Effect of period of harvest on drying characteristics of an improved variety cowpea (IT 97K-56S-IS)

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Abstract: Shattering loss and loss due to pest attack significantly reduce the quantity and quality of cowpea that can be harvested from the field, hence, the possibility of early harvest of cowpea was investigated. Thin-layer drying kinetics of IT 97K-56S-IS was experimentally investigated in a convective dryer and the data were fitted to five thin layer drying models. Samples harvested 60, 64, 68 and 72 Days After Planting (DAP) were dried at temperatures of 55℃, 65℃, 75℃ and 85℃. The effect of period of harvest and drying temperature on the drying characteristics and nutritional content of the dried products were discussed. The models' fitting was evaluated by comparing the Coefficient of Determination (R2) and Root Mean Square Error (RMSE) relating the experimental and predicted moisture ratios through non-linear regression analysis. Drying process was discovered to have taken place during falling rate period in all the samples. The R2 and RMSE vary from 0.967 - 1.000 and 0.001 - 0.061 respectively. Page and Logarithmic model gave the best fit with the highest R2 value of 0.998 and 1.000 and lowest RMSE values of 0.015 and 0.001 respectively. Proximate analysis result of IT 97K-56S-IS indicated that, carbohydrate content and crude protein ranges between 61.91% - 64.40%; 20.74% - 21.17% respectively.

Keywords: losses, Period of Harvest, Modeling, Thin-layer drying, Moisture content, Cowpea, IT 97K-56S-IS

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1 Introduction

Cowpea, *Vigna unguiculata (L.)* Walp (Family: Leguminosae) is an annual grain legume and the most important food grain legume in the dry savannas of tropical Africa. Its production has increased dramatically in the last 25 years (Olapade, 2010). It is grown in the semi-arid tropics covering Africa, Asia, Europe, Central America and South America. Fifty-two percent of Africa's production is used for food, 13% for animal feed, 10% for seeds, 9% for other uses and 16% is wasted (IITA, 2009). Cowpea seed contains 20%-25% protein and 65% carbohydrate and it is one of the cheapest food crops in Nigeria hence it contributes to the alleviation of malnutrition specifically amongst the poor (Modu et al., 2010). It is therefore often referred to as "the poor man's meat" (Aykroyd and Daughty, 1982). Musa et al. (2010) reported cowpea consumption is through direct cooking, processing into cowpea cake (*akara*), cooked mash (*moinmoin*), soup (*Gbegiri*) or as component of other meals (rice etc).

Generally, cowpea is classified into two categories by farmers depending on the time taken to reach maturity; early maturing varieties (<100 days) and late maturing varieties (>120 days) (DPP, 2011). In the field, cowpea plant is often attacked by pests during every stage of its life cycle. In cases of bad infestations, insect attack is responsible for over 90% loss in yield. The legume pod borer, Maruca (testulalis) vitrata, is the main pre-harvest pest of cowpea (Sharma et al., 1999). If cowpea is not harvested early enough after reaching its maturity stage, there may be the danger that the grain pods will shatter and also, there could be a delay in another planting season. However, to reduce these problems, dry pods should not be left in the field longer than two weeks after full pod maturity (DPP, 2011).

Drying is one of the oldest and most widely used methods of food preservation (Ojediran and Raji, 2010)

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and its main objective in drying of agricultural products is the reduction of moisture content to a level which allows safe storage over an extended period (Doymaz, 2007). The wide variety of dehydrated products, which today are available to the consumers and the concern for meeting quality specifications and energy conservation, emphasize the need for a thorough understanding of the drying process (Górnicki and Kaleta, 2007). Undesirable biochemical changes, subsequent contamination and spoilage of the products can only be prevented if the drying process is fast enough and the final product is dry enough (Maskan, 2000). Though field drying is the common method of drying grains in the tropics, the major challenge is slowness of the drying process due to ambient temperature that is used; hence, there is the need for alternative drying methods that will dry the product faster.

Drying as one layer of sample particles or slices is referred to as thin layer drying (Ojediran and Raji, 2010). Mathematical modelling and simulation of drying curves under different conditions is important to obtain a better control of this unit operation and an overall improvement of the quality of the final product. The principle of modelling is based on having a set of mathematical equations which can satisfactorily explain the system. Models are often used to study the variables involved in the process, predict drying kinetics of the product and to optimize the operating parameters and conditions (Karathanos and Belessiotis, 1999). They estimate drying times of several products and also generalize drying curves (Meisami-asl et al., 2009). Several investigators generally have proposed and worked on numerous mathematical models for thin layer drying of many agricultural products, though not based on different periods of harvest and thus include: cowpea (Shi et al., 2013), green bean and onion (Yaldiz and Ertekin, 2001), millet (Ojediran and Raji, 2010), soybean (Gely and Santalla, 2000), grains (Tagawa et al., 1996) and mango (Aremu et al., 2013).

Thin layer drying process of food products has been categorized into three namely: theoretical, semi-theoretical and empirical (Midilli et al., 2002; Panchariya et al., 2002). Theoretical models account for only the internal resistance to moisture transfer (Yagcioglu et al., 1999). It can be used for different materials and conditions but contains diffusion or heat and mass transfer equations (Meisami-asl et al., 2009). Semi-empirical and empirical approaches consider only the external resistance to moisture transfer between the product and air (Midilli et al., 2002). Semi-theoretical models contain parameters directly related to material properties. They are derived directly from statistical relations and they directly correlate moisture with time, having no physical connection with drying process itself (Meisami-asl et al., 2009). Among semi theoretical thin layer drying models, the exponential (Newton) model, Page model, the modified Page model (I and II), the Henderson and Pabis model, the Thomson model and the Wang and Singh model are the frequently used (Ojediran and Raji, 2010).

Although, several works have been done on modelling of cowpea, but information is parse on studies involving problems of losses as a result of delayed harvest. It is thus paramount to pay attention to the high losses often recorded on cowpea as a result of keeping them on the field until they dry after drying and these need to be reduced. One of the ways is to harvest cowpea immediately after maturity and subject them to artificial drying. Considering the previous works carried out on the drying of cowpea, it was observed that there is a need for studies relating the drying characteristics of cowpea to its period of harvest and nutritional content. Hence, this work aims at studying the drying kinetics of cowpea at varying periods of harvest, considering the losses encountered due to delayed harvest and also, the fact that, time of drying is essential in countries where energy cost is high.

