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MOISTURE-BASED SHELF LIFE ESTIMATION OF AMBIENT-STORED GRAIN FLOURS

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ABSTRACT

Flours are susceptible to rapid moisture uptake, caking up and discoloration consequently leading to mould growth when exposed to humid conditions in tropical and sub-topical zones of the world. This study therefore was designed to determine the shelf lives of flours from four indigenous crops (rice, maize, soy bean and bambara nut) stored under controlled accelerated ambient storage conditions (27±1°C, 92 % RH). Moisture and colour changes in the flours were monitored at three and seven day interval, respectively for six weeks. The water vapour permeability coefficient (K) of the low density polyethylene (LDPE) bags used was determined as K was 1.708 × 10^{-14} g.mm/day/mmHg. In terms of colour stability, redness (a*) changed more rapidly across all flour samples while Lightness (L*) was the most stable. Stability of L* values was least for rice flour while maize flour the greatest L* stability. Soy bean flour had the highest rate of moisture gain followed by bambara nut, maize and rice flour. The estimated shelf life based on 12% and 15% targeted moisture content was 1112 and 1528 days, 9 and 98 days, 160 and 244 days, 225 and 339 days for rice, maize, soy bean and bambara nut flours respectively.

Keywords: Accelerated Shelf lives, Moisture Sorption Isotherm, Cereals, and Legumes.

INTRODUCTION

Cereal and legumes are staple foods which play important role in supplying the nutrient and energy to the majority of Nigerians. Cereal and legumes complementary foods have been reported to possess high biological value, and high protein digestibility, especially when consumed together (Sichieri, 2002; Teba, Ascheri and Carvalho, 2009; Oghbaei and Prakash, 2016).

Rice (*Oryza sativa*), maize (*Zea maize*), soy bean (*Glycine max*) and bambara nut (*Vigna subterranea*) serve as major energy and protein sources. One of the ways of effectively utilizing these indigenous crops is by transforming them to flours which are more easily handled, packaged and stored. Indeed, the conversion of food grains to flour helps to increase bulk density (reduce packaging volume), and slow down diffusion of oxygen into the flour thereby, reducing oxidative processes and improve storage stability.

Flours, however, have lower shelf stability than their respective grain forms due to the increased surface area available for moisture adsorption and other deteriorative changes often influenced by storage time and environmental conditions (Hruskova and Machova, 2002). The transfer of moisture or oxygen can be controlled by thermodynamic and dynamic processes. The storage stability study of flours is a primary function of air (oxygen) diffusion, moisture content migration and water activity (Cenkowski *et al*., 2000). Packaging is a means of providing the correct and stable environmental conditions for food during storage and the choice of materials for packaging depends on the nature of the product, the storage and handling conditions (temperature, humidity, risk of physical deterioration) among other factors (Brown, 1992). Low-density polyethylene (LDPE) is a heat sealable, inert, odour free and shrinks when heated. It is a good moisture barrier but has a relatively high gas permeability, sensitivity to oils and poor odour resistance. LDPE is widely used because it is among the most available and affordable packaging material.

This work therefore investigated the thermodynamic hydration of ambient-stored flour from selected indigenous tropical cereals and legume and the colour changes during accelerated storage study at 92 % RH and 27±1 ˚C condition.

MATERIALS AND METHODS

Materials

Wholesome crops (rice, maize, soybean and bambara nut) were purchased at Kuto market, Abeokuta, Ogun state, Nigeria. The reagents used for the analysis were of analytical grade.

Methods

Rice flour, maize flour, soy bean flour and bambara nut flours were all processed and produced in the Food Processing Laboratory of the Federal University of Agriculture Abeokuta. Each flour sample was weighed (50 g) and packed inside a low density polyethylene (LDPE) film and stored at ambient temperature with 92 % RH.

Proximate composition

The proximate composition of the flour samples was determined according to the method described by A.O.A.C. (2000). Carbohydrate was obtained by difference.

