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Nutritional properties of fonio starch–defatted moringa seed flour blends prepared at different ratios

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ABSTRACT

Fonio starch was enriched with defatted moringa seed flour with the objective of determining the best blend that would give good quality attributes. A Central Composite Rotatable Design (CCRD) from the Response Surface Methodology was used for the process optimization. The independent variables were the proportions of the fonio starch powder (70-100 g) and the Defatted moringa seed flour (0-30 g) , while the responses were protein, moisture, crude fibre, fat, ash, vitamin C, riboflavin, thiamine, calcium, phosphorous, iron, potassium, sodium and overall acceptability. Data obtained from the study were analysed using ANOVA. The protein, moisture, crude fibre, fat, ash, vitamin C, riboflavin, thiamine, calcium, phosphorous, iron, potassium, sodium and overall acceptability ranged between 9.50-17.70%, 5.70-13.10%, 2.34-2.67%, 1.22-1.58%, 64.0-129.0%, 30.4-46.1 mg/100 g, 26.0-27.0 mg/100 g, 88.49-190.46 mg/100 g, 168.4-282.08 mg/100 g, 19.11-28.25 mg/100 g, 455.0-224.01 mg/100 g, 120.5-150.36 mg/100 g and 5.1-7.4 mg/100 g, respectively. The combined effect of the blends ratios significantly influenced all responses (p<0.05). High coefficient of determination R^2 (60-99%) indicated that the models had good fits. The best blend was 73.11 g (87.97%) fonio starch and 10 g (12.03%) of defatted moringa seed flour, which gave good quality attributes.

Introduction

Food is a necessity of life and an adequate food intake, in terms of quantity and quality is a key for healthy and productive life (Olayemi, 1996). The major problem that African continent faces is the food insecurity, which brings about famine that is a threat to peace and stability of the continent (Ibrahim, 2001). Africans have been cultivating their fruits, root/tubers and cereal crops at subsistence levels for thousands of years, but due to decline and total neglect of cultivation of some indigenous crops, they were regarded as "lost crops of Africa". Fonio *(Digistiria exilis staph, Digistiria iburua kippis*) is one of the lost crops of Africa and it was neglected because of its unique small size (0.4-0.5 mm) which makes fonio processing very laborious and tedious (Ibrahim, 2001). Recently, fonio is being rediscovered and considered for improvement as cultivated specie (Ibrahim, 2001; Morales-Payán et al., 2002). Fonio has an important potential not only as a survival food, but also as a complement for standard diets (NAS, 1996). Fonio based diets are easily digested and they can be recommended for people having difficulty in digesting other cereals (Cruz, 2004). The diets from fonio have relatively low free sugar and low glycemic index, which makes it a suggested diet for diabetic patients (Temple and Bassa, 1991). Like other cereals, fonio is a good source of carbohydrate and it is reputed to be richer in magnesium, zinc and manganese than other cereals. It is also significantly richer in

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thiamine (vitamin B_1), riboflavin (vitamin B_2), calcium and phosphorous than white rice (Temple and Bassa, 1991). Fonio contains about 7.0% crude protein that is high in leucine (9.8%), methonine (5.6%) and valine (5.8%) (Temple and Bassa, 1991). Despite the fact that fonio was once regarded as a lost crop of Africa, its significant nutritional values make it an important food crop for millions in West Africa (Ayo and Nkama, 2006).

Moringa oleifera belongs to the genus *Moringaceae* (a single genus with 14 known species). *M. oleifera* is the most widely known and utilized among them (Morton, 1991) and it is a fast growing, aesthetically pleasing tree. The specie is characterized by its long drumstick shaped pods that contain seeds within the first year of growth. *M. oleifera* has been shown to grow up to 4 meters and can bear fruit within the same first year (Oleveria et al., 1999). In different parts of the world, *M. oleifera* is known by diverse name; among the Igbos, it is known as "okwe oyibo", among the Hausas, it is called "zogale", among the Yorubas, it is called "ewe ile" and among the Fulanis, it is called "gawara". In English language *M. olefera* is also called "Miracle tree", "Mother's best friend", "Never die" and "Benzolive tree" (Ramachandran et al., 1980). The seeds of *M. oleifera* are considered to be antipyretic, acrid and bitter (Oliveira et al., 1999), and they possess antimicrobial activity (Gopalan et al., 2007). The seed is a good source of protein, vitamins, beta-carotene, amino acids and various phenolics (Anwar et al., 2007). The seeds can be consumed fresh as peas or processed to produce sweet and non-desiccating oil, commercially known as 'Ben oil' of high quality. The pressed seed cake, which contains polypeptides, can also be used as natural coagulants for water treatment (Ndabigengesere and Narasiah, 1998). However, despite the richness of its cake in protein, minerals and vitamins, it has not been fully explored for enrichment of cereals and tuber based low proteins foods.

The most abundant carbohydrate in fonio grains is starch and it is the main provider of calories as in other cereals. Fonio starch possesses good disintegrating and binding properties (Musa et al., 2008). Cruz et al. (2011) reported that the starch content of fonio grains was 68%. The value reported was lower than that established for sorghum and rice which was in average of 73.8 and 77.2%, respectively. Fonio based-meals are easily digested and are often recommended for diabetic patients and others who are experiencing difficulty in the digestion of other cereals. Therefore, fortification of fonio starch with defatted moringa seed flour in appropriate proportion should be considered, while the effect of the blend ratio on the nutritional quality should be investigated.

Materials and methods

Sample collection

Moringa seeds and fonio seeds were purchased from retailers in Ilorin, Kwara state, Nigeria, and they were brought to the Department of Food Science and Technology, Kwara State University, Nigeria for processing.

Sample preparation

The fonio starch and defatted moringa seeds flour used for this experiment were prepared following the standard procedures described below.

