VALIDATION OF SOME SELECTED THIN LAYER DRYING MODELS OF CASSAVA CHIPS

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ABSTRACT

Drying is a critical post-harvest process for preserving cassava as a staple food in many tropical countries. There is little or no enough data on the drying parameters and thin-layer drying models on this modified Force Convectional Solar Dryer (FCSD), and this gap hinder process optimization, reliable prediction of drying kinetics and large-scale application. The aim of this research was modification and validation of some selected thin layer drying models to improve the performance of the FCSD for quality product development of cassava chips. Drying process was observed for six months within dry season (January – March) and rainy season (July – September). Some selected thin-layer drying models were fit into the drying data of cassava chips using a nonlinear regression analysis programme. Three statistical criteria; R^2, X^2, and RMSE were used to evaluate the fitting performance of each drying model. The result show that the minimum drying time for the sample to reach safe moisture levels of (10 – 12%) was achieved at 14hrs from sample 3 in February, and march, followed by 16 hrs. in June and July from sample 3 as well as February and march from sample 2. The higher drying time was observed to be 20hrs in July, August and September from sample 1 and 18hrs from the 3 sample in some months within the dry and rainy season. It was observed that the smaller size cassava chips sample 3 dried at a much faster rate with no visible negative effect, followed by the moderate size sample 2 and the larger size sample 1. Page model was found to fit best the drying characteristics of three samples Viz; sample 2 and sample 3 in dry season while sample 3 in the rainy season. Other models are Hii model fitted best in dry and rainy season from sample 1. Also, Verma model fitted best in rainy season from sample 2. Hence, the best fitted model recommended for drying in this modified FCSD is page.

Keywords: Solar Dryer; Cassava Chips; Thin Layer Models

1 INTRODUCTION

Cassava (*Manihot esculenta Crantz*) is a major root crop in the tropical world, serves as a source of calorie. The crop is the fourth most important staple food in the world after rice, wheat & maize [16]. Cassava is extensively cultivated throughout the tropics for its starchy tubers. Fresh cassava root has a moisture content of about 60% which makes it a highly perishable crop, it also contains starch, sugars and fibre, thus needs to be processed or dried immediately after harvest [1]. Nigeria produces over 40 million metric tonnes of cassava annually, which ought to be processed rapidly into storable forms so as to avoid deterioration [10]. There are reasonable amounts of losses during the processing and preservation of the flour in Nigeria. Apart from the peeling losses, other losses (over 40%) occur during the drying [2]. Drying is one of the processing steps involved in the production of chips, thus has an effect on the quality of the chips. The drying process should be fast and the final product should be dry enough to prevent undesirable biochemical changes and subsequent

contamination and spoilage [17]. Sun drying is the common method of drying of cassava in the tropics due to its simplicity and small capital investment but its long drying time is undesirable because it may have adverse consequences on the product quality thus affecting the farmer's economic gain. This is because the final product may be contaminated from dust and insects or suffers from enzyme and microbial activity during this period [4, 7]. Solar drying is an alternative method that has been suggested and it focuses on the ways of improving the quality of the naturally dried products. Solar dryers have the advantages of more rapid rate of drying and hygienic products. Selection of a solar dryer for drying a particular agricultural product is determined by the drying characteristics of the product, quality requirements and economic considerations and most solar dryers are developed or designed for specific agricultural products [21]. Various studies on the drying characteristics and kinetics of various food crops have been carried out [12, 26]. Drying kinetics is generally affected by drying temperature, relative humidity, and product sizes and is crop specific [16]. [24] Reported that both airflow rate and the drying air temperature significantly affected the drying characteristics of cassava chips and grates. The drying rate for cassava was observed to increase with increase in temperature and that the drying was in the falling rate period. [11], also observed that in drying of cassava from an initial moisture content of 67% (wet basis) using a mixed-mode natural convection solar crop-dryer, drying occurred in the falling-rate period. These observations were not similar to the result of some studies carried out on solar drying of cassava and cassava leaves which reported that the solar drying of cassava and cassava leaves took place in the constant and falling rate period [27, 15]. The selection of good drying Addressing this shortcoming through dryer modification and model validation is therefore critical for improving efficiency, drying uniformity, product quality and reducing postharvest loses in the cassava value chain. Also, this will improve the drying techniques of the local processor and the quality of dried cassava chips for models for dryers helps to improve their efficiency. Models are often used to study the variables involved in a process, predict drying kinetics of the product and optimize the operating parameters and circumstances [11, 15]. Adequate and efficient village base drying systems for timely drying of cassava chips are not yet fully developed and operational. Undesirable biochemical changes and subsequent contamination and spoilage of the cassava chips can only be prevented if the drying process is fast enough, and the final product dried to the required moisture content of 12% to 14%. Many researches on drying methods and selection of drying models for thin-layer drying of some cassava by-products and other agricultural materials were reported [27, 21, 11, 15]. There are little or no enough data on the drying parameters and thin-layer drying models on this adopted FCSD, and this gap hinder process optimization, reliable prediction of drying kinetics and large scale application. Addressing this shortcoming through dryer modification and model validation is therefore critical for improving efficiency, drying uniformity, product quality and reducing postharvest losses in the cassava value chain. Also, this will improve the drying techniques of the local processor and the quality of dried cassava chips for the production of high quality cassava flour during a rural base processing method.