Determination colour of flour during storage

The colour of the flour was determined using a Lab colorimeter. The L^*, a^* and b^* values of the flour were determined with a colorimeter (Chroma meter CR-41D, Konica Minolta INC. B.8408286). Where L^*, a^* and b^*, represent lightness, redness or greenness and yellowness or blueness respectively.

The colour stability indices (C_p) were calculated as:

$$C_p\ (\%) = \frac{|x_i - x_f|}{P_i} \times 100 \qquad (1)$$

Where x_i and x_f are initial and final colour values while x_t is the value of colour parameter at time t. C_p is a measure of overall colour stability at the end of storage time.

Permeability of packaging material

In determining the water vapour permeability of the packaging material, 5 g of dehydrated silica gel was packed in a cup-like glass container, sealed with the determining packaging material, and was placed in an incubator. The environment temperature was maintained at 27±1°C by using a contact thermometer-type temperature sensor controller and 100% RH was established with a natural solvent. The weight of the cup-like glass containing the silica gel was determined at intervals, and the mean weight gain by the silica gel was calculated for each day (Labuza, 1984). The water vapour permeability, k (g/m^2/day/Pa), of the packaging material was calculated using:

$$k = \frac{d_w}{d\theta_p} \times \frac{1}{A_p P^*} \qquad (2)$$

where $d_w/d\theta_p$ is the slope of the linear plot between the time $d\theta_p$ (day) of incubation and cumulative moisture gain; d_w (kg) is the weight of the silica gel in the packaging material; A_p (mm) is the surface area of the packaging material and P^* (mmHg) is the saturation vapour pressure of water at 27°C (0.0364 bar), the temperature of the environment chosen for the experiment.

Storage studies

At a precise particle size 50g of each flour samples was packed inside a low density polyethylene (LDPE) film (16 cm × 19 cm), sealed and stored at ambient temperature (30 ± 3 °C; RH of 92 %) in a wooden box for six weeks. Stored samples were analyzed for moisture content, and colour at interval during storage.

RESULTS

Proximate composition of flour

Table 1 shows the proximate compositions of rice, maize, soy bean and bambara nut flour. The moisture content of the flours ranged from 6.03 to 10.09% with bambara nut flour having the least (6.03%) and rice flour had the highest (10.09%). Soy-bean had the highest ash content (3.99%) while rice had the least (0.63%). The result shows that soy bean flour had the highest value of protein (46.61%) while rice flour had the lowest value (5.90%). Similarly, the fat content of soy bean was highest value (29.9 %) while rice was the lowest value (8.0 %). However a reverse value was observed for carbohydrate as rice flour had the highest value (73.63%) while soy-bean had the lowest (11.73%). The crude fibre varied between 0.9% (rice flour) and 2.1% (maize flour).

Table 1: Proximate composition of cereals and legumes flours

	COMPOSITION (%)					
Sample	**Moisture**	**Ash**	**Protein**	**Fat**	**Carbohydrate**	**Fibre**
Maize	7.2	1.37	6.985	10.25	72.	2.10
Rice	10.9	0.63	5.94	8.00	73.63	0.90
Soybean	6.17	3.99	46.61	29.9	11.73	1.60
Bambara nut	6.03	3.61	29.78	22.09	36.97	1.52

Effect of storage on flour colour

The result in Figure 1 shows the changes observed in colour over the storage time at 27±1 °C and 92% RH while table 2 shows the values of colour stability index (SI) for the flour samples. The higher the SI the less stable is the flour. In terms of lightnes (L*) the values ranged from 1.84 to 2.40 with bambara nut flour having the least while soybean flour had the highest. In terms of redness, soybean flour was most stable (11.20) while maize flour was least stable (123.17). For yellowness, soybean flour had the highest stability (1.71) while rice flour was least stable (4.14).

