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EVALUATION OF A SUITABLE THIN LAYER MODEL FOR DRYING OF PRETREATED COCOYAM SLICES USING A CONVECTIVE HOT AIR DRYER

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Abstract— **This work evaluated the thin layer drying kinetics of pretreated cocoyam slices (*Xanthosoma sagittifolium)* in a convective hot air dryer. Seven thin layer theoretical and empirical models widely used in describing the drying behaviour of agricultural products were fitted to the experimental data in order to select the appropriate model for predicting the drying kinetics of cocoyam (*Xanthosoma sagittifolium*). The Page model showed the best fit under certain drying conditions based on the coefficient of determination (R^2) and sum of squares error (*SSE*). Comparison was made between the experimental and model predicted moisture ratio by non-linear regression analysis. Furthermore, the effect of drying temperature and pretreatment on the best model constants was evaluated. Consequently, the page model showed an excellent fit with the experimental data ($R^2 > 0.99$ and *SSE* < 0.0010) for the drying temperatures of 50, 60 and 70 °C at different sample pretreatments; untreated (raw), water soaked and brine soaked respectively. Thus, page model can adequately predict the drying kinetics of cocoyam under pretreatment conditions.**

Keywords— **Thin layer drying, pretreated cocoyam slices, drying kinetics, empirical models**

I. INTRODUCTION

Cocoyam (Taro; *Xanthosoma sagittifolium and Tannia; Colocasia esculenta*) is a very important root and tuber crop which possesses nutritional benefits over other root and tuber crops (Boakye *et al.*, 2018, FAO 2012, Ojinnaka and Nnorom, 2015). Cocoyams are characterized morphologically by subterranean stems, corms, enclosed by dry scale-like leaves. The cocoyams are differentiated in leaf attachment: tannia has the stalk attached to the leaf edge whereas in taro it emerges near the centre (Lewu *et al.*, 2010). The corms, cormels, and leaves are important sources of carbohydrates for human consumption and animal feed, and a good source of income to farmers. They contain digestible starch, good quality protein, vitamin C, thiamine, riboflavin, niacin, and high scores of essential amino acids (Lewu *et al.*, 2010). Cormels of Cocoyam can be eaten boiled, baked or partly boiled and fried in oil. The corms can also be peeled, dried and ground to powder for pastry that can be stuffed with meat or other fillings (Lim, 2015). Although, the nutritional benefits of cocoyam (Xanthosoma genre) are enormous, certain factors have limited their utilization and market opportunity. Their possession of antinutrients, mostly oxalates give an acid and a bitter-astringent taste and cause irritation in the throat and mouth when meal prepared from it are eaten, and these impede the bioavailability of calcium specially when the food prepared from it are not well processed (Sefa-Dedeh and Agyir-sackey, 2004., Owusu-Darko *et al*., 2014). Elimination or reduction of these high Oxalates adverse effects, has led to the development of numerous methodologies like, cooking, soaking, oven drying, sun drying, and fermentation (Igbabul *et al*., 2014; Sefa-Dedeh & Agyir-Sackey, 2004).

Also, high rate of post-harvest losses which lead to low storage and bulkiness is a problem associated with processing and utilization of cocoyam (Mbofung *et al*., 2006). Greater utilization of cocoyam can be achieved through drying for stability, better storage, convenience and ease in preparation into other food forms.

Drying works by the principles of heat and mass transfer and depends on conditions such as temperature, relative humidity, air velocity and material thickness (Pandey *et al*., 2010; Jangam, 2011). Application of appropriate drying technique that will describe the drying process accurately is very necessary for agricultural materials. Generally, the drying technique used for most biological and agricultural materials for efficient control and uniform distribution of drying air and temperature conditions over the material for improved overall quality of the final product is thin layer convective drying (Sacilik, 2007; Kadam *et al*., 2011., Da Silva *et al*., 2015). The evaluation of thin layer drying process involves the use of empirical and theoretical curve models to describe the drying process and to predict the drying kinetics of agricultural foods (Meisami-asl *et al*., 2010; Rayaguru and Routray, 2012; Erbay and Icier, 2010). Hence, the objective of this work was to

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evaluate the drying behaviour of cocoyam in order to select a suitable thin layer model for drying of pretreated cocoyam slices using a convective hot air dryer.

