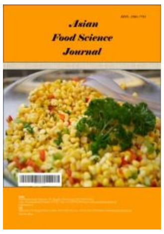

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Effects of Extrusion Cooking Variables on the Proximate Composition of Extruded Snacks from Blends of Cocoyam and Bambara Nut Flours

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Authors' contributions

This work was carried out in collaboration among all authors. Author BDS designed the study, performed the statistical analysis. Author IN wrote the protocol wrote the first draft of the manuscript and managed the analysis of the study. Author ECO managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Flour blends of cocoyam and Bambara groundnut were produced through extrusion cooking. Response Surface Methodology (RSM) Central Composite Rotatable Design (CCRD) was adopted for the formulations. Association of Analytical Chemist procedure was used to determine the proximate composition. The main objective was to determine the effects of the processing variables; feed blend composition (X_1), barrel temperature (X_2), and feed moisture content (X_3), on Snacks and the proximate composition (moisture, protein, lipids, fibre, ash, and carbohydrate) of the extrudate. The analysis of variance (ANOVA) showed a significance ($p< 0.05$) of the models fitted in describing the relationship between the input and output in its natural state. There was a non-significant lack–of–fit test. The result of the moisture showed that the model X_1, X_2, (linear) X_1^2, $X_2^{\ 2}$, (quadratic) were all significant ($P \leq 0.05$) while the interactive terms X_1^2, X_2^2, X_3^2, had an anta gonistic relationship at ($P < 0.05$). An upward increase in moisture at the linear and quadratic levels will positively affect the product quality. Moisture content ranged between 2.65 to 4.02%, protein content ranged between 3.40 to 7.01%, the ash content ranged from 1.36mg/100g to 2.33mg/100g, the fibre content varied between 0.18mgand100 to 1.94mg/100g, The ANOVA showed that the processing variables were significant ($P< 0.05$).

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Keywords: Cocoyam; snacks; extrusion proximate.

1. INTRODUCTION

Cocoyam (*Colocasia escolenta)* contributes a significant portion of the carbohydrate content of diets in many developing countries in the form of edible starchy corms or cormels. Although it's less critical than other roots, crops such as yam, cassava and sweet potatoes are an essential staple in some tropics and sub-tropics [1]. Cocoyam is rich in digestive starch, good quality protein, vitamin C, thiamine, riboflavin, niacin and some scores of essential amino acids [2,3]. Generally, cocoyam is poor in nutritional quality. Nutritionally cocoyam can be improved by blending with food materials rich in lysine, a limiting amino acid in cocoyam. Its combination with legumes which are comparatively rich in lysine can provide an ideal source of cheap and affordable dietary protein for Africa and developing countries.

Bambara groundnut remains one of the less researched crops [4], with great nutritional potential. Unfortunately, the Bambara groundnut has less attention in many parts of Africa because of the development of other crops. In Northern Nigeria, most of the Bambara groundnut produced is consumed locally; limited information on the industrial use of the crop has been reported.

The haulm is used for livestock feed, while the fresh pods are boiled and eaten as snacks. One of the critical factors for its underutilization is the hard-to-cook (HTC) phenomenon, in addition to inadequate processing techniques [5]. HTC in legumes is related to structural cell modifications (e.g., autolysis of cytoplasm organelles and lignification's of middle lamella) and changes in its composition (e.g., formation of insoluble pectate and interactions of proteins and phenolic compounds), which occur in the cotyledons and seed coats [5]. Bambara groundnut contains sufficient amounts of nutrients such as proteins, vitamins, and minerals. Bambara groundnut seeds supply an important source of crude protein up to 24%, carbohydrates 63%, and fats 6.5%. Awolu *et al.* [6] reported that the protein content composite flour of wheat and cocoyam improved with Bambara groundnut flour. The significant characteristics to be considered when using flour as a blend are its availability, cultural acceptance, and ability to provide nutritional requirements [7].

