Mathematical Modelling of Blanched and Unblanched Solar Dried Ginger Rhizome Varieties

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Abstract:

This research examines the mathematical modelling of blanched and unblanched solar dried ginger rhizome varieties. The Umudike ginger I and II (UG I and UG II) were blanched with an Electric water bath in the Soil and Water Laboratory, Agricultural and Bioresources Engineering Department, Michael Okpara University of Agriculture Umudike, Abia State. The samples UG I and UG II, were blanched for 3, 6, and 9 minutes at 50°C respectively. Each samples with the treatment were subjected to active solar drying in sequence. Also, blanched and unblanched UG I and UG II were subjected to active solar drying. The treatment was carried out at 10mm thickness for UG I and UG II rhizome. There were ten different mathematical drying models compared based on the correlation coefficient, mean bias error, root mean square error and reduced chi-square method. The various models used are efficient thin layer drying models and its best fitted model varies due to the blanched and unblanched treatments of UG I and UG II. It was also used to validate and predict equations for all the treatments. The Henderson and Pabis model was recommended for predicting the drying characteristics of blanched and unblanched UG I and UG II ginger rhizomes.

Keywords: Blanching, Drying models, Ginger rhizomes, Mathematical models, Solar drying

1. Introduction

Ginger can be refer to as a basic and essential medicinal spice [1]. It is one of the spices and condiments that have been cultivated for millennia around the world [2]. Nigeria is one of the major producers and exporters of ginger globally, with an annual production of about 160,000 metric tons on 48,910 hectares, which is 7.9% of world production [3]. Fresh ginger has a proximate composition of 6% of fatty oil, 60% carbohydrate, 9% protein, 8% ash, 3% volatile oil and 12% water [4] and [5]. Dry ginger contains 3% essential oil, 5% percent oleoresin, 50% starch, 12% moisture, and small amounts of protein, carbohydrate, fats, and ash as stated by [6].

Drying is a useful preservation method widely practiced globally. It is the act of extracting the moisture of a product to a specific threshold by evaporation then the product can be stored for an extended period to decrease the product's water activity, minimizes physical changes, reduces microbiological activity and chemical changes encountered when stored [7] and [8].

Blanching can simply be referred to as the scalding of vegetables in boiling water for a short period and this is followed by a quick and thorough cooling in cold water. Blanching stops enzyme actions which do lead to loss of flavour, colour and texture [9]. The change in food pigments according to the decimal reduction time (D value) gives Na2Co3 or CaO → Blancher water and loss of texture in some foods gives Cacl2 (+)→Blancher water This process consist of three stages which are pre-heating, blanching and cooling [10] and [11].

The method of drying in a thin layer of sample particle is known as thin layer drying [12]. The layer's depth (thickness) should be consistent, without exceeding three layers of particles is to minimize deterioration and microbial spoilage by reducing the water level to a certain threshold. [13] reported that Fick's second law is usually used to explain liquid diffusion theory, which describes agricultural products' drying phenomenon when employing thin-layer drying equations. Research carried out by [14] showed that ginger drying above 70°C appears to reduce its protein and change its sensory attributes by losing its aroma and colour variation. The antioxidant properties of ginger, which are obtained from the quantity of oleoresin and polyphenols present in it, have been linked to its medicinal value [15]. In the past six decades, the study of drying behaviour of various materials has been the subject of interest for different investigators on theoretical and practical grounds [16], [17] and [18]. Models like Newton, Page, Henderson and Pabis, Midilli-Kcuk, and Wang-Singh are commonly applied [19]. Different models established have been applied on many crops by researchers, and the best fitted selected to represent such crop's drying kinetic behavior [19] and [20]. Every crop has its own distinct drying behavioural pattern and is usually predicted by a particular drying model using some statistical indicators.