The extraction of starch

Fonio starch was prepared using Moorthy et al. (1996) method. Fonio seeds were winnowed, sorted, washed with water and drained. The drained seeds were wet milled using a locally made grinding machine. The paste obtained was mixed with water. The slurry obtained was filtered through muslin cloth to obtain starch solution. The starch was separated from the water by settling and pressing. The wet cake obtained was dried in an oven already set at 60 °C for 30 hours. The dried cake obtained was then milled using the blender, sieved and packed in transparent plastic containers.

The processing of moringa seed into defatted moringa seed flour

Moringa seeds were dehulled, weighed and roasted at 160 °C for 30 minutes, according to the method of Makeri et al. (2011). The roasted seeds were allowed to cool down for 5 hrs before they were ground to powdered form using a blender. The roasted moringa seed powder was subjected to fat extraction using cold ethanol extraction method, following Ismael and Yee (2006) procedure and modified as follows: the roasted moringa seed powder was soaked in ethanol, stirred vigorously for 15 min and it was kept at room temperature for 48 hrs before extraction. The extract in the solvent layer was collected and the cake was further washed with ethanol. Both the extract and the washing were filtered through Whatman filter paper (No. 44) into a beaker. The cake obtained was spread thinly on a tray and the tray was kept in an oven already set at 80 °C for 30 min in order to evaporate the residual ethanol. The dried cake obtained was milled to powder and kept in a clean bowl prior to further analyses.

Experimental design

Response surface methodology using the central composite rotatable design techniques was used for the experimental design. Design-expert version 6.0.10 (Stat Ease Minneapolis, MN) software was used for mathematical modeling, regression analysis, ANOVA, and optimization. Two independent variables, namely fonio starch powder (X_1:70-100) and defatted moringa seed flour (X_2:0-30) were chosen (Table 1), while the response variables were carbohydrate, fat, protein, ash, moisture, crude fibre, calcium, iron, sodium, potassium, phosphorous, vitamin C, thiamin, and riboflavin. The results of experimental trials and literature influenced the choice of variables levels. Optimum proportions were achieved by maximizing protein, ash, moisture, crude fibre, calcium, iron, sodium, potassium, phosphorous, vitamin C, thiamin, riboflavin and overall acceptability values, while moisture and fat content were minimized.

Chemical analysis

The proximate composition (moisture, protein, ash, fat, crude fibre and carbohydrate), mineral (iron, calcium, sodium, potassium and phosphorus) and vitamin contents (vitamin A, vitamin B and vitamin E) of the samples were evaluated using the standard AOAC procedure (AOAC, 2005). Data were expressed as mean ± SD and were analyzed for ANOVA and regression.

Sensory evaluation

The blends were made into slurries and kept in clean pots. Hot water was added with constant stirring until they formed gels. The prepared meals were then dished into sample plates labeled randomly. Sensory evaluation of the composite fonio meal samples was carried out by 31 trained panelists, comprising students and staff of Kwara State University Malete, Nigeria. The samples were served hot on randomly coded plates. The parameters tested were colour, taste, appearance, flavour and overall acceptability, using a nine point hedonic scale ranging from 9 = like extremely to 1 = dislike extremely. Data obtained were subjected to the one-way analysis of variance (ANOVA) using Statistical Package for Social Sciences (SPSS) V. 17.0. Following ANOVA, means were separated using Duncan Multiple Range Test (DMRT) at 95% confidence level ($p \leq 0.05$).

Results and discussion

The results obtained from various analyses carried out on the fonio starch powder and defatted moringa seed flour blends are shown in tables 2-4.

Table 1. Central composite design of the fonio starch and defatted moringa seed flour combinations

	Coded Values		Actual Values	
Runs	**Fonio starch(X_1)**	**Defatted moringa seed flour (X_2)**	**X_1(g)**	**X_2(g)**
1	0.00	-1.41	85.00	0.86
2	0.00	0.00	85.00	15.00
3	1.00	1.00	95.00	25.00
4	1.00	-1.00	95.00	5.00
5	1.41	0.00	99.14	15.00
6	-1.00	-1.00	75.00	5.00
7	-1.41	0.00	70.86	15.00
8	0.00	0.00	85.00	15.00
9	0.00	0.00	85.00	15.00
10	0.00	0.00	85.00	15.00
11	0.00	0.00	85.00	15.00
12	-1.00	1.00	75.00	25.00
13	0.00	1.41	85.00	29.14

X1=Fonio starch; X2=Defatted moringa seed flour

Table 2. Chemical compositions of fonio starch and defatted moringa seed flour

Chemical compositions	Fonio starch	Defatted moringa seed flour
Moisture (%)	10.40±0.60	5.39±0.22
Protein (%)	9.22±0.31	20.87±2.90
Fat (%)	2.30±0.10	5.25±0.11
Ash (%)	1.89±0.12	4.28±0.24
Crude fibre (%)	2.42±0.10	5.05±0.21
Vitamin C (mg/100 g)	38.50±0.00	223.50±54.80
Riboflavin (mg/100 g)	29.87±0.60	67.79±1.10
Thiamine (mg/100 g)	27.67±0.10	48.56±1.70
Sodium (mg/100 g)	132.14±0.25	152.28±0.32
Phosphorous (mg/100 g)	164.60±0.00	384.16±0.21
Calcium (mg/100 g)	103.46±0.31	202.53±0.12
Iron (mg/100 g)	17.14±0.26	30.09±0.11
Potassium (mg/100 g)	463.01±0.00	230.16±0.21

Table 3. Cemical compositions and vitamin contents of fonio starch blended with defatted moringa seed flour at different ratios