2 Materials and methods

2.1 Materials

Cowpea, IT 97K-56S-IS, a disease resistant, high yielding cowpea variety with maturity age of 60 days was used for this study. It was propagated by seeds during the period of a partially wet season at the International Institute of Tropical Agriculture (IITA), Ibadan, South Western Nigeria. This was done to ensure that the seeds tested were harvested at the periods needed. Matured pod samples were harvested by hand at 60, 64, 68 and 72 Days After Planting (DAP) in line with the recommendation of DPP (2011), which were within an interval of two weeks after maturity to avoid shattering of the pods. Freshly harvested cowpea pods were then cleaned and sorted to remove foreign materials. The initial moisture content of the samples for the four periods of harvest was determined. This was done by using samples of known weight (200g) measured with the use of a top loading digital weighing scale (Scout Pro, England) and thereafter placed in a cabinet tray dryer at 103℃±2℃ and weighed at intervals until constant weight were attained as recommended in ASABE standards (ASABE, 2003).

2.2 Methods

A Hotpack cabinet tray dryer (model: NG008295) was used for drying of the samples. The dryer consist of a drying chamber with perforations to uniformly distribute air within the dryer; set of tight - fitting trays to hold the samples and prevent air from by passing the materials to be dried, thermostat for regulating temperature (0℃ to 300℃±5℃), heating elements such that heated air is circulated vertically through the column with a circulating fan so that fresh air is brought into the cabinet and moist air is exhausted by a dehumidistat preset to 4%, 6%, 9% and 13% relative humidity for varying experiments, and a door to suite the design for loading and unloading the dryer.

Two hundred grams of the freshly harvested sample was used for each drying experiment according to Tunde-Akintunde and Afon (2009) and Aremu and Akintola (2014). Each experiment was replicated three times (Aremu et al., 2013) and triplicate samples were spread out in thin layer and placed in the dryer. The samples were dried at temperatures 55℃, 65℃, 75℃, 85℃ which are within the range of temperatures used by Mario et al. (2003), Mc Watters et al. (1988) and Wilton et al. (2008) for drying of cowpea. The drying process was monitored by weighing the samples every 10 mins for the first one hour; then every 30 mins for the next three hours and every 1hr for the next three hours till the end of drying according to Ojediran and Raji (2010). Weight loss was used to calculate the moisture content using the equation used by Ojediran and Raji (2010) given as:

$$M_t = \frac{M_i m_i - w_i}{m_i - w_i} \qquad (1)$$

where, M_t is the moisture content (m.c.) at time t, (% w.b.), M_i, the initial m.c. (%w.b), m_i, the initial weight, (g) and w_i is the weight loss at time, t (g). The moisture content was converted to moisture ratio (MR) using the non-exponential part of the thin-layer equations being considered. The moisture content obtained at different drying air temperature was converted to moisture ratio (MR) according to Ojediran and Raji (2010) using:

$$MR = \frac{M - M_e}{M_o - M_e} \qquad (2)$$

where, MR is the moisture ratio, M_o, the initial moisture content (% d.b), M_e, the equilibrium moisture content (% d.b), M, the moisture content at time t (% d.b), t, the drying time (hr), The drying curve for each experiment was thus obtained by plotting the dimensionless moisture ratio of the sample against the drying time.

2.3 Mathematical modeling of the drying process

Five of the commonly used mathematical models for thin layer drying as presented in Table 1 were used to select the appropriate drying models for describing the drying of cowpea at varying period of harvest. Moisture ratios obtained from the drying experiment were fitted into the models using non linear regression method to estimate the drying constants. In order to check the veracity of the found solutions, the regressions were repeated using several initial guessed values which include that obtained from the linearization of the models through logarithmic transformation using the linear regression approach. Model parameters were estimated by taking the moisture ratio (MR) to be the dependent variable and time as the independent variable. The coefficient of determination (R^2) and Root Mean Square Error (RMSE) were used as criteria for adequacy of fit. The models that satisfactorily described the thin layer drying characteristics of cowpea were chosen as the one with the highest R^2 and the least RMSE (Doymaz, 2004; Ojediran and Raji, 2011). The RMSE was calculated using:

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

where, subscript pre and exp indicate predicted and experimental. Furthermore, the plot of experimental moisture ratio against the predicted moisture ratio was obtained for the suitable models to verify their adequacy of fit.

Table 1 Mathematical models used for drying characteristics

Model	Equation
Exponential (Newton)	$MR = \exp(-kt)$
Henderson and Pabis	$MR = a.\exp(-kt)$
Page	$MR = \exp(-kt^n)$
Modified Page	$MR = \exp[-(kt)]^n$
Logarithmic	$MR = a.\exp(-kt) + c$

Source: Akpinar and Bicer (2006)

2.4 Proximate analysis

The Proximate Analysis of the cowpea seeds was carried out using the AOAC standard method (AOAC, 2000). This is with a view to determine the effect of drying and period of harvest on the nutritional qualities of the dried cowpea. Crude protein, ash content, crude fat, crude fiber and carbohydrate were determined. The result of determination of proximate analysis was subjected to analysis of variance, ANOVA at (p=0.05).

3 Results and discussion

3.1 Drying characteristics of an improved variety cowpea (IT 97K-56S-IS)

The initial moisture content and equilibrium moisture content of (IT 97K-56S-IS) for the four periods of harvest and drying temperatures are presented in Table 2.

Table 2 Initial moisture content and equilibrium moisture content of (IT 97K-56S-IS) for the various period of harvest and drying conditions

Period of Harvest (days)	Initial M. C. (x100%, d,b)	Equilibrium M. C. (x100%, d.b.)			
		55 (°C)	65 (°C)	75 (°C)	85 (°C)
60	2.26	0.039	0.028	0.030	0.021
64	1.88	0.022	0.029	0.026	0.016
68	0.86	0.017	0.021	0.022	0.018
72	0.65	0.011	0.022	0.022	0.022

The initial moisture content ranges between 0.65% and 2.26% while the equilibrium moisture content was found to be between 0.011% to 0.039%.