The best model can then be applied in designing dryers and processing of that product. The knowledge of the changes in agricultural products characteristics when subjected to drying process is of fundamental importance for correct storage, processing and the design, fabrication, and operation of equipment applied during the post-harvest processing of these products [21] and [22]. Thereby, it improves food productivity, reduces heavy post-harvest losses, and increases the farmers' income by recommending the best drying method for preserving ginger rhizomes. This work's objective is to carry out mathematical modelling of thin layer drying kinetics of ginger using solar energy to dry blanch and unblanched UG I and UG II varieties of ginger. This work's general objective is to determine the experimental and analytical studies of thin-layer drying process of ginger rhizomes for an active solar drying method of two varieties of ginger. There are no published work on modelling of ginger drying behaviour during their water removal stage. Efforts of most researches have been channeled mainly on physical and mechanical properties. As a result, much is not known about ginger's behavioural pattern during the period of drying. The drying of most fruits and other agricultural products has gained successful prediction using mathematical models [23] and [24].

2. Materials and methods

A custard bowl (4 kg) for each of the two ginger varieties, that is Umudike Ginger I and Umudike Ginger II (UG I and II), were procure from National Root Crop Research Institute (NRCRI), Umudike, Abia State, Nigeria. The ginger varieties which were whole, were sorted by their appearance and size, it was kept in the laboratory to obtain a uniformed room atmosphere for about 24 hours of purchase. It was noted that the ginger varieties were purchased after about five days to one week of harvest. Four Kilograms each of UG I and UG II was cleaned and sorted into samples. A sample of 4kg was peeled and splitted with a stainless-steel knife. The samples were split and whole (peeled and unpeeled) were blanched with the aid of an Electric water bath (DK420 model, Techmel and Techmel, USA) in the Soil and Water Laboratory, Department of Agricultural and Bioresources Engineering, Michael Okpara University of Agriculture, Umudike, Abia State. The UG I and UG II, were blanched for 3, 6, and 9 minutes, at temperature of 50℃, respectively. Each samples with various treatments was subjected to active solar drying in sequence. Also, blanched and unblanched UG I and UG II were subjected to active solar drying. Also, unblanched UG I and UG II were subjected to active solar drying. All treatments were done at 10mm thickness for UG I and UG II rhizome [25] and [26].

2.1 Experimental Procedures

An existing active solar dryer in Agricultural and Bioresources Engineering Department, Michael Okpara University of Agriculture, Umudike, was used in the experiment. It consists of a solar collector, solar panel 180W, DC aspirator fan, drying chamber, heat storage unit, drying trays and a solar battery rated 200Ah. The dryer body was constructed using a transparent cover made of perplex material. The solar panel traps solar energy and uses it to charge the dc battery, which powers the control box; the control box was programmed to regulate the dc blower periodically to aid the moisture removal at the drying chamber [27] and [28]. The drying chamber houses the dried products placed in perforated metal trays and has a door to allow for easy loading and unloading of crops in the tray. The heat storage unit was incorporated with black pebbles that trap the sunlight that falls on it and stores it in the form of heat for further use when there is no solar radiation [29] and [30]. There was an aspirator on top of the dryer that forces air from the inlet opening through a solar collector section through the product bed in the dryer's drying chamber. Solar radiation falling on the dryer was utilized to heat the air passing through the samples. Then, heated air was blown through the drying chamber and vents were provided through which moisture was removed [31] and [32]. The samples were spread in a single layer on the metal trays and dried until equilibrium moisture content was achieved. This procedure was followed for blanched and unblanched treatments respectively. Drying started from 8.00 a.m down to 6.00 p.m daily till equilibrium moisture content was reached. The experiment was carried out three times, and the average value was used for further calculations [33] and [34]. The process by which the data was obtained is shown below:

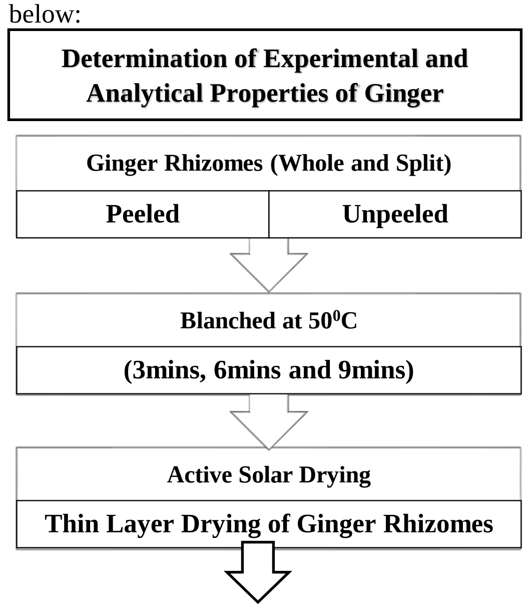

Figure 1: Flowchart showing the process of obtaining ginger rhizomes experimental data.