Samples (g) (X_1:X_2)	Moisture (%)	Protein (%)	Fat (%)	Ash (%)	Crude fibre (%)	Vitamin C (mg/100 g)	Riboflavin (mg/100 g)	Thiamine (mg/100 g)
85.00 : 0.86	13.1±1.10	9.5±2.10	2.67±0.31	1.58±0.01	2.67±0.00	56.9±2.81	46.1±3.12	27.1±0.00
95.00 : 5.00	12.4±0.52	11.1±1.15	2.35±0.02	1.22±0.14	2.44±0.00	38.4±0.02	30.5±0.70	26.0±0.00
70.86 : 15.00	10.7±0.34	11.3±2.63	2.49±0.11	1.51±0.22	2.52±0.12	61.6±1.52	34.6±0.11	26.2±0.10
75.00 : 15.00	9.7±0.52	10.6±0.42	2.52±0.07	1.52±0.23	2.55±0.00	64.5±2.61	35.0±5.11	26.2±0.00
85.00 : 15.00	7.8±2.01	10.1±0.41	2.34±0.00	1.23±0.12	2.49±0.00	34.4±1.30	30.4±0.21	26.0±0.00
85.00 : 15.00	7.8±2.01	10.1±0.41	2.34±0.00	1.23±0.12	2.49±0.00	34.4±1.30	30.4±0.21	26.0±0.00
85.00 : 15.00	7.8±2.01	10.1±0.41	2.34±0.00	1.23±0.12	2.49±0.00	34.4±1.30	30.4±0.21	26.0±0.00
85.00 : 15.00	7.8±2.01	10.1±0.41	2.34±0.00	1.23±0.12	2.49±0.00	34.4±1.30	30.4±0.21	26.0±0.00
85.00 : 15.00	7.8±2.01	10.1±0.41	2.34±0.00	1.23±0.12	2.49±0.00	34.4±1.30	30.4±0.21	26.0±0.00
99.14 : 15.00	9.4±2.71	11.8±0.76	2.42±0.12	1.26±0.00	2.5±0.31	34.4±2.81	30.4±0.72	26.0±0.10
95.00 : 25.00	11.1±0.63	15.3±1.07	2.47±0.21	1.27±0.05	2.48±0.22	39.6±2.41	30.9±3.30	26.0±0.00
75.00 : 25.00	6.0±0.90	12.9±2.61	2.55±0.01	1.55±0.01	2.62±0.31	70.8±1.42	38.8±0.31	26.4±0.00
85.00 : 29.14	5.7±0.22	17.7±0.9	2.48±0.11	1.32±0.04	2.47±0.00	36.5±1.11	31.6±1.81	26.1±0.10

X_1=Fonio starch; X_2= Defatted moringa seed flour

Table 4. Mineral contents of fonio starch blended with defatted moringa seed flour at different ratios

Samples (g) (X_1:X_2)	Calcium (mg/100 g)	Sodium (mg/100 g)	Phosphorous (mg/100 g)	Iron (mg/100 g)	Potassium (mg/100 g)
85.00:0.86	108.4±0.11	150.36±0.36	168.4±0.32	19.72±0.42	310.4±0.00
95.00:5.00	190.46±0.26	148.6±0.13	242.10±0.33	28.25±0.10	455.01±0.20
70.86:15.00	128.1±0.72	148.4±0.13	218.4±0.62	20.68±0.30	230.4±0.00
75.00:15.00	131.03±0.51	120.5±0.12	261.0±0.45	25.14±0.22	260.14±0.00
85.00:15.00	115.28±0.21	150.18±0.14	282.08±0.17	26.4±0.13	254.14±0.12
85.00:15.00	115.28±0.21	150.18±0.14	282.08±0.17	26.4±0.13	254.14±0.12
85.00:15.00	115.28±0.21	150.18±0.14	282.08±0.17	26.4±0.13	254.14±0.12
85.00:15.00	115.28±0.21	150.18±0.14	282.08±0.17	26.4±0.13	254.14±0.12
85.00:15.00	115.28±0.21	150.18±0.14	282.08±0.17	26.4±0.13	254.14±0.12
99.14:15.00	124.21±0.23	148.14±0.20	230.14±0.17	28.14±0.1	260.42±0.31
75.00:25.00	88.49±0.14	138.14±0.20	172.4±0.62	19.2±0.21	285.0±0.26
95.00:25.00	140.03±0.42	129.65±0.33	189.4±0.11	22.42±0.17	261.05±0.34
85.00:29.14	172.06±0.00	130.48±0.27	204.6±0.21	20.11±0.00	224.01±0.00

X_1=Fonio starch; X_2= Defatted moringa seed flour

Moisture content

The moisture content obtained from the blends ranged from 5.70-13.10% (Table 3) with a mean value of 9.40 ± 0.84%. A quadratic model was the best to describe their relationship. Eq. 1 expressed the relationship between fonio starch powder and defatted moringa seed flour. The coefficient of determination R^2 of the model was 0.88, suggesting a good fit. From response surface plot of the relationship as shown in Fig. 1a, it was observed that as the defatted moringa seed flour inclusion in the blend increased, the moisture content decreased. The observed decrease in the moringa powder fortified fonio flour could mean that inclusion of moringa cake powder decreased the moisture content of the blends. Decrease in moisture might also be due to the concurrent increase in protein contents of the blends, which has more affinity to moisture than carbohydrate (Agu and Okoli, 2014). Also, observed increase in moisture content in the blends might be due to hydrophobic nature of fonio starch, which made it to absorb moisture from the environment during mixing. The moisture content of food products is a measure of their suitability to microbial attack and hence spoilage (Olusanya, 2008). However, low moisture content obtained in the blends implies that they might have storage advantage over the 100% fonio starch powder.

$$\text{Moisture} = -87.84 + 2.18X_1 + 0.68X_2 - 0.02X_1^2 - 1.02X_2^2 - 1.43 \times 103X_1X_2 \quad \text{Eq. 1}$$