Starch-based snack foods are a typical example of extruded products. Studies on starch extrusion have shown that two significant operations occur during this process-heating, in the presence of water and shearing – impart structure to the final product through the transformation of starch granules by the mechanism of gelatinization [8]. It has been used in the cereal industry for several years to produce many foods and food ingredients such as breakfast cereals, snack foods, baby foods, pasta products, extruded bread, modified starches, beverages, powders, meat and cheese analogues, textured vegetable protein, and blended foods such as corn starch and grounded meats [9-13]. It is a technology with high versatility and efficiency, low cost, high output per unit time, and short reaction time, with relatively no waste generated [14].

This research is intended to study the effect of extrusion variables on the proximate composition of snacks from composite flours of cocoyam and Bambara groundnut.

2. MATERIALS AND METHODS

2.1 Source of Raw Materials

The cocoyam used in this study was obtained from Kafanchan in Jema, a Local Government Area of Kaduna State, Nigeria. The variety was identified in Root Crop Research Institute Ahmadu Bello University Samaru Zaria, while Bambara groundnut was purchased in Kaduna Central Market.

2.2 Cocoyam Flour Preparation

Cocoyam flour was manufactured using the procedure described by Oti and Okobundu [15] with slight modifications. The corms were manually cleaned before removing the diseased corms, washed, peeled, sliced, and blanched at 80°C for 4 min, and it was dried to 14% moisture content using hot air oven and milled using a locally fabricated attrition mill and sieved with 150µm laboratory sieve. (2%) sulphite was added to inhibit enzymic browning.

2.3 Bambara Groundnut Flour Preparation

The Bambara groundnut was soaked for 24h to facilitate dehulling. The seed grains were dehulled using mortar and pestle. The dehulled kernels were washed to remove the skin oven-dried at 65 ^{0}C to 14% moisture content before winnowing to have clean dehulled seeds. The dried seeds were then milled into flour using an attrition mill and sieved to pass through a 150µm laboratory sieve (Xin-Hai type). The samples were packaged in an air-tight plastic container at room temperature until needed.

2.4 Blend Formulation and Moisture Adjustment

Fifteen (15) formulations were prepared to contain cocoyam and Bambara groundnut flours (wet basis) ranging between 8- 29.45% based on the experimental layout (Table 1.) The samples were conditioned to appropriate moisture content by spraying with a calculated amount of water, and the cocoyam formulations were mixed continuously using Hobart laboratory mixer. The samples were put in a closed container and kept overnight (32 + 20 0^c .The samples were kept in a room temperature equilibrate pending extrusion processing.

The amount of water used was calculated using the equation below.

$$Y=\frac{Mf-Mi)x\ Sw}{100-Mf} \ldots\ldots\ldots \quad .(1)$$

Where;
Y = Amount of water to be added (ml)
Mf = Final moisture content
Mi = Initial moisture content
Sw = Sample weight (g)

2.5 Extrusion Exercise

The blends were subjected to extrusion cooking. Feeds were manually introduced into extruder through a screw operated conical hopper at a speed of 50rpm which ensures that the flight of the screw was filled and avoiding accumulation of feed in the hopper using a single screw extruder (Brabender, Duisburg DCE-330) equipped with a DC drive of variable speed and a strain gauge torque meter. The screw geometry was at constant and is linearly tapered. The rehydrated samples were then extruded and the extruded were cooled to room temperature and sealed in high density polyethylene films for further analysis.

2.6 Proximate Analysis of the of the Extrudate

The Association of Official Analytical Chemists [16] methods of analysis was adopted to determine the percentage of moisture, protein, crude fat, crude fibre, ash and the carbohydrate was determined by difference in the extrudate.

3. RESULTS AND DISCUSSION

The results of the proximate composition of cocoyam/Bambara groundnut extrudates are presented in Table 2. The moisture content ranged between 2.6 to 4.02%; protein content ranged between 3.40 to 7.01%. The feed composition, barrel temperature, and feed moisture composition of 23.18%, 1200 ^{0}C, and a moisture content of 16% has an optimum protein improvement [17] observed that fortification with legumes not exceeding 30% were generally considered able to improve amino acid composition. Lipid (fat content) ranged between 0.95 to 1.03%, fibre composition ranged between 0.18 to 1.94%. The low fibre retention may be a result of the hull removal before milling, Brough *et al.* [18] reported that the hull removal lowers the content of the fibres and minerals but improves the expansion during extrusion. The ash ranged from 1.33 to 2.33%. The high ash content is observed on the run 2 with 50% Bambara groundnut extrusion variables, 1000 ^{0}C barrel temperature, and a moisture content of 8%. High feed (Bambara g/nut) tends to improve the mineral composition of the extrudate at an average temperature of 1000 ^{0}C. Of all foods, the legume is the food that adequately meets the recommended dietary recommendation of the dietary regulation for healthy eating; they are high in carbohydrate and dietary fibre, low in fat, good protein and vitamin source, and high in minerals [19].