2.2 Experimental Design

This experiment was based on a factorial experiment in random block design consisting of two factors for solar drying. For solar drying, the two factors are Varieties, which has two levels (UG I and UG II). Treatments are at two levels (blanched and unblanched). The design matrix of the experiment is as shown in Table 1 and 2. These experiments were replicated thrice, and the average value was used for further calculations. The limitations and constraints for the adoption of this methodology includes lack of highly sensitive instruments and advanced techniques for research studies.

2.3 Mathematical Modeling of Drying Kinetics

The modeling of drying behavior of agricultural commodities is inevitable to effectively study their drying kinetics [35] and [36]. The data obtained from experimental drying of UG I and UG II for unblanched and blanched treatments were fitted with ten thin-layer drying mathematical models proposed by several authors, as listed in Table 3. The curve fitting was done using Microsoft excel (2016) solver add-ins.

2.4 Statistical evaluation of drying models

Statistical parameters were used to select the best drying model expressing the samples' drying curves and determine the fits' validity. The least-square method of parameter estimation was used to find the drying models' missing parameters [37]. Multiple models will be used to verify the errors by understanding the relationships among the data and other parameters. The use of multiple models help to determine the overall accuracy of the experiment. The coefficient of determination (R2), root mean square error (RMSE) and the reduced chi-square value (x2) are shown in equations 1, 2 and 3 were used to select the best equation expressing the drying curves of the sample. The highest values of R2 and the lowest values of x2 and RMSE will be used as a basis for determining the best fit [38] and [39]. The model was validated by comparing the experimental data with the predicted data for consistency to determine the unknown parameters.

$$R^2 = \frac{\sum_{i=1}^{N} MR_{Pre,i} MR_{exp,i} - \sum_{i=1}^{N} MR_{pre,i} \sum_{i=1}^{N} MR_{exp,i}}{\sqrt{(\sum_{i=1}^{N} (MR_{pre,i})^2 - (\sum_{i=1}^{N} MR_{pre,i})^2)(N \sum_{i=1}^{N} MR_{exp,i} - (\sum_{i=1}^{N} MR_{exp,i})^2)}} \quad 1$$

$$X^2 = \frac{\sum_{i=1}^{n} (MR_{exp,i} - MR_{pre,i})^2}{N-n} \quad 2$$

$$\text{RMSE} = [\sum_{i=1}^{N} \frac{1}{N} (MR_{exp,i} - MR_{pre,i})^2]^{\frac{1}{2}} \quad 3$$

Table 1 Experiments done to show factorial design (Solar dryer)

Treatments	Varieties UG I	UG II
Blanched ginger rhizome	Exp 1	Exp 2
Unblanched ginger rhizome	Exp 3	Exp 4

Where Exp: Experiment

Table 2 Thin layer mathematical models used

No	Model name	Model Equation	Reference
1	Newton	$MR = exp\ (-kt)$	Mujumdar (2006)
2	Page	$MR = exp\ (-kt^n)$	Flores *et al.* (2012)
3	Henderson and Pabis	$MR = a\ exp\ (-kt)$	Radhika *et al.*(2011)
4	Midilli and Kucuk	$MR = a\ exp(-kt^n) + bt$	Midilli and kucuk (2002)
5	Logarithmic	$MR = a\ exp\ (-kt)+c$	Yagcioglu *et al*. (1999)
6	Two-term	$MR = a\ exp(-K_1t) + b\ exp\ (-K_2t)$	Sacilik (2007)
7	Demir *et al.*	$MR = a\ exp\ (-K\ t)^n + b$	Demir *et al*. (2007)
8	Verma *et al.*	$MR = a\ exp(-kt) + (1 - a)exp\ (-gt)$	Akpinar (2006)
9	Approximation of diffusion	$MR = a\ exp(-kt) + (1 - a)\ exp\ (-kbt)$	Yaldyz and Ertekyn (2007)
10	Hii *et al*.	$MR = a\ exp(-K_1t^n) + b\ exp(-K_2t^n)$	Kumar *et al*. (2014)

Where MR = (M – M_e),)/(M_o – M_e), moisture ratio (dimensionless); a, b, c, g, k, k1, k2 and n = drying constants; t = drying time (mins).

