Optimization and characterization of rice–pigeon pea flour blend using extrusion cooking process

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Abstract
This study was carried out to formulate rice and pigeon pea flour blend with the aim of providing nutrient-enriched and inexpensive food for developing countries where the raw materials are found in abundance. Three factors (screw speed, feed moisture content and feed blend composition) affecting the extrusion cooking process were subjected to face-centred central composite design (FCCCD), and physical properties were used as the response. Analysis of variance showed that the developed quadratic model was significant with coefficient of determinations ($R^2$) of 0.96 for expansion index, 0.93 for bulk density and 0.88 for water absorption index. Validation experiments were carried out where four rice–pigeon pea flour blends were subjected to physical, mineral and amino acid analyses. Formulation 3 set at screw speed, feed moisture content and feed blend composition of 220 rpm, 30% and 25%, respectively, led to maximum expansion index of 9.98 ± 0.15, bulk density of 0.12 ± 0.01 g/mL and water absorption index of 6.41 ± 0.07. There was significant ($p < 0.05$) increase in essential amino acids in all the developed rice–pigeon pea flour blends, and Formulation 3 was found to be two- and fivefold higher in terms of methionine and lysine contents, respectively, than the control (extruded rice). Similarly, calcium (3.41 ± 0.07 mg/100 g), iron (12.64 ± 0.03 mg/100 g) and zinc (9.33 ± 0.02 g/100 g) contents in Formulation 3 were significantly ($p < 0.05$) higher than the values of 1.19 ± 0.13, 5.89 ± 0.10 and 2.67 ± 0.05 mg/100 g recorded, respectively, for the extruded rice (control). In conclusion, the extruded rice–pigeon pea flour blend showed better physical properties and nutritional quality than the extruded rice.

Keywords
characterization, extrusion cooking, face-centred central composite design, optimization

INTRODUCTION
Utilization of locally available raw materials by different innovative processing technologies where nutrient compositions and consumer acceptability are not compromised has been extensively studied by researchers (Anuonye, 2012; Filli et al., 2013; Singh, Sharma, & Singh, 2000). In most tropical and subtropical countries around the globe, cereals and legumes are widely cultivated and used as the major staple foods providing the appropriate amounts of energy and protein for significant population (Kaushal et al., 2012; Muller &
Krawinkel, 2005). The production of cereal-legume-based products to complement the limiting nutrients has increased significantly over the years; and some of the developed products include porridge, noodles, biscuits, cakes and breads (Muller & Krawinkel, 2005). Extrusion cooking technology has played an important role in enhancing food security for development of a variety of products such as ready-to-eat cereals, chips and flakes (Chaiyakul et al., 2009). This technology requires a high-temperature short-time (HTST) cooking process with considerable prospects, based on its ability to produce shelf-stable foods with minimal microbial loads, reduced anti-nutrient content, improved in vitro protein and starch digestibility and low moisture content (Filli et al., 2011; Nascimento et al., 2017). Products with these characteristics are needed especially in developing countries where food storage infrastructure is limited and inadequate (Filli et al., 2011). Products with these characteristics are needed especially in developing countries where food storage infrastructure is limited and inadequate (Filli et al., 2011).

Different factors have been reported to affect the quality of extruded products, and these include temperature, feed-related parameters (moisture, particle size, composition and proportion), screw speed and configuration, nature of the extruder and the geometry of the die (Gbenyi et al., 2015; Pansawat et al., 2008); these factors work synergistically in increasing the physical and chemical properties as well as consumers’ acceptability (associated with taste, texture, flavour and desired shapes) of the extruded products.

Rice (Oryza sativa) is a popular staple food for about half of the global population, and there has been a remarkable rise in its production to meet the current demand (FAO, 2016). The wider utilization of rice could be linked to its attractive colour, bland taste and ease of digestion (Kaushal et al., 2012). Thus, in most developing countries, rice accounts for daily provision of 27% energy, 20% protein and 3% fat (Kennedy & Burlingame, 2003).

Pigeon pea (Cajanus cajan) is one of the major leguminous seeds found in many tropical and subtropical countries (Troedson et al., 1990). It was ranked as number four after groundnut, cowpea and Bambara groundnut and highly cherished for its protein content (17%–30%), vitamin B complex, vitamin C and provitamin A (Kaushal et al., 2012). Pigeon pea has been considered to be highly under-utilized, and its major limitation is its inability to cook fast; however, it can serve as an ideal supplement to cereal- and tuber-based diets that are known to be generally protein deficient (Eneche, 2009). Therefore, blend of rice and pigeon pea may aid in producing meals with adequate nutrient compositions for utilization by both infants and adults. Hence, this study is aimed at optimizing the three factors (feed moisture content, feed blend composition and screw speed) affecting the extrusion process of rice-pigeon pea flour blend, and the formulated blends were further characterized based on their nutrient compositions.

