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Optimization of Extrusion Cooking on the Characteristics of Ready-to-Eat Breakfast Cereal Made from Bambara Groundnut Based Composite Flour

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ABSTRACT

Optimization of extrusion cooking effects on the proximate composition, anti-nutritional factors, mass flow rate, and torque, among other responses of Bambara groundnut-based flour blends, was the objective of this research. Bambara groundnut, pearl millet, malted sorghum, and banana flours were blended in the ratio of 50:20:20:10, respectively. Box–Behnken design of response surface methodology (RSM) was applied. Extrusion cooking reduced crude protein (20.01–17.19%), reduced the activities of oxalates, saponins, and trypsin inhibitors by 88.31%, 87.30%, and 82.35%, respectively, and increased carbohydrate content (57.48–68.82%). Barrel temperature had a strong increasing correlation ($R^2 = 0.9033$) with mass flow rate, while net torque increased (78.15–81.26%) with decreasing screw speed (350–300 rpm). The RSM was successfully used to design, process, and develop prediction model equations for the manufacture of the Bambara groundnut-based breakfast cereal. Therefore, up to 50% Bambara groundnut is acceptable for a nutritionally improved breakfast cereal using extrusion cooking.

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Introduction

Extrusion cooking is a process whereby starchy raw food materials are passed through a series of mixing, kneading, cooking, and forming operations that convert the ingredients into desired shapes, textures, and style (Singh, Sharma, & Sharma, 2017). Extrusion cooking has been found to be versatile in the manufacture of convenience foods and health-promoting products, using a variety of raw materials. The selection of appropriate raw materials for extrusion cooking is based on their functionality, taste, and other important benefits necessary to improve the nutrition of the extruded cereal products and to maintain consumer preferences. Therefore, providing acceptable taste, texture, and appearance to consumers could only be achieved through a deeper

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understanding of the impact of these ingredients on the parameters in relation to consumer preference. The increasing need for consumers to eat nutritious foods that keep them in shape, fit, and healthy cannot be overemphasized. However, there is a time constraint on many urban-based dwellers to go through the rigorous process of preparing an all-in-one meal from scratch, necessitating the development of healthy convenience foods from locally available staple crops.

Bambara groundnut (*Vigna subterranea*) is a leguminous plant of tropical African origin (Stephens, 2003) and is commonly known as okpa (Igbo), Njugo bean (South Africa), Congo groundnut (Congo), or Gurujia (Hausa). Nigeria is known for its high Bambara groundnut production, with a mean annual quantity of 0.1 million tons, followed by Burkina Faso (44,712 tons; Tan et al., 2020). The interesting nutritional makeup of Bambara groundnut has resulted in its increased utilization as a balanced composition of high protein, carbohydrate, and most basic essential nutrients (Tan et al., 2020) needed for healthy living, especially in the developing world. Depending on the variety, Bambara groundnut has a high protein content (24.6%), essential amino acids (6.6%), and significant iron (7.6 mg/100 g) and calcium (73 mg/100 g) contents (James et al., 2018). According to Stephens (2003), the methionine content of Bambara groundnut is much higher than other legumes. However, Bambara groundnut is one of the underutilized legumes cultivated in Nigeria. Moreover, it has hard-to-cook characteristics, an obvious beany flavor, high anti-nutrient factors, and hard milling and dehulling properties.

Sorghum (*Sorghum bicolor* (L.) Moench) and pearl millet (*Pennisetum glaucum* (L.) R. Br.) are cereal crops both with carbohydrate characteristics needed for extrusion. Sorghum has slightly more protein than maize but is deficient in tryptophan and lysine and contains carbohydrate (71%), moisture (11.60%), crude protein (10.40%), fat (4%), crude fiber (2%), and 1% ash (Bolarinwa, Olaniyan, Adebayo, & Ademola, 2015). Malting sorghum partly breaks down protein molecules/matrix and endosperm granules of starch, thereby making these nutrients more bioavailable for utilization in the body (Taylor, Hugo, & Yetnerberk, 2014). Pearl millet is nutritionally better than many cereals because its seed contains a high amount of iron, calcium, lipids, zinc, and quality protein and 5–7% oil (Hassan, Sebola, & Mabelebele, 2021). Pearl millet has carbohydrate (76.3%), crude protein (14%), fat (5.7%), ash (2.1%), and 2% crude fiber (Filli, Nkama, Jideani, & Abubakar, 2012), and while sorghum is used for its bright color input, pearl millet has a better micronutrient composition (Hassan, Sebola, & Mabelebele, 2021). Banana (*Musa sapientum*), belonging to the Musaceae family, is a fruit crop usually consumed fresh. It is also known for its sweet aroma and taste, which are suitable for all ages, from infants to elders. Bananas have low glycemic index and are a good source of potassium needed for maintaining normal heart function and blood pressure (Yap, Fernando, Brennan, Jayasena, & Coorey, 2017). However, it contains high moisture that makes it readily perishable, resulting in high post-harvest losses.