3.0 Results and Discussion

The statistical results of non-linear regression done using moisture ratio of solar drying experimental data is shown in Table 3. Validation of the best-fitted model was done statistically and graphically. The best three models were selected out of the ten models and also the best among the three were used for further validations. The tables present the results of non-linear regression analysis of the best model fitting the experimental data with the comparison criteria used to evaluate the goodness of fit, based on the requirements of the highest R2 and the lowest RMSE and reduced chi-square X2, the most suitable models, differs concerning various treatments of the UG I and II samples, representing the thin-layer drying behaviour of UG I and UG II for both unblanched and blanched treatments, using solar drying process [40] and [41].

Validation of statistical drying results for the various models was made by comparing the experimental moisture ratio and the predicted moisture ratio data. This was done by plotting the predicted MR values versus the observed/experimental MR values, as shown in Figures 1 to 4. From the figures, it is clear that the predicted MR values lie close to the graph's straight-line trend.

Table 3: Best fitted Statistical Results Obtained from the Drying Models (Solar Drying)

Sample type	Model Name	Model parameters/constants									Performance prediction		
		A	B	C	G	K	K_o	K_1	K_2	N	R^2	X^2	RMSE
			UNBLANCHED										
WP UG I	Twoterm	0.2875	0.2875					0	0		0.9817	1	0.1719
WP UG II	Twoterm	0.2875	0.2875					0	0		0.9739	1	0.1415
WUP UG I	Hii *et al*	2.28	2.28					2.0709	2.0709	0	0.9964	1	0.2487
WUP UG II	Hii *et al*	2.28	2.28					2.0709	2.0709	0	0.9761	1	0.2284
			BLANCHED AT 3 MINS										
WP UG I	Henderson and pabis	1.3799				0.8755				0	0.9936	0.99316837	0.1249
WP UG II	Henderson and pabis	1.3799				0.8755				0	0.9491	1	0.1601
WUP UG I	Demir *et al*	0.1787	0.1475			2.8002				2.8002	0.9710	1	0.1358
WUP UG II	Demir *et al*	0.1787	0.1475			2.8002				2.8002	0.9621	1	0.0944
			BLANCHED AT 6 MINS										
WP UG I	Logarithmic	0		0.1475		3.1606					0.9835	1	0.1012
WP UG II	Henderson and pabis	1.3799				0.8755				0	0.9909	0	0.1528
WUP UG I	Demir *et al*	0.1787	0.1475			2.8002				2.8002	0.9769	1	0.0872
WUP UG II	Hii *et al*	2.28	2.28					2.0709	2.0709	0	0.6067	1	0.0794
			BLANCHED AT 9 MINS										
WP UG I	Logarithmic	0		0.1475		3.1606					0.9786	1	0.1370
WP UG II	Henderson and pabis	1.3799				0.8755				0	0.9910	1	0.1621
WUP UG I	Demir *et al*	0.1787	0.1475			2.8002				2.8002	0.9755	1	0.1363
WUP UG II	Hii *et al*	2.28	2.28					2.0709	2.0709	0	0.9550	1	0.1621

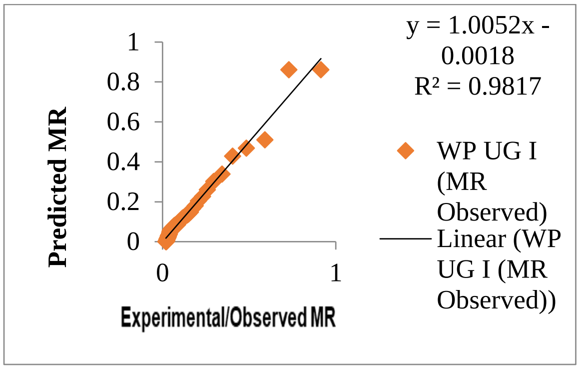

Fig 1: Experimental and predicted moisture ratio values by Two-term model for UG I blanched sample