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II. MATERIALS AND METHODS

A. Materials

Healthy sample of cocoyam cormels (Xanthosoma sagittifolium) was collected from a local farm in Ikot Ekpene Local Government of Akwa Ibom state. All the samples were harvested within 8-10 month of planting (the maturation period of tannia). The sample selection was based on large, middle and small corms (cormels) sizes that are not damaged or attacked by pests. The samples were washed; drained and other extraneous materials were removed completely. The cocoyam was peeled and sliced into uniform thickness of about 3 mm. The sliced tubers were washed again with clean water and divided into portions. A portion was left raw which served as a control others were treated with two processing techniques; soaking in water and soaking in brine before the drying. The samples were stored at a room temperature in a desiccator during the drying duration which lasted for one week. A total of 9 experimental runs were carried out in three replications. The experiments were conducted in the Food Engineering laboratory of the Department of Agricultural and Food Engineering, Faculty of Engineering, University of Uyo. The peeled sliced samples were labeled and dried at three (3) different temperature levels with an average relative humidity of 45% ± 3% and a constant air velocity.

B. Convective hot-air dryer

An Electric Convection Oven dryer (NFC-3D Series) with an operating voltage of 380V/220V, a power of 4.5 kW and a frequency of 50Hz was used for the research work. The dryer was made up of five basic units including; a fan that gives the desired drying air velocity, electrical heaters which are meant for controlling drying air temperature, a drying chamber, a dehumidifier which regulates the relative humidity of the drying chamber, and a system unit where all the data was stored automatically. The exterior dimensions of the dryer were 860 mm x 111 mm x 500 mm with a tray size of 600 mm x 40 mm x 20 mm. The dryer had a single door which was opened at the front to allow the insertion or removal of the drying tray. The dryer also had an air velocity control button which comprised of just two levels of speed. The authentic speed was measured using a vane anemometer sensor with an accuracy of ± 0.03 m/s, placed opposite to the blowing fan and 1 cm above the drying tray.

C. Experimental procedure

Samples were selected and some portions from every piece were sliced into a thin layer of the required dimension. Prior to start of each set of experimental runs, the dryer temperature was made to attain a stable state of equilibrium condition by running it empty for about 45 minutes. For each experimental run, the drying of the cocoyam began with an initial moisture content of 70.59 % (wet basis) and continued until a constant weight (to three decimal places) of each sample was observed. A total of twenty seven (27) runs were conducted with three (3) levels of air temperature (50, 60 and 70°C) and three (3) levels of pretreatment at a constant air velocity of 1.16 m/s. Each experimental run was completed in triplicate and the average values were taken. A 40 minute time interval was adopted for the collection of experimental data.

D. Moisture Content determination

The moisture content of the cocoyam slices was determined with the use of a digital moisture analyzer (OHAUS MB45, UK) set at 105˚C. The slice was weighed in a sample plate and measurements were made in triplicate. The moisture analyser was allowed to cool between tests for each cocoyam slices.

E. Mathematical Modeling

The moisture ratio was used to plot the drying curves instead of the moisture content because the initial value for all the drying experiments which is 1 is a uniform value. The moisture ratio during drying was obtained from the moisture content values using the first order exponential model equation.

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

Where *MR* is the dimensionless moisture ratio, M_t is moisture content at any time of drying (kg water/kg dry matter), M_i is the initial moisture content (kg water/kg dry matter) and M_e is the equilibrium moisture content (kg water/ kg dry matter), respectively. The drying rate is determined using the following equation:

$$DR = \frac{M_{t+dt} - M_t}{dt} \qquad (2)$$

Where *DR* is the drying rate; M_{t+dt} is the moisture content at t + *dt* (kg water/kg dry matter); t is the time (min).