The regression modeling and the coefficients for the effects of extrusion variables on proximate composition (moisture, protein, fat, ash, and fibre) of cocoyam- Bambara ground for the linear, quadratic, and the interaction term are presented in Table. 3**,** the range for the coefficient of determination (R_2) was 26.33 % to 90.00 % for cocoyam- Bambara g/nut; this result indicates a good fit for the model in describing the effects of feed composition, barrel temperature, and feed moisture composition for Cocoyam-Bambara g/nut extrudate samples. Hence, this model could be used in determining the independent variables in the production cocoyam- Bambara g/nut base extrudate having optimum protein, moisture, fat, ash and fibre indices. All the responses in the various extrudates (samples) have positive coefficients. Filli et al. [20] posits that a negative coefficient denotes a decrease in the response with an increase in the parameter level. In contrast, a positive coefficient indicates an increase in the response as the level of parameter increases.

Moisture= 3.498+ 0.108X_1 – 0.0679X2 + 0.284X_3 +0.101X_1^2 + 0.079X_2^2 – 0.069X_3^2 – 0.054X_1 X_2 – 0.082X1X3 – 0.104X_2 X_3 …………………………………….……….. (2)

The equation (2) above shows the regression model's moisture response for cocoyam/ Bambara groundnut. The result of the ANOVA showed that the model X_1, X_3, (linear) X_1^2, X_2^3, (quadratic) were all significant (P ≤0.05) while the interactive terms X_1^2, X_2^2, X_3^2, had an antagonistic relationship at (P ≤0.05). The R_2 and Radj. were 84.98% and respectively. An upward increase in moisture at the linear and quadratic levels will positively affect the product quality.

Protein = 6.678 – 0.142X_1 + 0.075X_2 + 0.126X_3 – 0.244X_1 ^{2} – 0.205X_2 ^{2} – 0.070X_3^2 – 0.064X_1 X_2 – 0.097X_1 X_3 + 0.052 X_2 X_3………………………………………………. (3)

Table 1. Composite flour obtained from the optimal mixture model of RSM

	X_1	X_2	X_3	X_1	X_2	X_3
1	-1	-1	-1	30	100	8.00
2	1	-1	-1	50	100	8.00
3	-1	1	-1	30	140	8.00
4’	1	1	-1	50	140	8.00
5	-1	-1	1	30	100	24.00
6	1	-1	1	50	100	24.00
7	-1	1	1	30	140	24.00
8	1	1	1	50	140	24.00
9	-1.682	0	0	23.18	120	16.00
10	1.682	0-1.682	0	56.82	120	16.00
11	0	1.682	0	40	86.36	16.00
12	0	0	0	40	153.63	16.00
13	0	0	-1.682	40	120	2.55
14	0	0	-1.682	40	120	29.45
15	0	0	0	40	120	16.00

X_1=feed composition, X_2=barrel temperature, $X_{3=}$feed moisture composition

Table 2. Effects of feeds composition(X_1), barrel temperature(X_2) feed moisture content (X_2) on the proximate composition of cocoyam - Bambara groundnut extrudate