2 METHODOLOGY

2.1 Sample collection and preparation

A Fresh sweet cassava sample (98/0581) was collected from a local farmer at Bali LGA, Taraba State; the area is synonymous with cassava production and processing. For each experiment about 2,000g of the fresh cassava is obtain to prepare for three samples and in three replicates. Therefore, for the six experiments both in dry season and in rainy season about 12,000g of the fresh cassava was used to perform the drying experiment in the FCSD. The samples was washed, peeled, and cut into various rectangular shapes in accordance with the specific dimension of each of the three sample such as; sample one (S1 = 7 x 3 x 1.0 cm), sample two (S2 = 5 x 2 x 0.5 cm) and sample three (S3 = 3 x 1 x 0.5 cm), [18, 20]

2.2 Drying procedure

The drying process was carried out in the modified FCSD to investigate the effect of drying temperature, drying time, final moisture content; shape; size and product quality on the rate of drying the fresh cassava chips from initial moisture content [18, 20]. To determine the initial moisture content, the sample of the fresh cassava chips was spread on a tray of an electric oven; the samples were weighed using a digital weighing balance. The weight loss of samples was measured at a time interval of 2 hrs

during the drying test. When there are no further changes in three consecutive weights observed, the experiment was terminated. The drying experiment was carried out at specific temperature of FCSD between (50 – 65ºC) [18].

2.3 Determination of moisture ratio

The moisture ratio of the sample for each experiment was determine as recommended in literature [18], as shown in the mathematical expression below;

$$MR = \frac{Mt - Me}{Mi - Me} \tag{1}$$

During drying of food materials, drying kinetics or diffusion from the internal regions to the surface can be represented generally by equation below.

$$MR = \frac{Mt - Me}{Mi - Me} = \exp(-Kt) \tag{2}$$

Were, MR = moisture ratio, Mt = moisture content of the material at a given time, Me = equilibrium moisture content, Mi = initial moisture content, k = drying constant and t = drying time (min).

2.4 Thin Layer drying model validation

Some thin layer drying models have been applied in cassava chip drying viz; Newton model; this is a simple exponential equation, often underestimates non-linear drying. Page model; is a modification of Newton's model with a power term flexible for food materials. Henderson and Pabis model; this includes a scaling factor to improve fit. Logarithmic model; this incorporates a constant term to account for experimental deviations. Midilli model; this combines exponential and linear terms, often cited as highly accurate [23, 22, 20]. Thin layer drying models have been widely used to describe drying kinetics of food materials by relating moisture ratio (MR) to drying time under controlled conditions. However, accurate validation of these models is crucial, as it enables researchers to identify the best-fit models that predict drying performance under specific conditions [21, 9]. Model validation was conducted by comparing predicted moisture ratios with experimental drying data using statistical indices such as coefficient of determination (R^2) indicates closeness of fit. Standard Error of Estimation (SEE) to measure the average amount by which an observed data point is expected to deviate from its predicted value on a regression line. Root Mean Square Error (RMSE) measures deviations between predicted and experimental values. Chi-square (χ^2) evaluates goodness of fit. For a model to be validated as reliable, it should achieve $R^2 > 0.95$, RMSE close to zero and χ^2 minimal [8, 5, 6]. Thin-layer drying models (Table 1) were selected to fit into the drying data of cassava chips by using a nonlinear regression analysis programme. The criteria for the selection of the best fitted model will be based on goodness of fit statistical parameters. To evaluate the fitting performance of each drying model, three statistical criteria were used viz; the coefficient of determination (R^2), reduced chi-square (X^2) and the root mean square error (RMSE) [25, 8, 5, 20].

$$R^2 = 1 - \left[\frac{\sum_{i=1}^{N}(MR_{pre,i} - MR_{exp,i})^2}{\sum_{i=1}^{N}(\overline{MR}_{pre,i} - MR_{exp,i})^2}\right] \tag{3}$$

$$\chi^2 = \frac{\sum_{i=1}^{N}(MR_{exp,i} - MR_{pre,i})^2}{N - z} \tag{4}$$

$$RMSE = \left[\frac{1}{N}\sum_{i=1}^{N}(MR_{exp,i} - MR_{pre,i})^2\right]^{1/2} \tag{5}$$

Where; R^2 = Coefficient of determination, X^2 = Reduced chi-square, RMSE = Root mean square error, MR = Moisture ratio, N = Number of observations, z = Number of constant in the models, a,b,c = Drying constant in the models, t = Drying time, and k, n = Drying constant in the models

Table 1. Thin layer drying models

S/N	Model	Equation
1	Diffusion Approach	MR = a.exp(-kt) + (1-a) exp(-kbt)
2	Hii	MR = a.exp(-ktn) + c.exp(-gt^n)
3	Henderson and Pabis	MR = a.exp (-kt)
4	Logarithmic	MR = a.exp (-kt) + c
5	Midilli	MR = a.exp (-ktn) + bt
6	Newton	MR = exp (-kt)
7	Page	MR = exp (-kt^n)
8	Two Term	MR = a.exp (-k_0t) + b.exp (-k_1t)
9	Two Term Exponential	MR = a.exp (-kt) + (1-a) exp (-k.a.t)
10	Verma et al	MR = a.exp(-kt) + (1-a) exp(-gt)
11	Wang & Singh	MR = 1+at+bt^2

Source: [18, 20, 8]