Protein content

The protein content obtained from the blends varied from 9.5-17.7% (Table 3) with a mean value of 12.37±0.90%. A quadratic model was used to represent their relationship. Equation 2 expressed the relationships between fonio starch powder and defatted moringa seed flour. R^2 of the model was 0.92. From the response surface plot shown in Fig. 1b, it was observed that the protein content increased significantly as the percentage of defatted moringa seed flour in the bends increased.Increase in protein content could be due to the increase in the proportion of defatted moringa seed flour in the blends. Proteins play important roles in proper maintenance and growth of the body (Duru-Majesty et al., 2012). The enrichment of cereal meals with legumes had been reported by Philip and Itodo (2006) to result in a higher protein quality than if administered only as cereal meals. Hence, incorporation of defatted moringa seed flour into fonio flour might contribute significantly to the daily protein requirements of 22–56 g (NRC 1975).

$$\text{Protein} = 162.40 - 3.32X_1 - 0.54X_2 + 0.02X_1^2 + 0.02X_2^2 - 20 \times 10^{-4} X_1X_2 \quad \text{Eq. 2}$$

Fat content

The fat content obtained from the blends ranged from 2.34-2.67% (Table 3) with a mean value of 2.43±0.064%. Responses surface plot of the relationship is shown as Fig. 1c. The graph showed a cubic relationship and equation 3 expressed relationships between fonio starch powder and defatted moringa seed flour. The coefficient of determination R^2 of the model was 0.79 indicating a good fit. The fat content increased respectively with increase in percentage of defatted moringa seed flour in the blends. The fat content of the moringa fortified variants were relatively higher than the unfortified fonio starch powder (control). The lower levels of fat in the blends were the same as a result of fortification with defatted moringa seed flour which had initial fat content of 5.25%. Relatively lower fat contents obtained for the variants could be advantageous to health as well as extending the product shelf life in terms of delaying onset of rancidity (Arisa et al., 2013).

$$\text{Fat} = 6.65 - 0.09X_1 - 0.06X_2 + 4.69 \times 10^{-4} X_1^2 + 1.07 \times 10^{-3} X_2^2 + 2.25 \times 10^{-4} X_1X_2 \quad \text{Eq. 3}$$

Ash content

The ash content obtained from the blends varied from 1.22-1.58% (Table 3) with a mean value of 1.34 ± 0.069%. To establish the best performance, there was a need to transform the model and quadratic model was considered to perfectly represent the effect of blend ratio on the ash contents of the variants (Equation 4). The model satisfied lack of-fit test at $p<0.05$ and the coefficient of determination R^2 was 0.87. The effect of the blend ratio was significant ($p<0.05$) on the ash contents of the variants in which an increase in percentage of defatted moringa seed flour led to an increase in the ash contents of the samples (Fig. 1d). Ash content is an index of mineral contents in biota (Akubugwo et al., 2007). Samples analyzed possessed considerable amount of ash contents, indicating that they might contain moderately high mineral values.

$$\text{Ash} = 7.68 - 0.13X_1 - 0.04X_2 + 7.06 \times 10^{-4} X_1^2 + 1.03 \times 10^{-3} X_2^2 + 5.00 \times 10^{-5} X_1X_2 \quad \text{Eq. 4}$$

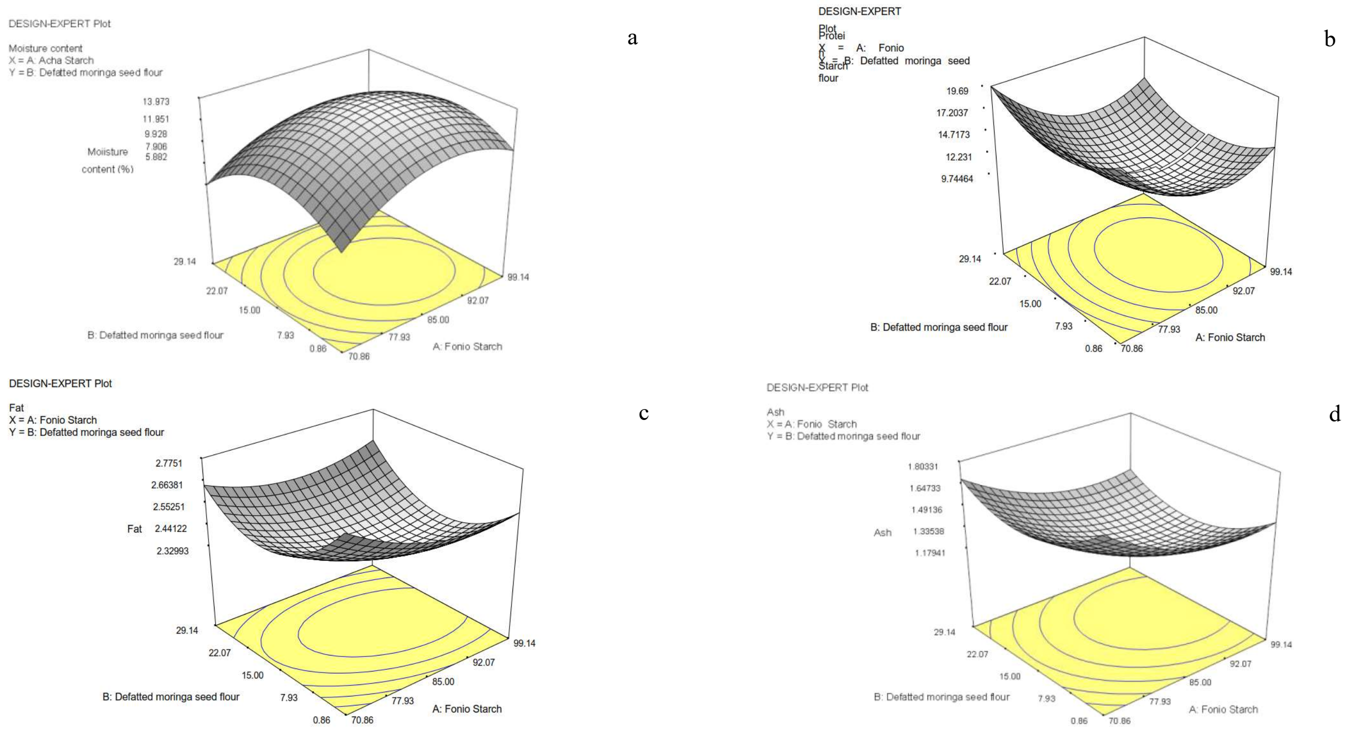

Fig. 1. The effect of blend ratio of fonio starch and defatted moringa seed flour on: a) moisture content; b) protein content; c) fat content; d) ash content