Kinetics of moisture adsorption by the stored flours

Figure 2 shows the result of moisture uptake by silica gel against storage time at ambient temperature. The value of water vapor permeability coefficient (*k*) of LDPE film was calculated to be 1.708×10^{-14} g.mm/day/mmHg. Figure 3 depicts data on moisture changes in the flours stored at ambient temperature. The initial moisture content before the storage study for maize, rice, soybean and bambara nut flours was 7.2, 10.9, 6.17 and 6.03 % respectively. The slope from the linear plot varied between 0.0003x to 0.0015x and the coefficient of determination (R^2) ranged from 0.97 to 0.98 with rice flour having the least while soybean had the highest. The accelerated shelf life study was estimated (based on 12 % and 15 % moisture content) to be 1112, 223, 225, 161 and 1528, 848, 339, 244 days for rice, maize, bambara nut and soy bean flour respectively.

Modeling adsorption isotherm of flours

Figure 4 shows the moisture sorption curves of the flours against storage time at ambient condition. The modeled parameters indicated in Table 3 shows the level of fitting of the flours. In the MPM, the statistics showed that parameter **A** values ranged between 0.148 to 0.806, with bambara nut flour having the least while rice flour had the highest. Similarly, for parameters **B**, the values varied between 0.12 to 0.204, with bambara nut flour having the least while rice flour had the highest. The statistical results further showed that the residual sum of square (RSS) and root mean square error (RMSE) varied between 0.095 to 1.376 and 0.509 to 41.638 respectively. The coefficient of determination (R^2) ranged from 0.990 to 0.996 with bambara nut having the highest while maize had the least. Percentage error (%E) was high in bambara nut and soybean flours (6.312 and 6.321) when compared to maize and rice (0.197 and 0.108).

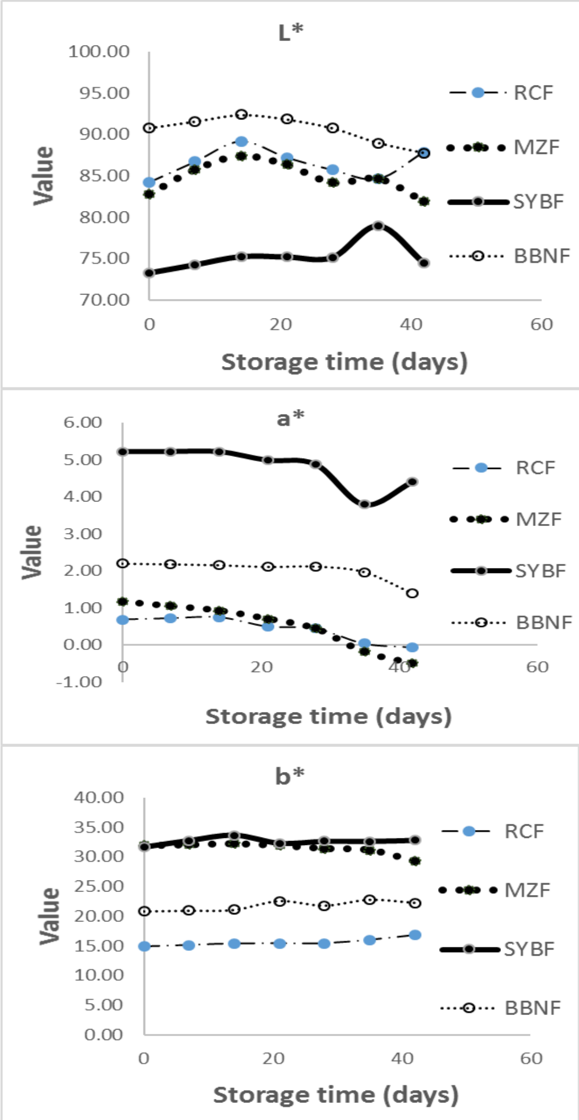

Figure 1: Effect of storage time (days) on colour parameters (L*, a*, b*) of flour samples RCF: rice flour; MZF: maize flour; SYBF: soy bean flour; BBNF: Bambara nut flour.

