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Evaluation of Hot-Air Drying Kinetics of Cashew (*Anacardium occidentale*) Pomace in Ogbomoso

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ABSTRACT

Cashew pomace is a byproduct of the cashew fruit after the extraction of juice from its apple. Therefore, this study assessed drying kinetics of hot air drying using cabinet and solar drying methods on the Cashew Pomace (CP). Ripe cashew apples were sorted, washed and their juice squeezed out to obtain pomace. The pomace was sliced to a thickness of 2 mm and dried in the cabinet (55, 65 and 75 ^oC) and solar dryers. The drying processes were evaluated for the CP through appropriate modelling considering six thin layer drying models (Newton, Page, Modified Page, Henderson and Pabis, Logarithmic and two-term). Drying kinetics data were fitted into six thin-layer drying models to select the best model based on the highest R^2, lowest $\chi 2$ and RMSE value. Data were analyzed using Analysis of variance, with mean separation by Duncan's Multiple Range Test ($p<0.05$). The considered models had values of R^2 (coefficient of determination) that ranged from 0.510 to 0.998 and 0.866 to 0.996, and χ^2 (chi-square) values ranged from 0.001 to 0.225 and 0.002 to 0.124 for the cabinet and solar drying models, respectively. The D_{eff} (effective moisture diffusivity) ranged from 3.716-277.666 x 10^{-5} m^2/s. The Page model was the preferred drying model for pomace amongst the investigated kinetic models, and drying by cabinet produced samples with better industrial potential. Overall, the investigation suggests the potential for sustaining CP to support industrial growth and generate additional income for smallholder farmers.

INTRODUCTION

Cashew (*Anacardium occidentale*) tree, which produces the fruit from which the pomace is obtained, is ranked second to almond among the nine tree nuts that are of importance in the world trade (Akubor *et al*., 2013). The emanating waste from the processing creates disposal and pollution problems and hence contributes to the loss of valuable nutrients in several instances. However, several such wastes could be industrially utilized in the food industry after appropriate evaluation of the inherent chemical composition and potential functional properties (Akpata and Akubor, 2018). Cashew residue after expression of juice from the apple is called cashew pomace, and it is such a food waste that could be explored for beneficial secondary use. Products processed from cashew apples that are presently on an experimental basis include fruit paste, candied fruit, canned fruit, jam, jelly, juice, wine and vinegar (Akubor *et al.*, 2013) and thus indicating the potential volume of cashew pomace that may be obtained. Fresh cashew pomace has been reported to contain 72% moisture, 2.3% protein, 10.9% carbohydrate, 1.4% fat, 1.5% crude fiber, 1.1% ash, calcium, phosphorus and iron (Akpata and Akubor, 2018). In this regard, Aderiye *et al*. (2020) suggested that the pomace could be processed into flour and used as one of the ingredients in food and animal feed formulations.

One of the ways of preserving food items, including the pomace, is through drying, which is one of the major unit operations in food engineering. Drying is a moisture removal process due to simultaneous heat and mass transfer (Ravinder, 2014). Conventional food drying techniques are associated with issues such as case hardening, prolonged drying time, and high energy consumption (Zhang *et al*., 2010). Therefore, constant temperature hot-air drying has been used to dry a variety of food materials, including lemon, pumpkin, pepper, and ginger (Ghafoor *et al.,* 2020). Heat and mass transfer, moisture diffusivity, and activation energy have all been extensively investigated for a better understanding of the physical properties and thermal mechanisms that could be used to improve drying efficiency and food product quality (Aghbashlo *et al.,* 2008). Therefore, an adequately processed pomace into flour could be used in several ways that other plant by-products are used. This suggests that for efficient utilization and acceptance of cashew pomace flour, studies on its desirable keeping, processing and nutritional properties are important. Therefore, this study investigated the drying kinetics using solar and cabinet drying methods on cashew pomace.

METHODOLOGY

Materials

The cashew variety used for this study is prominent in the Ogbomoso axis. Fresh Cashew apples were harvested from a local farm in Ogbomoso, Oyo state. The time from harvesting to processing was ensured not to exceed 24 h to maintain its freshness and avoid deterioration of its apple. Only non-damaged and unspoiled fruits were used for drying. The experiment was conducted at the Owodunni Food Processing Laboratory, LAUTECH, Ogbomoso.