3 RESULT AND DISCUSSION

3.1 Effect of Moisture Ratio and Drying Time

The moisture ratio for drying of cassava chips in FCSD varied with drying time as indicated in Fig. 10, 11 and 12 for sample S1, S2 and S3 respectively. The drying process was observed for six different months within dry and rainy season. The months were January, February and March in dry season while July, August and September in rainy season. From the result of moisture ratio there is an indication that sample size and different months of drying has effects on the drying time of cassava chips. During the drying process for S1, the drying time for the sample to reach safe moisture levels of (10 – 12%) in JN, FB and MR were 18hrs, while for JL, AU and SP was 20hrs. The drying time for S2 in JN was 18 hrs FB and MR were 16hrs, while for JL, AU and SP was 18hrs. Likewise, the drying time for S3 in JN and JL was 16 hrs, FB and MR were 14hrs while AU and SP was 18hrs. From this research, it was observed that the minimum drying time for the sample to reach safe moisture levels of (10 – 12%) was achieved at 14hrs from S3 in FB and MR, followed by 16 hrs in JN and JL from S3 also FB and MR from S2. While the higher drying time was observed to be 20hrs in JL, AU and SP from S1 then followed by 18hrs in JN, FB and MR from S1, JN, JL, AU, and SP from S2 as well as AU and SP from S3. It was observed that the smaller size cassava chips S3 dried at a much faster rate with no visible negative effect, followed by the moderate size S2 and the larger size S1, this result is in line with the findings of [18, 3]. This study revealed that the moisture ratio in all the sample decreased continually with drying time as observed in Fig. 10, 11 and 12, same observations have been reported for drying of cassava (Tan *et. al.*, 2006) and peach slices [14]. Fig. 13, 14 and 15 shows the drying rate curves for S1, S2 and S3 samples. It is shown that generally all the samples had the highest drying rate for most parts of the drying period in JN, FB and MR, while the lowest drying rate were observed in drying period within JL, AU and SP. Similar observation was reported by [18]. Furthermore, it was observed that most of the samples exhibited both the constant-rate and falling-rate periods. The constant rate period took place in the early stage of drying, after which the falling-rate period started. The falling-rate period exhibited by all the samples showed that the drying mechanism was diffusion controlled. Similar observations were reported for cocoyam (Afolabi *et. al.*, 2015). It was observed that the decline in moisture content was greater in S3. After 14hrs of drying cassava chip from the initial moisture content 66±1% were dried to EMC of 10.10% and 10.34% (db) in S3-FB and S3-MR respectively. The decline of moisture content was average at the moderate sample S2, the EMC attained at 16hrs of drying were 10.14% and 10.02% in S2-FB and S2-MR. Also, at 18hrs were 10.43%, 11.94%, 11.65% and 11.00% for samples in S2-JN, S2-JL, S2-AU and S2-SP respectively. The decline of moisture content for the larger sample size S1 was slow at 18hrs (JN, FB & MR) and 20hrs (JL, AU & SP) with EMC of (11.27%, 11.86% & 11.13%) db and (12.27%, 11.74% % 11.91%) db respectively. The final moisture ratios obtained are the point beyond which any changes in the mass of the sample could not occur. This represents the moisture equilibrium between the sample and the drying air, under the FCSD conditions. Therefore, the use of FCSD has a significant positive effect on the drying cassava chips. By ensuring drying rates, uniform heat distribution, improved moisture diffusivity, and energy efficiency, FCSD overcomes the limitations of traditional drying methods [3]. Hence, the technology enhances the safety, nutritional quality, and storability of dried cassava products.

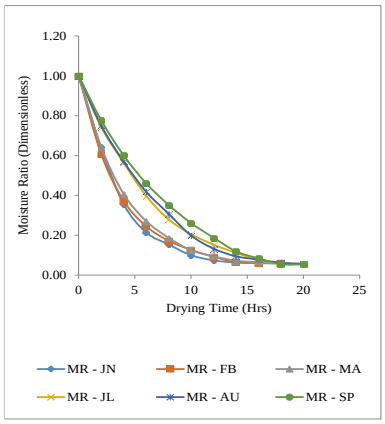

Figure 1. Variation in moisture ratio of cassava chips for S1

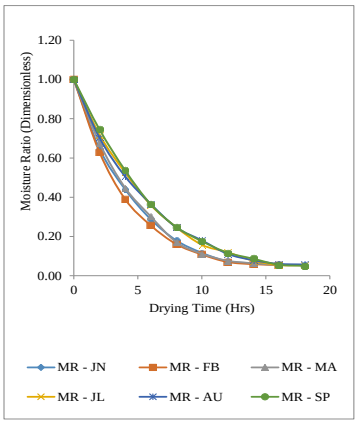

Figure 2. Variation in moisture ratio of cassava chips for S2

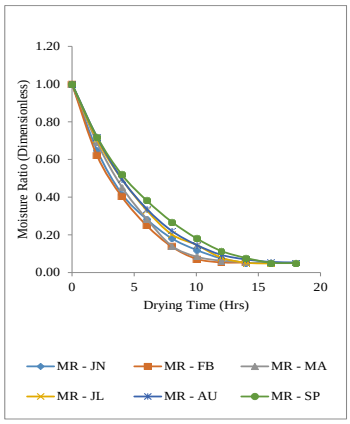

Figure 3. Variation in moisture ratio of cassava chips for S3

3.2 Model Validation using Statistical Criteria for Dry Season Drying Parameters

Table 1 present the result of drying model for S1 in dry season, the result from this table indicate that Hii model show best curve fitting that could be used to successfully describe the drying data for S1 in dry season, the model show highest values of R^2 = 0.995578 with a low values of RMSE = 0.00097 and SEE = 0.01756. Table 2 present the result of drying model for S2 in dry season. The result from this table indicate that page model show good curve fitting that could be used to successfully describe the drying data for S2 in dry season, the model show highest values of R^2 = 0.99645 with a low values of RMSE = 0.00102 and SEE = 0.02128. Table 3 present the result of drying model for S3 in dry season. The result from this table indicate that page model show good curve fitting that could be used to successfully describe the drying data for S3 in dry season, the model show highest values of R^2 = 0.99540 with a low values of RMSE = 0.00100 and SEE = 0.02109. Experimental drying data of the cassava chips were fitted to some selected thin layer drying models. Model performance was validated using statistical indicators; Coefficient of determination (R^2), Root mean square error (RMSE), Standard error of estimation (SEE) and Chi-square (χ^2). The best fit model for the drying characteristics was selected based on the highest R^2, and least SEE and RMSE. Experimental drying curves of cassava chips show a falling-rate period, consistent with most food materials. Analysis from previous studies indicates that; The Newton model provides a poor fit as it over simplifies the drying process. The Page model and Midilli model generally provide the highest R^2 (>0.98) and lowest RMSE and χ^2 values [6]. The Henderson and Pabis model and Logarithmic model give reasonable fits but are less accurate than Page and Midilli. Newton's model is often inadequate in describing cassava drying behaviour because it assumes a constant drying rate. [23] Reported lower R^2 values (0.90 – 0.93) for cassava drying under convective conditions, indicating poor predictive capacity. Henderson and Pabis improved slightly but were still less accurate compared to Page and Midilli models. [5] Reported that Page consistently matched experimental data in drying root and tuber crops due to its ability to describe the falling-rate period accurately. The Midilli model with its combined exponential and linear components provides a highly accurate description of cassava drying.