Breakfast cereal can either be made out of only a particular cereal, a combination of cereals, or together with other food crops. The essence of the combinations is either to enhance the nutritive value, reduce/increase the unit cost of the products, or utilize the available resources in the locality (Bolarinwa, Olaniyan, Adebayo, & Ademola, 2015). For instance, combining cereal crops with legumes would make up for the essential amino acids balance, and addition of fruits will further increase its micronutrients level as required by the body, but legumes will lower the expansion ratio due to their starch quality. Okafor and Falade (2021) had reported the chemical, physico-chemical, in vitro digestibility, microbial, and sensory characteristics of Bambara groundnut-based ready-to-eat (RTE) breakfast cereal using extrusion cooking. Response surface methodology (RSM) is a mathematical modeling technique used to randomize the process variables and ensure that the best combinations of the independent factors are utilized in the manufacture of the optimum-quality product. The objective of the research was to investigate the effects of barrel temperature (180–220°C), screw speed (300–350 rpm), and feed moisture (12–16%) on proximate composition, anti-nutritional factors, mass flow rate (MFR), and torque, among other responses of blends of Bambara groundnut, pearl millet, malted sorghum, and banana flours at a ratio of 50:20:20:10, respectively, using the Box–Behnken design of RSM for the manufacture of a Bambara groundnut-based RTE breakfast cereal by extrusion cooking.

Materials and methods

Bambara groundnut (cream), sorghum, pearl millet, and ripe banana fruit (stage 5) were all purchased from Ogboette market, Enugu, Nigeria. Other ingredients such as sucrose (sugar) and banana flavor were obtained from Lagos, Nigeria.

Bambara groundnut, malted sorghum, pearl millet and banana flours were seprpepared using the following methods. Malted sorghum flour was prepared using the method described by Bolarinwa, Olaniyan, Adebayo, and Ademola (2015). Pearl millet flour was prepared as described by Eke-Ejiofor and Oparaodu (2019), with some modifications. The grains were sorted, properly washed, and semi-wet milled using a mill (Romer serial II mill, Romer Labs, USA). Afterward, it was dried and re-milled into flour. The method used by Okafor and Falade (2021) was employed for banana flour. Washed banana fruits were peeled and weighed, and equal weight of the aforementioned malted sorghum flour was added and bound together forming a dough. The dough was rolled out into thin layers with a rolling pin and dried at 38°C for 3 h in an oven (Model: Labmill-257; Gibbons, Essex, UK). The resultant pellets were milled in a hammer mill into flour. The method described by Mazahib, Nuha, Salawa, and Babiker (2013) was employed with some modifications for Bambara groundnut. Bambara groundnut seeds were cleaned, boiled with caustic soda (5%) for 5 min, and dried in the oven drier (Model: Labmill-257; Gibbons, Essex, UK) at 42°C for 6 h. After drying, they were winnowed to remove the seed coat, milled to flour in a hammer mill (Romer serial II mill, Romer Labs, USA), and then sieved with a screen (250 µm mesh). All samples were blended in the ratio of 50:20:20:10 for Bambara groundnut, sorghum, pearl millet, and banana, respectively.

Experimental design

The Box–Behnken experimental design of RSM was employed in the design of the experiment. The design had only low and high ranges (two-level model), with no center points. Based on preliminary studies, both the responses and factors were altered within their minimum and maximum windows. Screw speed (300–350 rpm), feed moisture (12–16%), and barrel temperature (180–220°C) were the selected factors, while crude protein, carbohydrate, moisture content, overall acceptability, expansion index (EI), and MFR were the responses.