EXP RUN	Ind. Variable in their natural forms	Proximate Analysis (%)					
	(X_1 X_2 X_3)	Moisture	Protein	Lipid	Fibre	Ash	Carboh.
1	30 100 8	2.65	3.40	1.03	1.94	1.36	89.61
2	50 100 8	3.63	5.99	0.96	1.87	2.33	85.22
3	30 140 8	3.24	5.51	0.96	1.75	1.54	87.02
4	50 140 8	3.29	5.96	0.97	1.76	1.54	86.48
5	30 100 24	4.02	6.25	1.01	1.81	1.54	85.37
6	50 100 24	3.96	6.57	0.93	1.79	1.59	85.46
7	30 140 24	3.48	6.68	0.98	1.78	1.59	85.57
8	50 140 24	3.91	6.63	1.01	1.83	1.59	85.04
9	23.18 120 16	3.89	7.01	0.99	1.83	1.59	84.60
10	56.82 120 16	3.93	5.10	0.95	1.85	2.02	86.15
11	40 86.36 16	4.02	6.01	0.96	1.88	1.74	85.39
12	40 153.63 16	3.67	6.29	0.97	1.89	1.71	85.47
13	40 120 2.55	3.04	6.96	0.97	1.88	1.65	85.50
14	40 120 29.45	3.82	6.08	0.97	0.18	1.65	87.30
15	40 120 16	3.49	6.66	0.95	1.79	1.66	85.45

X_1= Feed composition, X_2= Barrel temperature, X_2= Feed moisture composition

Table 3. Regression equation coefficient for response variable composition cocoyam/Bambara g/nut proximate composition

Term	Moisture	Protein	Fat	Ash	Fibre
Constant	3.498	6.678	0.940	1.630	1.793
X_1	0.108	-0.142	-0.011	0.046	- 0003
X_2	-0.067	0.075	-0.001	- 0.05	- 0.023
X_3	0.284	0.126	0.004	- 0.042	0.0003
Quadratic					
X_1^2	0.101	- 0.244	0.0065	0.1240	0.008
X_2^2	0.079	- 0.205	0.0065	0.0010	0.023
X_3^2	-0.069	- 0.070	0.0109	- 0.033	0.011
Interaction					
X_1X_2	-0.054	- 0.064	0.0262	- 0.103	0.023
X_1X_3	-0.082	- 0.097	0.0050	- 0.920	0.006
X_2X_3	-0.104	0.052	0.0112	0.1050	0.036
R square	76.90%	26.33%	91.00%	68.51%	62.02%
R. adj	35.33%	0.000%	74.79%	11.84	0.00%

$y= \beta o+ \beta_1 x_1+ \beta_2 x_2+ \beta_3 x_3+ \beta_{11} x_{11} + \beta_{22} x_{22} + \beta_{33} x_{32} +\beta 1x1x2 +\beta 13x1x3 +\beta 23x2x3$ $x_{1=}$ feed blend composition, $x_{2=}$ barrel temperature, x_3= feed moisture composition

Table 2 shows protein content which ranged between 3.40 to 7.01%. The low protein in the result might result from barrel temperature, which might have resulted in protein denaturation. The Bambara groundnut protein is of good quality and has surplus lysine, which complements cereals in the diet [21]. In food fortification, the quality of the protein rather than the quantity is the most critical factor [22]. The ANOVA indicated a significance (P≤ 0.05) model, linear; X_2 and X_3, and interactive; $_{X2X3}$, while the R2 and Radj were 44.49% and 0.00%. These low values indicate a low contribution of protein to cocoyam flour [22].

Fat = $0.947 – 0.0107X_1 – 0.0009X_2 – 0.004X_3 + 0.0065X_1^2 + 0.00654X22 +0.0109X32 + 0.0262X1X2 + 0.0050X1X3 + 0.011X_2 X_3$……………………………………………… (4)

The fat content ranged from 0.93% to 1.03%. The values obtained fall within the acceptable limits of flours for food formulations [23]. One of the significant concerns in extrusion is the excessive amount of fat which affects the shearing effectiveness on the screws in the barrel during the transition or compression. During extrusion, fat provides lubrication effects in the compressed polymer mix in the extruder and modifies the eating quality of food products [24,25]. There was an antagonistic linear (X_1, X_2, X_3) relationship, while the quadratic ($X1^2$, X_2 ^{2}, X_3^2) and the interactive (X_1 X_2, X_1 X_3, X_2 X_3) had a synergistic relationship from the model. An antagonistic relationship showed a negative outcome when the processing variables were adjusted upward, while a synergistic relationship showed a positive effect.