Table 1. Values of statistical parameters and model constants for S1 in dry season

S/N	Model	Equation	Constants	Value	Parameters	Value	Remark
1	Diffusion Approach	MR = a.exp(-kt) + (1-a) exp(-kbt)	a	1.10223	R^2	0.98290	Fairly
			b	1.21334	AR^2	0.97902	fitted
			k	0.34368	RMSE	0.00258	
					SEE	0.06824	
2	Hii	MR = a.exp(-ktn) + c.exp(-gt^n)	a	0.46384	R^2	0.99578	Best fitted
			c	0.03468	AR^2	0.99496	
			g	0.00077	RMSE	0.00097	
			k	0.00266	SEE	0.01756	
			n	1.53424			
3	Henderson and Pabis	MR = a.exp (-kt)	a	1.01304	R^2	0.98537	Fairly
			k	0.34737	AR^2	0.98461	fitted
					RMSE	0.00214	
					SEE	0.04243	

4	Logarithmic	MR = a.exp (-kt) + c	a	1.21084	R^2	0.99443	Good fitted
			c	0.21708	AR^2	0.99159	
			k	0.28743	RMSE	0.00114	
					SEE	0.03076	
5	Midilli	MR = a.exp (-ktn) + bt	a	0.01774	R^2	0.99150	Good fitted
			b	0.00178	AR^2	0.99017	
			k	3.21555	RMSE	0.00114	
			n	0.04534	SEE	0.03033	
6	Newton	MR = exp (-kt)	k	0.34364	R^2	0.98400	Fairly
					AR^2	0.98389	fitted
					RMSE	0.02100	
					SEE	0.04256	
7	Page	MR = exp ($-kt^n$)	k	0.30593	R^2	0.99350	Good fitted
			n	1.13910	AR^2	0.99142	
					RMSE	0.00124	
					SEE	0.03133	
8	Two Term	MR = a.exp ($-k_0t$) + b.exp ($-k_1t$)	a	0.31666	R^2	0.98741	Fairly
			b	0.70254	AR^2	0.98636	fitted
			k_0	3.24413	RMSE	0.00223	
			k_1	0.33957	SEE	0.04475	
9	Two Term Exponential	MR = a.exp (-kt) + (1-a) exp (-k.a.t)	a	1.32032	R^2	0.99118	Good fitted
			k	0.66186	AR^2	0.99006	
					RMSE	0.00133	
					SEE	0.03266	
10	Verma et al	MR = a.exp(-kt) + (1-a) exp(-gt)	a	13.28466	R^2	0.99282	Good fitted
			g	0.40166	AR^2	0.99074	
			k	0.33764	RMSE	0.00124	
					SEE	0.03080	
11	Wang & Singh	MR = $1+at+bt^2$	a	0.25908	R^2	0.98741	Fairly
			b	0.01998	AR^2	0.98636	fitted
					RMSE	0.00164	
					SEE	0.03469	

Table 2. Values of statistical parameters and model constants for S2 in dry season

S/N	**Model**	**Equation**	**Constants**	**Value**	**Parameters**	**Value**	**Remark**
1	Diffusion Approach	MR = a.exp(-kt) + (1-a) exp(-kbt)	a	1.10188	R^2	0.98285	Fairly
			b	1.21299	AR^2	0.97897	fitted
			k	0.34333	RMSE	0.00246	
					SEE	0.06812	
2	Hii	MR = a.exp(-ktn) + c.exp($-gt^n$)	a	0.46349	R^2	0.99373	Good
			c	0.03433	AR^2	0.99291	fitted
			g	0.00042	RMSE	0.00185	
			k	0.00231	SEE	0.02744	
			n	1.53389			
3	Henderson and Pabis	MR = a.exp (-kt)	a	1.01269	R^2	0.98532	Fairly
			k	0.34702	AR^2	0.98456	fitted
					RMSE	0.00202	
					SEE	0.04231	
4	Logarithmic	MR = a.exp (-kt) + c	a	1.21049	R^2	0.99438	Good
			c	0.21673	AR^2	0.99154	fitted
			k	0.28708	RMSE	0.00102	
					SEE	0.03064	
5	Midilli	MR = a.exp (-ktn) + bt	a	0.01739	R^2	0.99145	Good
			b	0.00143	AR^2	0.99012	fitted
			k	3.2152	RMSE	0.00102	
			n	0.04499	SEE	0.03021	
6	Newton	MR = exp (-kt)	k	0.34329	R^2	0.98395	Fairly
					AR^2	0.98384	fitted
					RMSE	0.02088	
					SEE	0.04244	
7	Page	MR = exp ($-kt^n$)	k	0.30558	R^2	0.99645	Best fitted
			n	1.13875	AR^2	0.99487	
					RMSE	0.00102	
					SEE	0.02128	
8	Two Term	MR = a.exp ($-k_0t$) + b.exp ($-k_1t$)	a	0.31631	R^2	0.98736	Fairly
			b	0.70219	AR^2	0.98631	fitted
			k_0	3.24378	RMSE	0.00211	
			k_1	0.33922	SEE	0.04463	
9	Two Term Exponential	MR = a.exp (-kt) + (1-a) exp (-k.a.t)	a	1.31997	R^2	0.99113	Good
			k	0.66151	AR^2	0.99001	fitted
					RMSE	0.00121	
					SEE	0.03254	

10	Verma et al	MR = a.exp(-kt) + (1-a) exp(-gt)	a	12.98432	R^2	0.99277	Good
			g	0.40131	AR^2	0.99069	fitted
			k	0.33729	RMSE	0.00112	
					SEE	0.03068	
11	Wang & Singh	MR = 1+at+bt^2	a	0.25873	R^2	0.98736	Fairly
			b	0.01963	AR^2	0.98631	fitted
					RMSE	0.00152	
					SEE	0.03457	