F. Model Validation

The goodness of fit of the thin layer models to the experimental data was evaluated using the coefficient of determination (R^2) and the sum of squares error (SSE) such that the higher the value of R^2 and the lower the SSE value, the better was the goodness of fit (Yaldiz *et al*., 2001; Rayaguru and Routray, 2012; Tahmasebi *et al*., 2014). R-squared (R^2) is also known as the coefficient of determination, or the coefficient of multiple determination for multiple regression and measures how close the statistical data could fit the regression line. The higher the value of R-squared, the better the model fits the data (Erbay and Icier, 2010). This is computed mathematically as:

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$$R^2 = \frac{\sum_{I=1}^{N}\left(MR_{exp,ii} - MR_{pre,i}\right)^2}{\sum_{i=1}^{N}\left(MR_{pre,i} - MR_{exp,i}\right)^2} \quad (3)$$

SSE is also known as the sum of squares error, which measures the differences between each observation and the mean of the group. It can be used as a measure of variation within a cluster. Mathematically, it can be written as:

$$SSE = \frac{1}{N}\sum_{i=1}^{N}\left(MR_{pre,i} - MR_{exp,i}\right)^2 \quad (4)$$

where $MR_{pre,i}$ is the *ith* predicted moisture ratio, $MR_{exp,i}$ is the ith experimental moisture ratio, and N is number of observations.

Table 1.Thin layer mathematical models used to describe cocoyam drying

Model name	Model	References
Exponential	$MR=exp(-kt)$	Udomkun *et al*., 2015
Page	$MR = exp(-kt^n)$	Akoy, 2014
Logarithmic	$MR=a\ exp(-kt)+c$	Kaur and Singh, 2014
Two-term	$MR = a.exp(-k_0t) + b.exp(-k_1t)$	Chayjan *et al*., 2013
Generalized exponential	$MR=A\ exp(-kt)$	Hashim *et al*., 2014
Parabolic	$MR=a+bt+ct^2$	Doymaz (2010)
Wang and Singh	$MR=1+at+bt^2$	Manikantan *et al*., 2014

Note*: a, b, c, k, k0, k1,* and *n* are model constants

G. Statistical design and data analysis

The data collected was analysed at the 95% confidence level using GraphPad Prism 5.0 software (GraphPad Software Inc., La Jolla, CA, USA). The statistical design employed used a factorial 3 × 4 arrangement (Pretreatment x temperature x time x Moisture Ratio), with 9 runs completed in triplicate which amounted to a total of 27 experimental units. The mean values of all levels were used for the mathematical modelling. The experimental data was regressed non-linearly and fitted to all the selected models.

III RESULTS AND DISCUSSION

The non-linear dimension moisture ratio (MR) was obtained during drying from the experimental moisture content values using the first order exponential model equation (equation 1), in order to choose an appropriate model to predict the dying kinetics of cocoyam. The value for standard initial moisture content of cocoyam samples used was 70.59 ±0.23 (% wet basis). Seven thin layer drying models (see Table 1) were compared using their statistical indicators of R^2 and *SSE* as seen in Table 2.

Table 2 Statistical parameters for moisture ratio models for dried cocoyam slices

Model name	Pretreatment method	Drying air temperature					
		50 °C		60 °C		70 °C	
		R^2	SSE	R^2	SSE	R^2	SSE
Parabolic	Raw	0.991	0.0011	0.958	0.0044	0.897	0.0087
	Water soaked	0.991	0.0010	0.990	0.0012	0.873	0.0110
	Brine soaked	0.998	0.0002	0.989	0.0011	0.902	0.0090
Exponential	Raw	0.929	0.0089	0.977	0.0023	0.998	0.0002
	Water soaked	0.890	0.0128	0.991	0.0011	0.984	0.0014
	Brine soaked	0.953	0.0055	0.951	0.0061	0.987	0.0012
Logarithmic	Raw	0.986	0.0017	0.984	0.0017	0.998	0.0002
	Water soaked	0.991	0.0011	0.917	0.0011	0.985	0.0012
	Brine soaked	0.995	0.0006	0.975	0.0061	0.989	0.0010
Wang and	Raw	0.988	0.0014	0.949	0.0052	0.834	0.0137
Sings	Water soaked	0.988	0.0014	0.983	0.0016	0.818	0.0159
	Brine soaked	0.997	0.0004	0.989	0.0031	0.861	0.0139
Generalized	Raw	0.944	0.0068	0.980	0.0021	0.999	0.0002
Exponential	Water soaked	0.918	0.0096	0.992	0.0001	0.985	0.0012
	Brine soaked	0.964	0.0043	0.958	0.0050	0.982	0.0011
Page	Raw	0.993	0.0008	0.996	0.0004	0.999	0.0001
	Water soaked	0.996	0.0006	0.997	0.0003	0.998	0.0002
	Brine soaked	0.996	0.0005	0.992	0.0010	0.999	0.0000
Two Term	Raw	0.944	0.0068	0.979	0.0021	0.999	0.0002
	Water soaked	0.918	0.0096	0.992	0.0010	0.985	0.0012
	Brine soaked	0.964	0.0043	0.958	0.0050	0.988	0.0012