The drying curves of (IT 97K-56S-IS) illustrating the variation of moisture content with drying time in relation with period of harvest and drying temperature are also presented in Figures 1a-d. Period of harvest and drying air temperature are the main factors influencing the drying characteristics of cowpea. An increment in drying air temperature and delayed harvest was accompanied by a reduction in time taken to reach equilibrium moisture content. Constant rate drying was not well pronounced as the drying took place in the falling rate for the four periods of harvest and at the four drying temperatures considered. In all the cases, at the beginning of the drying process, drying rate was higher, but decreased continuously with decreasing moisture content as the drying time progressed which is similar to the result reported by Ojediran and Raji (2010). This is due to the fact that drying at higher temperature implies a larger driving force for heat transfer. Similar behaviour was also observed by Methakhup (2003). It can be seen also in Figures 1a-d that drying times were longer when the seeds were harvested early. This is because the initial moisture content was higher; hence, a longer period of time was required for drying the product.

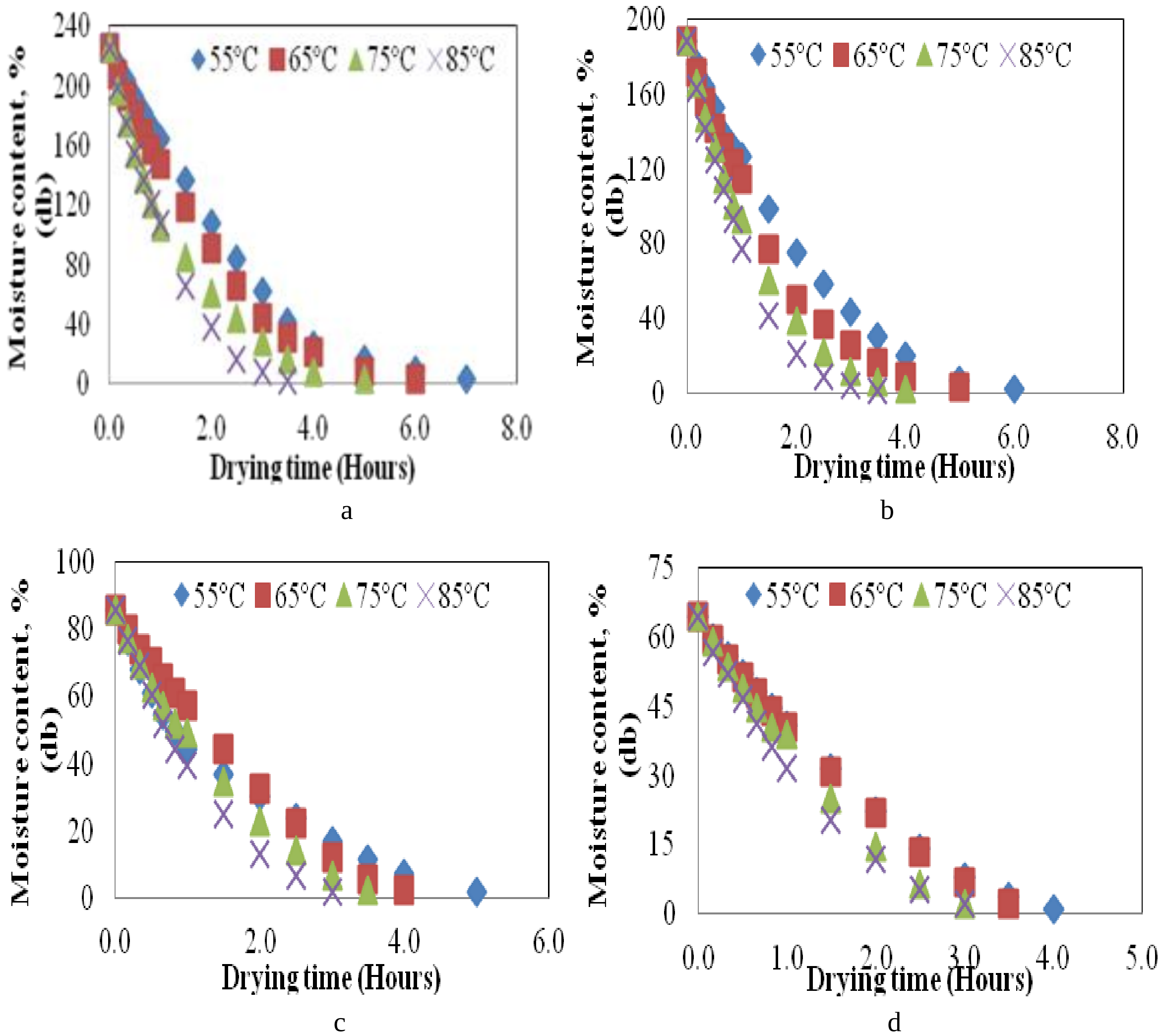


Figure 1 a. Drying curve of (IT 97K-56S-IS) at period of harvest of 60days

b. Drying curve of (IT 97K-56S-IS) at period of harvest of 64days

c. Drying curve of (IT 97K-56S-IS) at period of harvest of 68days

d. Drying curve of (IT 97K-56S-IS) at period of harvest of 72days

The variation of moisture ratio with drying time at different temperatures and period of harvest are as presented in Figures 2-5. The moisture ratio decreased exponentially with time and the time required to reaching equilibrium moisture content decreases with increasing temperature. This is a general trend reported for other food products e.g. mulberry, tomatoes, sweet pepper and peach slices. (Doymaz, 2004; Doymaz, 2007: Vengaiah and Pandey, 2007; Kingsly et al., 2007). Hence, the effect of period of harvest and temperature on drying rate has been established for IT 97K-56S-IS.

