Shelf-Life Prediction Model of Bambara Nut (*Vigna Subterranea*) Flour: Polynomial Model, Sorption Isotherms and Physico-Mechanical Properties

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KEYWORDS

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ABSTRACT

Bambara nut samples were obtained, milled, packaged in Low Density Polyethylene and stored for a period of 12 weeks under controlled temperatures of 20°C, 30°C and 40°C respectively. At weekly intervals, the flours were analyzed for proximate composition, Physico-mechanical properties and sorption isotherms. The data obtained from the study were analyzed using the Design-Expert software (Version 7.0.0, Stat-Ease Inc., Minneapolis, USA). The experimental data generated was fitted to a polynomial regression model for predicting maximum shelf-life. In order to correlate the response variables to the independent variables, multiple regressions were used to fit the coefficient of the polynomial model. The quality of fit of the model was evaluated using analysis of variance (ANOVA). The suitability of the models was compared and evaluated using correlation coefficient (R^2). The study showed that all the parameters studied were significant in predicting the shelf-life of Bambara nut flour. The results obtained in the study showed that the response surface model developed is a good one. The model correlation coefficient (R^2) of the responses was found to be 0.9983, 0.9701, 0.9688, 0.9862, 0.9138 and 0.9531 for the flour moisture, ash, protein, fat, fibre and carbohydrate contents, respectively. Levels of significance obtained were 0.001, 0.02, 0.03, 0.01, 0.03 and 0.02 for the flour moisture, ash, protein, fat, fibre and carbohydrate contents which were high and attested to the fitness of the model in evaluating the responses. Optimum moisture content and storage time were found to be 6.32% (wb) and 23.62 weeks. The study confirmed that the model developed is adequate to optimize these process conditions.

INTRODUCTION

Control of Diabetes with the use of plant foods has become an area of interest in research globally. Studies have shown that the fibre and protein contents of Bambara nut can weaken the absorption of sugar, reduce sugar response and increase insulin sensitivity and therefore recommended as a supplement for type II diabetes. Ngabea, (2022) reported that diabetic patients in Nigeria rely on Bambara nut flour as food because of its insulin building ability in the body system, but the challenge is the unavailability of the processed one in the market when needed. Presently, there is paucity of information on the storage techniques of Bambara nut flour that can prolong the shelf-life for later usage.

Temegne *et al*., (2018) reported that Bambara nut is now widely cultivated throughout tropical Africa, Indonesia, Malaysia, India, Sri Lanka, Philippines, South Pacific, parts of Northern Australia, Central and

South America. Nigeria is one of the major producers of the crop and it is locally called Fyegbankpo (Jukun), Okpa (Ibo), Epiroro (Yoruba) and Gurjiya (Hausa). It is the third most important grain legume after ground nut and cowpea in Nigeria (Lacroix *et al*., 2003; Ngabea, 2022). Beyond Africa, Bambara nut is cultivated in Brazil where it is known as Mandubi d‟Angola‟ as well as in West Java and southern Thailand. Other tropical locations such as Middle East, Syria and Greece could also grow Bambara nut. Small-scale cultivation trials of Bambara nut have been successful in Florida, United States (Ferry, 2002; Ngabea *et al.*, 2021) Bambara nut is extensively cultivated in West Africa, Nigeria produced over 100,000 metric tons, follow closely by Niger with 30,000 metric tons and Ghana 20,000 metric tons annually (Asiedu, 1989). The seeds are ground into powder, which is used for bread making or prepared into stiff porridge, a very popular semi-fluid food in some parts of Nigeria (Ngabea *et al*., 2020).

Torrieri, (2016) defined Shelf-life as the period of time, established under intended conditions of distribution, storage, retail and use, that the food would remain safe and suitable. Ngabea *et al*., (2019) reported that shelf-life is the length of time food can be held without loss of nutritive value and quality. The shelf life of many foods can be extended through various means including controlled storage. It may be possible to manipulate certain factors to extend the shelf life. Although the composition of food material, its formulation, processing or packaging also some of the factors that may inadvertently lead to a decrease in the shelf life or make the food more susceptible to the growth of spoilage or even pathogenic microorganisms.

Aris, (1994) opined that a model is a simplified representation of a system at some particular point in time or space intended to promote understanding of the real system. Modeling involves identifying and selecting relevance features of a real work situation, representing those features symbolically, analyzing and reasoning about the model and characteristics of the situation and considering the accuracy and limitation of the model (Law, 2007).