Extrusion cooking of the blended flours

The flour blend was fed through an inlet feed hopper, which passed through the barrel to the die with variations in the extrusion conditions using the Box–Behnken's experimental design (Table 1). Extrusion cooking was done in a twin-screw extruder (Model DZ65-III, Brabender, Duisburg,

Table 1. RSM Process Variables and the Extrusion Responses

Run	SS (rpm)	BT (°C)	MC (%)	CP (%)	CHO (%)	MC (%)	OA	EI	MFR (g/s)
1	325	180	16	17.5	68.94	6.45	6.8	5.94	25.7
2	325	200	14	16.86	69.01	6.78	7.3	6.77	29.61
3	325	200	14	16.99	68.48	6.88	6.9	6.32	28.33
4	300	220	14	13.87	71.56	6.85	6.5	7.89	26.22
5	325	220	12	14.99	70.39	7.01	6.2	7.78	29.71
6	350	180	14	15.91	69.84	6.99	6.7	5.48	30.69
7	325	200	14	16.73	69.03	6.37	7.3	6.66	25.66
8	325	200	14	16.88	67.96	7.23	6.7	6.45	27.99
9	350	220	14	17.05	68.4	7.12	6.8	7.34	30.42
10	350	200	16	15.15	70.88	6.77	6.1	6.11	33.71
11	300	200	16	15.82	70.07	6.95	7.4	6.53	25.81
12	300	200	12	15.77	69.75	6.86	6.8	6.96	26.33
13	325	200	14	16.91	69.4	6.83	6.7	6.78	28.61
14	300	180	14	14.82	70.82	6.91	6.9	5.86	25.81
15	325	220	16	15.23	70.96	6.52	7.1	7.13	26.97
16	350	200	12	15.64	70.13	6.97	6.6	6.89	32.67
17	325	180	12	17.87	68.36	6.84	6.8	5.87	29.11

SS – Screw Speed; BT – Barrel Temperature; MC – Moisture Content; CP – Crude Protein; CHO – Carbohydrate; OA – Overall Acceptability; EI – Expansion Index; MFR – Mass Flow Rate.

Germany) having three heating zones (feed zone, central zone, and die zone), and a die with a diameter of 0.24 mm and a length of 0.5 m was employed. Experimental runs were randomized with the aim to reduce bias from systematic observation of responses resulting from extraneous factors. After extrusion, some samples were collected (unsweetened) and others were treated further as sweetened and sweetened-flavored. The unsweetened samples were conveyed straight into the drier (Model no. ALC-5, Blaw-Knox, New York), while 10 kg of the remaining extrudates was sprayed with 2 L of sucrose solution (50% brix). Then, 5 kg of it was placed in the drier as sweetened. The other 5 kg was also sprayed with 0.75 L of banana flavor (Mekang Resources and Allied Distribution, Lagos) and dried as sweetened-flavored. Generally, unsweetened, sweetened, and sweetened-flavored extrudates were dried in a drier (Model no. ALC-5, Blaw-Knox, New York) for 15 min at 55°C (Caparino et al., 2012).

Optimization and verification

The main criterion for determining the optimization was the resultant outcome of the processing standards, as measured by RSM, that corresponded with the maximum values of crude protein content (17%), target values of carbohydrate (68%), moisture content (7%), overall acceptability (7), EI (7), and MFR (30 g/sec) while alternating processing parameters such as screw speed (300–350 rpm), extruder barrel temperature (180–220°C), and feed moisture (12–16%). A duplicate experimental run was done to ascertain the validity of the experimental models using the Box–Behnken design system.

Chemical analysis of the extrudates

Proximate composition

Proximate composition of the flour and extrudates was analyzed using the method described by the Association of Official Analytical Chemists (2005), and the carbohydrate content was calculated by difference.

Anti-nutritional factors

Quantitative method of analysis was used to determine the tannin content of the samples, as reported in the manual of food quality control (Association of Official Analytical Chemists, 1984). Saponin analysis was conducted using the spectrophotometric method described by Brunner (1984). Phytate extraction from the sample was done according to the modified procedure of Harland and Oberleas (1977). The phytate was calculated according to the method described by the Association of

Official Analytical Chemists (2005). Titration method was used to evaluate the oxalate content in the samples, as described by Munro (2000). Trypsin inhibitors were evaluated using the method described by Shi, Mu, Arntfield, and Nickerson (2017).