2 | MATERIALS AND METHODS

2.1 | Materials and processing of samples

Rice was obtained from the National Cereals Research Institute, Badeggi, Niger State, Nigeria, and pigeon pea was also purchased from Samaru Market, Zaria, Kaduna State, Nigeria. Processing of rice consists of winnowing and dry cleaning. The kernels were removed using a rice dehuller (Tokyo M3, Rice Dehuller, Japan). The dried grains were milled into flour and sieved using a 2-mm standard sieve and then stored tightly in a polythene bag for extrusion. Pigeon pea seeds (2 kg) were cleaned manually from all the foreign materials and soaked in water for 8 h (28 ± 2°C), where the seed coats were completely removed. Thereafter, the seeds were dried in a hot air oven maintained at 60°C until constant weight was obtained. The dried seeds were ground into powder using attrition mill (Galenkamp, England) and sieved using a 2-mm standard sieve as described by Anuonye (2012).

2.2 | Composite flour formulation

Pigeon pea flour was mixed at different proportions (10%–30%, w/w) with rice flour. The initial moisture content of the rice–pigeon pea flour blends was determined using hot air oven method, which was designated as M_i. Thus, the amount of water to be added in the formulation was calculated according to Wilmot (1998).

\[ W_d = \frac{W_w(1-M_i)(1-M_b)}{M_a-M_b} \]

where \( W_d \) is the weight of dried flour blend, \( W_w \) is the amount of water to be added, \( M_i \) is the initial moisture content and \( M_b \) is the desired moisture content.

2.3 | Extrusion experiment by face-centred central composite design

Face-centred central composite design (FCCCD) was carried out to determine the effects of three important factors on the extrusion process. In this study, the factors considered were screw speed (150–250 rpm), feed moisture content (20–30 w/w) and feed blend composition (10–30 w/w); and the experimental design matrix and analyses were done using Design-Expert software 6.0.8 (Stat-Ease, Inc., Minneapolis, USA). Thus, 20 experiments where the factors were considered at three levels, designated as high (+1), medium (0) and low (−1), and the centre points were replicated six times as shown in Table 1. A laboratory single screw extruder (Duisburg DCE-330 Model, Germany), which consists of three zones (feeding, cooking and die zones) integrated with a screw feeder and a 3-mm die, was used for the extrusion of different formulations. The extruded samples were collected and dried for 12 h in an oven at 60°C. The dried samples were then kept in a desiccator and used for subsequent analyses.
2.4 | Determination of physical properties

2.4.1 | Bulk density

Bulk density (BD) relates the weight of the extruded sample to its volume as described by Jafari et al. (2017). Ten g of the extruded sample was measured into a clean measuring cylinder (100 mL), and the bottom of the cylinder was tapped repeatedly until no further reduction in volume was observed. All measurements were done in triplicates, and the average volume was calculated as the packed volume. The weight of the extruded sample per unit volume was considered as the BD using the general formula:

\[
\text{Bulk density (g/mL)} = \frac{\text{weight of extruded sample (g)}}{\text{volume occupied by the extruded sample (mL)}}
\]

2.4.2 | Expansion index

Expansion index (EI) shows the relationship between the diameter of the extruded sample and that of the die nozzle of the extruder. Different lengths of the extruded samples were selected at random during collection, and vernier caliper was used to measure the diameter at different positions as described by Alvarez-Marnitez et al. (1988). EI was calculated using the formula:

\[
\text{Expansion index} = \frac{\text{diameter of the extruded sample}}{\text{diameter of the die nozzle of the extruder}}
\]

2.4.3 | Water absorption index

The water absorption index (WAI) was estimated as determined by Jafari et al. (2017), where 1 g of the extruded sample was dissolved in water at a temperature of 25°C for 20 min with gentle stirring at 5-min interval. Thereafter, the mixture was centrifuged at 3000 × g for 15 min, and the WAI was calculated as the weight of hydrated sample obtained after removal of the supernatant per unit weight of the original sample.