Fangchao *et al*., (2023) reported in a review and classified shelf life models, detailed the application background and characteristics of commonly used models to better understand the different uses and aspects of the commonly used models. In particular, the structural framework, application mechanisms, and numerical relationships of commonly used models were elaborated. In addition, the study focused on the application of commonly used models in the food field. Besides predicting the freshness index and remaining shelf life of food, the study addressed aspects such as food classification (maturity and damage) and content prediction.

Stephanie *et al.*, (2013) also developed a model for predicting the safe storage of fresh fish under modified atmospheres with respect to *Clostridium botulinum* toxigenesis by modeling length of the lag phase of growth.

Various models for monitoring food quality have been developed and applied to predict food shelf life (Tanoj *et al*., 2018; Hybertson, 2009). Most of the studies on shelf-life prediction models in the literature are on the composition of the stored materials. No study has been reported considering both the compositions and the environmental parameters. In this study, both the compositional and environmental conditions are put into consideration. This study is the first to be carried out on predicting the shelf-life of Bambara nut flour considering its hygroscopic nature and sorptive behavior under controlled storage conditions; all the equations used in this study were formulated, and first used in this study.

The objective of this study was to use sorption isotherms and response surface methodology to optimize the process variables for predicting maximum shelf life, appropriate temperature and relative humidity for storing Bambara nut flour.

MATERIALS AND METHODS

Study and Experimental Locations

The study was conducted at the Department of Agricultural Engineering, Federal University Wukari while the experiments were carried out at the laboratories of the Departments of Food Science and Technology, University of Nigeria Nsukka and Modibbo Adama University of Technology Yola, respectively.

Research Materials

The materials used for this study were Bambara nuts- *Vigna subterranean,* low density polythene bags, plastic containers, food grade chemicals and water.

Source of Bambara nut

Bambara nut was purchased from a local market in Donga Township, Taraba State. North-eastern Nigeria. To remove foreign matter, immature and damaged seeds, the seeds were manually washed.

Chemicals and reagents

All the chemicals used were of analytical grade (Distilled water, sulphuric acid, sodium Hydroxide, Selenium tablets, Boric acid, Methyl red, Hydrochloric acid and Refined Vegetable oil). Some were purchased from Nsukka market while others from VEKO Scientific Chemical Shop, Jimeta-Yola.

Methods

The experiment was in three stages, the first stage was conducted for the determination of Proximate Composition of the stored packaged Bambara nut flour. The second stage involved the determination of the Physico-mechanical and functional properties. The third stage involved the determination of Bambara nut flour Moisture Sorption characteristics.

Preparation of experimental samples

The Bambara seeds were milled into flour using a magnetic sieve grinding machine as described by Ngabea *et al*, (2015). Particle size distribution using sieve analysis was carried out to separate the flour at a range of 20 - 100 mesh numbers (850 - 150μm) as designed in the face central composite design (FCCD) response surface methodology of Design Expert 7.0.0 software.

Determination of Proximate Composition of Bambara nut flour

The crude protein, crude fat, moisture, ash and crude fibre contents of the Bambara nut flour were determined using the methods of AOAC (2010). The carbohydrate content was calculated by difference as% Carbohydrate = 100 – (% Protein + % Ash) + % Moisture + % Fat (Egan *et al.,* 1981).

Determination of moisture content

Five grams of each sample were weighed into pre-weighed aluminium drying dish. The sample was dried to a constant weight in an oven at 105ºC for four hours (AOAC, 1990).

The moisture content was determined as follows:

$$\frac{M1 - M2}{M1 - M0} \times 100 \qquad (1)$$

Where: M_0 = Weight of aluminium dish, M_1 = Weight of fresh sample + dish, M_2 = Weight of dried sample + dish

Determination of Ash Content

Five grams of each sample were weighed into a porcelain crucible. The material was ignited and charred on a hot plate in the fume cupboard. The sample on the crucible was placed in the Vecstar Muffle Furnace in a controlled temperature of 550ºC for six hours. When the sample was fully charred, it was then cooled in a dessicator and was weighed out.