Sensory analysis of the extrudates

Sensory evaluation of the extruded samples was done for 17 runs. Twenty-five untrained panelists who represent the regular consumers analyzed the extrudates using 9-point Hedonic scale (from like extremely to dislike extremely). The evaluation was basically aimed at determining the overall acceptability of the extruded samples in line with appearance, flavor, and taste.

Determination of EI, MFR, and extruder parameters

Determination of EI

The procedure described by Fan, Mitchell, and Blanchard (1996) was followed to determine the expansion ratio. The mean of 20 random measurements of the extrudates diameter was determined using a vernier calliper (Model 500-196; Mitutoyo, USA). Then, the ratio of expansion was calculated using the following equation:

$$\mathrm{EI} = \frac{\text{mean diameter of the extrudates } \in \text{mm}}{\text{diameter of the die } \in \text{mm}}$$

Determination of MFR

MFR was determined according to the method described by Singh, Sharma, and Sharma (2017). The extrudates were collected in plastic plates for 2 min immediately after they came out of the extruder die, and their weights were determined as soon as they were cooled to ambient temperature (±27°C).

$$\mathrm{MFR(g/s)} = \frac{\text{Weight of collected sample(g)}}{\text{Time used to collect sample(s)}}$$

Determination of extruder parameters

Specific mechanical energy (SME) was evaluated using the method described by Liang, Huff, and Hsieh (2002). The extruder was operated at motor power of 25 kW, die pressure of 17,000 kPa, and rated screw speed of 1600 rpm, while the actual screw speed varied between 300 and 350 rpm. Also, parameters of the extruder including the length (1500 mm) and width (250 mm) of the barrel, feed rate (33.33 g/sec), residence time (2.25 min), and die size (5 mm) were measured. Other parameters such as SME and torque were calculated using the following equation:

$$\mathrm{SME} = \frac{\mathrm{n(actual)} \times \%\,\mathrm{net\,torque} \times \mathrm{P(rated)}}{2\pi \mathrm{Nn(rated)} \times 100 \times \mathrm{Fr}}$$

where, net torque is the measured torque less the frictional torque due to bearings and gear drive assembly; Fr – feed rate (kg/s); P – motor power (kW); and n – screw speed (rpm).

The torque was calculated using the stated equation (Khurumi, 2006)

$$\mathrm{T} = \frac{60\mathrm{P}}{2\pi \mathrm{N}}$$

P – motor power (kW); N – the screw speed (rpm).

Torque = actual operational torque – empty operational torque value.

$$\%\mathrm{torque} = \frac{\mathrm{Torque\,x\,100}}{\mathrm{Actual\,operational\,torque}}$$

Statistical analysis

Mean values were obtained from duplicate experimental runs and calculated for each analysis. Data were statistically analyzed using analysis of variance method (Statistical Analysis System, version 9.2 program (2008), SAS Inc., USA). Duncan's (1955) multiple-range test was applied for the least significance test difference used to separate means at $p < 0.05$, where significant differences existed. The Box–Behnken design with three independent factors was used to select the optimum extrusion conditions.

Results and discussion

RSM extrusion responses in relation to independent variables

Crude protein

Crude protein content of the extruded products ranged from 13.87% to 17.87%, with the lowest values obtained at barrel temperature of 220°C, screw speed of 300 rpm, and 12% feed moisture and the highest values obtained at 180°C, 325 rpm, and 14%, respectively (Table 1). Also, screw speed significantly affected the mean protein content of the samples ($p <$ 0.001). It increased with an increase in crude protein until 325 rpm, before an insignificant reduction with an increase in protein was observed. Barrel temperature decreased slowly with increasing crude protein. However, feed moisture did not significantly ($p < 0.001$) affect the protein composition.

This is lower than the mean protein (6.8–12.7%) obtained by Navam, Tajudini, Srinivas, Sivarooban, and Kristofor (2014) for a blend of extruded soybean and millet at barrel temperature and screw speed of 275°C and 85 rpm, respectively. This difference in protein content could be due to the use of a higher barrel temperature as compared to a lower temperature used in this study. This protein content is also higher than that obtained from the use of cereals alone, indicating an improvement in the composition of protein by supplementation of the blend with Bambara groundnut flour.