Ash = 1.630 + 0.046X1 – 0.0579X2 – 0.0421X3 + 0.124X12 + 0.0005X22 – 0.0339X32 0.01038X1X2 – 0.0925X1X3+ 0.1050X2X3 ……………………………………………… (5)

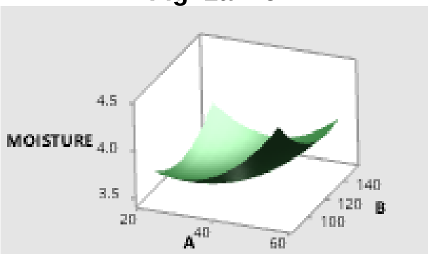
The ash content ranged from 1.36mg/100g to 2.33mg/100g. The result shows a corresponding increase in ash with an increase in Bambara g/nut and cocoyam, which shows that the extrudate contains an appreciable amount of minerals. The model terms; linear X1, quadratic X12, and the interaction terms were significant (P≤ 0.05). Minerals are vital to the body, and they are needed to maintain the osmotic balance of the body fluids and regulate muscle and nerve irritability [23]. The ash content is an index of inorganic elements present as minerals.

Fibre = 1.793 – 0.0034X1 – 0.0230X2 + 0.0003X3 + 0.008X12 + 0.0230X22 + 0.0115X32 + 0.0237X1X2 + 0.0063X1X3 + 0.0363X2X3 ……………………………………………. (6)

The fibre content varied between 0.18mg/100g to 1.94mg/100g. The result of the lower limit (1.94g/100g) falls within the range (1.3 - 7.20g/100g that has been obtained for Bambara groundnut /cocoyam flours [23]. It has been observed that insoluble dietary fibre decreases apparently as the process parameters changes. These changes may be due to disruptions of covalent and non-covalent bonds in the carbohydrate and protein moieties leading to smaller and more soluble molecular particles [24]. The fibre showed negative linear and a positive quadratic and interactive (X3), (X12 X22 X32), and (X1 X2, X1X3, and X2X3) terms, respectively. The ANOVA proves that the processing variables are significant (P≤ 0.05).

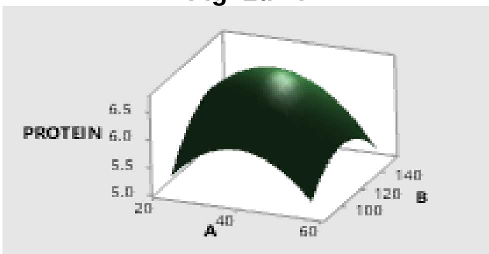
Proximate Composition of Cocoyam – Bambara g/nut based extrudate using 3D graphs

Fig. 1a – c



(a)

Fig. 1d - f



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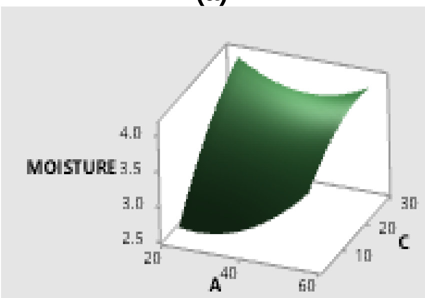

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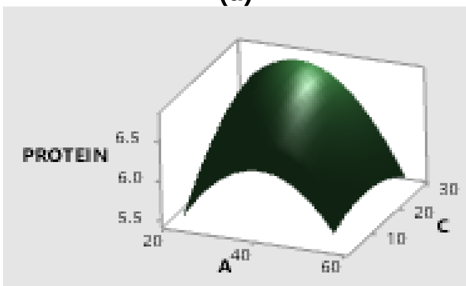

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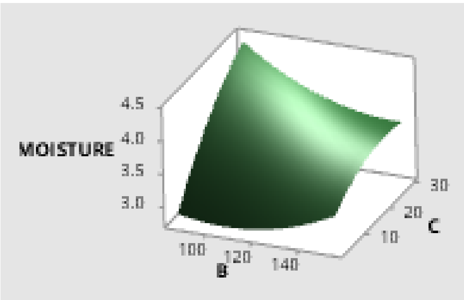