Table 3. Values of statistical parameters and model constants for S3 in dry season

S/N	Model	Equation	Constants	Value	Parameters	Value	Remark
1	Diffusion Approach	MR = a.exp(-kt) + (1-a) exp(-kbt)	a	1.10176	R^2	0.98280	Fairly
			b	1.21287	AR^2	0.97892	fitted
			k	0.34321	RMSE	0.00234	
					SEE	0.06800	
2	Hii	MR = a.exp(-ktn) + c.exp(-gt^n)	a	0.46337	R^2	0.99368	Averagely
			c	0.03421	AR^2	0.99286	fitted
			g	0.00030	RMSE	0.00173	
			k	0.00219	SEE	0.02732	
			n	1.53377			
3	Henderson and Pabis	MR = a.exp (-kt)	a	1.01257	R^2	0.98527	Fairly
			k	0.34690	AR^2	0.98451	fitted
					RMSE	0.00190	
					SEE	0.04219	
4	Logarithmic	MR = a.exp (-kt) + c	a	1.21037	R^2	0.99433	Averagely
			c	0.21661	AR^2	0.99149	fitted
			k	0.28696	RMSE	0.00090	
					SEE	0.03052	
5	Midilli	MR = a.exp (-ktn) + bt	a	0.01727	R^2	0.99140	Averagely
			b	0.00131	AR^2	0.99007	fitted
			k	3.21508	RMSE	0.00290	
			n	0.04487	SEE	0.03009	
6	Newton	MR = exp (-kt)	k	0.34317	R^2	0.98390	Fairly
					AR^2	0.98379	fitted
					RMSE	0.02076	
					SEE	0.04232	
7	Page	MR = exp (-kt^n)	k	0.30546	R^2	0.99540	Best fitted
			n	1.13863	AR^2	0.99432	
					RMSE	0.00100	
					SEE	0.02109	
8	Two Term	MR = a.exp (-k_0t) + b.exp (-k_1t)	a	0.31619	R^2	0.98731	Fairly
			b	0.70207	AR^2	0.98626	fitted
			k_0	3.24366	RMSE	0.00199	
			k_1	0.33910	SEE	0.04451	
9	Two Term Exponential	MR = a.exp (-kt) + (1-a) exp (-k.a.t)	a	1.31985	R^2	0.99108	Averagely
			k	0.66139	AR^2	0.98996	fitted
					RMSE	0.00109	
					SEE	0.03242	
10	Verma et al	MR = a.exp(-kt) + (1-a) exp(-gt)	a	13.15419	R^2	0.99272	Averagely
			g	0.40119	AR^2	0.99064	fitted
			k	0.33717	RMSE	0.00100	
					SEE	0.03056	
11	Wang & Singh	MR = 1+at+bt^2	a	0.25861	R^2	0.98731	Fairly
			b	0.01951	AR^2	0.98626	fitted
					RMSE	0.00140	
					SEE	0.03445	

3.3 Model Validation using Statistical Criteria for Rainy Season Drying Parameters

Table 4 present the result of drying model for S1 in rainy season. The result from this table indicate that Verma model show good curve fitting that could be used to successfully describe the drying data for S1 in rainy season, the model show highest values of R^2 = 0.99280 with a low values of RMSE = 0.00113 and SEE = 0.03069. Table 5 present the result of drying model for S2 in rainy season. The result from this table indicate that Verma model show good curve fitting that could be used to successfully describe the drying data for S2 in rainy season, the model show highest values of R^2 = 0.99581 with a low values of RMSE = 0.00113 and SEE = 0.02069. Table 6 present the result of drying model for S3 in rainy season. The result from this table indicate that Page model show good curve fitting that could be used to successfully describe the drying data for S3 in rainy season, the model show highest values of R^2 = 0.99638 with a low values of RMSE = 0.00089 and SEE = 0.02076. The summary

results of the best models for drying behaviour of cassava chips from the entire samples are presented in table 7. The choice of the best-fitting drying kinetic models for each drying process indicates the moisture removal behavior differences under several drying conditions. [22] Observed very high accuracy ($R^2 = 0.99$) for cassava chips in convective drying, suggesting its robustness. Its flexibility makes it applicable across different drying temperatures and air velocities in FCSD. Tunde-Akintunde (2010) also examined sun versus solar drying with varied pre-treatments. [6] Found Page achieved $R^2 > 0.98$, RMSE < 0.01, outperforming other models in FCSD drying of cassava. Accurate model validation enables better dryer design, optimization of drying parameters, and improved quality of dried cassava products [23, 8, 5]. These outcomes of this study highlight the varying drying kinetics and effectiveness of each approach, with controlled and forced drying environments leading to high dynamic moisture removal tendencies compared to other drying methods.

Table 4. Values of statistical parameters and model constants for S1 in rainy season