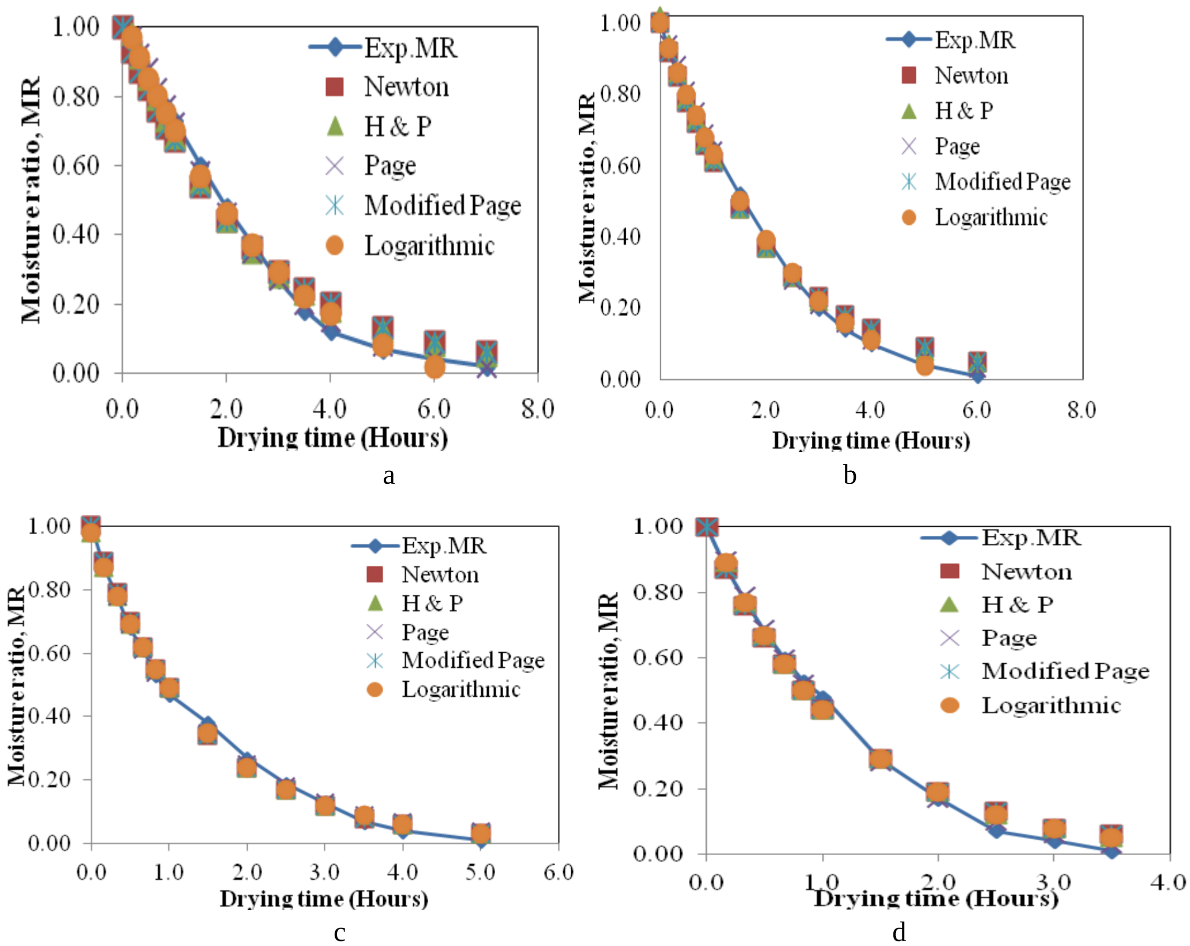


Figure 2 a. Drying model fittings at period of harvest of 60days at 55 ℃

b. Drying model fittings at period of harvest of 60days at 65 ℃

c. Drying model fittings at period of harvest of 60days at 75 ℃

d. Drying model fittings at period of harvest of 60days at 85 ℃

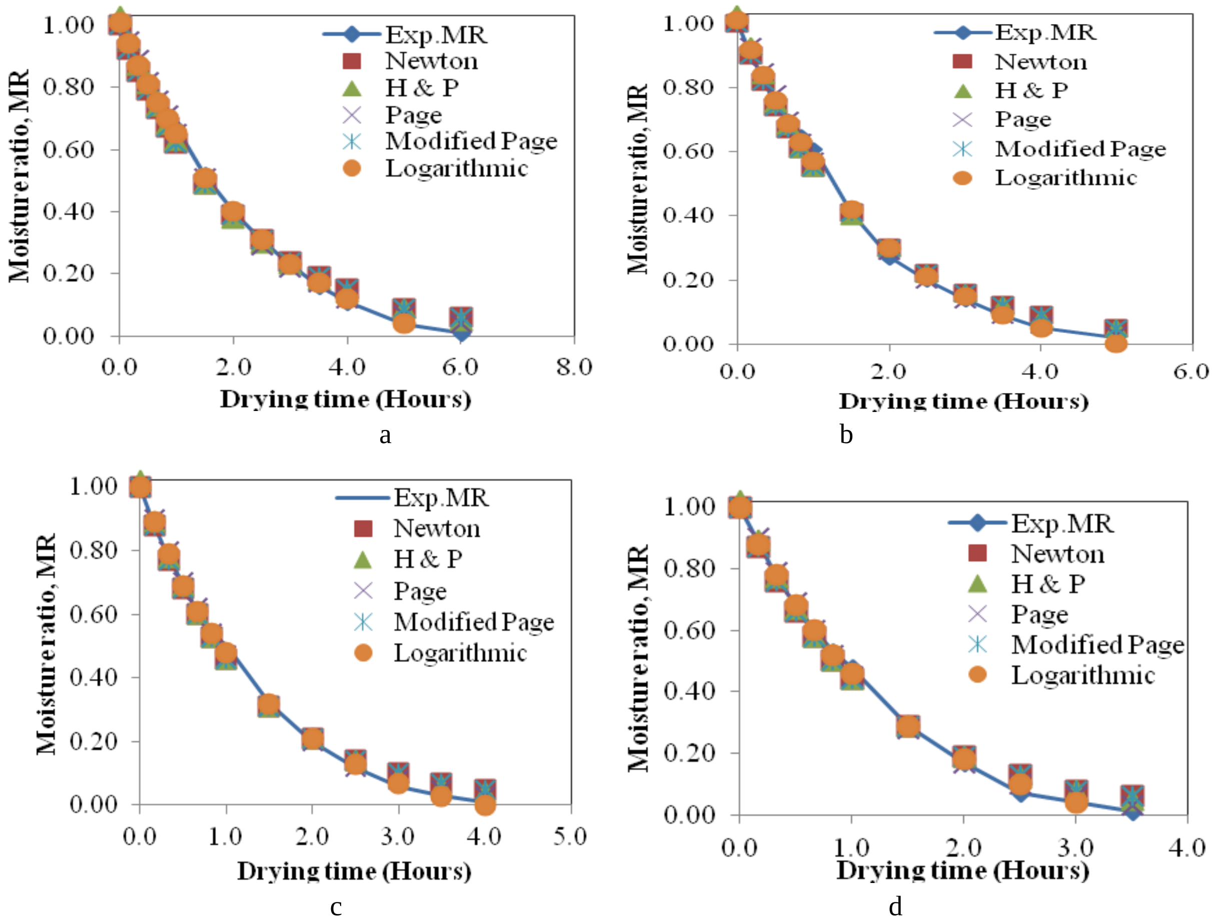


Figure 3 a. Drying model fittings at period of harvest of 64days at 55 ℃

b. Drying model fittings at period of harvest of 64days at 65 ℃

c. Drying model fittings at period of harvest of 64days at 75 ℃

d. Drying model fittings at period of harvest of 64days at 85 ℃

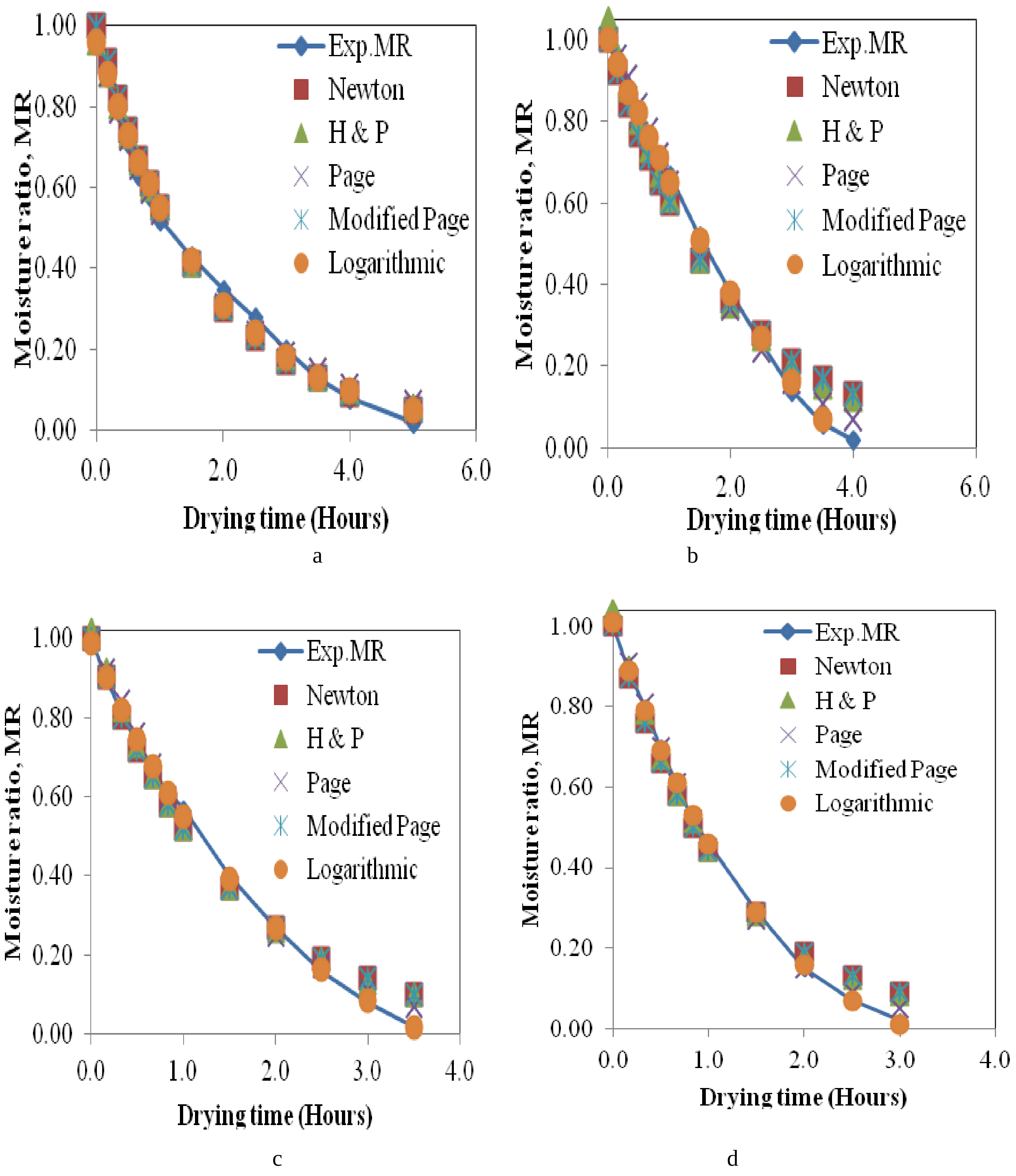


Figure 4 a. Drying model fittings at period of harvest of 68days at 55 ℃

b. Drying model fittings at period of harvest of 68days at 65 ℃

c. Drying model fittings at period of harvest of 68days at 75 ℃

d. Drying model fittings at period of harvest of 68days at 85 ℃

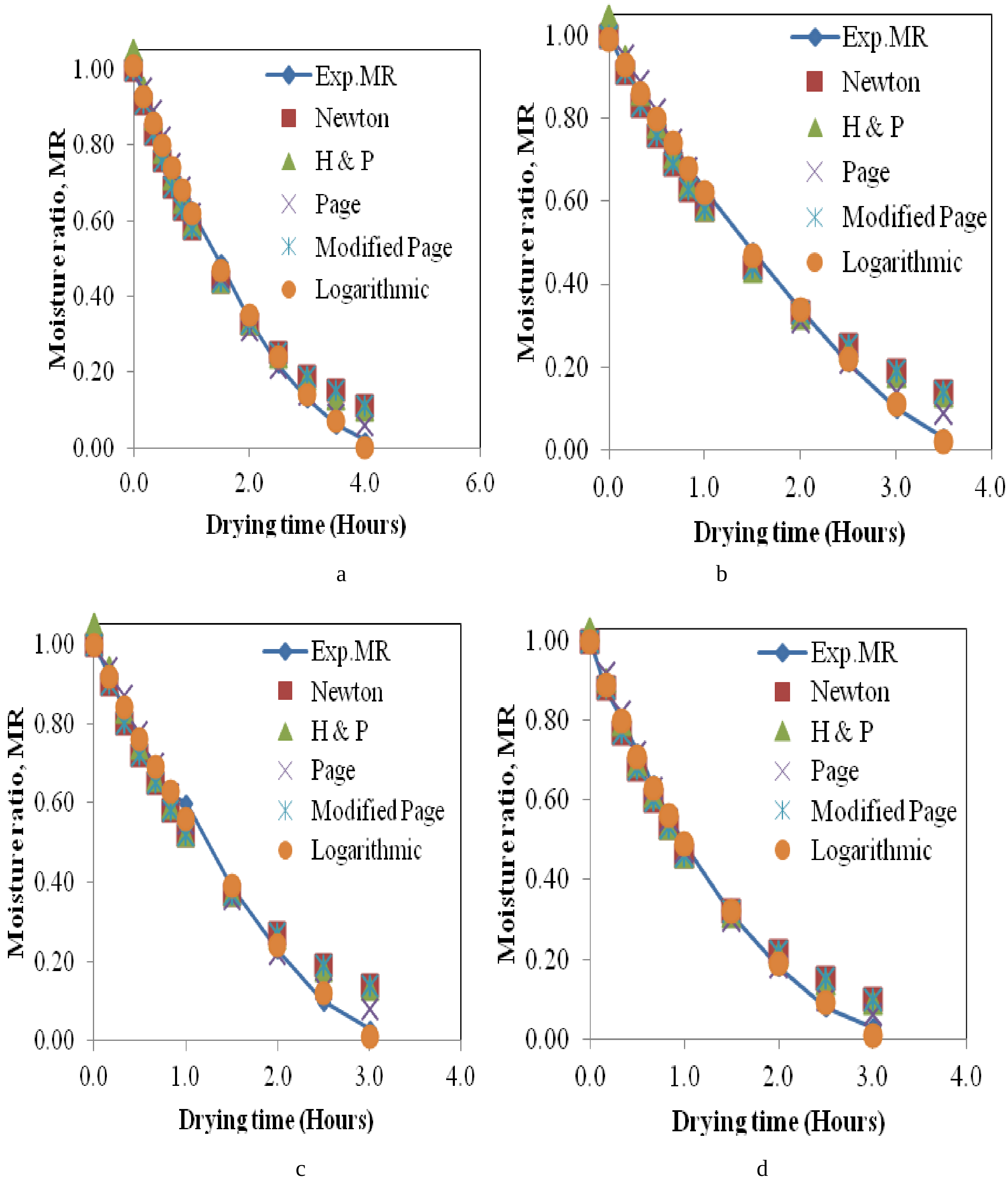


Figure 5 a. Drying model fittings at period of harvest of 72days at 55 ℃