Carbohydrate content

Interaction existed only between the barrel temperature and screw speed for carbohydrate content ($p = 0.331$) of the extruded Bambara groundnut-based breakfast meal. The mean obtained values of carbohydrate for the extruded products ranged from 67.96% and 71.56%, with the lowest values obtained at barrel temperature of 200°C, screw speed of 325 rpm, and 14% feed moisture and the highest values obtained at 220°C, 300 rpm, and 14%, respectively (Table 1). Both barrel temperature and screw speed significantly ($p < 0.001$) reduced the carbohydrate content of the samples. However, feed moisture showed insignificant changes with increased carbohydrate.

Moisture content

When the extruder was operated at a screw speed of 325 rpm, 14% feed moisture, and barrel temperature of 200°C, moisture content ($p < 0.0001$) among the extruded samples varied significantly between 6.37% and 7.23% (Table 1). From the study, there was no need to further increase or decrease the independent variables as they show no significant difference at $p = 0.790$. The moisture content increased with increased feed moisture. This is explainable because the increased moisture content of the feed with the same extrusion conditions would naturally increase the moisture in the product. Interaction was only observed between the screw speed and barrel temperature at $p = 0.726$.

Overall acceptability

The overall acceptability is an important parameter in food product development. Increasing feed moisture resulted in an increase in the overall acceptability (Table 1), probably due to the availability of the required moisture in the feed needed for effective cooking of the feed in the extrudate, which enhanced sensory attributes. However, increased screw speed and barrel temperature resulted in decreased overall acceptability; increased screw speed would not give sufficient time for complete cooking, while increased barrel temperature would cause burning or improper cooking of the feed. Interaction was observed in all the extrusion independent factor combinations at $p = 0.475$ (screw speed with barrel temperature), 0.141 (screw speed with feed moisture), and 0.216 (barrel temperature with screw speed). The overall acceptability values ranged from 6.1 to 7.4, with a lower value obtained at barrel temperature of 200°C, 16% feed moisture, and screw speed of 350 rpm and a higher value obtained at barrel temperature of 200°C, 16% feed moisture, and screw speed of 300 rpm.

Expansion index

EI shows the degree of puffing in an extruded product (Filli, Nkama, Jideani, & Abubakar, 2012). Barrel temperature, screw speed, and feed moisture individually affected the EI of the extruded Bambara groundnut breakfast meal. An interaction between screw speed and feed moisture was observed on the expansion ratio ($p < 0.0001$). Although the interaction was significant, only the barrel temperature significantly affected the EI ($p < 0.0001$). The EI ranged from 5.48 to 7.89 when the extruder was operated at a screw speed of 350 rpm, 14% feed moisture, and barrel temperature of 180°C, and at 300 rpm (screw speed), 14% (feed moisture), and 220°C (barrel temperature), respectively (Table 1). The lowest EI (5.48) was observed at the highest barrel temperature. However, Navam, Tajudini, Srinivas, Sivarooban, and Kristofor (2014) reported a reduction in EI as temperature increased. The EI is remarkably affected by the compositional makeup of the used raw materials, and the effects that the processing will have on the transformations of these materials will depend on their composition.