Crude fiber content

The crude fiber content obtained from the blends ranged from 2.49-2.67% (Table 3) with a mean value of 2.52±0.011%. The blend ratio was effectively significant at 95% confidence level. Quadratic model was the best for predicting the relationship between the blend ratio and the crude fibre contents of the variants. High coefficient of determination R^2 (0.99) suggested that the model might fit well for the data. A visual illustration of the relationship is shown in Fig. 2a and its mathematical relationship is expressed in Eq 5. The crude fibre content decreased respectively with increase in percentage of defatted moringa seed flour in the variants. Adequate intake of dietary fiber can lower the level of serum cholesterol and reduce the risk of developing hypertension, constipation, diabetes, colon cancer and coronary heart disease (Ishida et al., 2000). The lowest value (0.41%) of crude fiber content for the raw fonio seeds was presented by Jideani and Akingbala (1993) while the highest value (11.3%) was reported by Serna (2003). The crude fiber contents (2.49-2.67%) reported for this study fell within the range mentioned above.

$$\text{Crude fibre} = 2.49 - 0.18X_1 + 0.19X_2 + 1.30 \times 10^{-2} X_1^2 + 8.0 \times 10^{-2} X_2^2 - 1.70 \times 10^{-2} X_1X_2 + 0.19X_1^3 - 0.33X_2^3 \quad \text{Eq. 5}$$

Vitamin C content

The vitamin C content obtained from the blends varied from 34.4-70.8 mg/100 g (Table 3) with a mean value of 47.38±6.82 mg/100g. The effect of blending of fonio starch with defatted moringa seed flour in order to obtain the best blend was significant on vitamin C content (p<0.05). The coefficient of determination (R^2) was 0.90, which shows that the model fits well for the data. The plot of the interaction is shown in Fig. 2b and the quadratic model was the best to establish the interaction between the variants and the vitamin C contents (Eq 6). All the model terms were significant (p<0.05). The defatted moringa seed flour contained vitamin C content of 223.5 mg/100 g, while acha starch powder contained vitamin C content of 38.5 mg/100 g. It was observed that the vitamin C content increased significantly as the percentage of defatted moringa seed flour in the blends increased. However, increase in vitamin C content of the vatiants might be due to higher percentage of vitamin C content in the defatted moringa seed flour.

$$\text{VitaminC} = 575.58 - 10.78X_1 - 3.92X_2 + 0.06X_1^2 + 0.16X_2^2 - 0.01X_1X_2 \quad \text{Eq. 6}$$

Riboflavin content

The riboflavin content obtained from the blends ranged from 30.4-46.1 mg/100 g (Table 3) with a mean value of 33.11±3.56 mg/100g. There was a significant effect (p<0.05) of blend ratio on the riboflavin values of blends obtained. A quadratic model was applicable to express their relationship (Fig. 2c), and the coefficient of determination R^2 was 0.67. Equation 7 shows the mathematical relationship between the riboflavin values of the variants and the blend ratios. The defatted moringa seed flour contained riboflavin content of 67.79 mg/100 g while foniostarch flour contained riboflavin content of 29.87 mg/100 g. The riboflavin contents of the blends increased significantly as the percentage of defatted moringa seed flour in the bends increased. Similarly, increase in riboflavin contents of the variants might be due to higher percentage of riboflavin content in the defatted moringa seed flour.

$$\text{Riboflavin} = 92.84 + 1.10\text{X}_1 - 0.61\text{X}_2 + 5.86 \times 10^{-3}\,\text{X}_1^2 + 0.04\text{X}_2^2 - 8.56 \times 10^{-3}\,\text{X}_1\text{X}_2 \qquad \text{Eq. 7}$$

Thiamine content

The thiamine content obtained from the blends ranged from 26.0-27.0 mg/100 g (Table 3) with a mean value of 26.20±0.24%. The effect of the blend ratio was significant (p<0.05) on the thiamine contents of the variants (p<0.05). The quadratic model was the best to predict the effect of the blend ratio on thiamine contents of the variants (Equation 8). High coefficient of determination R^2 (0.65) indicated that the model had a good fit. The defatted moringa seed flour contained thiamine content of 48.56 mg/100 g while acha starch powder contained thiamine content of 27.67 mg/100 g. Inclusion of deffatted moringa seed flour in the fonio starch significantly increased the thiamine contents of the variants (Fig. 2d). Paul and Pearson (2005) reported that thiamine was needed for maintenance of the nervous system and it helped in releasing energy from carbohydrate during metabolism. Blending of acha starch powder with thiamin rich defatted moringa seed flour indicates that the blends can meet the daily requirements of thiamine (RDA for adults is >63 µg/day) (Okeke and Eze, 2006).

$$\text{Thiamine} = 27.08 + 2.28 \times 10^{-3}\,\text{X}_1 - 0.73\text{X}_2 - 5.79 \times 10^{-5}\,\text{X}_1^2 + 2.65 \times 10^{-3}\,\text{X}_2^2 - 2.48 \times 10^{-3}\text{X}_2^2 \qquad \text{Eq. 8}$$