b. Drying model fittings at period of harvest of 72days at 65 ℃

c. Drying model fittings at period of harvest of 72days at 75 ℃

d. Drying model fittings at period of harvest of 72days at 85 ℃

3.2 Model fitting

The model constants and the coefficients for the five models presented in Table 1 are given in Tables 3-6 for the various periods of harvest and drying temperatures. The model fittings are illustrated as presented in Figures 2-5.

Table 3 Drying constants and coefficients of the models for IT 97K-56S-IS at period of harvest of 60days

	Constants and coefficients	Exponential (Newton)	Henderson and Pabis	Page	Modified Page	Logarithmic
55 ℃	k	0.407	0.437	0.324	0.158	0.340
	a		1.054			1.159
	n			1.279	2.577	
	c					-0.127
	R^2	0.982	0.987	**0.998**	0.982	**0.994**
	RMSE	0.047	0.039	**0.017**	0.047	**0.026**
65 ℃	k	0.492	0.506	0.452	0.138	0.400
	a		1.022			1.112
	n			1.130	3.552	
	c					-0.113
	R^2	0.992	0.993	0.997	0.992	0.998
	RMSE	0.030	0.026	0.019	0.030	0.013
75 ℃	k	0.713	0.694	0.723	0.245	1.135
	a		0.981			0.981
	n			0.951	2.909	
	c					