Plate 1: The Muffle Furnace used for the determination of Ash Content

The percentage ash content was determined as shown in equation 2

% Ash = $\frac{(Weight\ of\ crucible\ and\ sample)(Weight\ of\ empty\ crucible)}{Weight\ of\ sample} \times 100$ (2)

Determination of crude fibre

Defatted sample (2g) was placed in a 600 ml conical flask, 1.25% sulphuric acid solution was added to 160 ml boiling. The sample was digested for 35 min and washed with boiling distilled water after when the acid was drained out. Then, 1.25% sodium hydroxide solutions (160 ml) were added. The sample was then digested for 35min, thereafter the sodium hydroxide solution was drained out and the sample was then washed with boiling distilled water. Lastly, the sample was placed in a dried crucible and oven dried at 120ºC overnight. The sample was allowed to cool in a desiccator and then weighed (W_1). The sample was ashed at 550ºC in a muffle furnace for two hours, cooled in a desiccator and then reweighed (W_2). Extracted fibre was articulated as percentage of the original sample and calculated according to the formula:

Crude Fibre (%) = $\frac{Digested\ sample\ (W1) - Ashed\ sample (W2)}{Weight\ of\ sample} \times 100$ (3)

Determination of crude protein content

Kjedahl nitrogen method was used for the determination of the protein. 1.5 gram of the sample from each treatment was introduced into 900 ml digestion flask. 5 selenium tablets were added to the sample as catalyst. 25 ml of concentrated H_2SO4 was added to each sample and fixed to the digestion flask until a clear solution was obtained. The cooling digest was poured into 100 ml volumetric flask and was made up to mark with distilled water.

The distillation apparatus were rinsed and arranged for 15 minutes. The apparatus were boiled, 20 ml of 4% boric acid was pipetted into conical flasks, 6 drops of methyl red was added to each flask as indicator and the digest was diluted with 75 ml distilled water. Alkaline was produced from 10 ml of the digest with 20 ml of 20% sodium hydroxide and distilled. The steam exit of the distillatory was closed and the boric acid solution colour changed to green. The mixture was distilled for 15 minutes (AOAC, 1990) and boric acid along with distillate was then titrated against 0.1N Hcl and thus, the percentage total nitrogen was calculated as shown in equations 4 and 5:

% total of nitrogen = $\frac{\text{Titre} \times \text{Normality} \times 0.014}{Weight\ of\ sample} \times 100$ (4)

% Crude Protein = % total nitrogen × 6.25 (5)

Where: is a constant (AOAC, 1990)

Determination of crude fat content

Five grams of the sample was weighed in a thimble and plugged with cotton wool. The thimble was then inserted in a soxhlet apparatus. A formerly weighed clean dried 250 ml flask was filled with 180 ml of petroleum ether of 45 – 65ºC boiling points.

Plate 2: Soxhlet apparatus for fat determination (DHG-9023A, England)

The soxhlet apparatus (plate 2) were assembled and allowed to reflux for 6.5 hours, the solvent was recovered and the flask with the extract was dried in the oven (DHG-9023A, England) at 105ºC for 30 minutes. It was then cooled in the dessicator and weighed. The crude fat was calculated as stated in equation 6

$$\% \text{ Fat} = \frac{W3 - W2}{W1} \times 100 \quad (6)$$

Where: W_1 = weight of sample, W_2 = weight of empty flask, W_3 = weight of flask extracted oil

Determination of carbohydrate content

The determination of carbohydrate was obtained by subtracting the sum of the percentage protein, ash, fibre,moisture and fats from 100 as described by Egan *et al*, (1981).

% Carbohydrate = 100 – (% Protein + % Ash) + % Fibre + % Moisture + % Fat (7)

Determination of Moisture Sorption Isotherm

The adsorption isotherms of the samples were obtained using static gravimetric method as described by Labuza, (1984). An incubator was used as temperature control chamber. The experimental set up consists of saturated salt of lithium chloride, potassium acetate, Mgcl, KCO_2, MgN_2, sodium nitrate, Nacl, ammonium sulphate and barium chloride solutionswhich created different relative humidity environmental storage conditions with the corresponding water activities of 0.11, 0.21, 0.33, 0.43, 0.50, 0.67, 0.76, 0.86 and 0.90, respectively. The samples were arranged in dessicators. The duplicate flour samples of 3g each were placed on the saturated salt solutions in the dessiators and kept in a cabinet at a controlled temperatures of 20, 30, 40 and 50ºC, respectively. The weight of the samples was taken after every 24 hours with a digital weighing balance until constant weight is attained. Each of the samples was oven dried at 110ºC to a constant weight to obtain the equilibrium moisture content (dry basis). Graph of equilibrium moisture content against water activities (relative humidity) was plotted.

Experimental design and data analysis

A face central composite design (FCCD) of Response Surface Methodology (RSM) was used for the experimental design. The factors or independent variables were storage time and particle size, while the responses were the proximate composition (moisture, protein, fat, carbohydrates, ash and fibre contents).