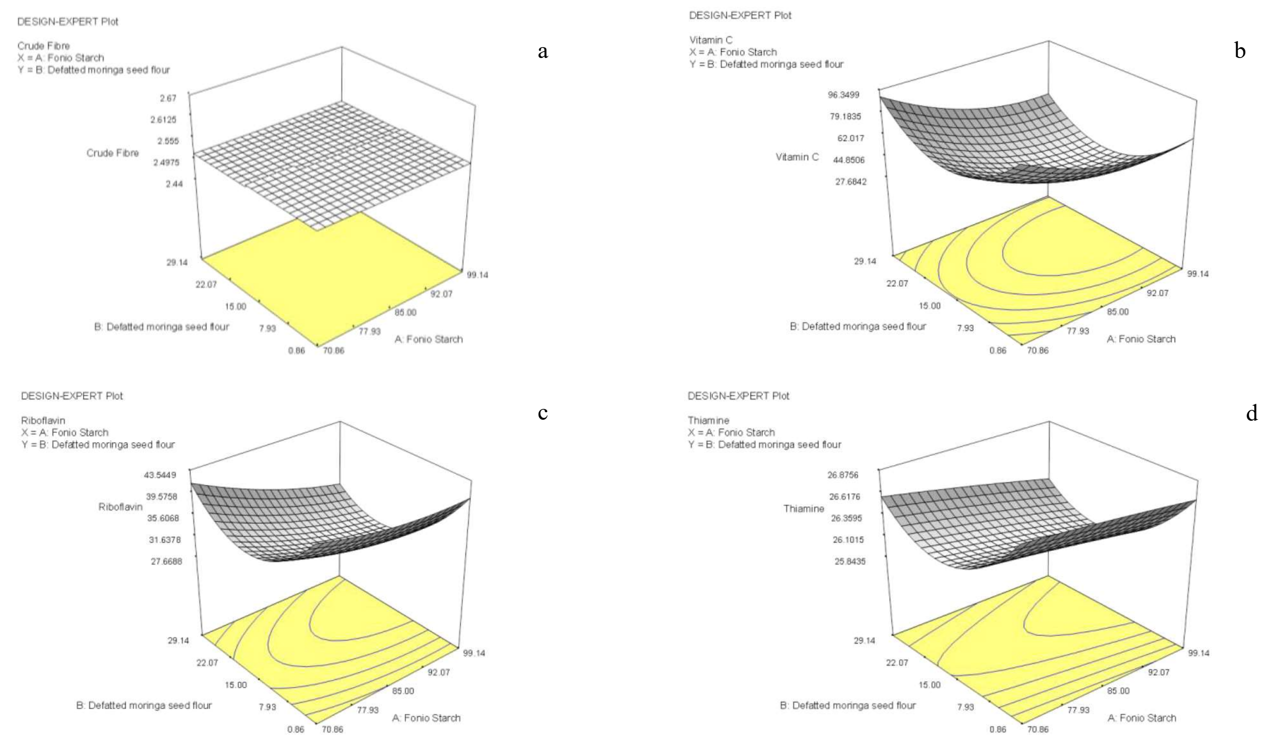

Fig. 2. The effect of blend ratio of fonio starch and defatted moringa seed flour on: a) crude fiber content; b) vitamin C content; c) riboflavin content; d) thiamine content

Calcium content

The calcium content obtained ranged from 88.49-190.46 mg/100 g (Table 4) with a mean value of 127.63±2.72 mg/100 g. A cubic model was considered to perfectly represent the effect of blending ratio on the calcium contents of the variants (Eq. 9). The model satisfied lack of-fit test at p<0.05 and the coefficient of determination R^2 was 0.99. The mixing effect was significant (p<0.05) on the calcium contents of the blends, whereby percentage increase in defatted moringa seed flour in the blends led to an increase in the calcium contents of the samples (Fig. 3a).The defatted moringa seed flour contained 202.53 mg/100 g of calcium, while fonio starch contains calcium of 192.46 mg/100 g. The fortification of acha starch with deffatted moringa seed flour significantly increased the calcium contents of the variants. Calcium is a macro mineral needed in highest amounts for proper body functions (Sanni et al., 2010). Calcium is needed for muscle contraction regulation and it is also required by children, pregnant and lactating women for bones and teeth development (Olusanya, 2008). The variants had relatively high levels which can contribute significantly to recommended daily calcium intake of 1000-1200 mg/day for adults and 1300 mg/day for adolescence.

$$\text{Calcium} = 115.28 + 85.32X_1 - 103.53X_2 + 14.66X_1^2 + 30.50X_2^2 - 4.44X_1X_2 - 98.33X_1^3 + 154.51X_2^3 \quad \text{Eq. 9}$$

Sodium content

The sodium content obtained ranged from 120.5-150.36 mg/100 g (Table 4) with a mean value of 143.49±9.23%. There was a significant effect (p<0.05) of blend ratio on sodium contents of the samples obtained. A 2FI model was used to represent the relationship between the blends and the sodium contents (Fig. 3b), while the coefficient of determination R^2 was 0.60. Equation 10 shows the mathematical relationship between the sodium contents of the variants and the blend ratios.

The defatted moringa seed flour contained 152.28 mg/100g of sodium, while fonio starch flour contain 132.14mg/100 g of sodium. The fortification of fonio starch with deffatted moringa seed flour significantly increased the sodium contents of the variants. Sodium is needed in the highest amounts for proper functioning of the body system and it is the major positive ion in the extracellular fluid and a key factor in retaining body water (Sanni et al., 2010). High amount of sodium was observed in the variants which can contribute significantly to the recommended daily intake of 2400 mg (Greely, 1997). The ratio of sodium to potassium (Na/K) in the body is of utmost concern for proper regulation of blood pressure and prevention of hypertension. Therefore, Na/K ratio that is less than one is recommended (FND, 2002). All the samples had Na/K ratios that were less than one. Hence, consumption of fonio starch powder fortified with moringa seeds powder might not be connected with high blood pressure disease.