	R^2	0.996	0.997	0.997	0.996	0.997
	RMSE	0.020	0.019	0.018	0.020	0.019
85 ℃	k	0.824	0.850	0.810	0.328	1.168
	a		1.025			1.025
	n			1.144	2.515	
	c					-0.728
	R^2	0.991	0.992	0.996	0.991	0.992
	RMSE	0.031	0.028	0.018	0.031	0.028

Table 4 Drying constants and coefficients of the models for IT 97K-56S-IS at period of harvest of 64days

	Constants and coefficients	Exponential (Newton)	Henderson and Pabis	Page	Modified Page	Logarithmic
55 ℃	k	0.824	0.850	0.810	0.328	0.669
	a		1.025			1.113
	n			1.144	2.515	
	c					-0.113
	R^2	0.991	0.992	0.996	0.991	0.999
	RMSE	0.031	0.028	0.018	0.031	0.013
65 ℃	k	0.601	0.624	0.564	0.179	0.519
	a		1.029			1.094
	n			1.146	3.364	
	c					-0.084
	R^2	0.992	0.993	0.997	0.992	0.997
	RMSE	0.029	0.029	0.018	0.029	0.017
75 ℃	k	0.773	0.791	0.757	0.281	0.661
	a		1.018			1.076
	n			1.105	2.746	
	c					-0.078
	R^2	0.995	0.995	0.998	0.995	0.999
	RMSE	0.024	0.021	0.015	0.024	0.001
85 ℃	k	0.824	0.850	0.810	0.328	0.669
	a		1.025			1.113
	n			1.144	2.515	
	c					-0.113
	R^2	0.991	0.992	0.996	0.991	0.999
	RMSE	0.031	0.028	0.018	0.031	0.013