The outline of experimental design with the coded levels is given on Table 1

Table 1: Variation of parameter for two (2) numerical factor designs in surface response

Numerical Factor		
Variable	Low level (-1)	High level (+1)
Time (weeks)	8	24
Particle size	20 mesh number	100 mesh number

Note that, the low level and high level interval of 8 and 24 for the time (weeks) was obtained from the result of the preliminary investigation conducted to study the changes of the values of proximate composition of Bambara nut flour under controlled storage condition.

Modeling of the flour shelf-life with respect to particle size and time

Each design point was performed in duplicates, except the centre points that were performed four times. The experiment was carried out according to design. The data obtained were analyzed using the Design-Expert software (Version 7.0.0, Stat-Ease Inc., Minneapolis, USA). The experimental data generated was fitted to a polynomial regression model for predicting maximum shelf-life. In order to correlate the response variables to the independent variables, multiple regressions were used to fit the coefficient of the polynomial model of the response. The quality of fit of the model was evaluated using analysis of variance (ANOVA).

Validation of the regression model

The model developed was examined for Test for significance, lack-of-fit and coefficient of determination (R^2) which was integrated into the analysis of variance (ANOVA) to examine the adequacy of the regression model while response surface and contour plots were designed with the Design-Expert software (Version 7.0.0, Stat-Ease Inc., Minneapolis, USA). R^2 was calculated as:

$$R^2 = \frac{\text{Sum of square residual}}{\text{Model sum of square} + \text{sum of square residual}} \quad (10)$$

$$R^2\ \text{adj} = 1 - \frac{n-1}{n-p}(1 - R^2) \quad (11)$$

Process Optimization

To optimize the response variables, contour and surface plots were plotted using the Design Expert software as described by Floros and Chinnan (1988). A second order polynomial was used to predict the experimental behavior (Equation 3.12).

$$Y = \beta o + \beta_1 X_1 + \beta_2 X_2 + \beta_1 X^2_1 + \beta_2 X^2_2 + \beta_{11} X_1 X_2 + \beta_{12} X_1 X_2 + \varepsilon \quad (12)$$

Where,

X_1, and X_2 are the factors: storage time and particle sizes

β is a constant coefficient of linear, interaction and square terms respectively

ε is the random error term.

Pearson correlation analysis ($p = 0.05$) was performed using the Design-Expert software (Version 7.0.0, Stat-Ease Inc., Minneapolis, USA).

RESULTS AND DISCUSSIONS

The results of the proximate composition (moisture, ash, protein, fat, fibre and carbohydrate contents) of Bambara nut flour are presented on Table 2. The mean effect of storage duration on the percentage proximate composition of Bambara nut flour showed that there were substantial differences in the moisture content of the flour sample at the beginning (week zero) of the storage period and at the end of the storage period.

Modeling the effect of storage time and particle size on the proximate composition of Bambara nut flour

The experimental ranges and levels of the independent variables for the experimental design for proximate analysis of Bambara nut flour are summarised in Table 2 as presented.

Table 2: Experimental ranges and levels of the independent variables for the proximate analysis of Bambara nut flour

Run	Storage Time (Weeks)	Particle Size (Mesh.number)	Moisture (%)	Ash (%)	Protein (%)	Fat (%)	Fibre (%)	Carbohydrate (%)
1	24.00	20.00	6.33	3.33	36.76	8.10	2.96	42.53
2	8.00	60.00	12.0	3.00	20.13	4.67	2.33	57.87
3	8.00	100.0	11.67	3.00	21.01	5.33	2.00	56.12
4	8.00	20.00	9.33	2.67	22.76	5.33	2.67	56.36
5	16.00	100.00	9.33	3.00	19.26	7.33	3.00	58.08
6	16.00	20.00	7.67	3.30	21.01	8.00	3.33	56.69
7	16.00	60.00	10.0	3.30	20.13	7.67	2.67	56.23
8	24.00	60.00	8.00	3.33	29.76	7.50	2.66	48.75
9	16.00	60.00	10.0	3.30	20.13	7.67	2.67	56.23
10	16.00	60.00	10.0	3.30	20.13	7.67	2.67	56.23
11	24.00	100.0	7.33	2.67	33.26	7.00	3.00	46.74
12	16.00	60.00	10.0	3.30	20.13	7.67	2.67	56.23
13	16.00	60.00	10.0	3.30	20.13	7.67	2.67	56.23

The coefficient of the regression equations for the measured responses, the linear, quadratic and interaction terms of the selected variables are presented in Table 3.The results of the proximate composition of the flour showed that the linear (A, B), interaction (AB) parameters and square (A^2,B^2) terms were all significant at $p<0.05$ as shown in Table 3.