Table 2: Colour stability indices (%) values for different flour over the storage period

Colour Index	RCF	MZF	SYBF	BBNF
L*	2.03	2.31	2.40	1.84
a*	74.69	123.17	11.20	14.23
b*	4.14	3.31	1.71	3.57

RCF-Rice flour, MZF- Maize flour, SYBF-Soy bean flour, BBNF- Bambara nut flour, L* - Lightness, a* - Redness, b* - Yellowness.

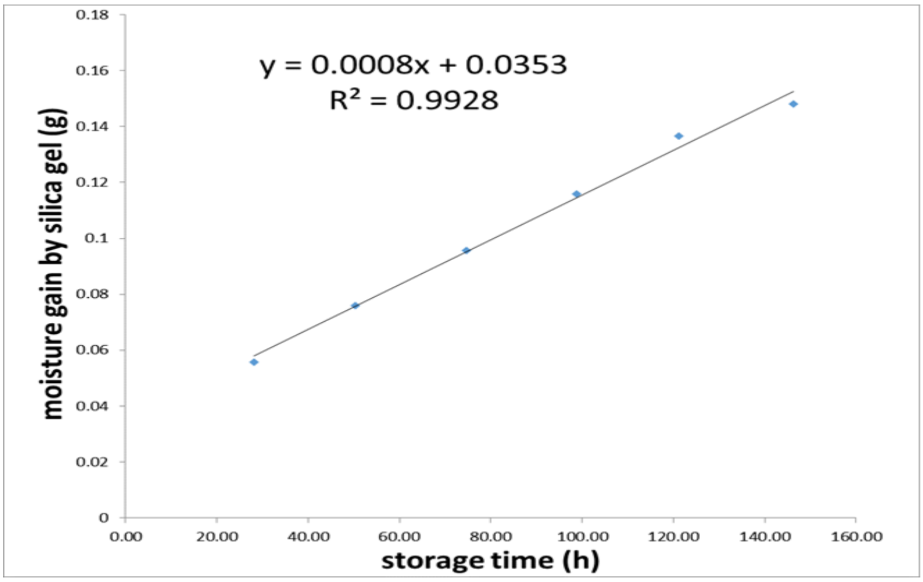

Figure 2: Moisture gain by silica gel through low density poly ethylene film with time of storage in controlled environment