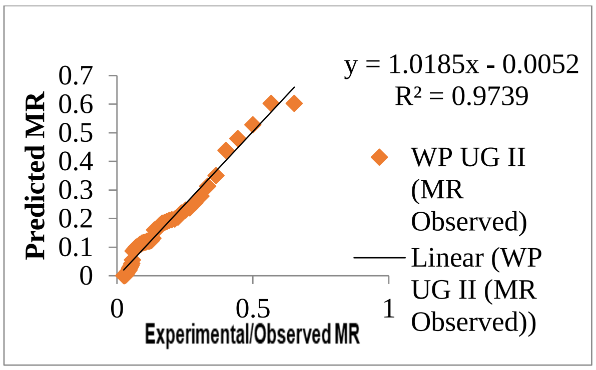

Fig 2: Experimental and predicted moisture ratio values by Two-term model for UG II unblanched sample

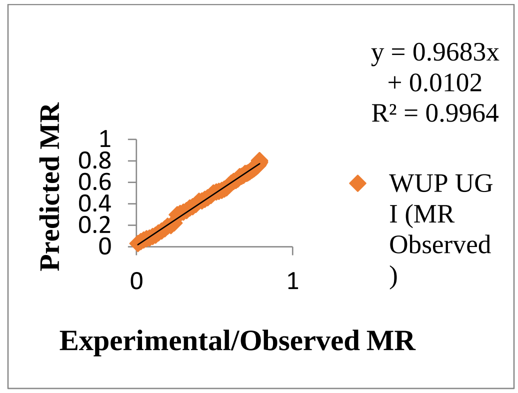

Fig 3: Experimental and predicted moisture ratio values by Hii *et al.* model for UG I blanched sample

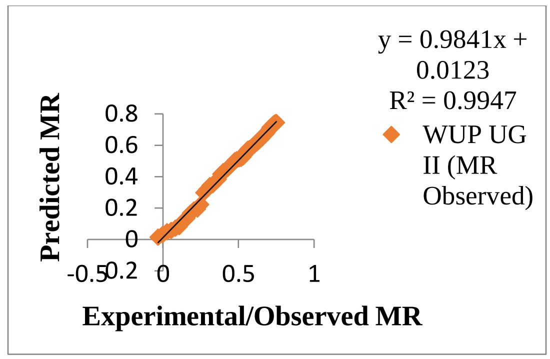

Fig 4: Experimental and predicted moisture ratio values by Hii *et al.* model for UG II unblanched sa

By considering the constants, coefficients, and factors of the drying models for active solar dryer. The moisture ratio for dried UG I and UG II, Unblanched under active solar dryer, can be predicted successfully using equation 4 to 7.

UG I (Blanched); MR = 0.2875 Exp (t) + 0.2875 Exp (t) 4

UG II (Blanched); MR = 0.2875 Exp (t) + 0.2875 Exp (t) 5

UG I (Unblanched); MR = 2.28 Exp (-2.0709t) + 2.28 Exp (-2.0709t) 6

UG II (Unblanched); MR = 2.28 Exp (-2.0709t) + 2.28 Exp (-2.0709t) 7

Validation of the statistical drying result for the various models was made by comparing the experimental moisture ratio and predicted moisture ratio data. This was done by plotting the predicted MR values versus the observed/experimental MR values. From the figures, it is clear that the predicted MR values lie close to the graph's straight-line trend. Predicted moisture ratio values versus the observed moisture ratio values, as shown in Figures 5 to 8. From the figures, it is clear that the predicted moisture ratio values lie close to the graph's straight-line trend.

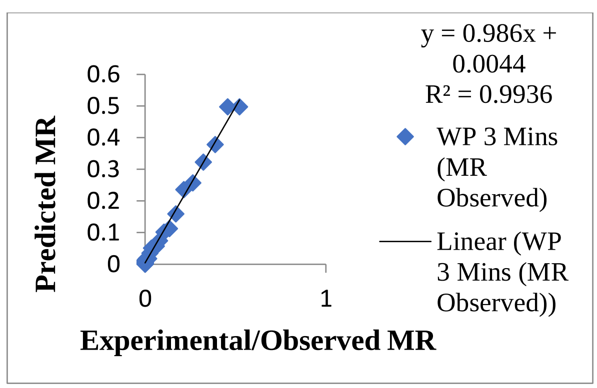

Fig 5: Experimental and predicted moisture ratio values by Henderson and Pabis model for UG I (Blanched 50°C at 3mins)