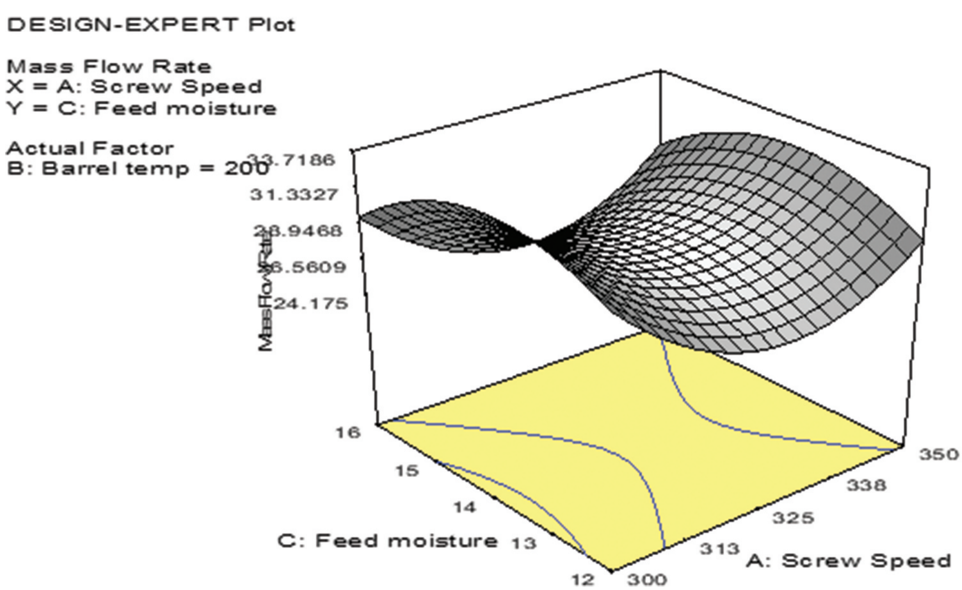

Figure 1. Effect of extrusion conditions on mass flow rate of extrudates.

Table 2. RSM Model Equations for Actual Factors

Independent variable	Model equation
Crude protein	−147.21200 + 1.02343(**SS**) −0.0945(**BT**) +1.10838(**FM**) −1.81120E-003(**SS2**) −8.23750E-004 (**BT2**) −0.03675(**FM2**) +1.04500E-003(**SS*BT**)−2.70000E-003(**SS*FM**)+3.81250E-003 (**BT*FM**)
Carbohydrate	+233.48075−0.82733(**SS**)−0.040937(**BT**)−3.83400(**FM**)+1.53920E-003(**SS2**)+1.04250E-003 (**BT2**)+0.11738(**FM2**)−1.09000E-003(**SS*BT**)+2.15000E-003(**SS*FM**)−6.25000E-005 (**BT*FM**)
Moisture content	+26.34475−0.16994(**SS**)−3.68750E-003(**BT**)+1.20987(**FM**)+ 2.65600E-004(**SS2**)−4.12500E-005(**BT2**)−0.024125(**FM2**)+9.50000E-005(**SS*BT**)−1.45000E-003(**SS*FM**)−6.25000E004 (**BT*FM**)
Overall acceptability	−24.44000 + 0.15260(**SS**)−0.036250(**BT**)+1.61750(**FM**)−2.04000E-004(**SS2**)−3.18750E-004 (**BT2**)−0.031875(**FM2**)+2.50000E-004(**SS*BT**)−5.50000E-003(**SS*FM**)+5.62500E−003 (**BT*FM**)
Expansion index	−18.51675 + 0.040120(**SS**)+0.082313(**BT**)+1.13288(**FM**) −8.80000E-006(**SS2**) +1.30000E-004 (**BT2**)+8.00000E-003(**FM2**)−8.50000E-005(**SS*BT**)−1.75000E-003(**SS*FM**)−4.50000E-003 (**BT*FM**)
Mass flow rate	+1.35875−2.01590(**SS**)+2.13319(**BT**)+18.40438(**FM**)+7.60200E-003(**SS2**)+7.48437E-003(**BT2**) −0.79031(**FM2**)−0.015340(**SS*BT**)+7.80000E-03(**SS*FM**)+4.18750E-003(**BT*FM**)

BT – Barrel Temperature; SS – Screw Speed; FM – Feed Moisture.

Mass flow rate

MFR increased with feed moisture ($p < 0.0019$) until it crossed 30 g/sec, where it started to reduce with increased feed moisture (Figure 1). This could be due to higher-moisture-content-aided flow rate up to a given level. The barrel temperature had a strong increasing correlation (R^2 of 0.9033) with MFR. The highest MFR occurred at a screw speed of 300 rpm, 14% feed moisture, and barrel temperature of 220°C, while the lowest MFR was observed when the extruder was operated at screw speed of 325 rpm, 16% feed moisture, and barrel temperature of 180°C (Table 1).