Table 3: Regression coefficients of predicted quadratic model for proximate composition of Bambara nut flour

			Dependent	Variables		
Coefficients	**Moisture**	**Ash**	**Protein**	**Fat**	**Fibre**	**Carbohydrate**
Intercept	9.98	3.31	19.65	7.62	2.72	56.79
A	-1.89	0.11	5.98	1.21	0.27	-5.39
B	0.83	-0.11	-1.17	-0.30	-0.16	0.89
AB	-0.33	-0.25	-0.44	-0.27	0.18	1.11
A^2	0.080	-0.18	6.50	-1.41	-0.34	-4.86
B^2	-1.42	-0.20	1.69	0.17	0.33	-0.79
R^2	0.9983	0.9701	0.9688	0.9862	0.9138	0.9531
Adj. R^2	0.9971	0.9488	0.9465	0.9763	0.8522	0.9197
C.V (%)	0.95	1.77	5.76	2.51	4.61	2.55
Adeq. Precision	94.538	18.900	17.203	26.362	12.962	14.459
Mean	9.36	3.14	23.43	7.05	2.71	54.18
Std. Dev.	0.089	0.056	1.35	0.18	0.13	1.38

A = Storage time, B = Particle size

Fitting of the quadratic model

The quadratic model fittings are shown in Table 4. The analysis of variance (ANOVA) showed that the model was significant ($p<0.05$) for the predicted flour moisture, ash, protein, fat, fibre and carbohydrate contents. The correlation coefficient (R^2) 0.9983, 0.9701, 0.9688, 0.9862, 0.9138 and 0.9531 for the flour moisture, ash, protein, fat, fibre and carbohydrate contents, respectively were obtained. The R-squared value is an indication of the level of responses that can be explained by a particular model. These results showed that 99.83%, 97.01%, 96.88%, 98.62%, 91.38% and 95.31% of the responses could be explained by the model. Levels of significance obtained were 0.001, 0.02, 0.03, 0.01, 0.03 and 0.02 for the flour moisture, ash, protein, fat, fibre and carbohydrate contents, respectively. These levels were high and attested to the fitness of the model in evaluating the responses. The results obtained in the study showed that the model employed is a good one and could be used for the prediction of the flour maximum shelf life, particle size and storage time in respect to the proximate composition of Bambara nut flour for the production, handling and storage of the flour.

Table 4: Moisture content ANOVA for Response Surface Quadratic Model

Source	SS	Df	MS	F - Value	P - Value
Model	32.31	5	6.46	820.75	<0.0001
A	21.43	1	21.43	2722.38	<0.0001
B	4.17	1	4.17	529.25	<0.0001
AB	0.45	1	0.45	57.02	0.0001
A^2	0.018	1	0.018	2.23	0.1793
B^2	5.57	1	5.57	707.73	<0.0001
Residual	0.055	7	7.873E-003		
Lack of fit	0.055	3	0.018		
Pure Error	0.000	4	0.000		
Total	32.36	12			
	R^2 = 0.9983	Adj. R^2 = 9971	Pred. R^2=0.9846		

Using the experimental data in Table 4, second degree polynomial equation model for the flour moisture, ash, protein, fat, fibre and carbohydrate contents, respectively were regressed and the final equations in term of coded factor for the linear, interaction and square terms, respectively are shown in equations 13 – 18

$$\text{Moisture content} = +9.98 - 1.89A + 0.83B - 0.33AB + 0.08A^2 - 1.42B^2 \quad (13)$$
$$\text{Ash content} = +3.31 + 0.11A - 0.11B - 0.25AB - 0.18A^2 - 0.2B^2 \quad (14)$$
$$\text{Protein content} = +19.65 + 5.98A - 1.17B - 0.44AB + 6.50A^2 + 1.69B^2 \quad (15)$$
$$\text{Fat content} = +7.62 + 1.21A - 0.30B - 0.27AB - 1.41A^2 + 0.17B^2 \quad (16)$$
$$\text{Fibre content} = +2.72 + 0.27A - 0.16B + 0.18AB - 0.34A^2 + 0.33B^2 \quad (17)$$
$$\text{Carbohydrate content} = +56.79 - 5.39A + 0.89B + 1.11AB - 4.86A^2 - 0.79B^2 \quad (18)$$

Numerical Optimization of particle size and storage duration on the proximate composition of Bambara nut flour

The graphical representation of 3 dimensional surface and contour plots of response surface in Figures 1-12 showed the relationships between the dependent and independent variables of the proximate compositions for predicting the shelf-life of Bambara nut flour.