S/N	Model	Equation	Constants	Value	Parameters	Value	Remark
1	Diffusion Approach	MR = a.exp(-kt) + (1-a) exp(-kbt)	a	1.10200	R^2	0.98288	Fairly
			b	1.21311	AR^2	0.97900	fitted
			k	0.34345	RMSE	0.00247	
					SEE	0.06813	
2	Hii	MR = a.exp(-ktn) + c.exp(-gt^n)	a	0.46361	R^2	0.99486	Best
			c	0.03445	AR^2	0.99394	fitted
			g	0.00054	RMSE	0.00086	
			k	0.00243	SEE	0.01745	
			n	1.53401			
3	Henderson and Pabis	MR = a.exp (-kt)	a	1.01281	R^2	0.98535	Fairly
			k	0.34714	AR^2	0.98459	fitted
					RMSE	0.00203	
					SEE	0.04232	
4	Logarithmic	MR = a.exp (-kt) + c	a	1.21061	R^2	0.99441	Good
			c	0.21685	AR^2	0.99157	fitted
			k	0.28720	RMSE	0.00103	
					SEE	0.03065	
5	Midilli	MR = a.exp (-ktn) + bt	a	0.01751	R^2	0.99148	Good
			b	0.00155	AR^2	0.99015	fitted
			k	3.21532	RMSE	0.00103	
			n	0.04511	SEE	0.03022	
6	Newton	MR = exp (-kt)	k	0.34341	R^2	0.98398	Fairly
					AR^2	0.98387	fitted
					RMSE	0.02089	
					SEE	0.04245	
7	Page	MR = exp (-kt^n)	k	0.30570	R^2	0.99248	Good
			n	1.13887	AR^2	0.99140	fitted
					RMSE	0.00113	
					SEE	0.03122	
8	Two Term	MR = a.exp (-k_0t) + b.exp (-k_1t)	a	0.31643	R^2	0.98739	Fairly
			b	0.70231	AR^2	0.98634	fitted
			k_0	3.24390	RMSE	0.00212	
			k_1	0.33934	SEE	0.04464	
9	Two Term Exponential	MR = a.exp (-kt) + (1-a) exp (-k.a.t)	a	1.32009	R^2	0.99116	Good
			k	0.66163	AR^2	0.99004	fitted
					RMSE	0.00122	
					SEE	0.03255	
10	Verma et al	MR = a.exp(-kt) + (1-a) exp(-gt)	a	13.08444	R^2	0.99280	Good
			g	0.40143	AR^2	0.99072	fitted
			k	0.33741	RMSE	0.00113	
					SEE	0.03069	
11	Wang & Singh	MR = 1+at+bt^2	a	0.25885	R^2	0.98739	Fairly
			b	0.01975	AR^2	0.98634	fitted
					RMSE	0.00153	
					SEE	0.03458	

Table 5. Values of statistical parameters and model constants for S2 in rainy season

S/N	Model Name	Equation	Constants	Value	Parameters	Value	Remark
1	Diffusion Approach	MR = a.exp(-kt) + (1-a) exp(-kbt)	a	1.10165	R^2	0.98283	Fairly
			b	1.21276	AR^2	0.97895	fitted
			k	0.34310	RMSE	0.00235	
					SEE	0.06801	
2	Hii	MR = a.exp(-ktn) + c.exp(-gt^n)	a	0.46326	R^2	0.99371	Good
			c	0.03410	AR^2	0.99289	fitted
			g	0.00019	RMSE	0.00174	
			k	0.00208	SEE	0.02733	
			n	1.53366			
3	Henderson and Pabis	MR = a.exp (-kt)	a	1.01246	R^2	0.98530	Fairly
			k	0.34679	AR^2	0.98454	fitted
					RMSE	0.00191	
					SEE	0.04220	
4	Logarithmic	MR = a.exp (-kt) + c	a	1.21026	R^2	0.99436	Good
			c	0.21650	AR^2	0.99152	fitted
			k	0.28685	RMSE	0.00191	
					SEE	0.03053	
5	Midilli	MR = a.exp (-ktn) + bt	a	0.01716	R^2	0.99143	Good
			b	0.00120	AR^2	0.99010	fitted
			k	3.21497	RMSE	0.00091	
			n	0.04476	SEE	0.03010	
6	Newton	MR = exp (-kt)	k	0.34306	R^2	0.98393	Fairly
					AR^2	0.98382	fitted
					RMSE	0.02077	
					SEE	0.04233	
7	Page	MR = exp (-kt^n)	k	0.30535	R^2	0.99243	Good
			n	1.13852	AR^2	0.99135	fitted
					RMSE	0.00101	
					SEE	0.03110	
8	Two Term	MR = a.exp (-k_0t) + b.exp (-k_1t)	a	0.31608	R^2	0.98734	Fairly
			b	0.70196	AR^2	0.98629	fitted
			k_0	3.24355	RMSE	0.00200	
			k_1	0.33899	SEE	0.04452	
9	Two Term Exponential	MR = a.exp (-kt) + (1-a) exp (-k.a.t)	a	1.31974	R^2	0.99111	Good
			k	0.66128	AR^2	0.98999	fitted
					RMSE	0.00110	
					SEE	0.03243	
10	Verma et al	MR = a.exp(-kt) + (1-a) exp(-gt)	a	13.12384	R^2	0.99581	Best
			g	0.40108	AR^2	0.99472	Fitted
			k	0.33706	RMSE	0.00113	
					SEE	0.02069	
11	Wang & Singh	MR = 1+at+bt^2	a	0.25850	R^2	0.98734	Fairly
			b	0.01940	AR^2	0.98629	fitted
					RMSE	0.00141	
					SEE	0.03446	

Table 6. Values of statistical parameters and model constants for S3 in rainy season

S/N	Model Name	Equation	Constants	Value	Parameters	Value	Remark
1	Diffusion Approach	MR = a.exp(-kt) + (1-a) exp(-kbt)	a	1.10141	R^2	0.98278	Fairly
			b	1.21252	AR^2	0.97890	fitted
			k	0.34286	RMSE	0.00223	
					SEE	0.06789	
2	Hii	MR = a.exp(-ktn) + c.exp(-gt^n)	a	0.46302	R^2	0.99366	Good
			c	0.03386	AR^2	0.99284	fitted
			g	-0.00005	RMSE	0.00162	
			k	0.00184	SEE	0.02721	
			n	1.53342			
3	Henderson and Pabis	MR = a.exp (-kt)	a	1.01222	R^2	0.98525	Fairly
			k	0.34655	AR^2	0.98449	fitted
					RMSE	0.00179	
					SEE	0.04208	
4	Logarithmic	MR = a.exp (-kt) + c	a	1.21002	R^2	0.99431	Good
			c	0.21626	AR^2	0.99147	fitted
			k	0.28661	RMSE	0.00179	
					SEE	0.03041	
5	Midilli	MR = a.exp (-ktn) + bt	a	0.01692	R^2	0.99138	Good
			b	0.00096	AR^2	0.99005	fitted
			k	3.21473	RMSE	0.00079	
			n	0.04452	SEE	0.02998	