Also, the best model describing the thin layer drying characteristic of cocoyam was chosen from sample with highest R^2 value and lowest SSE value. From Table 2, the Page model gave the best fit at all temperature levels for all the pretreatment methods, based on R^2 and SSE values. The R^2 values of the page model ranged from 0.992 to 0.999 and SSE values from 0.0000 to 0.0010. Hence, the page model suitably represented the experimental values of the moisture ratio of both the raw and

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pretreated Cocoyam (Xanthosoma sagittifolium). The individual constants of the best model are presented in Table 3.

Table 3. Drying kinetic constants of the best model under different drying conditions

Model Name	Temperature ^{0}C	Model constant		
		Raw	Water soaked	Brine soaked
Page Model	50	K=0.008, n=0.994	K=0.004, n=0.988	K=0.010, n=0.991
	60	K=0.002, n=0.997	K=0.007, n=1.008	K=0.006, n=0.992
	70	K=0.003, n=0.996	K=0.007, n=0.987	K=0.001, n=0.998

K represents kinetic coefficient constant and n is the model number constant

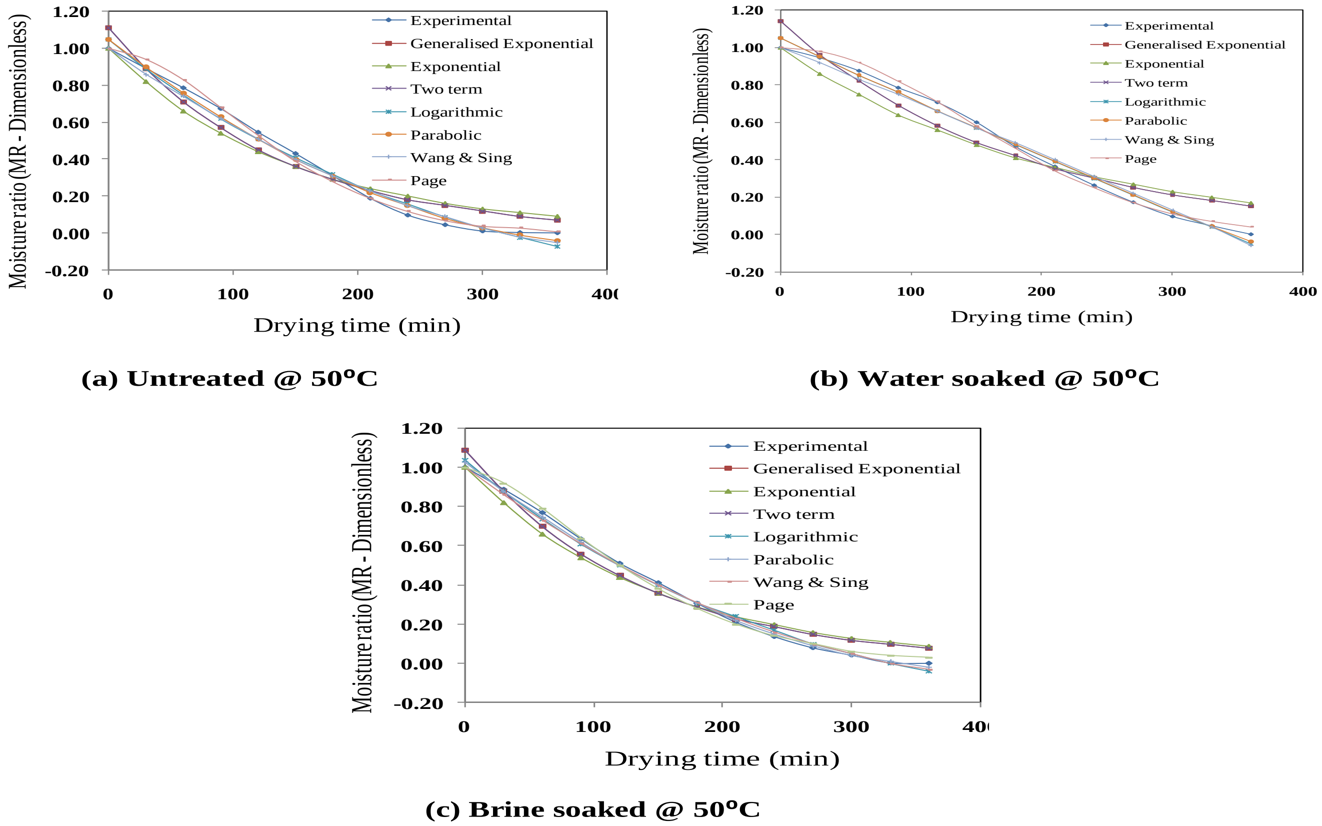

Figure 1. Comparison of models for different pretreatment levels at 50°C

The drying experiment at 70°C was an example showing the comparison of models for different pretreatment levels with the highest values of R^2 and lowest SSE at all pretreatment levels. The results of fitting each of the drying models are shown in Figure 1 for pretreatments of untreated (raw), water soaked and brine soaked samples respectively. As anticipated, drying occur during the falling rate period. Figure 1 also shows that the moisture ratio of the samples decreased as the drying time increased. From Figures 2a to 2d, both experimental and predicted moisture ratio were very similar at each pretreatment and increase in the total drying time reduces the moisture ratio. Generally, as also noticed from Figures 2a to 2d, moisture ratio reduces with an increase in drying temperature and increase in the drying time. Considering the individual drying temperatures, it was observed that at 70 ^{0}C, water soaked pretreated samples was the fastest to reach a safe moisture ratio after about 120 minutes, followed by the brine soaked pretreated