Process optimization (desirability), validation of RSM optimization, and RSM model equations

All parameters were achieved using quadratic models and the independent variables coded between −1 and 1 ranges. Table 1 shows the optimization findings of 17 runs as deduced from RSM design. It was further narrowed down to the combination with optimum desirability. The optimum point of fit was at the following conditions: 324 rpm (screw speed), 14% (feed moisture), and 207°C (barrel temperature), resulting in a desirability of 0.843. These were selected due to higher protein content compared to the second solution. The values predicted by the calculative models for the responses were 17.19% protein content, 68.63% carbohydrate content, overall acceptability of 6.52, 6.55% moisture content, EI of 7.62, and MFR of 30.68 g/sec. The experimental values of the obtained extruded products were 16.50% protein content, 68.08% carbohydrate content, overall acceptability of 7.33, 6.53% moisture content, EI of 7.27, and MFR of 2.44 g/sec. No significant difference ($p < 0.05$) was observed between the predicted and the actual experimental values. Their percentage deviation were all within the acceptable safe level of ≤5%. Therefore, the RSM prediction model equations (Table 2), are very useful for predicting possible values of responses using the given independent variables before going to the laboratory for actual values confirmation.

Chemical composition of raw materials and extrudates

Proximate analysis

Extrusion decreased all other parameters except for carbohydrate content (Table 3). It is a possibility because cooking at such high temperature is expected to cause some changes such as protein denaturation, Maillard browning, and elimination of anti-nutrients. Although this reduction/increase was significant at different levels, it was still within the acceptable nutritional standards for a breakfast meal. The decrease in the content of crude protein could be due to protein denaturation. The crude protein (17.24%) after extrusion could be said to be all biologically available, unlike the initial crude protein value of the blend that could have been locked up by anti-nutrients. Moisture loss is expected since part of the moisture is evaporated at the final extrusion and expansion stage. Dry extruded products are remarkably known for their shelf life stability at room temperature. An earlier report states that fat reduction could have been caused by the formation of lipid–amylose complexes usually obtained at very high temperature (>200°C) and high screw speed (>300 rpm), which interfered with fat determination (Lee, Kim, Park, Hur, & Auh, 2020). Since carbohydrate is calculated by difference, a percentage decrease in the other proximate parameters would result in an increase in its content.

Anti-nutritional factors

When anti-nutritional factors are present, they reduce the nutritional quality of that food, either by interfering with their digestibility or complete utilization of the affected nutrient. Extrusion cooking is very effective in the reduction of anti-nutritional factors like amylose inhibitors, trypsin, etc., in foods

Table 3. Proximate Composition of the Flour Blend and Extrusion Samples

Samples	Protein (%)	Crude fiber (%)	Fat (%)	Ash (%)	Moisture content (%)	Carbohydrates (%)
Flour blend	$20.03^{b} \pm 0.007$	$4.12^{b} \pm 0.056$	$3.99^{b} \pm 0.014$	$2.51^{b} \pm 0.014$	$11.27^{b} \pm 0.042$	$57.48^{b} \pm 0.085$
Unsweetened extrudate	$17.24^{a} \pm 0.028$	$2.99^{a} \pm 0.028$	$2.41^{a} \pm 0.042$	$1.96^{a} \pm 0.028$	$6.81^{a} \pm 0.014$	$68.82^{a} \pm 0.014$
% Difference	13.93	27.43	39.60	8.84	39.57	19.73
LSD	0.0887	0.1924	0.136	0.0962	0.1360	1.3602

Means in the same column with same superscript letters are not significantly different at $p \geq 0.05$.

Table 4. Anti-Nutritional Factors of the Flour Blend and Extrudate

Samples	Tannin (mg/g)	Oxalate (mg/g)	Phytate (mg/g)	Saponin (mg/g)	Trypsin inhibitors (mg/g)
Flour blend	0.82[b] ± 0.014	0.77[b] ± 0.013	0.94[b] ± 0.007	0.63[b] ± 0.004	0.51[b] ± 0.020
Extrudate	0.27[a] ± 0.007	0.09[a] ± 0.029	0.28[a] ± 0.005	0.08[a] ± 0.014	0.09[a] ± 0.001
% Reduction	67.0 7	88.31	70.21	87.30	82.35
LSD	0.0481	0.0962	0.4357	0.0304	0.0608

Means in the same column with same superscript letters are not significantly different at $p \leq 0.05$.