Figures 1 showed 3D dimensional surface plots of moisture content and figure 2 plots contours. The function has the optimizer values 11.1972%, 10.2074%, 9.2176%, 8.2278% and 7.2971% with the maximum response moisture content value of 6.33%. The optimal particle size, moisture content and storage duration was estimated to be 120.12µm, 6.32% (wb) and 23.62 weeks, respectively. However, the optimized result from the moisture content is significantly influenced by particle size and storage time for Bambara nut flour. The predicted result is in agreement with the recommended moisture content (6 – 14%) for storing food flour by Standard Organization of Nigeria (SON, 2003).

Figures 3 and 4 showed the 3 dimensional plots of the effect of particle size and storage duration on the ash content of Bambara nut flour. The ash content has the optimizer values of 3.28%, 3.16%, 3.04%, 2.92% and 2.80% with the maximum response ash content value of 3.39%. However, there were no significant differences on the ash content. The ash content slightly decreased with storage. The reduction could be as result of biochemical activities of microorganisms. This is in perfect agreement with the result of Awoyale *et al*, 2013.

Figures 5 showed 3D dimensional surface plots of protein content and figure 6 plots contours. The protein content has the optimizer values 21.03%, 23.91%, 26.78%, 29.63% and 32.54% with the maximum response protein content value of 35.17%. The optimal particle size, protein content and storage duration was estimated to be 120.12µm, 35.17% (wb) and 23.62 weeks, respectively. However, the optimized result from the protein content is significantly influenced by particle size and storage time for Bambara nut flour handling and storage. The protein content of the flour increased with decrease in particle size. The increase on the protein content of the flour with storage might be due to the decrease in the moisture content of the flour. This response finding is in agreement with Adebowale *et al.,* (2005) who reported that liquid retention is an index of the ability of proteins to absorb and retain oil/water which is in turn influences the texture and mouth feel characteristics of foods and food products.

Figures 7 and 8 showed the effect of particle size and storage time on the fat content of Bambara nut flour. There was no significant difference (P>0.05) in the fat content of the flour within the first three months of storage. *At al*l the particle sizes (850 - 150µm) the fat content ranged between 5.0 – 6.3%.The 3 dimensional plots in figures 9 and 10 showed the effect of particle size and storage duration on the fibre content of Bambara nut flour. The fibre contents of the flour ranged from 2.00 – 3.33%. It was not significantly affected by the storage duration and particle size. The fibre content was slightly increased as the storage period progressed due to the decrease in moisture content of the flour. This is in agreement with result reported by Mpotokwane *et al.,* (2008) for wheat flour during storage.

Figures 11 showed three dimensional surface plots of carbohydrate content and figure 12 plots of contours. The carbohydrate content has the optimizer values 56.87%, 53.44%, 51.01%, 48.59% and 46.16% with the maximum response carbohydrate content value of 43.94%. The optimal particle size, carbohydrate content and storage duration was predicted to be 120.12µm, 43.94% and 23.62 weeks, respectively. However, the optimized result from the carbohydrate content is significantly influenced by particle size and storage time for Bambara nut flour. The predicted result is in agreement with Awolu *et al.,* (2017) on the carbohydrate contents of five different varieties of cassava flour. The measured responses were very much close to the predicted values of which confirming the adequacy of the response models. Hence, the optimized storage conditions ware recommend for handling and storage of Bambara nut flour.

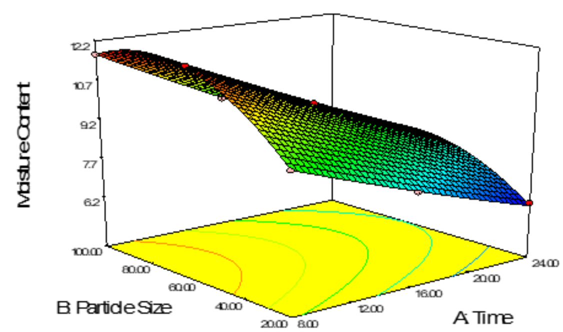


Fig. 1: 3D Surface plot of the effect of particle size and storage time on the moisture content of Bambara nut flour