Preparation of cashew pomace

About 500 grams of apples were sorted, washed with clean water to remove adhering substances. Then the cleaned cashew apple juice was squeezed out to obtain pomace, which was sliced to a thickness range of 2mm with a Vernier caliper placed on the tray of a cabinet dryer.

Drying of CP

The sliced pomace was placed inside the cabinet dryer. The cabinet dryer was maintained at 55, 65 and 75 ºC, respectively and the moisture content was measured at an interval of 1h until constant weight was obtained. The same process was carried out in a solar dryer. The temperature in the solar dryer was recorded throughout the drying period using a thermometer reported by Asiru *et al*. (2013).

Determination of drying rate

The drying rate of the pomace was computed using

$$DR = \frac{M_{t+\Delta t-}\ M_t}{\Delta t}, \qquad (1)$$

Where, DR is the drying rate (kg H_2O/min) and

M_t and M_t + dt are the moisture contents in kg H_2O/kg at drying time (t) and change in drying time Δt.

Determination of Moisture Diffusivity and Activation Energy

Fick's modified second law of diffusion (equation (2)) was used to describe the moisture movement through food materials during drying to calculate the effective moisture removal, considering constant moisture diffusivity, infinite slab geometry, and uniform initial moisture

$$MR = \frac{8}{\pi^2}\sum_{n=0}^{\infty} \frac{1}{2n+1} exp\left(-\frac{(2n+1)\pi^2}{4L^2} D_{eff}t\right) \qquad (2)$$

D_{eff} is the effective moisture diffusivity (m² /s) and

L is half the thickness of the sample (m). Equation (2) simplifies to equation (3) for long drying times

$$MR = \frac{8}{\pi^2} exp\left(-\frac{(2n+1)^2\pi^2 D_{eff}t}{4L^2}\right) \qquad (3)$$

The equation was linearized as in Equation (4).

$$In\ MR = In\ \frac{8}{\pi^2} - \frac{\pi^2 D_{eff}t}{4L^2} \qquad (4)$$

The activation energy was calculated by using the Arrhenius equation, which describes the relationship between the diffusion coefficient and the drying temperature (equation (5)

$$D_{eff} = D_O exp\left(-\frac{Ea}{RT}\right) \quad (5)$$

Where Ea is the activation energy (J mol-1),
R is the gas constant (J mol-1 K-1), and
T is the absolute temperature (K).
To obtain Ea, the equation was linearized using the natural logarithm into:

$$In\ D_{eff} = In\ D_O - \frac{Ea}{RT}\frac{1}{T} \quad (6)$$

Then the activation energy was calculated using equation (7);

$$B = \frac{Ea}{R} \quad (7)$$

Where

B is the slope of the D_{eff} plot of 1/T and
R is the gas constant (J mol-1 K-1).

Thin-layer drying Equation

Existing thin-layer equations were selected to fit the experimental data obtained for cashew pomace by the direct least square method using SPSS, as shown in Table 1. The constant final moisture contents were considered as the equilibrium moisture contents of the samples. The equations were evaluated in terms of coefficients of determination (R^2), chi-square errors and root mean square errors (RMSE) as indicated in Equations (9) to (11):

$$\chi 2 = \frac{\sum_{i=1}^{N} (MR_{expt,i} - MR_{pred,i})^2}{N-z}, \quad (9)$$

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N} (MR_{expt,i} - MR_{pred,i})^2}, \quad (10)$$

$$R^2 = \frac{N\sum_{i=1}^{N} MR_{pred,j}MR_{expt,j} - \sum_{i=1}^{N} MR_{pred,j}\sum_{i=1}^{N} MR_{expt,j}}{\sqrt{[N\sum_{i=1}^{N} MR^2{}_{pred,j} - (\sum_{i=1}^{N} MR_{pred,j})^2][N\sum_{i=1}^{N} MR^2{}_{expt,j} - (\sum_{i=1}^{N} MR_{expt,j})^2]}} \quad (11)$$

Where $MR_{expt,i}$ is the experimental moisture ratio, $MR_{pred,i}$ is the predicted moisture ratio, N is the number of observations, and z is the number of constants in the drying model

Statistical Analysis

The proximate data obtained were statistically analyzed using SPSS 20.0 (International Business Machine Corp, Armonk, NY, USA). Through this, the effect of drying methods (cabinet and solar) was assessed. Regression analyses such as coefficient of determination (R^2), chi-square (χ^2), and root-mean-square error (RMSE) were therefore determined (AOAC, 2010).