Table 5 Drying constants and coefficients of the models for IT 97K-56S-IS at period of harvest of 68days

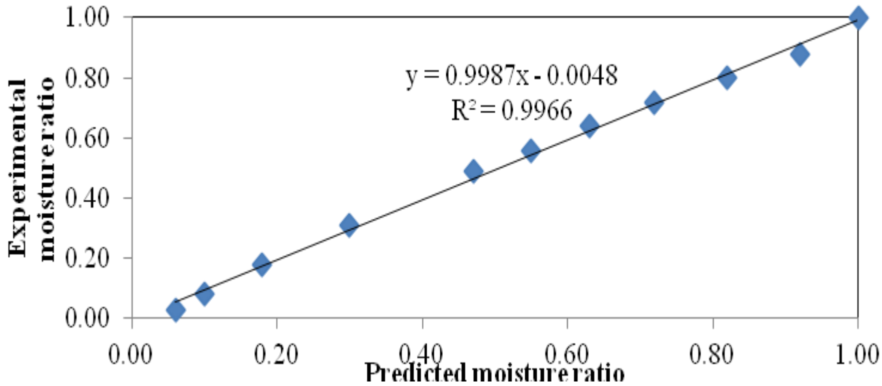
	Constants and coefficients	Exponential (Newton)	Henderson and Pabis	Page	Modified Page	Logarithmic
55 ℃	k	0.594	0.563	0.622	0.283	0.543
	a		0.965			0.976
	n			0.902	2.097	
	c					-0.015
	R^2	0.989	0.992	0.993	0.989	0.992
	RMSE	0.030	0.027	0.025	0.030	0.027
65 ℃	k	0.513	0.551	0.427	0.331	0.236
	a		1.054			1.646
	n			1.326	1.548	
	c					-0.647
	R^2	0.967	0.973	0.991	0.967	0.998
	RMSE	0.061	0.053	0.033	0.061	0.013
75 ℃	k	0.655	0.677	0.624	0.299	0.431
	a		1.024			1.244
	n			1.154	2.188	
	c					-0.257
	R^2	0.986	0.988	0.993	0.986	0.999
	RMSE	0.036	0.036	0.026	0.036	0.009
85 ℃	k	0.822	0.865	0.809	0.237	0.628
	a		1.040			1.182
	n			1.207	3.463	
	c					-0.172
	R^2	0.987	0.990	0.998	0.987	0.999
	RMSE	0.037	0.032	0.015	0.037	0.007

Table 6 Drying constants and coefficients of the models for IT 97K-56S-IS at period of harvest of 72days

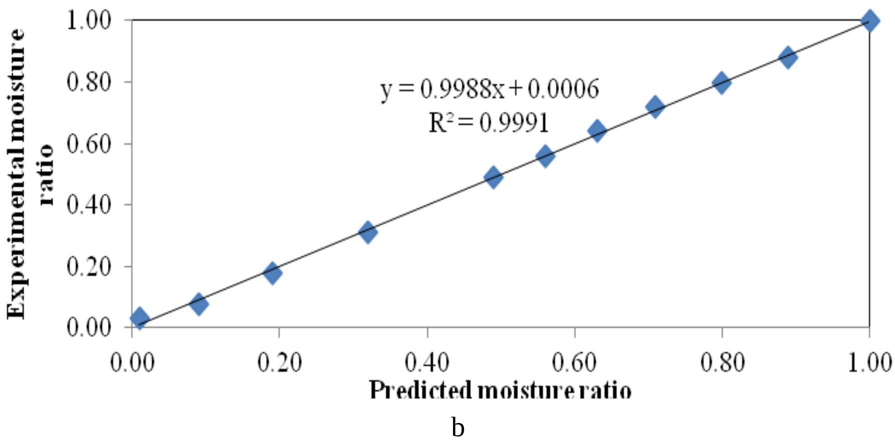
	Constants and coefficients	Exponential (Newton)	Henderson and Pabis	Page	Modified Page	Logarithmic
55 ℃	k	0.768	0.804	0.748	0.268	0.316
	a		1.034			1.612
	n			1.209	2.865	
	c					-0.612
	R^2	0.985	0.987	0.996	0.985	0.998
	RMSE	0.040	0.035	0.019	0.040	0.010
65 ℃	k	0.553	0.590	0.487	0.223	0.248
	a		1.047			1.679
	n			1.285	2.483	
	c					-0.685
	R^2	0.971	0.976	0.991	0.971	1.000
	RMSE	0.052	0.049	0.030	0.052	0.008
75 ℃	k	0.655	0.703	0.604	0.301	0.316
	a		1.052			1.612
	n			1.315	2.178	
	c					-0.612
	R^2	0.967	0.973	0.991	0.967	0.998
	RMSE	0.056	0.052	0.029	0.056	0.016
85 ℃	k	0.768	0.804	0.748	0.268	0.316
	a		1.034			1.612
	n			1.209	2.865	
	c					-0.612
	R^2	0.985	0.987	0.996	0.985	0.998
	RMSE	0.040	0.035	0.019	0.040	0.010

It was discovered that the models prediction fitted well to the experimental moisture ratio during the first 1hr of drying for period of harvest with shorter durations (60 and 64 days). This is as a result of the higher initial moisture content compared to the other subsequent time interval and was close to giving an approximate constant rate; also because the time interval was small compared to the others and so gave a relatively good approximation solution at those points for the numerical computation.