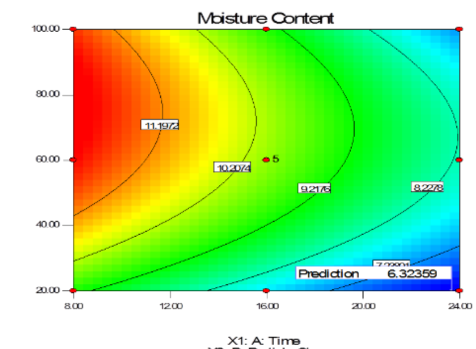
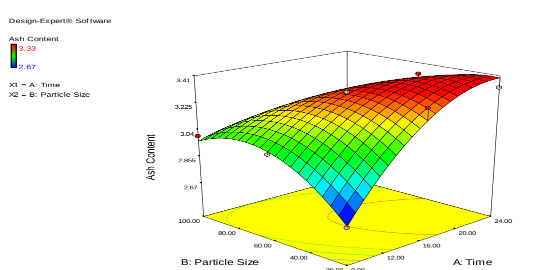


Figure 2: Contour plot of the effect of particle size and storage time on the moisture content of Bambara nut flour



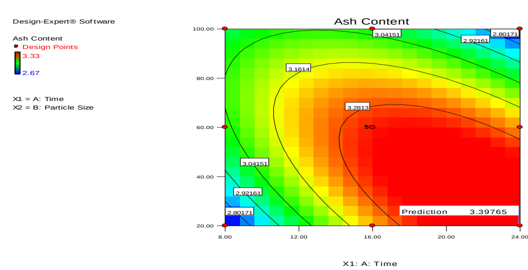


Figure 3: 3D surface plot of the effect of particle size and storage time on the Ash content of Bambara nut flour

Figure 4: Contour plot of the effect of particle size and storage time on the Ash content of Bambara nut flour

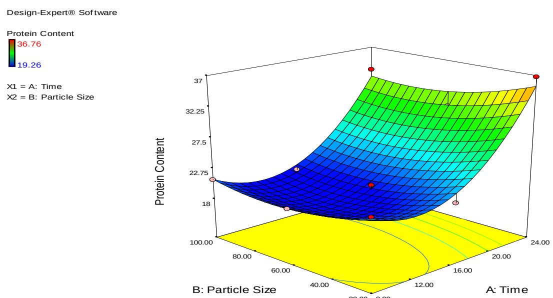


Figure 5: 3D surface plot of the effect of particle size and storage time on the Protein content of Bambara nut flour

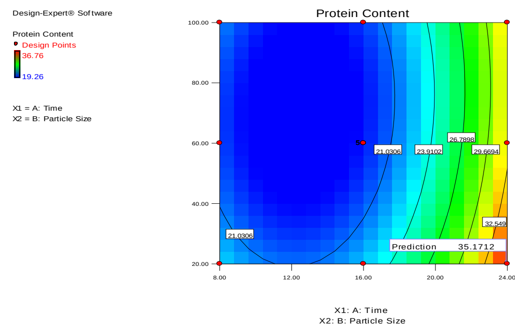


Fig. 6: Contour plot of the effect of particle size and storage time on the Protein content of Bambara nut flour

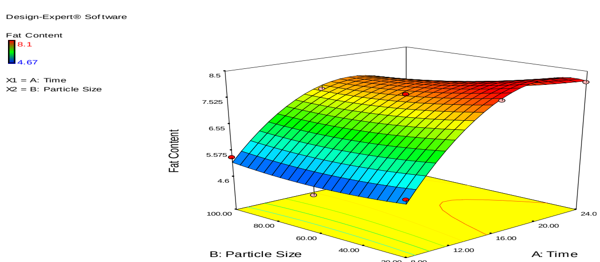


Figure 7: 3D surface plot of the effect of particle size and storage time on the fat content of Bambara nut flour

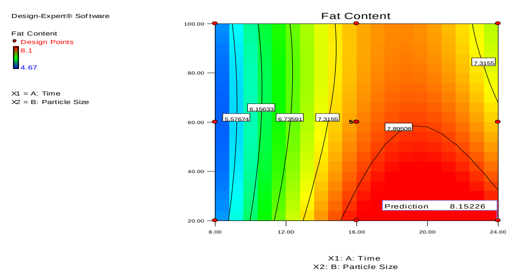


Fig. 8: Contour plot of the effect of particle size and storage time on the fat content of Bambara nut flour