samples at about 150 minutes before the untreated (raw) sample at about 180 minutes. Hence, at higher temperatures (70 ^{0}C being the highest drying temperature used for this research), pretreatment of cocoyam enhances drying rate. This trend was not the same at lower temperatures (50 ^{0}C and 60 ^{0}C), as the raw (untreated) samples of cocoyam had the least drying time to get to a safe moisture ratio at 300 minutes and 200 minutes with 50 ^{0}C and 60 ^{0}C temperatures respectively. The water soaked and brine soaked pretreated samples took more drying time. Also, Figures 2a to 2d showed that brine soaked pretreated cocoyam samples took less time

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(350 minutes and 250 minutes) at 50 ^{0}C and 60 ^{0}C temperatures respectively, to get to safe moisture ratio compared to water soaked pretreated samples that took 370 minutes and 300 minutes respectively. The Page model gave the finest fit and stability for the experimental drying curve under all drying conditions. It is also suitable to note that all the other models used closely followed the page model.

Furthermore, Figure 2a-c show the variations between the experimentally determined moisture ratio and the page model predicted moisture ratio at different drying temperatures for different pretreatment; untreated (raw), water soaked and brine soaked respectively. According to the results, the page model predicted drying curve was in agreement with the experimental drying curve under all drying conditions tested. The effects of temperature and pretreatment on the model constants (Table 3) were also investigated by multiple regression analysis.

The multiple combinations of the model constants and the drying conditions of temperature and sample pretreatment were used to validate the page model by comparing the experimental moisture ratio values with the predicted values, and these values fitted along a linear line where the 70 ^{0}C drying temperature gave the best fit with the regression R^2 of 0.999 (Figure 2d). Thus it can be concluded that the page model is valid for predicting the drying kinetics of cocoyam within a drying temperature ranges of 50°C to 70°C at different pretreatment conditions.

