudged to have the best fit for the model with R^2 of 0.989. This means Page model described best the solar drying behavior of banana peels.

Table 3 shows values of various constants in the models. The constant (a_1) and (k_1) in Henderson and Pabis ranged from 1.045 to 1.118 and 0.234 to 0.298, respectively. For Logarithms model, the values of (a_2), (c_2) and (k_2) ranged from 1.00-1.067, -0.273-0.01 and 0.161-0.306, respectively. Also, the values of k_3 in Newton model ranged from 0.132-0.285. The two constants in Page model namely n and k_4 had the lowest value of 1.127 and highest values of 1.302 for n while the lowest and highest values for k_4 are 0.078 and 0.112, respectively. The values of a_5 in Two Term model are -0.148, -0.142 and -0.159 for solar, tunnel and sun drying, respectively while the values of b_5 in Two Term model are -0.005, 0.005 and 0.006 for solar, tunnel and sun drying, respectively. Wang and Sing has four (4) constants. The values of a_6 are 45.035, 0.92 and 1.048; the values of b6 are -43.97, 0.198 and 0.001; the values of j are -0.199, -0.234 and 0.160 while the values of k_6 are -0.2, -0.234 and -0.302 for solar, tunnel and sun drying, respectively. These values are close to other values of other researchers such as Ajala, *et al.* (2012a) and Ahmad et al. (2014)

Table 2. Values of Statistical Parameters

Models	**Drying mode**	**R^2**	**χ^2**	**MBE**	**RMSE**
Henderson and Pabis	Solar	0.967	8.0E-05	0.0018	0.0085
	Tunnel dryer	0.935	0.0010	-0.0067	0.0305
	Sun	0.972	0.0004	0.0043	0.0196
Logarithms	Solar	0.967	2.0E-05	0.0009	0.0041
	Tunnel dryer	0.936	5.5E-06	-0.0005	0.0022
	Sun	0.972	1.4E-34	2.4E-18	1.1E-17
Newton	Solar	0.985	0.0005	0.0047	0.0216
	Tunnel dryer	0.924	5.0E-06	0.0005	0.0022
	Sun	0.970	0.0011	0.0071	0.0327
Page	Solar	0.989	0.0053	0.0152	0.0696
	Tunnel dryer	0.970	0.0088	0.0195	0.0895
	Sun	0.979	0.0053	0.0152	0.0698
Two term	Solar	0.967	0.0004	0.0037	0.0172
	Tunnel dryer	0.935	0.0011	-0.0067	0.0305
	Sun	0.973	0.0624	0.0491	0.2247
Wang and Sing	Solar	0.922	0.0336	0.0380	0.1743
	Tunnel dryer	0.922	0.0485	0.0457	0.2095
	Sun	0.872	0.0189	0.0285	0.1309

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3.3 EFFECTIVE DIFFUSIVITY

Table 4 presents the values for effective moisture diffusivity of the fermented cardaba banana peels. The highest moisture diffusivity was 2.92 x 10^{-11} m^2/s which took place in tunnel drying at 50 ° C followed by 1.98 x 10^{-11} m^2/s in solar drying at 40° C and the least was 1.09 x 10^{-11} m^2/s in sun drying at 37 ° C. Therefore, the effective diffusivity is temperature dependent as earlier asserted by several authors such as Ajala *et al.* (2019), Ajala and Ajala (2014), Velic *et al*. (2007). Rizvi (1986) also asserted that not only temperature but the tissue and structure of the sample being dried have effect on moisture diffusivity. The values of effective moisture diffusivity obtained are within the range of food product (10^{-11} to 10^{-6} m^2/s) as reported by Ajala and Ajala (2014). However, the value of moisture diffusivity was less than that of cassava chips which has D_{eff} range of 4.54x10^{-10} - 1.30 x$10^{-9}$$m^2/s$ as reported by Ajala *et al.* (2018). The lower values in banana peels when compared to cassava chips were due to effect of fermentation on the peels which has soften internal structure of the peels and offered less resistance to the moisture diffusion. The higher the value of effective moisture diffusivity, the faster the drying process.

3.4 ACTIVATION ENERGY

Figure 3 shows the plot of ln D versus T inverse which produced activation energy (E_a) of the system. The values of E_a were calculated to be 64.9kJ/mol which is greater than the values reported by Ajala *et al.* (2019) for fermented cassava peels (41.616 kJ/mol). The value is greater than the values of cassava chips (30kJ/mol) as reported by Ajala *et al.* (2012a) and also greater than the values of shrimps (33.851kJ/mol.) by Ajala and Ajala (2014). Activation energy is the minimum energy that would be required to effect drying in banana peels. It is important because if the drying medium used could not deliver this energy, drying the sample becomes unnecessarily prolonged. The higher the activation energy of the sample, the higher the energy that would be needed in drying the banana peel samples (Engkos *et al.*, 2020).

Table 3. Values for model constants

Models	Drying mode	Constants			
		a_1			k_1
Henderson and Pabis	Solar	1.069			0.251
	Tunnel dryer	1.118			0.234
	Sun	1.045			0.298
		a_2		c_2	k_2
Logarithms	Solar	1.067		0.003	0.253
	Tunnel dryer	1.00		-0.273	0.161
	Sun	1.039		0.010	0.306
					k_3
Newton	Solar				0132
	Tunnel dryer				0.212
	Sun				0.285
			n		k_4
Page	Solar		1.127		0.100
	Tunnel dryer		1.302		0.078
	Sun		1.143		0.112
		a_5	b_5		
Two term	Solar	-0.148	0.005		
	Tunnel dryer	-0.142	0.005		
	Sun	-0.159	0.006		
		a_6	b_6	J	k_6
Wang and Sing	Solar	45.035	-43.97	-0.199	-0.2
	Tunnel dryer	0.92	0.198	-0.234	-0.234
	Sun	1.048	0.001	0.160	-0.302

Table 4. Effective moisture diffusivities for fermented cardaba banana peels

Drying mode	**Effective moisture diffusivity (m^2/s) (D_{eff}x 10^{-11})**
Solar (40 °C)	1.98
Tunnel dryer (50 °C)	2.92
Sun drying (37 °C)	1.09

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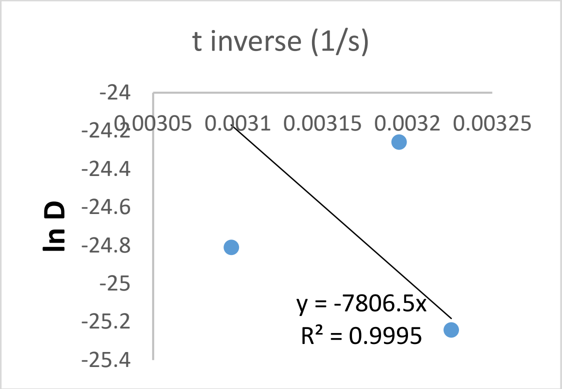

Fig. 3: Plot of ln D versus Temperature Inverse

4 CONCLUSION

From the study, the samples experienced second falling rate period prominent with tunnel dried samples; the statistical tools used to adjudge the good fit of the model proved that Page model of solar dying had the best fit for the drying process. Therefore, modeling of the banana peel drying would lead to development of an effective solar dryer to dry the peels which could be useful as a raw a material for citric acid production like cassava peels had proved. Optimization of the drying process is recommended for further study.

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