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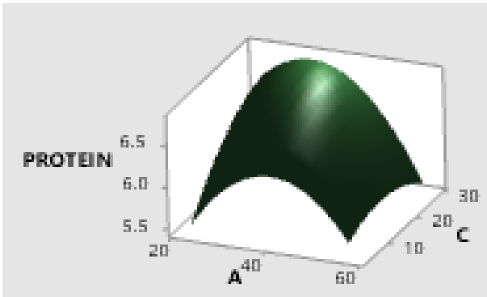


(f)

Fig. 1 (a). 3D surface plot of the effects of FBC and BT on the moisture of the cocoyam-bambara g/nut extrudate holding FMC at 16%, (b) 3D plot of the effect of FBC and FMC on moisture cocoyam- bambara g/nut extrudate holding BT at 120^{0}C (c) 3D surface plot of the effect BT and FMC on moisture of cocoyam- bambara g/nut extrudate holding FMC at 40% Fig.1 (d). 3D surface plot of the effect of FBC and BT on the protein of the cocoyam- bambara g/nut formulation holding FMC at 16% (e) 3D surface plot of the effect of protein of the cocoyam- bambara g/nut extrudate holding BT at 140^{0}C (f) 3D surface plot of the effect of BT and FMC on the protein of the cocoyam- bambara g/nut extrudate holding FBC at 40%

Fig. 2a – c

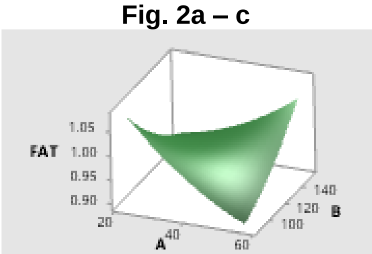
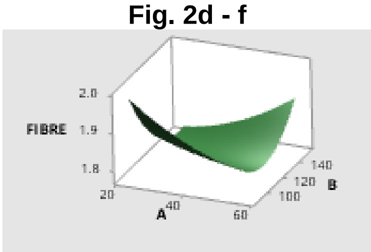
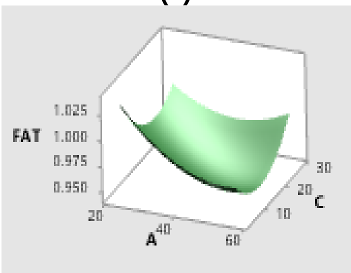


Fig. 2d - f



(a)



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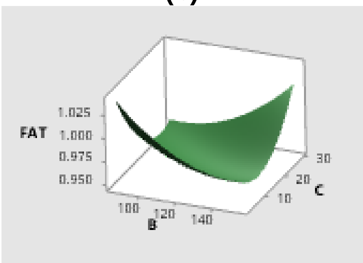

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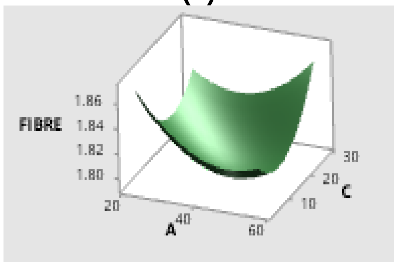

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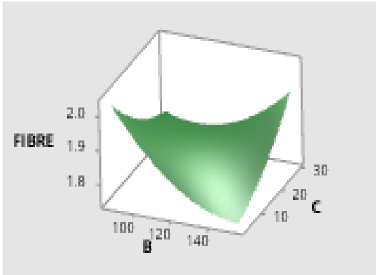
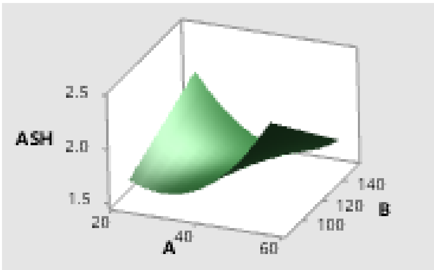


(f)