2.5 | Validation of the model

Four sets of experiments (termed Formulations 1–4) were carried out based on the optimum concentrations of the selected factors following the FCCCD experiments using the point prediction feature of the

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**TABLE 1** Face-centred central composite design of rice–pigeon pea blend based on three independent variables using physical properties as the response

| Run | Screw speed (rpm) | Feed moisture content (%) | Feed blend composition (%) | Expansion index | Bulk density (g/mL) | Water absorption index |
|-----|------------------|---------------------------|---------------------------|----------------|-------------------|-----------------------|
|     |                  |                           |                           | Experimental   | Predicted         | Experimental         | Predicted            |
| 1   | 150 (-)          | 20 (-)                    | 10 (-)                    | 4.26           | 4.34              | 0.07                 | 0.06                 | 6.26                 | 6.41                 |
| 2   | 250 (+)          | 20 (-)                    | 10 (-)                    | 6.26           | 6.34              | 0.09                 | 0.08                 | 5.85                 | 5.77                 |
| 3   | 150 (-)          | 30 (+)                    | 10 (-)                    | 4.48           | 4.63              | 0.06                 | 0.06                 | 6.12                 | 6.19                 |
| 4   | 250 (+)          | 30 (+)                    | 10 (-)                    | 5.23           | 5.63              | 0.08                 | 0.08                 | 4.87                 | 5.08                 |
| 5   | 150 (-)          | 20 (-)                    | 30 (+)                    | 2.13           | 1.83              | 0.11                 | 0.11                 | 3.96                 | 3.85                 |
| 6   | 250 (+)          | 20 (-)                    | 30 (+)                    | 2.88           | 2.83              | 0.11                 | 0.11                 | 5.72                 | 4.29                 |
| 7   | 150 (-)          | 30 (+)                    | 30 (+)                    | 7.11           | 8.13              | 0.06                 | 0.06                 | 5.58                 | 5.76                 |
| 8   | 250 (+)          | 30 (+)                    | 30 (+)                    | 8.11           | 8.13              | 0.06                 | 0.06                 | 5.77                 | 5.73                 |
| 9   | 150 (-)          | 25 (0)                    | 20 (0)                    | 6.01           | 6.06              | 0.07                 | 0.07                 | 5.37                 | 5.41                 |
| 10  | 250 (+)          | 25 (0)                    | 20 (0)                    | 7.51           | 7.06              | 0.09                 | 0.08                 | 5.48                 | 5.07                 |
| 11  | 200 (0)          | 20 (-)                    | 20 (0)                    | 6.46           | 6.65              | 0.06                 | 0.07                 | 5.10                 | 4.83                 |
| 12  | 200 (0)          | 30 (+)                    | 20 (0)                    | 9.56           | 9.44              | 0.05                 | 0.04                 | 5.55                 | 5.44                 |
| 13  | 200 (0)          | 25 (0)                    | 10 (-)                    | 5.76           | 5.06              | 0.06                 | 0.06                 | 5.69                 | 5.67                 |
| 14  | 200 (0)          | 25 (0)                    | 30 (+)                    | 4.76           | 5.06              | 0.07                 | 0.07                 | 5.06                 | 4.71                 |
| 15  | 200 (0)          | 25 (0)                    | 20 (0)                    | 7.19           | 7.21              | 0.07                 | 0.06                 | 5.09                 | 5.09                 |
| 16  | 200 (0)          | 25 (0)                    | 20 (0)                    | 7.18           | 7.21              | 0.07                 | 0.06                 | 5.00                 | 5.09                 |
| 17  | 200 (0)          | 25 (0)                    | 20 (0)                    | 7.23           | 7.21              | 0.06                 | 0.06                 | 5.10                 | 5.09                 |
| 18  | 200 (0)          | 25 (0)                    | 20 (0)                    | 7.20           | 7.21              | 0.06                 | 0.06                 | 5.07                 | 5.09                 |
| 19  | 200 (0)          | 25 (0)                    | 20 (0)                    | 7.25           | 7.21              | 0.07                 | 0.06                 | 5.08                 | 5.09                 |
| 20  | 200 (0)          | 25 (0)                    | 20 (0)                    | 7.22           | 7.21              | 0.06                 | 0.06                 | 5.09                 | 5.09                 |

Note: (+) = high level; (−) = low level; (0) = centre.
Design-Expert 6.0.8 (Stat-Ease, Inc., Minneapolis, USA) so as to validate the model as shown in Table 3. The physical properties (BD, EI and WAI) were used as the response. Also, mineral and amino acid analyses were used to come up with the best rice–pigeon pea flour blend formulation. Extruded rice was used as a control, which was prepared using the laboratory single screw extruder (Duisburg DCE-330 Model, Germany) at screw speed of 220 rpm and moisture content of 30%.

2.6 Mineral compositions and amino acid analysis

Five mineral compositions (magnesium, calcium, zinc, iron and phosphorus) were determined using atomic absorption spectrophotometry (Model AA280FS; Agilent Technologies, Santa Clara, CA, USA), whereas flame photometry (Model PFP7; Cole-Parmer, Vernon Hills, IL, USA) was used to analyse for sodium (Na) and potassium (K) according to the method of AOAC (2003). The amino acid content of the extruded samples was also determined by the method of Sotelo et al. (1994), which involves acid hydrolysis, evaporation, extraction and analysis using phenylthiohydantoin amino acid analyser model 120A (Applied Biosystems, Inc., Foster City, CA, USA). Amino acid contents were calculated as g/100 g protein.