Table I: Standard thin-layer drying models

S/No	Model Name	Model
1	Newton	MR = exp(-kt)
2	Page	MR = exp(-kt^n)
3	Modified Page	MR = exp[-(kt)n]
4	Henderson and Pabis	MR = aexp(-kt)+c
5	Logarithmic	MR = aexp(-kt)+c
6	Two Term	MR =aexp(k_0t)+bexp(-k_1t)

Sources: Wang, *et al*. (2012).

RESULTS AND DISCUSSION

Evaluation of the drying models for cashew pomace

The existing models considered in this study were the Newton, Page and Henderson and Pabis Logarithmic, Two-Term Exponential and Wangh and Singh models were statistically evaluated. Table 2 shows that the values of statistical parameters varied with different drying methods and temperature. The values of R^2 for cabinet dried samples ranged from 0.796 to 0.863, 0.933 to 0.997 and 0.510 to 0.998 for all samples at drying temperatures of 55, 65 and 75 ºC, respectively. The values of χ^2 for cabinet dried samples ranged from 0.081 to 0.225, 0.001 to 0.044 and 0.001 to 0.035 for all the samples dried at drying temperatures of 55, 65 and 75 °C, respectively. The corresponding values of RMSE for cabinet dried samples were 0.303 to 0.691, 0.051 to 0.317 and 0.040 to 0.285, respectively.

For solar-dried samples, the values of R^2 ranged from 0.866 to 0.996, χ^2 from 0.002 to 0.124 and RMSE from 0.063 to 0.533. Based on these values, the model that best describes the drying of the pomace was the Page model and it was observed for the cabinet dried samples at 75 ^{0}C. The validation of the predicted moisture ratio was done by comparing the predicted moisture ratio with the experimental values, as shown in Figures 1 and 2. Generally, there was good agreement between the experimental and predicted variables except for the sample dried at 50 ºC, which tended to deviate. This might be because drying at low temperature may not be as effective as that at high temperature. This indicates that the Page model could be used to predict the thin-layer drying of cashew pomace with cabinet drying at 75 °C.

Drying and Drying Rate Curves

Plots of moisture contents against time yielded the drying curves as shown in Figure 1, while a plot of drying rate against average moisture content gave the drying rate curve shown in Figure 2. Figure 1 shows the drying curves for cashew pomace samples using different drying methods (solar and cabinet drying at 55, 65 and 75 ºC).

At a drying temperature of 55 °C, equilibrium moisture content was reached in 4 h. At the temperatures of 65 and 75°C, drying took 6 h and 4 h for solar drying to reach the final weights. A gradual decrease in moisture content with an increase in drying time was observed, with the drying curve exhibiting a gentle downward curve. It was observed that the highest loss of moisture was in the early period of drying for the drying methods, and this was as a result of the evaporation of free water in cashew apple pomace samples. This result is in line with existing observations during the drying of food crops as reported by Rashid and Nakorn (2018) for mango slices, Lagnika *et al*. (2019) for green banana slices, Joardder *et al.* (2015) for pumpkin slices and Karthanos *et al*. (2019) for tomato slices.

The drying time for samples with the cabinet was shorter than that of the solar drying method, as previously observed in Eke (2021) for okra drying using the sun and solar dryer. The drying rate, however, decreased as drying progressed, as shown in Figure 2, but increased with an increase in drying air temperature in accordance with the findings of Baballs and Belessiotis (2020) for the drying of cocoa beans. The D_{eff} values were obtained from the slope of the linear graph of lnMR against time, as shown in Figure 3. It was observed that D_{eff} increased with an increase in temperature.
This was in line with Bobby (2022) that D_{eff} increased with an increase in temperature from 60 to 80 °C for a slice thickness of 3 mm during the drying of mango slices. This could be as a result of the fact that moisture movement in the falling rate drying period, where most of the drying took place, was mainly by diffusion.