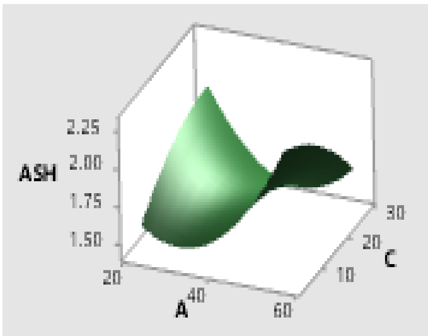
Fig. 2a. 3D surface plot of the effects of FBC and BT on the fat of the cocoyam- bambara g/nut extrudate holding FMC at 16%, (2b) 3D plot of the effect of FBC and FMC on moisture cocoyam- bambara g/nut extrudate holding BT at 120^{0}C (2c) 3D surface plot of the effect BT and FMC on moisture of cocoyam- bambara g/nut extrudate holding FMC at 40%

Fig. 2d. 3D surface plot of the effect of FBC and BT on the protein of the cocoyam- bambara g/nut formulation holding FMC at 16% (2e) 3D surface plot of the effect of protein of the cocoyam- bambara g/nut extrudate holding BT at 140^{0}C (2f) 3D surface plot of the effect of BT and FMC on the protein of the cocoyam- bambara g/nut extrudate holding FBC at 40%

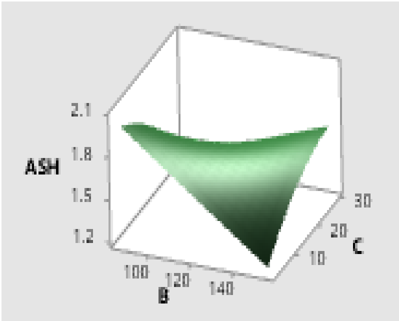
Fig. 3a – c



(a)



(b)



(c)

Fig. 3a 3D. surface plot of the effect of FBC and BT on the ash of the cocoyam- bambara g/nut formulation holding FMC at 16% (3b) 3D surface plot of the effect of ash of the cocoyam- bambara g/nut extrudate holding BT at 140^{0}C (3c) 3D surface plot of the effect of BT and FMC on the ash of the cocoyam- bambara g/nut extrudate holding FBC at 40%

4. CONCLUSION

The RSM was used to study the effect of extrusion on the set of responses (proximate). It was established that varying the feed composition, barrel temperature, and feed moisture content ($p< 0.005$) affects the quality of the proximate properties and characteristics of cocoyam and Bambara groundnut noodles. There was a synergistic relationship for protein at linear (X_1 and X_2) and at quadratic (X_1^2 X_2^2); likewise, fat and ash content varied ($p<0.005$). The number of fibre changes as the parameters changes significantly. These variables are essential considerations for commercial and mass production of healthy and nutritious extruded cocoyam snacks supplemented with legumes. Therefore, it points to the fact that extrusion is a viable alternative in transforming cocoyam into a value-added product.

DISCLAIMER

The products used for this research are commonly and predominantly use products in our area of research and country. There is absolutely no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge. Also, the research was not funded by the producing company rather it was funded by personal efforts of the authors.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1 Onu PN, Madubuike FN, Esonu BO, Onu DO. The effect of wild cocoyam (*Caladium bicolor*) on the performance and internal organ weights of finisher broiler" Journal of Science Agriculture Food Technology and Environment 2001; 1:19 – 24.

2 2.Onyeka, J. Status of Cocoyam (*Colocasia esculenta* and *Xanthosoma spp*) in West and Central Africa: Production, Household Importance and the Threat from Leaf Blight. Lima (Peru). CGIAR Research Program on Roots, Tubers and Bananas (RTB); 2014.

3 3.Lewu L. M, Adebola P.O and Afolayan, A.J. Effect of cooking on the Proximate composition of the leaves of some accession of colocasia esculenta (l)Schott in Kwazulu – Natal Province of South Africa. African Journal of Biotechnology. 2009; 8(8):1619- 1622

4 Bamshaiye OM, Adegbola JA, Bamishaiye EI. Bambara groundnut: An under-utilized nut in Africa. Adv. Agric. Biotechnol. 2011;1:60–72.

5 Mubaiwa J, Fogliano V, Chidewe C, Linnemann AR. Hard-to-cook phenomenon in bambara groundnut (*Vigna subterranea (L.) Verdc*.) Processing: Options to improve its role in providing food security. Food Rev Int. 2017;33(2):167–94.