2.7 Statistical analysis

Measurements made in this study were in triplicates and expressed as mean ± standard deviation. Analysis of variance (ANOVA) and post hoc test (Duncan) were carried out to determine the differences among the samples, and significant differences were accepted at p < 0.05. The responses obtained from the FCCCD were used to determine the effects of the selected factors (feed moisture content, feed blend composition and screw speed) on the responses. The coefficient of determination ($R^2$), lack of fit and $F$-values obtained following the regression analysis were used to evaluate the model fitness.

3 RESULTS AND DISCUSSION

3.1 Effect of extrusion parameters on the physical properties of rice–pigeon pea blend

Physical properties associated with EI, BD and WAI are among the important quality attributes required in food formulation (Filli et al., 2013). Thus, extrusion cooking process is generally dependent on some parameters, and the effects of the three independent variables associated with moisture content, feed blend composition and screw speed were determined. The combined effects of these factors in terms of physical properties and nutrient compositions of the extruded samples contribute to the overall assessment of the final products.

3.1.1 EI

The EI of the extruded samples was reported by Ding et al. (2005) to be dependent on feed moisture content; and in this study, EI was found to reach its maximum in Run 12 (9.56), and the lowest value was obtained in Run 5 (2.13) as indicated in Table 1. The higher value of EI observed in Run 12 could be as a result of increase in moisture content and screw speed at decreased feed blend composition. Seker (2005) stated that screw speed and feed composition were the most significant factors that contributed to the increase in EI during extrusion of soybean–corn flour. Similarly, high starch content may lead to increase in EI, especially where significant gelatinization occurs due to dough viscosity (Seker, 2005). High shear force aids in disrupting intermolecular hydrogen bonds, thereby promoting gelatinization and elasticity of the dough, and this could be achieved by changing the screw speed and feed composition during extrusion cooking process (Filli et al., 2013). In case of extruded samples obtained from rice-based expanded snacks, moisture content and barrel temperature affected the EI, which was dependent on dough viscosity and elastic force (Ding et al., 2005).

Also, increase in protein content of rice–pigeon pea blend (based on feed blend composition) could cause puffiness, which breaks down because of its viscoelastic characteristics. Thus, Chaiyakul et al. (2009) found that extrudate of low moisture and low protein contents tend to have higher EI as observed in high-temperature extruded rice-based snacks. Based on the estimated mathematical model, the relationship between the EI as the response and the selected variables is expressed in terms of coded values by the Equation 4:

$$\text{Expansion index} = 0.50 + 7.21A + 1.40B - 0.65A^2 + 0.83B^2 - 2.16C^2 - 0.25AB - 0.25AC + 1.50BC$$

The ANOVA and $p$-values obtained in this study were used to determine the fitness of the developed model as indicated in Table 2. The overall model had a $p$-value of <0.0001, which suggested that the model was significant.

The ANOVA (Table 2) shows that two of the linear coefficients, that is, screw speed ($A$) and feed moisture content ($B$), one quadratic (feed blend composition) and one interaction (feed moisture content and feed blend composition [BC]) coefficients were significant at $p < 0.05$. In addition, the non-significant lack of fit was desirable with a $p$-value of 0.3800. In case of coefficient of determination ($R^2$) and adjusted $R^2$, values of 0.9592 and 0.9224 were obtained (Table 2), which showed the efficacy of the model and that up to 95.92% and 92.24% of the variations could be accounted for by the model equation, respectively. Adequate precision value of 20.551 indicated the appropriateness of the model because any value greater than 4 signifies its desirability (Salihu et al., 2011). Also, the lower the value of the coefficient of variation (CV = 8.41), the better is the precision and reliability of the experiment; Nath and Chattopadhyay (2007) reported that no reliable models should have CV greater than 10%.
The response surface plots showing the synergistic effects of the selected parameters on the EI of the developed pigeon–pea flour blend were presented in Figure 1. The significance of the interactions is determined by the shape of the response surface, based on the circular or elliptical nature as well as the overall ANOVA values (Manimekalai & Swaminathan, 1999). In Figure 1a, the effect of feed blend composition and feed moisture content on EI at fixed screw speed of 200 rpm (centre point) revealed that EI is dependent on all the factors and their synergistic effect resulted in optimum response, as indicated in Table 2, with a \( p \)-value of <0.0001.