6	Newton	MR = exp (-kt)	k	0.34282	R^2	0.98388	Fairly
					AR^2	0.98377	fitted
					RMSE	0.02065	
					SEE	0.04221	
7	Page	MR = exp ($-kt^n$)	k	0.30511	R^2	0.99638	Best
			n	1.13828	AR^2	0.99530	fitted
					RMSE	0.00089	
					SEE	0.02076	
8	Two Term	MR = a.exp ($-k_0t$) + b.exp ($-k_1t$)	a	0.31584	R^2	0.98729	Fairly
			b	0.70172	AR^2	0.98624	fitted
			k_0	3.24331	RMSE	0.00188	
			k_1	0.33875	SEE	0.04440	
9	Two Term Exponential	MR = a.exp (-kt) + (1-a) exp (-k.a.t)	a	1.31950	R^2	0.99106	Good
			k	0.66104	AR^2	0.98994	fitted
					RMSE	0.00098	
					SEE	0.03231	
10	Verma et al	MR = a.exp(-kt) + (1-a) exp(-gt)	a	13.12384	R^2	0.99270	Good
			g	0.40084	AR^2	0.99062	fitted
			k	0.33682	RMSE	0.00089	
					SEE	0.03045	
11	Wang & Singh	MR = $1+at+bt^2$	a	0.25826	R^2	0.98729	Fairly
			b	0.01916	AR^2	0.98624	fitted
					RMSE	0.00129	
					SEE	0.03434	

3.4 The Best Fitted Thin Layer Drying Models

The summary of the result for the six best models that expressed the drying behaviour of cassava chips from different sample and drying period in the modified FCSD is presented in Table 7 and the findings indicate that Hii model fitted best the drying characteristic of S1 in dry season with values of R^2 = 0.995778, RMSE = 0.00097 and SEE = 0.01756. Also Hii model fitted best the drying characteristic of S1 in the rainy season with values of R^2 = 0.99486, RMSE = 0.00086 and SEE = 0.01745. For S2 in the dry season it was found that Page model fitted best the drying characteristic with values of R^2 = 0.99645, RMSE = 0.00102 and SEE = 0.02128. While, in the rainy season for S2 it was Verma model that fitted best the drying characteristic with values of R^2 = 0.99581, RMSE = 0.00113 and SEE = 0.02069. Page model fitted best the drying characteristic of S3 in dry season with values of R^2 = 099540, RMSE = 0.00089 and SEE = 0.03076. Also Page model fitted best the drying characteristic of S3 in the rainy season with values of R^2 = 0.99638, RMSE = 0.00089 and SEE = 0.03076. Based on this study the overall best fitted model recommended for drying in FCSD is page model, because it was found to fit best the drying characteristics of three sample Viz; S2 and S3 in dry season as well as S3 in the rainy season. The Page model is validated as the most suitable for cassava chips under FCSD, as it accounts for non-linear diffusion and variable drying rates [23]. The Hii and Verma models were also validated as other predictive tool for cassava chips under FCSD. Validation across independent datasets shows consistent performance, confirming the robustness of these models. Among the models studied the Page, Hii and Verma models provide the best performance based on R^2, RMSE and SEE values [8]. Across Henderson-Pabis, Newton, Logarithmic, and Page models, the Page model again was superior based on superior statistical metrics, and solar drying yielded higher effective diffusivity than conventional sun drying. A study conducted by [19] investigated the drying characteristics of cassava chips in a FCSD using different thin layer drying models such as Page, Henderson & Pabis, Logarithmic, and Two-term models. The results showed that the Page model best described the drying behaviour of cassava chips in the FCSD, with a high coefficient of determination (R^2= 0.98). The study recommended the use of the Page model for predicting the drying kinetics of cassava chips in FCSD.

Table 7. The six best models that express the drying behaviour of the cassava chips

S/N	Sample	Model name	Equation	R^2	AR^2	RMSE	SEE
1	DS-S1	Hii	MR = a.exp(-ktn) + c.exp($-gt^n$)	0.99578	0.99496	0.00097	0.01756
2	RS-S1	Hii	MR = a.exp(-ktn) + c.exp($-gt^n$)	0.99486	0.99394	0.00086	0.01745
3	DS-S2	Page	MR = exp ($-kt^n$)	0.99645	0.99487	0.00102	0.02128
4	RS-S2	Verma et al	MR = a.exp(-kt) + (1-a) exp(-gt)	0.99581	0.99472	0.00113	0.02069
5	DS-S3	Page	MR = exp ($-kt^n$)	0.99540	0.99432	0.00100	0.02109
6	RS-S3	Page	MR = exp ($-kt^n$)	0.99638	0.99530	0.00089	0.03076

DS – Dry Season, RS – Rainy Season, S1, S2 and S3 are Sample One, Two and Three Respectively

4 CONCLUSIONS

The minimum drying time for the sample to reach safe moisture levels of (10 – 12%) was achieved at 14hrs from sample 3 in February, and March, followed by 16 hrs in June and July from sample 3 as well as February and March from sample 2. While the higher drying time was observed to be 20hrs in July, August and September from sample 1. Trailed by 18hrs in June, February and March from sample 1; also, June, July, August, and September from sample 2 while August and September from sample 3. The result for the thin-layer drying models fitted into the drying data of cassava chips indicates that the Page, Hii and Verma models provide the most reliable predictions in achieving the highest R^2 and lowest RMSE values. The study on thin layer drying models is significant, as it helps in optimizing the drying process and improving the overall efficiency of the system.