$$\text{Sodium} = 11.33 + 1.62X_1 + 7.47X_2 - 0.09X_1X_2 \quad \text{Eq. 10}$$

Phosphorous content

The phosphorous content obtained ranged from 168.4-282.08 mg/100 g (Table 4) with a mean value of 245.91±44.87 mg/100 g. The mixing effect was found to be significant at 95% level of significance. From Fig. 3c, a quadratic model was the best to describe their relationship. The coefficient of determination R^2 was 0.60. Equation 11 expressed functional relationships between fonio starch and defatted moringa seed flour. The defatted moringa seed flour contained 384.14 mg/100 g of phosporous, while fonio starch powder contained 164.6 mg/100 g of phosporous. It was discovered that as the percentage of defatted moringa seed flour in the blends increased, the phosporous content increased. Phosphorus helps to facilitate some functions of calcium in the body system (Dosunmu, 1997; Turan et al., 2003) and its deficiency may contribute to bone loss in elderly women (Wardlaw, 1999). The blends had a very high level of phosphorus and this indicates that they can meet the daily requirements of phosphorus (RDA for adults is >700 mg/day) (Kayode et al., 2010).

$$\text{Phosphorous} = 1536.74 + 37.74X_1 + 22.89X_2 - 0.20X_1^2 - 0.38X_2^2 - 0.16X_1X_2 \quad \text{Eq. 11}$$

Iron content

The iron content obtained ranged from 19.11-28.25 mg/100 g (Table 4) with a mean value of 24.28±1.94 mg/100 g. The effect of blending of fonio starch with defatted moringa seed flour in order to obtain the best blend was significant on iron content (p<0.05). The coefficient of determination (R^2) was 0.80. The plot of their relationship is shown in Fig. 3d and the quadratic model was the best to represent the relationship between the variants and the iron contents (Eq. 12). All the model terms were significant (p<0.05). The defatted moringa seed flour contained 30.09

mg/100 g of iron while fonio starch contained 17.14 mg/100 g of iron. The blending of deffatted moringa seed flour with fonio starch significantly increased the iron contents of the variants. The blends have high level of iron, indicating that the blend might meet the adult daily dietary iron requirements of 10 mg/day for men and 15 mg/day for women (Wardlaw, 1999, Kayode et al., 2010).

$$\text{Iron} = 38.64 + 1.22X_1 + 0.69X_2 - 0.97 \times 10^{-3} X_1^2 - 0.03X_2^2 + 2.75 \times 10^{-4} X_1X_2 \quad \text{Eq. 12}$$

Potassium content

The potassium content obtained ranged from 224.01- 455.01 mg/100 g (Table 4) with a mean value of 281.32±53.11%. The effect of blending of fonio starch with defatted moringa seed flour with the aim of establishing the best blend was significant on potassium content ($p<0.05$). The coefficient of determination (R^2) was 0.70, which shows that the model fits well for the data. The plot of the interaction is shown in Fig. 3e and the cubic model was the best to establish the interaction between the variants and the potassium contents (Eq. 13).