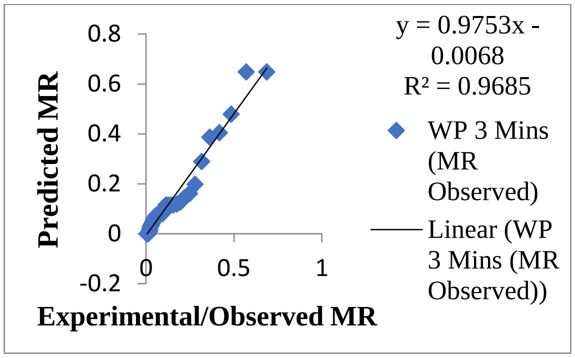

Fig 6: Experimental and predicted moisture ratio values by Henderson and Pabis model for UG II (Blanched 50℃ at 3mins)

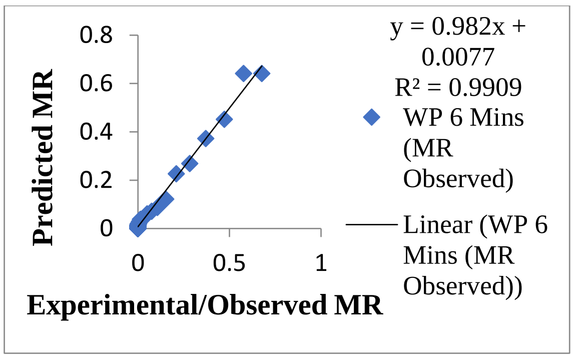

Fig 7: Experimental and predicted moisture ratio values by Henderson and Pabis model for Whole UG I (Blanched 50℃ at 6mins)

By considering the constants, coefficients, and factors of the drying models for active solar dryer. The moisture ratio for dried UG I and UG II, blanched 50°C at 3, 6, and 9 minutes, respectively, can be predicted successfully using equations 8 to 13.

UG I (Blanched 50°C at 3mins); MR = 1.3799 Exp (-0.8755×t) 8

UG II (Blanched 50°C at 3mins); MR = 1.3799 Exp (-0.8755×t) 9

UG I (Blanched 50°C at 6mins); MR = 0 Exp (-3.1606× t) + 0.1475 10

UG II (Blanched 50°C at 6mins); MR = 1.3799 Exp (-0.8755×t) 11

UG I (Blanched 50°C at 9mins); MR = 0 Exp (-3.1606× t) + 0.1475 12

UG II (Blanched 50°C at 9mins); MR = 1.3799 Exp (-0.8755×t) 13

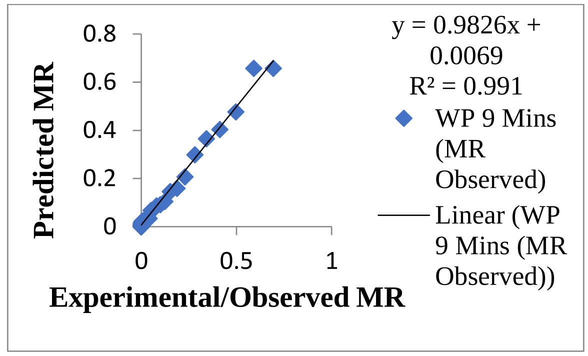

Fig 8: Experimental and predicted moisture ratio values by Handerson and Pabis model for Whole UG II (Blanched 50℃ at 9mins)

Authors [42] and [43] obtained similar results to that of [38]. model as best fit during the thin layer drying of carrots in a microwave oven. The Page model was however selected as the best fit during thin layer drying of carrot slices in a semi-industrial continuous band dryer by [44] and [45]. The Page model was also reported as having best fit to the drying data for carrot pomace by [46].

4.0 Conclusion

The effect of blanching on the drying characteristics of the ginger samples indicates that blanching do increase the drying rate. The various models used are efficient thin layer drying models and the best fitted model varies due to treatments on the ginger samples. The Henderson and Pabis model was recommended for predicting the drying characteristics of blanched and unblanched UG I and UG II ginger rhizomes.

Recommendations

Further study should be carried out on the effect of drying methods on physio-functional properties such as water-binding capacity, PH, bulk density, solubility power, and rehydration ratio.

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