### 3.1.2 Bulk density

The BD of rice–pigeon pea blend was found to be highest (0.11 g/mL) in Runs 5 and 6, and the lowest value was observed in Run 12 (0.05 g/mL) as presented in Table 1. BD serves as an important physical property that is used in assessing the level of expansion during the extrusion process (Filli et al., 2013). Filli et al. (2011) found that feed blend composition and moisture content were the major factors responsible for the observed increment in BD of soybean–millet extrudate. However, no clear trend was observed in this study as both feed blend composition and feed moisture contents showed different trends on the BD. Also, increase in feed moisture content favours increment in BD by reducing the elasticity, gelatinization and expansion (Ding et al., 2006). The higher BD observed in this study could be related to homogeneous protein matrix of the developed rice–pigeon pea flour blend with compact or no air cavity layers, making it non-spongy upon hydration (Filli, 2009). Thus, the BD values could be linked to the amount of flour particles that are held together and the energy content derivable from the developed blend. Based on this, the developed rice–pigeon pea flour blend may give a desired nutrient density and consistency, which could meet the feeding requirements of different types of people.

Table 2 shows the ANOVA of the developed quadratic model, where the linear effect of the three factors has significant influence on the production of the blend at \( p < 0.05 \). Two interaction terms, that is, screw speed and feed blend composition (AC) and feed moisture content and feed blend composition (BC), were significant with \( p \)-values of 0.0478 and 0.0011, respectively. Similarly, \( R^2 \) and adjusted \( R^2 \) values were found to be 0.9250 and 0.8580, which suggested that 92.5% and 85.8% of the variations, respectively, could be explained by the model equation. Adequate precision and CV were found to be 14.49 and 8.70, respectively, which indicate the reliability of the experiments (Nath & Chattopadhyay, 2007). The quadratic model obtained from regression analysis for BD in terms of coded levels of the variables is expressed in Equation 5:

\[
\text{Bulk density (g/mL)} = 0.06 + 6.00A + 0.01B + 5.00C + 0.02A^2 - 6.36B^2 + 3.64C^2 - 5.00AC - 0.10BC
\]

Thus, synergistic effect of two of the factors (feed moisture content \[ B \] and feed blend composition \[ C \]) at fixed concentration of screw speed \( A \) on the response (BD) was shown in Figure 1b. This observation was consistent with what was presented in Table 2, where all the three factors were found to be significant with \( p \)-values of less than 0.05.

| Source | Expansion index \( p \)-value | Bulk density (g/mL) \( p \)-value | Water absorption index \( p \)-value |
|--------|-------------------------------|---------------------------------|-------------------------------|
| Model  | <0.0001                       | 0.0002                          | 0.0013                        |
| A (screw speed) | 0.0129                      | 0.0128                          | 0.1064                        |
| B (feed moisture content) | <0.0001                     | <0.0001                         | 0.0993                        |
| C (feed blend composition) | 1.0000                       | 0.0304                          | 0.0005                        |
| \( A^2 \) | 0.0647                       | 0.0006                          | 0.4323                        |
| \( B^2 \) | 0.0252                       | 0.1235                          | 0.7969                        |
| \( C^2 \) | <0.0001                      | 0.3591                          | 0.6002                        |
| \( AB \) | 0.2065                       | 1.0000                          | 0.2979                        |
| \( AC \) | 0.2065                       | 0.0478                          | 0.0283                        |
| \( BC \) | <0.0001                      | 0.0011                          | 0.0005                        |
| Lack of fit | 0.3800                      | 0.3037                          | 0.5440                        |
| Other model parameters |                          |                                 |                               |
| Coefficient of variation | 8.4100                      | 8.7000                          | 5.7200                        |
| Coefficient of determination \( (R^2) \) | 0.9592                       | 0.925                           | 0.8800                        |
| Adjusted \( R^2 \) | 0.9224                       | 0.8580                          | 0.7800                        |
| Adequate precision | 20.5510                     | 14.4900                         | 12.1200                       |
3.1.3 | WAI

The highest value for WAI of 6.26 (Run 1) and the lowest value of 3.96 (Run 5) were shown in Table 1. WAI is an indirect measure of starch digestibility that depends on the extent of gelatinization and dextrinization of starch components (Pardhi et al., 2019). The hydrophilic nature of the developed blend determines its interaction with water molecules. Thus, screw speed was reported by Pardhi et al. (2019) to be one of the key factors that have significant influence on WAI during the production of rice grits snacks. However, high WAI was reported to be undesirable in the formulation of complementary foods as it affects the nutrient density (Filli, 2009). The model indicating the relationship between WAI and the selected factors is expressed in Equation 6:

\[
\text{Water absorption index} = 5.09 - 0.17A + 0.30B - 0.48C + 0.15A^2 + 0.05B^2 + 0.10C^2 - 0.12AB + 0.27AC + 0.53BC
\]