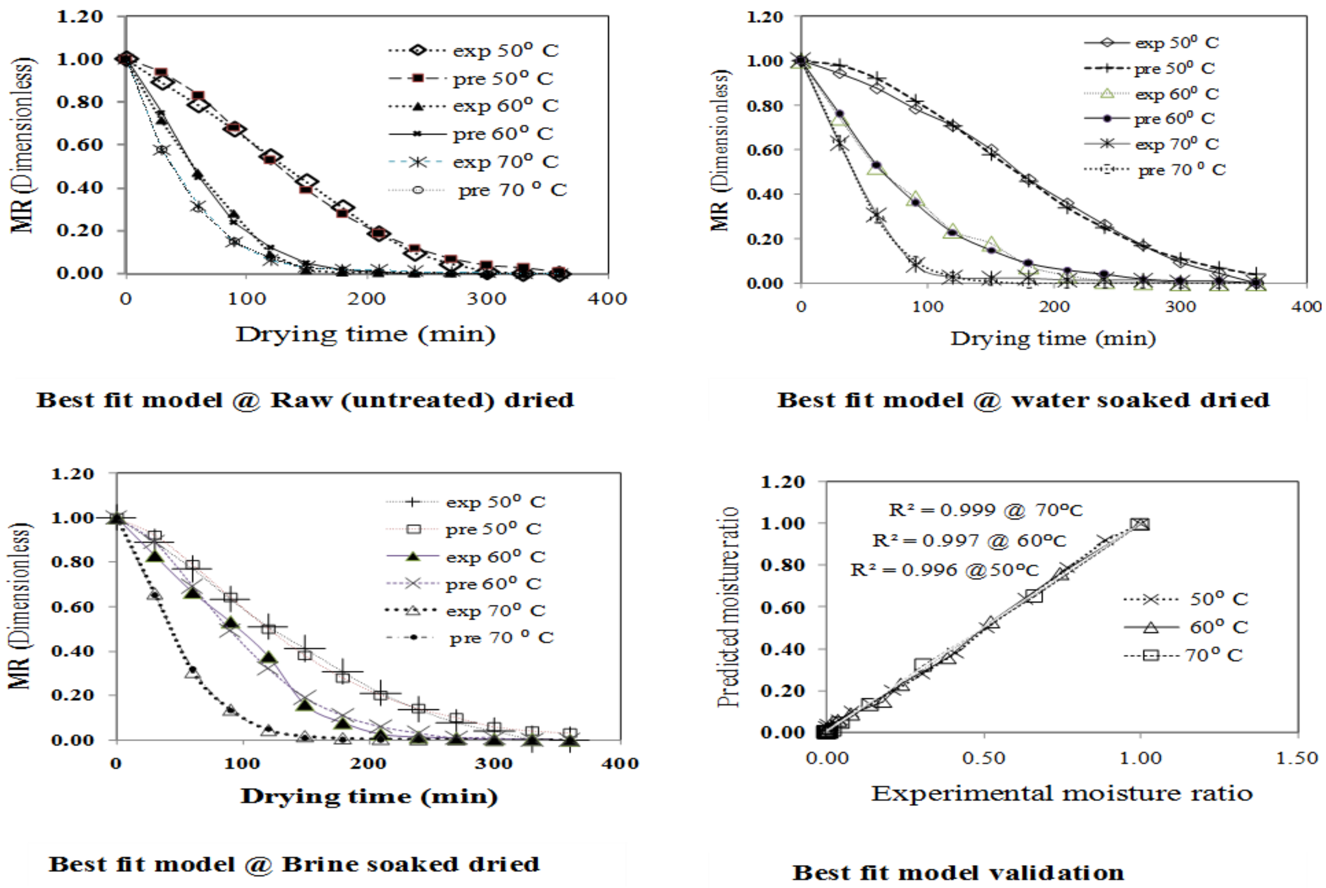

Figure 2. Variations and validation of page model under different drying conditions

IV. CONCLUSION

In determining a suitable model for predicting the drying kinetics of cocoyam, the moisture ratio was experimentally investigated using a convective hot air dryer at different temperature and pretreatment levels. The results of fitting the experimental data to 7 selected thin layer models showed that the page model resulted in an excellent fit for all drying temperatures of 50, 60 and 70°C and sample pretreatment conditions; untreated (raw), water soaked and brine soaked. It was clear that the page model was most suitable for predicting the drying curve of cocoyam. At all drying temperatures tested, the value of R^2 was higher than 0.99 and the SSE value was less than 0.0010. The page model was further validated by comparing the predicted moisture ratio against the experimental moisture figures. The data points were identified to lie on a straight line, showing the suitability of the model in describing the drying kinetics of pretreated cocoyam at a temperature range of 50°C to 70°C. Hence, the Page model can be applied in describing the drying behaviour and predicting the drying kinetics of cocoyam (*Xanthosoma sagittifolium*).

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