REFERENCES

1. Abass, A.B., Towo, E., Mukuka, I., Ranaivoson, R., Tarawali, G. and Kanju, E. (2014). Growing cassava: a trainy manual from production to postharvest. IITA, Ibadan, Nigeria, pp. 382-391.
2. Adebayo, K., White, J.L., Morris, M.J., Dipeolu, A.O., Ayinde, I.A., Sanni, T.S., Oyewole, O.B., Tomlins, K. and Westby, A. (2003). Innovativeness and stakeholdership in the *fufu* processing systems in Southwest Nigeria. *International Journal of Agricultural Sciences, Science, Environment and Technology Series A*, vol. 3, no. 4, pp. 15-27.
3. Afolabi, I.S., Tunde-Akintunde, T.Y. and Adeyanju, J.A. (2015). Mathematical modelling of drying kinetics of cassava chips in a forced convection dryer. *NFJ*, vol. 33, no. 1, pp. 83-89.
4. Andritsos N., Dalampakis P. and Kolios N. (2003). Use of geothermal energy for tomato energy. *Journal of Food Engineering*, vol. 79, pp. 23-30.
5. Aregbesola, O.A., Ogunsina, B.S. and Chime, N.N. (2015). Mathematical modelling of thin layer drying characteristics of dika nuts and kernels. *Nigerian Food Journal*, vol. 33, no. 1, pp. 83-89.
6. Balogun, S.A., Ajayi, O.O. and Sobukola, O.P. (2020). Thin layer modelling of drying kinetics of cassava chips in a solar dryer. *Journal of Food Process Engineering*, vol. 43, no. 8, pp. 621-630.
7. Chen H., Hernandez C.E. and Huang T. (2005). A study of the drying effect on lemon slices using a closed-type solar dryer. *Solar Energy*, vol. 78, pp. 97-103.
8. Darvishi, H., Banakar, A. and Zarein, M. (2012). Mathematical modelling and thin layer drying kinetics of carrot slices. *Glob. J. Sci. Front. Res*., vol. 12, pp. 57-64.
9. Doymaz, I. (2014). Mathematical modelling of thin layer drying of mango slices. *Journal of Food Processing and Preservation*, vol. 38, no. 5, pp. 2231-2239.
10. Food Agricultural Organization (2012). Global market analysis. *Food Outlook Report*, pp. 34-35.
11. Forson F.K., Nazha M.A.A. and Rajakaruna H. (2007). Modelling and experimental studies on a mixed-mode natural convection solar crop-dryer. *Solar Energy*, vol. 81, pp. 346-357.
12. Goyal, R.K., Mujjeb, O. and Vinod, KB. (2008). Mathematical Modelling of Thin Layer Drying Kinetics of Apple in Tunnel Dryer, IJFE, vol. 4, issue 8, pp. 107-115.
13. IFAD/FAO (2000). The world cassava economy. Facts, trends and outlook. *Rome: IFAD/FAO*, pp. 58-97.
14. Kingsly, A.R.P. and Singh, D.B. (2007). Drying kinetics of pomegranate arils. *Journal of Food Engineering*, vol. 79, no. 4, pp. 1210-1217.
15. Koua K.B., Fassinou W.F. and Toure S. (2009). Mathematical modelling of the thin layer solar drying of banana, mango & cassava. *Energy*, vol. 34, issue 10, 1594-1602.

16. Kudra, T. (2004). Energy aspects in drying. *International Journal of Science and Technology; Drying Technology*, vol. 22**,** no. 5, pp. 917-932.

17. Maskan, M. (2000). Microwave, air & microwave finish drying of banana. JFE, vol. 44**,** no. 2, pp. 71-78.

18. Mujaffar, S. and Lalla, A. (2020). Drying Behaviour of Cassava (*Manihot esculenta*) Chips. The International Conference on Emerging Trends. *Engineering and Technology (IConETech-2020) Faculty of Engineering. The UWI, St. Augustine*, pp. 241-248.

19. Ogunrinde, L.A., Bendel, D.N. and Ariwo, S.T. (2016). Drying Characteristics of Cassava Chips in a Fluidized Bed Dryer. *IJERT*, vol. 5, no. 6, pp. 392-398.

20. Pornpraipech, P., Khusakul, M., Raksuda, S., Prysathryd, S. and Chinnathan, A. (2017). Effect of temperature and shape on drying performance of cassava Chips. *JANR*, vol. 51, pp. 402-409.

21. Purohit, P., Kumar, A. and Kandpal, T.C. (2006). Solar drying vs. open sun drying: A framework for financial evaluation. Solar Energy, vol. 80, pp. 1568-1579.

22. Sobukola, O.P. and Dairo, O.U. (2007). Modelling drying kinetics of some tropical fruits in a convective hot air dryer. *Journal of Food Technology*, vol. 5, no. 2, pp. 57-61.

23. Sobukola, O.P., Tijani, S.R. and Ajayi, O.O. (2008). Mathematical modelling of drying of cassava and yam slices. *International Agrophysics*, vol. 22, no. 3, pp. 231-237.

24. Tan, D.L.S., Perez, J.H. and Diamante, L.M. (2006). Thin-layer drying of cassava chips and grates. *Proceedings of the 2nd International symposium on sweet potato and cassava: (innovative technologies for commercialization) (Kuala Lumpur, Malaysia, June 14-17, 2005). No2, Kuala Lumpur, MALAISIE*, pp. 872-883.

25. Taheri-Garavand, A., Rafiee, S. and Keyhani, A. (2011). Mathematical modeling of thin layer drying kinetics of tomato influence of air dryer conditions. *JEMAST*, vol. 2, 147-160.

26. Therdthai R.K. and Zhou J.M. (2009). Thin layer drying of diced cassava roots. Intern. Journal of Science and Technology. *Science and Engineering series*, vol. 2, no. 2, pp. 94-100.

27. Toure, S. and Kibangu, S. (2004). Comparative study of natural solar drying of cassava, banana and mango. *Renewable Energy*, vol. 29, issue 6, pp. 975-990.

28. Tunde-Akintunde, T.Y. (2010). Mathematical Modelling of Thin Layer Sun and Solar Drying of Cassava Chips. *International Journal of Food Engineering*, vol. 6, no. 6, pp. 324-335.