The results of experimental data fitting in the five thin-layer drying models are illustrated in Tables 3-6. Generally, Logarithmic and Page model gave the best prediction for all the periods of harvest being those with the least RMSE and highest R^2. Using the approach of Ojediran and Raji (2010), it was further validated by plotting the experimental moisture ratio against the predicted and this was done at periods of harvest of 72days and drying temperature of 55 ℃ and the plots of the model prediction against the experimental data were derived as presented in Figure 6a and 6b. The experimental and predicted moisture ratio lay around the straight line which fits perfectly with a straight line dividing the plot area to two equal halves having slope of approximately one and intercept of almost zero. This clearly demonstrates that these models could be used to explain the thin layer convective drying behaviour of cowpea (IT 97K-56S-IS) at varying periods of harvest.



a



b

Figure 6 a. Model fitting for period of harvest of 72days for Page model

b. Model fitting for period of harvest of 72days for Logarithmic model

The Page model is an empirical modification and a special case of Henderson and Pabis that has corrected its shortcomings (Ojediran and Raji, 2010). It has been used to test the experimental data of grains and leguminous crops such as soybean, white bean, green bean and corn, millet (Yaldiz and Ertekin, 2001; Aghbashlo et al., 2009; Ojediran and Raji, 2010). Its use as an immediate check is therefore appropriate. Empirical models derive a direct relationship between average moisture content and drying time. They neglect fundamentals of the drying process and their parameters have no physical meaning. Therefore, they cannot give clear accurate view of the important processes occurring during drying although they may describe the drying curve for the conditions of the experiments (Ozdemir and Devres, 1999; Ojediran and Raji, 2010). Page also came up with a model appropriate for soybean, rough rice, shelled corn, melon and sunflower seed which is referred to as Logarithmic which is now found to fit well with this variety of cowpea.

A wide variation is observable in the curves for the Henderson and Pabis model and the Newton model against the experimental data implying that the two models are not suitable for the prediction of the drying behaviour of IT 97K-56S-IS. This indicates that the power index ‘n’ in the equations plays a role in prediction than the constant ‘a’ but there was an exception in the Logarithmic model having drying constants a, k and c but with no power index and was found suitable. Similar result was observed by Ojediran and Raji (2010) for the drying of millet varieties.

3.3 Proximate composition result of IT 97K-56S-IS

In terms of drying characteristics, the drying temperature was found to have no significant effect on the nutritional content of the samples dried. The result of the proximate composition of IT 97K-56S-IS is graphically represented in Figures 7a-d.

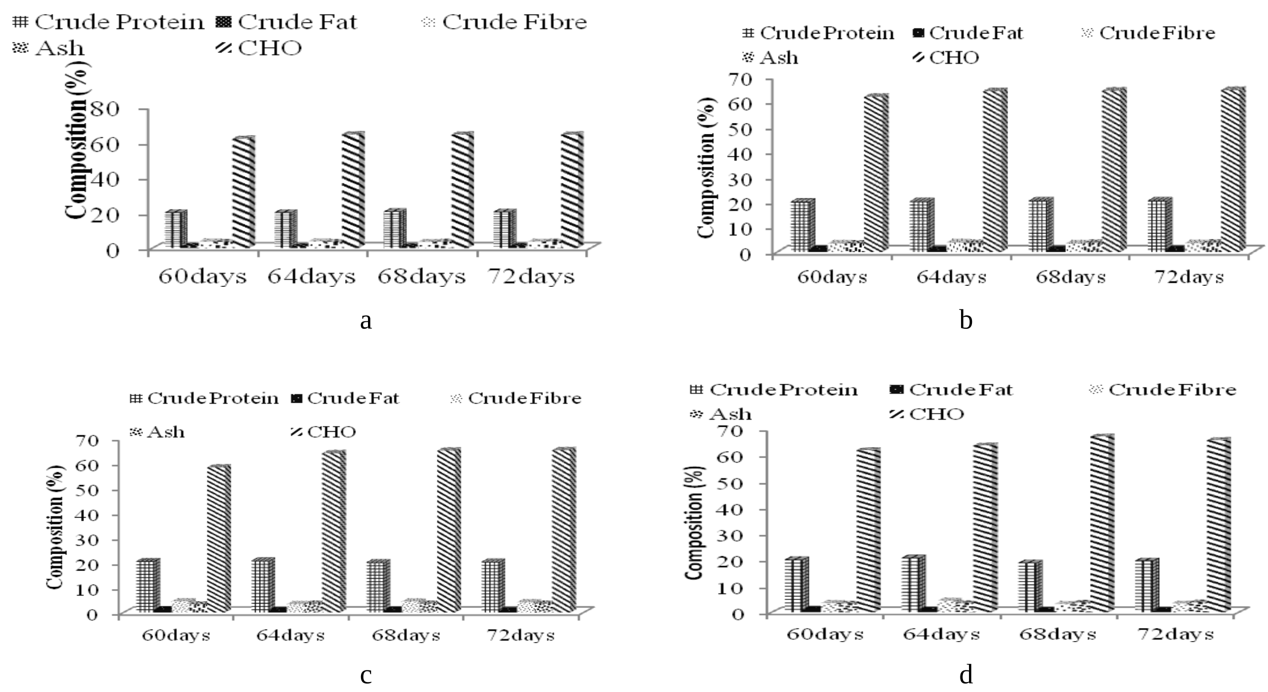


Figure 7 a. Representation of nutritional values of cowpea at varying period of harvest at 55 ℃

b. Representation of nutritional values of cowpea at varying period of harvest at 65 ℃

c. Representation of nutritional values of cowpea at varying period of harvest at 75 ℃

d. Representation of nutritional values of cowpea at varying period of harvest at 85 ℃

It also indicates that, carbohydrate has the highest value, then protein, crude fibre, ash and crude fat. Similar results of proximate composition of cowpea were reported with protein content of (18% - 35%) and (50% - 65%) carbohydrate content by Prinyawiwatkul et al. (1996); Mogbo et al. (2014) and (0.9% - 2.4%) fat content by Hedley (2001). ANOVA results indicates that period of harvest have significant effect on crude fat, Ash and CHO while there was no significant effect on crude protein and crude fibre (p = 0.05).

4 Conclusions

This study has shown that the drying of IT 97K-56S-IS at period of harvest of 60, 64, 68 and 72days with a temperature range of 55℃-85℃ can be best predicted using Page and Logarithmic models. Moisture transfer can be described by diffusion in the falling rate. The result of proximate analysis indicates that there was a good retention of nutrients (crude protein, crude fibre, ash content, crude fat and CHO for all the samples at various periods of harvest and drying temperature.

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