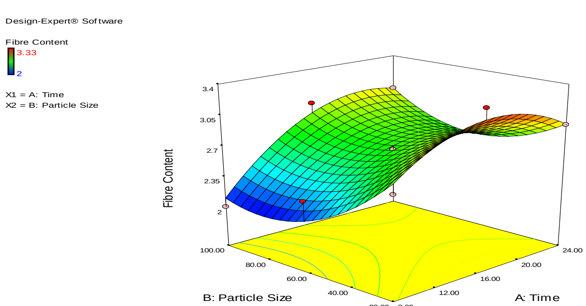


Fig. 9: 3D surface plot of the effect of particle size and storage time on the Fibre content of Bambara nut flour

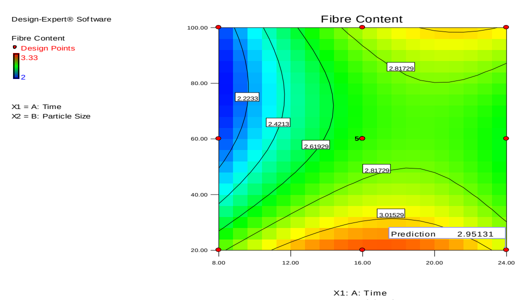


Fig. 10: Contour plot of the effect of particle size and storage time on the Fibre content of Bambara nut flour

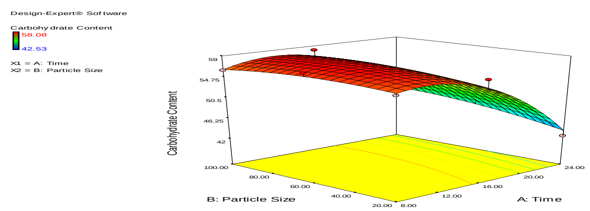


Fig. 11: 3D surface plot of the effect of particle size and storage time on the carbohydrate content of Bambara nut flour

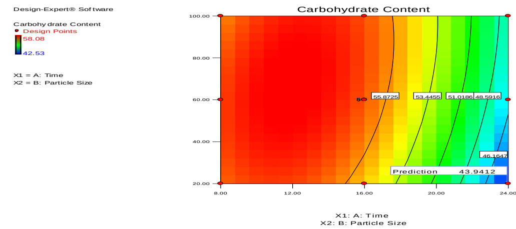


Fig. 12: Contour plot of the effect of particle size and storage time on the carbohydrate content of Bambara nut flour

Predictive model verification

In verifying the capacity of the model to predict the optimum storage conditions, maximum desirability was used for the proximate composition of the flour. Optimum particle size and storage times were generated by the software and were found to be 250.12µm, 6.32% (wb), and 23.62 weeks, respectively as shown in Figure 13. These values were close with the experimental values presented on Table 2. This showed the reliability of the model in optimizing the process.

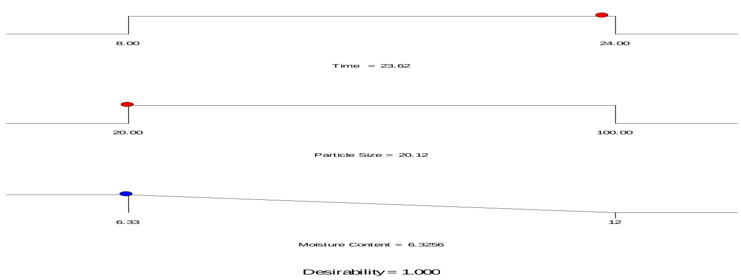


Fig. 13: Graphical representation of optimized levels of independent variables of Bambara nut flour

CONCLUTION

Response surface methodology was successfully used to predict and optimize the process conditions for the storage of Bambara nut flour. Based on the results obtained, Shelf life of Bambara nut flour depends on the moisture content, temperature and relative humidity of the storage environment. The result revealed the temperature dependence of the sorptive behavior with increase in temperature, the moisture adsorption capacity of the flour also increased. The equilibrium moisture content of Bambara nut flour at the three temperatures studied increased slowly at low water activities of 0.1 – 0.6 but increased rapidly at high water activity of 0.6 – 0.9. The equilibrium moisture content of the flour increased with increase in temperature at high water activity. The central composite design of Response surface methodology was found to be effective to determine the model parameter, sorptive behavior, particle size and storage duration for Bambara nut flour. The optimal storage conditions of the flour parameters can, therefore, be used for the storage and optimum shelf-life determination of Bambara nut flour. The results obtained in the study showed that the response surface model employed is a good one and could be used for the prediction of the responses (proximate composition) from the production and storage of Bambara nut flour.

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