6 Hashimoto JM, Grossmann MVE. Effects of extrusion conditions on quality of cassava bran/cassava starch extrudates. Int. J. Food Sci. Technol. 2003;38:511–51.

7 Akobundu ENT, Cherry JP, Simmons G. Chemical, functional and nutritional

properties of Egusi (*Citrullus vulgaricus*) seed protein products. J. Food Sci. 1982;47:829-835.
8 Patricia G. Owusu-Darko, Alistair Paterson, *Emmanuel L.* Omenyo. Cocoyam (corms and cormels)—An underexploited food and feed resource. Journal of environmental Chemistry, 2014;3(1):22-29.
9 Anderson RA, Conway HF, Pfeifer VF, Griffin EL. Gelatinization of corn grits by roll and extrusion cooking. Cereal Science Today. 1969;14(1):4–12.
10 Pardeshi IL, Chattopadhyay PK. Whirling bed hot air puffing kinetics of rice-soy ready-to-eat (rte) snacks. Journal of Ready to Eat Food. 2014;1(1):01–10.
11 Abd El-Hady EA, Mostafa GA, El-Samahy SK, El-Saies IA. Production of high fiber corn extrudates. J. Agric. Sci. Mansoura Univ. 1998;23(3):1231-1245.
12 Ding Q, Ainsworth P, Tucker G, Marson H. The effect of extrusion conditions on the physicochemical properties and sensory characteristics of rice-based expanded snacks. J. Food Eng. 2005;66:283-289.
13 Rhee KS, Kim ES, Kim BK, Jung BM, Rhee C. Extrusion of minced catfish with corn and defatted soya flours for snack foods. J Food Process Pres. 2004;28:288–301.
14 Tiwari Jitta, Jha SK. Extrusion Technology: Principal mechanism and effect on Direct expanded Snaks-an Overview; 2017.
15 Oti E, Akobundu ENT. Physical, Functional and Amylography Pasting Properties of Cocoyam- Soybean-crayfish Flour Blends. Nigeria Food Journal. 2007;(1):161-170.
16 AOAC. Official Method of Analysis.14th edition. Association of Official Analytical Chemist. Arlington; 2012.
17 Brough SH, Am- Ali SN, Taylor AJ. The potential of Bambara groundnut in vegetable milk production and basic protein functionality systems Journal of Food Chemistry. 1993;47:277- 283.
18 Brough SH, Azam-Ali SN, Taylor AJ. The potential of Bambara groundnut (*Vigna subterranea*) in vegetable milk production and basic protein functionality systems. Food Chem. 1993;47:277-283.
19 Apata DF, Ologbobo AD. Influence of phytic acid on the availability of minerals from selected tropical legume seeds. Nigerian Journal of Science. 1989;88 – 91.
20 Filli KB, Nkama I, Jideani VA, Abubakar UM. The Effect of Extrusion Conditions on the Physicochemical Properties and Sensory Characteristics of Millet – Cowpea Based Fura. European Journal of Food Research & Review. 2012;2(1):1-23.
21 Ocran VK, Delimini LL, Asuboah RA, Asiedu EA. Seed management. Manual for Ghana, MOFA, Accra, Ghana. 1998;67.
22 Hashimoto JM, Grossmann MVE. Effects of extrusion conditions on quality of cassava bran/cassava starch extrudates. Int. J. Food Sci. Technol. 2003;38:511–51.
23 Frunji F, Niess N. AND Pfeffer, E. Effects of raw and heat-treated Bambara groundnut (*Vigna subterranea*) on the performance and body composition of growing broiler chicks. Archives of Animal Nutrition. 2003;6:443 – 453.
24 Danbaba N, Nkama I, Badau MH, Ukwungwu MN, Maji AT, Abo ME, et al. Optimization of Rice Parboiling Process for Optimum Head Rice Yield: A Response Surface Methodology (RSM) Approach. International Journal of Agriculture and Forestry. 2014;4(3).
25 Guy A, Horne W. Extrusion and Co-Extrusion of Cereals. In: Food Structure-Its creation and evaluation, Blanshard JMV, Mitchell JR. (Eds.). Butterworth Press, London, UK. 1996; 331-349.

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