The estimated model was significant with a \( p \)-value of 0.0013 as shown in Table 2. Two of the linear (B and C) and the interaction terms (AC and BC) were found to be significant at \( p < 0.05 \). About 88% of the variation in the rice–pigeon pea flour blend could be linked to the independent variables based on its \( R^2 \) value of 0.88. Although this value appears to be low, it is still acceptable due to diverse characteristics of biological systems. In fact, Gassara et al. (2011) suggested that a model can be adequately accepted once the \( R^2 \) value is greater than 0.75. A signal-to-noise ratio greater than 4 indicates adequate precision (Salihu et al., 2011), and in this case, an adequate signal was obtained with a value of 12.12. Also, lack of fit that serves as a tool for measuring the failure of a model is expected not to be significant, and a \( p \)-value greater than 0.05 (0.544) was obtained.

The response surface plot (Figure 1c) showed the effects of feed blend composition and feed moisture content on WAI. The interaction was statistically significant with a \( p \)-value of 0.0005 (Table 2), which suggested that the interaction was significant even at 99.99% confidence level. Thus, increase in feed moisture content resulted in increased WAI (Figure 1c).

3.2 | Validation of the physical properties based on the developed quadratic model

The FCCCD requires three stages for ascertaining the validity of the developed model, which involves conducting experiments according to the design matrix, and in this study, the physical properties were used as the responses. The responses are then subjected to ANOVA in order to estimate the coefficients in a mathematical term; and finally, the developed model is verified through validation experimental steps.

Based on the results of the design matrix (Table 1) and the ANOVA (Table 2), four sets of experiments were carried out to validate the model as represented in Table 3. The four validated runs were termed as Formulations 1, 2, 3 and 4. Extruded rice was used as a control where EI, BD and WAI were found to be 5.48 ± 0.03, 0.05 ± 0.01 g/mL and 5.13 ± 0.09, respectively; this indicates that incorporation of pigeon pea in the developed formulations (1–4)
resulted in higher physical properties. Our previous findings (Ndaliman et al., 2017) on the effect of rice-pigeon pea blend composition suggested that addition of pigeon pea in the preparation of rice-based complementary diet aids in improving the functional properties. Similarly, Dalbhagat et al. (2019) reported that incorporation of fibre-rich pulses in rice-based extruded products provides functional and nutrient-enriched products with desirable organoleptic properties. Among all the developed formulations presented in Table 3, Formulation 3 resulted in maximum EI of 9.98 ± 0.15, BD of 0.12 ± 0.01 g/mL and WAI of 6.41 ± 0.07. Also, the formulations were further subjected to characterization involving determination of mineral and amino acid compositions to be able to come up with the best formulation of rice–pigeon pea flour blend that meets some nutritional specifications.

### 3.2.1 | Mineral compositions of the formulated rice–pigeon pea flour blend

Minerals are indispensable components of foods that are required for normal metabolic activities of the body (Kadan et al., 2003). Sodium is one of the minerals whose low intake is always encouraged because its high concentration in form of salt has been implicated in hypertension and other coronary complications (Kadan et al., 2003). The concentration of sodium observed in the control (extruded rice) was found to be 1.53 ± 0.11 mg/100 g, and there was significant (p < 0.05) increase in sodium content (Table 4) in the developed formulations, which could be linked to the presence of different concentrations of pigeon pea. This agrees with the findings of Kaushal et al. (2012) that most cereals tend to have low sodium contents. The highest concentration of sodium of 2.86 ± 0.05 mg/100 g was recorded in Formulation 3 (Table 4). Thus, sodium is an essential cation required for acid–base balance, muscle contraction and regulation of osmotic pressure (Kanu et al., 2009). Potassium is primarily an intracellular cation, whose functions include maintenance of electrolyte balance, transmission of impulses and muscle contraction. It also functions in synergy with sodium in maintaining the normal pH equilibrium (Adeyeye & Agenes, 2007). The highest potassium content was found in Formulation 3 (5.01 ± 0.01 mg/100 g), and the lowest (3.73 ± 0.09 mg/100 g) was found in the control (Table 4). Calcium has several functions, where it acts as an intracellular messenger and an indispensable component required for bone formation (Kanu et al., 2009). Calcium and phosphorus act synergistically in preventing rickets, osteomalacia and osteoporosis (Adeyeye & Agenes, 2007). The calcium contents of all the four formulations were significantly (p < 0.05) higher than the value obtained for the control. Reddy et al. (2017) indicated that due to low calcium content of rice, blending with other pulses improves the functional properties and mineral compositions. Singh, Sharma and Singh (2000) attributed the increase in calcium, phosphorus and iron contents during the production of cereal-based products to feed blend composition and water content.