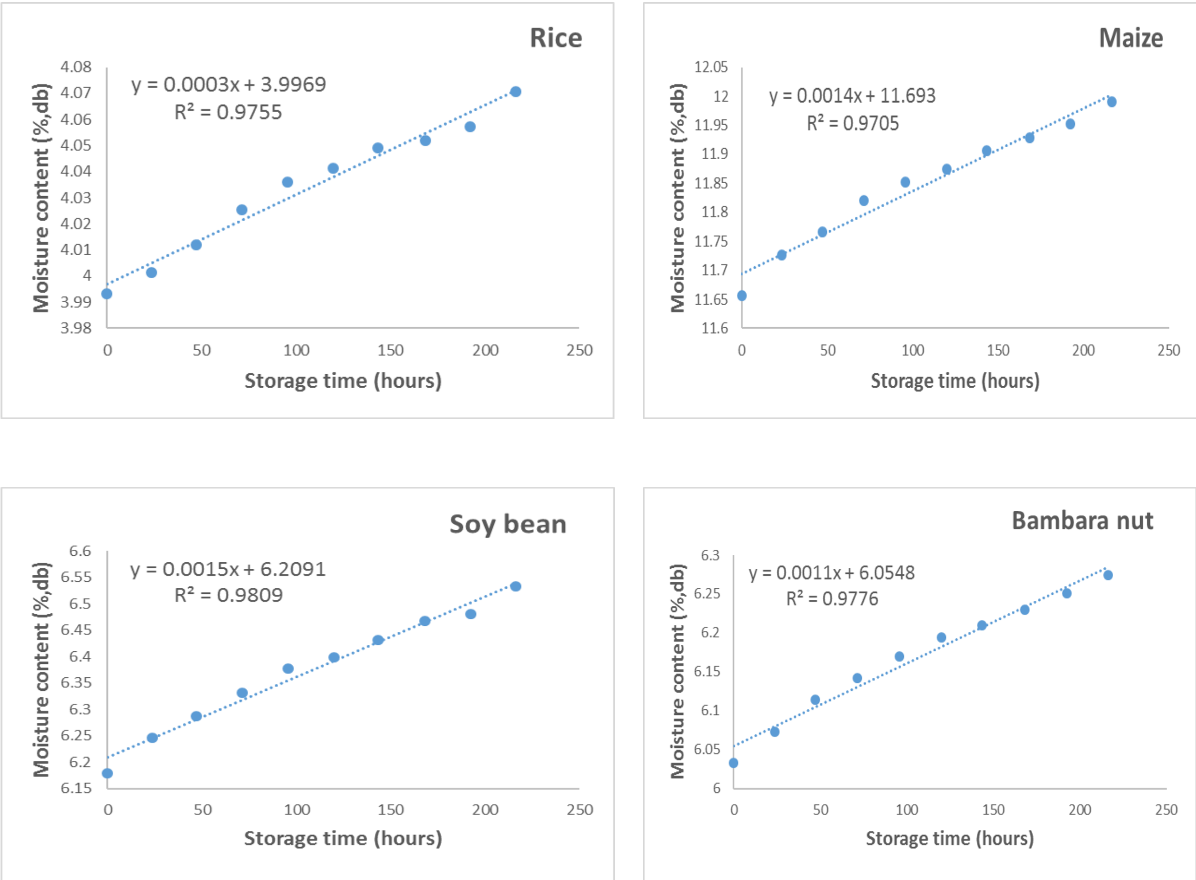

Figure 3: Linear regression plots of moisture content against the storage time for root and legume flours stored at ambient temperature

Table 3: Estimated shelf life of flour based on moisture content at 27±1˚C and 92% RH

Samples	Accelerated Shelf life (days)	
	Targeted Moisture Content (%, db)	
	12%	15%
Rice flour	1112	1528
Maize flour	223	848
Soy bean flour	161	244
Bambara nut flour	225	339