Table II: Statistical Parameters for Selected Thin Layer Model on the Drying of Cashew Apple Pomace using Cabinet (55, 65 and 75 ^{0}C) and Solar Dryer

Drying Method	**Model**	**$\chi 2$**	**RMSE**	**R^2**
55 ^{0}C	Newton	0.096	0.691	0.796
	Page	0.081	0.401	0.863
	Henderson and Pabis	0.113	0.474	0.808
	Logarithmic	0.117	0.342	0.851
	Two-Term Exponential	0.225	0.335	0.808
	Wangh and Singh	0.183	0.303	0.844
65 ^{0}C	Newton	0.020	0.317	0.933
	Page	0.001	0.051	0.997
	Henderson and Pabis	0.022	0.209	0.941
	Logarithmic	0.015	0.123	0.969
	Two-Term Exponential	0.044	0.148	0.941
	Wangh and Singh	0.022	0.104	0.971
75 ^{0}C	Newton	0.016	0.285	0.943
	Page	0.001	0.040	0.998
	Henderson and Pabis	0.017	0.186	0.951
	Logarithmic	0.013	0.113	0.973
	Two-Term Exponential	0.035	0.132	0.51
	Wangh and Singh	0.018	0.094	0.75
Solar	Newton	0.057	0.533	0.866
	Page	0.002	0.063	0.996
	Henderson and Pabis	0.062	0.352	0.883
	Logarithmic	0.040	0.201	0.943
	Two-Term Exponential	0.124	0.249	0.883
	Wangh and Singh	0.067	0.184	0.936

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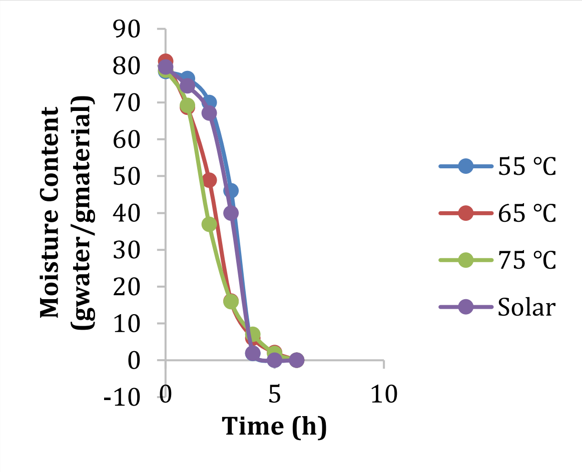

Figure 1: Effect of temperature on drying rate for cashew apple pomace

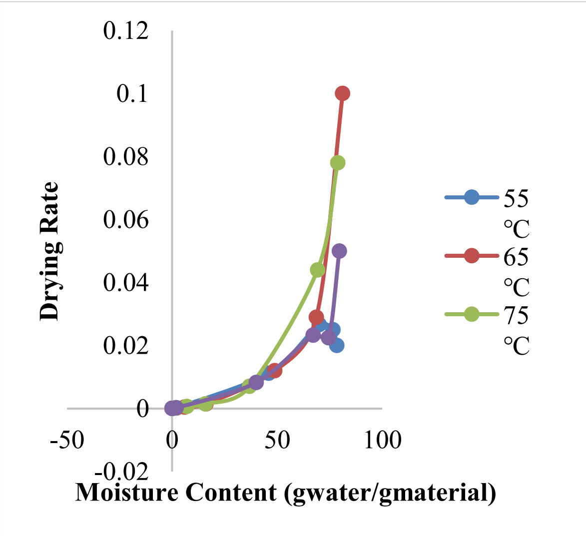

Figure 2: Effect of temperature on drying rate against moisture content for drying cashew apple pomace

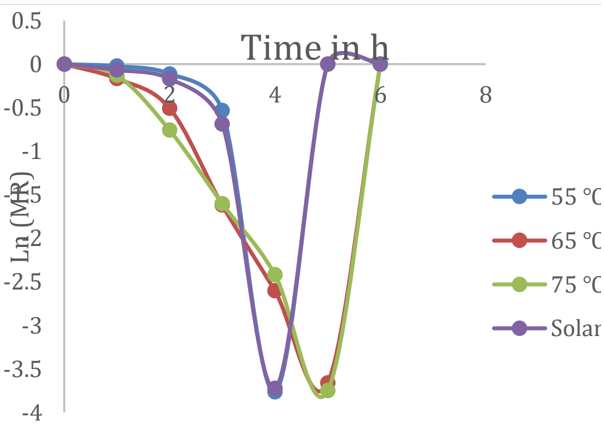

Figure 3: Estimation of moisture diffusivity for cashew pomace

CONCLUSION

This study has demonstrated the impact of hot-air drying on the kinetics of the prominent cashew in Ogbomoso. It was observed that the drying of cashew apple pomace occurs mainly in the falling rate period, and drying time decreased with temperature. The Page model was the preferred drying model for pomace amongst the investigated kinetic models and drying by cabinet produced samples with better industrial potentials. This indicates the possibility of sustaining the cashew pomace for industrial growth and additional income for the small holder farmers and consequently as a valuable index to reverse the nutritional and economic loss associated with cashew apples in tropical developing countries.