Magnesium as an activator of many enzyme systems is required in energy metabolic processes. It works in tandem with calcium during muscle contraction, blood clotting and the regulation of blood pressure (Adeyeye & Agenes, 2007). Thus, the findings from this work as presented in Table 4 showed that Formulation 1 had significantly (p < 0.05) higher magnesium (2.99 ± 0.05 mg/100 g) and phosphorus (1.52 ± 0.10 mg/100 g) contents when compared with the other formulations and the control. Similarly, there was no significant (p > 0.05) difference between the control and Formulation 2 in terms of phosphorus contents. Also, there were significantly (p < 0.05) higher iron and zinc contents in Formulation 3, with values of 12.64 ± 0.03 and 9.33 ± 0.02 mg/100 g, respectively (Table 4). Similarly, iron and zinc act as cofactors for enzyme-catalysed reactions during the normal

### TABLE 3  Validation experiments of the estimated model

| Experiment | Screw speed (rpm) | Feed moisture content (%) | Feed blend composition (%) | Expansion index | Bulk density (g/mL) | Water absorption index |
|------------|------------------|---------------------------|---------------------------|----------------|-------------------|-----------------------|
| Formulation 1 | 150 | 30 | 30 | 7.11 ± 0.47 | 0.06 ± 0.02 | 5.58 ± 0.18 |
| Formulation 2 | 250 | 25 | 20 | 7.51 ± 0.15 | 0.09 ± 0.02 | 5.62 ± 0.14 |
| Formulation 3 | 220 | 30 | 25 | 9.98 ± 0.15 | 0.12 ± 0.01 | 6.41 ± 0.07 |
| Formulation 4 | 200 | 30 | 20 | 9.56 ± 0.27 | 0.07 ± 0.01 | 5.67 ± 0.16 |

Note: Values are presented as mean ± standard deviation, and values with different superscripts on the same column are significantly different at p < 0.05.

### TABLE 4  Mineral composition (mg/100 g) of formulated rice–pigeon pea blend

| Formulation | Sodium (mg/100 g) | Potassium (mg/100 g) | Calcium (mg/100 g) | Phosphorus (mg/100 g) | Magnesium (mg/100 g) | Iron (mg/100 g) | Zinc (mg/100 g) |
|-------------|------------------|---------------------|-------------------|----------------------|----------------------|----------------|----------------|
| Formulation 1 | 1.92 ± 0.08ᵇ | 4.59 ± 0.03ᵇ | 2.46 ± 0.02ᵇ | 1.52 ± 0.10ᶜ | 2.99 ± 0.05ᵈ | 11.89 ± 0.04ᶜ | 5.96 ± 0.06ᵇ |
| Formulation 2 | 2.65 ± 0.06ᶜ | 4.65 ± 0.04ᵇ | 2.55 ± 0.05ᶜ | 1.00 ± 0.15ᵃ | 1.93 ± 0.03ᶜ | 11.24 ± 0.02ᵇ | 8.62 ± 0.08ᵈ |
| Formulation 3 | 2.86 ± 0.05ᶜ | 5.01 ± 0.01ᶜ | 3.41 ± 0.07ᵇ | 1.27 ± 0.12ᵇ | 1.59 ± 0.10ᵇ | 12.64 ± 0.03ᵃ | 9.33 ± 0.02ᵇ |
| Formulation 4 | 2.77 ± 0.04ᶜ | 4.63 ± 0.02ᵇ | 2.86 ± 0.03ᵈ | 1.23 ± 0.11ᵇ | 1.61 ± 0.09ᵇ | 12.10 ± 0.06ᵈ | 6.74 ± 0.03ᶜ |
| Control (extruded rice) | 1.53 ± 0.11ᵃ | 3.73 ± 0.09ᵃ | 1.19 ± 0.13ᵃ | 0.89 ± 0.10ᵃ | 1.38 ± 0.03ᵃ | 5.89 ± 0.10ᵃ | 2.67 ± 0.05ᵃ |

Note: Values are presented as mean ± standard deviation, and values with different superscripts on the same column are significantly different at p < 0.05.
metabolic processes (Agunbiade & Ojezele, 2010). In addition, iron forms an important component of two essential proteins (myoglobin and haemoglobin), whereas zinc is a component of living cells required for membrane stabilization and immune functions (Agunbiade & Ojezele, 2010). Generally, researchers (Dalbhagat et al., 2019; Singh, Chauhan, et al., 2000) reported significant increase in mineral compositions (especially iron, calcium, phosphorus and copper) of extruded snacks developed from rice flour blends.