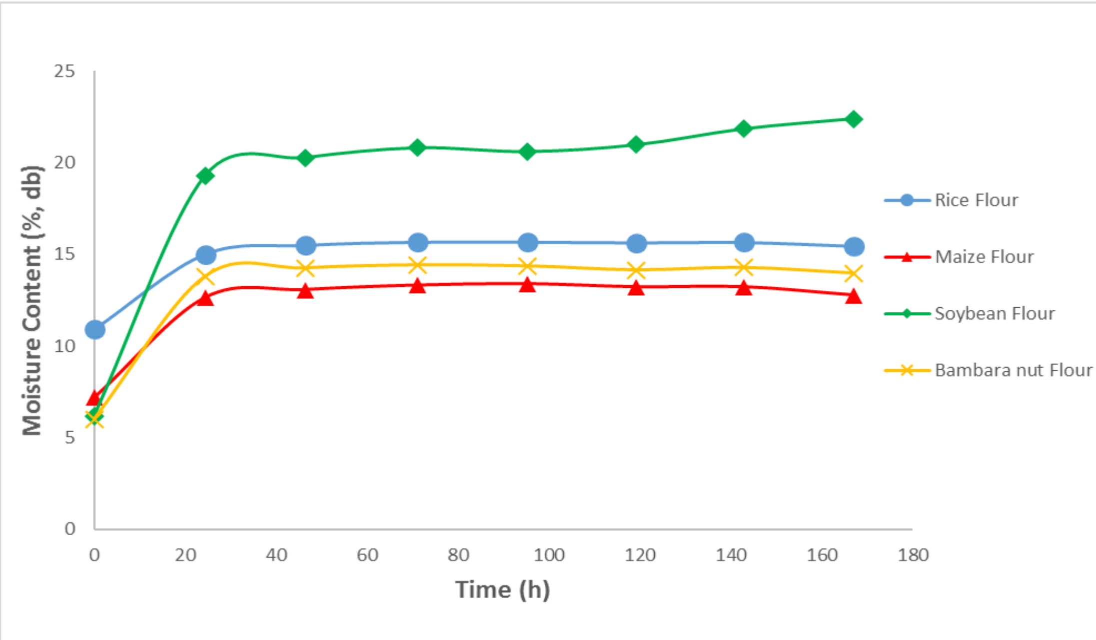

Figure 4: Moisture absorption curves at 92% RH as a function time for the flour samples

Table 4: Peleg model constant, coefficient of determination, residual sum of square, percentage and root mean square error of different flours.

Samples	A	B	M_o	RSS	R^2	RMSE	%E
Rice	0.806	0.204	10.901	0.095	0.995	0.509	0.108
Maize	0.386	0.164	7.204	0.31	0.99	1.075	0.197
Soybean	0.369	0.63	6.185	1.376	0.993	28.279	6.321
Bambara nut	0.148	0.12	6.033	0.206	0.996	41.638	6.312

Note: A and B – constant, M_o – Moisture content, RSS – Residual sum of square, R^2 – Coefficient of determination, RMSE – Root mean square error, %E – Percentage error

DISCUSSION

The moisture content among other intrinsic compositions play an important role in determining the stability of a flour product. The moisture content of the flour formulations was within the acceptable limit of not more than 10 % for long term storage of flour (Singh *et al.*, 2005) except for rice flour that had 10.9 %. This indicates that the flour may serve a longer time on the shelf before the beginning of any form of physicochemical or biological changes. More so, moisture content and water activity have been reported to have great effects on the keeping quality and shelf life of foods (Eke-Ejiofor and Owuno, 2012). Scientific investigations have reported that the amount of moisture content in food products will determine the shelf-life of the products (Olitino *et al*., 2007; Alozie *et al*., 2009). This being that the microbial spoilage organism and certain food chemical reactions are influenced by moisture content in the food product. Moisture sorption isotherm behaviors often depend on the chemical composition makeup, physical state and processing conditions of a food crop (Fabra *et al.*, 2009). Changes in chemical composition of a food can substantially influence the sorption isotherm behavior of foods and therefore, its shelf life (Kaya *et al*., 2002; Gabas *et al*., 2007). Ash was found to differ in all the flours but was more for legumes base flours when compared to cereal in this study. However, high ash content is indicative of more mineral elements in the flour blends which could be of immense benefits to the body and has been discovered to be abundant in leguminous food and soy-supplemented cereal meals (Alabi and Anuonye 2007). Similarly, the fat and protein content was high for soybean and bambara nut while maize and rice had the least. Flours high in fats have been reported to be good as flavour enhancers and useful in improving palatability when incorporated in foods during food formulation and processing (Aiyesanmi and Oguntokun, 1996). Fat is also important for providing energy for the body, storing energy for later use, insulating and protecting the body and transporting fat soluble vitamins (Wardlaw and Kkessel, 2002). While high protein helps in building up the body, repairing of worn out tissue and regulation of the process. In a reverse other, maize and rice had the highest carbohydrate while soy bean and bambara nut flour had the least. The high carbohydrate content of maize and rice flour indicates that the flours can serve as a good sources of carbohydrate which might result in high energy content of the composite flour. Awolu *et al*. (2016) reported in his work that high carbohydrate content is directly proportional to the energy content of the food product. The result showed that cereals based flour (maize) in this study had the highest fibre than other flours. The importance of crude fibre was explained in the study of Islam *et al*. (2007) who reported that soluble fibres are effective in reducing total blood cholesterol, whereas insoluble fibres controls constipation and reduce the risk of colon cancer. Neha and Ramesh, (2012) reported that the total dietary fibre intake required for adult men and women is 38 and 25 g/day, respectively.