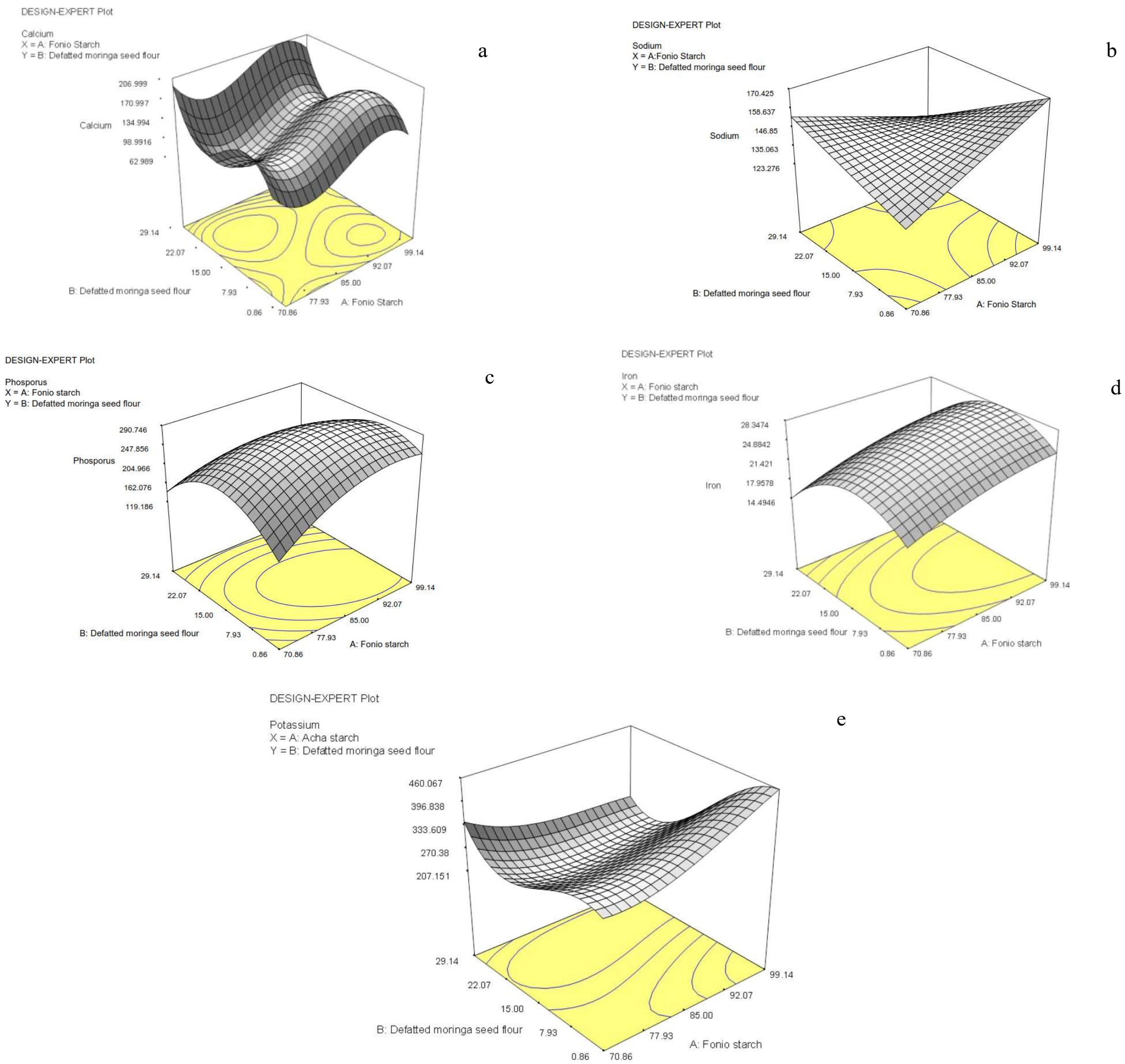

Fig. 3. The effect of blend ratio of fonio starch and defatted moringa seed flour on: a) calcium content; b) sodium content; c) phosphorous content; d) iron content; e) potassium content

Table 5. Sensory evaluation of fonio starch fortified with defatted moringa seed flour

Sample	Taste	Colour	Appearance	Flavour	Overall Acceptability
FOC	7.4±1.22^{a}	7.0±1.11^{a}	6.7±1.61^{ab}	6.7±1.62^{a}	7.4±1.52^{a}
GPZ	4.8±1.92^{d}	5.0±2.01^{c}	4.9±1.91^{e}	5.1±1.91^{b}	5.1±2.01^{c}
JBC	4.8±2.21^{d}	5.9±1.30^{bc}	6.0±1.60^{abcd}	5.2±1.98^{b}	5.5±1.81^{bc}
KDE	5.3±2.02^{cd}	5.9±1.42^{bc}	5.8±1.41^{bcde}	5.0±1.96^{b}	5.2±1.50^{c}
KDW	5.2±1.91^{cd}	5.2±1.91^{c}	5.5±1.91^{cde}	5.4±1.81^{b}	5.8±1.43^{bc}
LXQ	6.1±1.60^{bc}	6.2±1.33^{ab}	6.3±1.44^{abc}	5.9±1.31^{ab}	6.0±1.82^{bc}
PGD	5.2±2.20^{cd}	5.5±1.91^{bc}	5.5±2.01^{cde}	5.4±1.80^{b}	5.7±1.71^{bc}
SJT	6.0±1.70^{bc}	6.4±1.30^{ab}	6.1±1.61^{abcd}	5.3±2.10^{b}	6.0±1.45^{bc}
URB	6.5±1.50^{ab}	6.9±1.20^{a}	6.8±1.10^{a}	6.0±2.21^{ab}	6.4±1.52b
URV	4.8±1.71^{d}	5.7±1.60^{bc}	5.3±1.90^{de}	5.1±1.65^{b}	5.9±1.50^{bc}

The mean values having different superscript within a column are significantly different ($p<0.05$). Legends: FOC=100 g of fonio starch; JBC=85.00 g of foniostarch +15.00 g of defatted moringa seed flour; KDE=99.14 g fonio starch +15.00 g of defatted moringa seed flour; LXQ=95.00 g of fonio starch +5.00 g of defatted moringa seed flour; GPZ=95.00 g of fonio starch +25.00 g of defatted moringa seed flour; URV=85.00 g of fonio starch +29.14 g of defatted moringa seed flour; PGD=70.86 g fonio starch +1 .00 g of defatted moringa seed flour; SJT=75.00 g fonio starch +5.00 g of defatted moringa seed flour; KDW=75.00 g of fonio starch +25.00 g of defatted moringa seed flour; URB=85.00 g of fonio starch +0.86 g of defatted moringa seed flour.

All the model terms were significant ($p<0.05$). The defatted moringa seed flour contained 230.16 g/100 g of potassium, while fonio starch flour contained 463.01 mg/100 g of potassium. Defatted moringa seed flour inclusion in the bends significantly decreased their potassium contents. Potassium is a macro mineral needed in highest amount for proper body functions (Sanni et al., 2010). High amounts of potassium were observed in this study and the variants are expected to contribute to proper functioning of the body system

$$\text{Potassium} = 254.13 + 37.27X_1 - 156.03X_2 + 37.45X_1^2 + 61.97X_2^2 - 66.83X_1X_2 - 24.02X_1^3 + 124.02X_2^3 \quad \text{Eq. 13}$$

Sensory evaluation

The results of sensory properties of samples are shown in table 5. Organoleptic characteristics assessed (taste, colour, aroma, consistency and overall acceptability) revealed significant differences ($p<0.05$). Sample containing only fonio starch was rated significantly ($p<0.05$) higher than the others and it was the mostly preferred, while sample containing 99.14 g fonio starch and 15.00 g of defatted moringa seed flour had the lowest scores in terms of overall acceptability. Panelists rated variant containing 85.00 g of fonio starch and 0.86 g of defatted moringa seed flour significantly ($p<0.05$) higher than other blends for overall acceptability. The inclusion of deffatted moringa seed flour in the fonio starch powder significantly influenced the sensory attributes of the moringa fortified fonio starch powder, whereby samples with higher percentage of deffatted moringa seed flour were rated low. Lower rating might be due to the astringent taste of the deffatted moringa seed flour.

Conclusion

Fonio based meal fortified with defatted moringa seed flour is a good source of nutrients with better nutrient quality. The blend ratio significantly influenced the quality of fonio starch fortified with defatted moringa seed flour at 95% confidence level. Predictive models were developed for all the responses and the models had good fits. The best blend is 73.11 g fonio starch powder and 10 g of defatted moringa seed flour which give the optimum quality attributes.

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