(Nikmaram et al., 2017). Extrusion remarkably reduced all anti-nutritional factors that were available in the blended flour samples. Tannins, oxalates, phytates, saponins, and trypsin inhibitors showed (Table 4) percentage reduction of 67.07%, 88.31%, 70.21%, 87.30%, and 82.35%, respectively. Due to the high-temperature short-time process, extrusion technology retained the nutrients; however, the temperature was high enough to destroy most anti-nutritional factors present in the flour samples (Nikmaram et al., 2017) such that the anti-nutritional values of the extrudates were significantly below the threshold (0.5 mg/g) of nutritional concern (Mairo, Aina, Gabi, Aimola, & Toyin, 2011). Also, the proportion of Bambara groundnut used in the flour blend was adequate to maintain the overall acceptable extrusion characteristics as well as sufficient nutritional makeup of the extruded products.

Extruder parameters

Specific mechanical energy

SME is the net mechanical ratio to the MFR (Table 5). The SME of the extruder for the blended legume–cereal varied between 114.382 kJ/kg (300 rpm) and 128.218 kJ/kg (350 rpm), with only 300 rpm being significantly lower than 350 rpm and 325 rpm. Therefore, increasing the screw speed (rpm) decreased the torque and increased the SME of the extruder. The SME values obtained in this study were higher than those observed by Meng, Threinen, Hansen, and Driedger (2010) for an extruded blend of chickpea, whey protein, potato starch, and lecithin. This could mainly be attributed to difference in the composition of the feed and extrusion conditions. In this study, the feed blend had protein–carbohydrate values of 20.00% and 57.48%, while those of Meng, Threinen, Hansen, and Driedger (2010) were 25.00% and 53.00%, respectively. Onwulata and

Table 5. Extrusion Process Parameters

Parameters	350 rpm	325 rpm	300 rpm	LSD
Empty torque	0.149	0.149	0.149	
Operational torque	0.682	0.734	0.795	
Net	0.533	0.585	0.646	
% Net torque	78.152[a] ± 0001	79.706[ab] ± 0.001	81.257[b] ± 0.005	3.084
SME (kJ/kg)	128.218[b] ± 0.003	121.549[b] ± 0.002	114.382[a] ± 0.003	7.151

Means in the same row with same superscript letters are not significantly different at $p \geq 0.05$.

Konstance (2006) showed that increased starch and protein content in extruder feed blend caused lower melt viscosity that resulted in lower SME. In this research, lower protein content showed higher SME values than the chickpea-based blend. The SME is used to evaluate the energy entering an extrusion system per unit mass of motor work formed. During extrusion cooking, majority of the energy from the extruder motor is utilized in the form of friction, which heats up the foods (Omeire, Iwe, & Nwosu, 2013). A total energy balance is required in a food system as this allows for proper calculation of specific energy delivered to the product, which is an important indicator of food treatment severity. Expansion of extrudates, as well as gelatinization of starch degree, is mostly affected by increased SME values.

Torque

Increase in screw speeds resulted in a significant decrease in torque (Table 5). Screw speed at 350 rpm and 325 rpm showed similarities at 5% level, while 325 rpm showed similarity with 300 rpm, and 300 rpm was significantly different from 350 rpm screw speed. This would help the designers to plan properly for power consumption at different screw speeds. Torque denotes the power consumption of the extruder. The torque needed to rotate the screws is associated with its speed, viscosity of food materials, and fill in the screw chamber (Omeire, Iwe, & Nwosu, 2013). The effect of process variables on product recreation (like hardness and expansion) is confirmed by the effect of those variables on the torque. For instance, when the feed rate was constant, higher screw speed reduced the filled flight length. This causes a decrease in the motor load of the screw shaft, thus reducing its net extrusion torque (Oke, Awonorin, & Workneh, 2013).

Conclusion

Bambara groundnut, sorghum, pearl millet, and banana flours were blended in the ratio of 50:20:20:10, respectively. A twin-screw extruder with barrel temperature of 207°C, 14% feed moisture, and screw speed of 324 rpm was successfully used to cook the flour blend into an RTE breakfast cereal. Including the RTE breakfast cereal which was further sweetened then, sweetened and flavored; all showed favorable properties.

Disclosure statement

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