The colour parameters varied with the storage condition and time. The colour values decreased with storage time. Redness (+a*) had the most decreasing rate, especially for maize and rice flour, it was observed that the colour started changing into green (-a*) followed by lightness (L*). This characteristic observed could be as a result of the anthocyanin pigment present in the aleurone layer of the flours in the same crop family. In terms of the degree of yellowness (b*), all flours showed a similar behavior when compared to other colour parameters as soy bean retained it yellowness while rice flour faded over the storage period. The higher the SI the less stable is the flour. Redness changed more rapidly across all flour samples while Lightness was the most stable. In terms of lightness soybean flour changed most while bambara nut flour showed the least colour change. In terms of redness and yellowness, soy bean flour showed the greatest stability while rice and maize was observed to be instable respectively. The colour stability index further clarifies based on this study that selected cereals flours are likely to be unstable than legume based flours if stored at 27±1˚C and 92 % RH. The instability observed might be due to characteristics colour pigments in each crop.

The diffusion of water vapor into the flour is an important property of flour stability during storage and is dependent on the nature of the food, packaging material, water vapor transmission rate and the immediate extrinsic condition of the environment. Water has a deteriorative effect on foods, so water vapour barrier property of LDPE films is an important factor in the packaging area. A main function of food packaging is often to avoid or least to decrease moisture transfer between the food and the surrounding atmosphere, or between two components of a heterogeneous food product. Thus the water vapour permeability should be as low as possible (Gontard *et al*., 1992).The value for water vapor permeability coefficient (*K*) of the packaging material (LDPE) in this study was similar result was reported by Rosa *et al.* (2012) in the evaluations for water activity of sweet potato packed in LDPE. Furthermore, a linear regression plot was used to describe the adsorption of the flours (Figure 3). It is obvious that soybean had the highest rate of moisture uptake while rice flour had the least. The rate of moisture uptake experienced by the flours in this study may be due to their hygroscopic properties, type of packaging material used and accelerated storage condition (Butt *et al.,* 2003; Dar *et al.,* 2012). Based on the plot, a linear equation was generated and the coefficients of determination (R^2) were found to be high for all flours, ranging from 0.97 to 0.98. The equation therefore can be used based on a targeted moisture content to determine the rate of moisture uptake and shelf life of the flours (Table 3) which showed that rice can be stored for a longer number of days, followed by maize, bambara nut and soy bean. The differences observed in the estimated shelf life of the flours could also be attributed to differences in their chemical composition, molecular and structural change during drying, and rate of adsorption (Roongruangsri and Bronlund, 2016).

Moisture adsorption isotherm was more rapid in the initial stages, but later near equilibration with increasing time (figure 4). Similar result was reported by Baucour and Daudin (2000) that at high relative humidity, the mass transfer is very slow, making it difficult to reach equilibrium in the range 0.9–1.0 a_w. The adsorption isotherms of the flours were modeled using the modified peleg model (MPM). The modeled parameters indicated in Table 3 shows the level of fitting of the flours. The statistical results shows the linear empirical models to be accurate, (with $R^2 > 0.993$ and % $E < 6.312$), indicative of a satisfactory agreement between the experimental and predicted values. The linear model can be used to describe the equilibrium moisture content behavior over the storage time.

CONCLUSIONS

It can be concluded from this study that rice flour (based on moisture uptake rate) could be stored for a longer period of days than other flours. The colour indices of selected cereals and legume based flours varied with redness during storage. Soybean flour was more stable in terms of redness and yellowness while bambara nut flour was more stable in terms of lightness. Moisture adsorption of the flours was more rapid in the initial stages with lesser amount of moisture adsorbed as time increased. Soy bean flour had the highest rate of moisture gain followed by bambara nut, maize and rice flour. MPM fitted the experimental data to an accuracy of 99 % and with a percentage error range between 0.108 and 6.321.

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