REFERENCES

Aderiye, B.I., Akpapunam, M.A. and Akubor, P.I. (2020). Effect of fermentation variable on the quality of cashew wine. *Journal of Agriculture, Science and Technology,* 1(1):66 – 69.

Aghbashlo, M., Kianmehr, M. H. and Samimi-Akhijahani, H. (2008). Influence of drying conditions on the effective moisture diffusivity, energy of activation and energy consumption during the thin-layer drying of berberis fruit (Berberidaceae). *Energy Convers. Management* 49: 2865–2871

Akpata, M.I. and Akubor, P.I. (2018). Proximate composition and selected functional properties of orange seed flour. *Plant Foods for Human Nutrition,* 54:353-362.

Akubor, P. I., Egbekun, M. K. and Obiegbuna, J. E. (2013). Quality assessment of cakes supplemented with cashew pomace and soybean flour. *Discovery,* 9(20):8 -19

Aremu, A. K., Adedokun, A. J. and Abdulganiyu, O. R. (2013). Effects of slice thickness and temperature on the drying kinetics of mango. *International journal of research and reviews in Applied Sciences*, 15(1):41-50.

Asiru (2013). Mathematical modelling of thin-layer drying of cashew kernels. *Agricultural Engineering International*: CIGR Journal S 1-23

Baballs, J. and Belessiotis, V. G. (2020). Influence of the drying conditions on the drying contents and moisture diffusivity during the thin-layer drying of figs. *Journal of Food Engineering*. 65, 449-458.

Bobby (2022). Drying temperature-dependent profile of bioactive compounds and prediction of antioxidant capacity of cashew apple pomace using coupled Gaussian Process Regression and Support Vector Regression (GPR–SVR) model. *Agricultural Engineering International: CIGR Journal*, 2-20.

Eke, A. B. (2013). Identification of suitable materials for solar thermal collectors in rural areas of Zaria, Nigeria. International Journal of Engineering and Technology. 3 (8) 834-841. Enwere, J.N. (2016). Food of plant origin. Afro-Orbis Publications Ltd, Nsukka, Nigeria. Pp. 123- 236.

Ghafoor, K., Juhaimi, F.A., Ozcan, M. M., Uslu, N., Babiker, E. E. and Ahmed, I. A. M. (2020). Total phenolic, total carotenoids, individual phenolic and antioxidant activity of ginger (Zingiber officinale) rhizome as affected by drying methods. *LWT-Food Science Technol*ogy, 126: 109354.

Joardder, M.U.H., Brown, R.J., Kumar, C. and Karim, M.A. (2015). Effect of Cell Wall Properties on Porosity and Shrinkage of Dried Apple. 18: 2327–2337.

Karthanos, V. T., Villabos, G. and Saravacos, G. D. (2019). Comparison of two methods of estimation of the effective moisture diffusivity from drying data. *Journal of Food Science* 55, (1), 218-231. Lagnika (2019). "Effect of Blanching and Ultrasound on Drying Time, Physicochemical and Bioactive Compounds of Dried Cashew Apple." Handbook of Food Engineering. Marcel Dekker Inc., New York, p. 362.

Rashid and Nakorn (2018). Optimization of process variables for drying of cashew nuts by superheated steam. *Agricultural Engineering International*: *CIGR Journal* S 1-23

Ravinder, K.S. (2014). Open sun and greenhouse drying of agricultural food products: a review. *International Journal of Engineering Research and Technology* 3(3):1053-1065

Shahzad, F., Ruhi, T. and Vishal, K. (2013). Performance Evaluation and Process Optimization of Potato Drying using Hot Air Oven. *Journal of Food Processing and Technology*, 4(10):1 – 9

Wang, Y., Zhang, M., Mujumdar, A.S., Mothibe, K. J. and Azam, S.M.R. (2012). Effect of blanching on microwave freeze drying of stem lettuce cubes in a circular conduit drying chamber. *Journal of Food Engineering,* 113: 177-185.

Zhang, M., Jiang, H. and Lim, R.X. (2010). Recent Developments in Microwave-Assisted Drying of Vegetables, Fruits, and Aquatic Products: Drying Kinetics and Quality Considerations. *Drying Technology,* 28: 1307–1316.