### 3.2.2 Essential amino acid composition of the formulated rice–pigeon pea flour blend

Essential amino acids are needed to be supplied in the diet for growth and development. Table 5 shows the compositions of essential amino acids: significant ($p \leq 0.05$) differences in amino acid compositions were observed in the four formulations when compared with the control (extruded rice), and these could be linked to variations in feed blend composition. The limiting essential amino acids in rice and pigeon pea are lysine and methionine, respectively. Lysine is thermolabile, and any attempt to retain its composition during extrusion cooking process is of primary interest. The lysine content of extruded rice (control) was found to be 0.66 ± 0.13 g/100 g, and the rice–pigeon pea blends showed up to five-fold increment in lysine content with maximum value of 3.44 ± 0.04 g/100 g recorded in Formulation 3. Similarly, the methionine content of Formulation 3 was found to be 1.48 ± 0.02 g/100 g, which was two times higher than what was obtained in the control (0.72 ± 0.03 g/100 g). Masatcioglu et al. (2014) found that decrease in lysine contents in some extruded products could be attributed to low moisture contents, longer period of extrusion and the nature of the extruder. Leucine was found to be the most predominant amino acid where the control had a value of 2.93 ± 0.14 g/100 g, and higher values were obtained in Formulation 3 (5.53 ± 0.10 g/100 g) and Formulation 4 (5.60 ± 0.07 g/100 g) as shown in Table 5. This agrees with the findings of Aremu et al. (2010) that plant products of Nigerian origin have leucine as the most abundant essential amino acid.

In this study, there was significant ($p < 0.05$) increase in the compositions of eight essential amino acids (leucine, isoleucine, lysine, phenylalanine, valine, methionine, arginine and threonine) in the developed formulations when compared with the control (extruded rice), which could be linked to the addition of pigeon pea. Leucine was found to be the most predominant amino acid where the control had a value of 2.93 ± 0.14 g/100 g, and higher values were obtained in Formulation 3 (5.53 ± 0.10 g/100 g) and Formulation 4 (5.60 ± 0.07 g/100 g) as shown in Table 5. This agrees with the findings of Aremu et al. (2010) that plant products of Nigerian origin have leucine as the most abundant essential amino acid.

In this study, there was significant ($p < 0.05$) increase in the compositions of eight essential amino acids (leucine, isoleucine, lysine, phenylalanine, valine, methionine, arginine and threonine) developed in Formulation 3 compared with the control (extruded rice), which could be linked to the addition of pigeon pea. However, no significant ($p > 0.05$) difference exists between Formulation 2 and the control in terms of tryptophan and histidine contents (Table 5). Several studies including that of Filli et al. (2011) reported that addition of soybean flour during the production of extruded fura resulted in higher essential amino acid content. Singh et al. (2007) also showed that mild extrusion conditions enhance the nutrient contents including the amino acids and some physical characteristics, whereas high extrusion conditions associated with high screw speed (>250 rpm), low moisture (<20%) and/or improper feed blend compositions affect the nutrient contents of extruded products. In contrast to this study, Anuonye et al. (2010) found a significant reduction in essential amino acids.

| TABLE 5 | Essential amino acid compositions (g/100 g of formulated rice–pigeon pea flour blend) |
|-----------------------------------------------|---------------------------------------------|
| Formulation | Leucine (g/100 g protein) | Isoleucine (g/100 g protein) | Lysine (g/100 g protein) | Phenylalanine (g/100 g protein) | Valine (g/100 g protein) | Methionine (g/100 g protein) | Arginine (g/100 g protein) | Histidine (g/100 g protein) | Threonine (g/100 g protein) | Tryptophan (g/100 g protein) |
|-----------------------------------------------|---------------------------------------------|
| Formulation 1 | 4.17 ± 0.03b | 3.27 ± 0.01d | 3.16 ± 0.05c | 3.01 ± 0.04b | 3.14 ± 0.07b | 1.15 ± 0.09b | 4.03 ± 0.03c | 2.20 ± 0.02c | 3.38 ± 0.07c | 1.20 ± 0.09p |
| Formulation 2 | 5.19 ± 0.08b | 2.94 ± 0.08b | 3.34 ± 0.03b | 3.24 ± 0.02b | 3.94 ± 0.06c | 1.48 ± 0.02c | 4.30 ± 0.07b | 2.27 ± 0.05b | 2.04 ± 0.08b | 3.27 ± 0.09c |
| Formulation 3 | 5.53 ± 0.04c | 3.01 ± 0.08b | 3.34 ± 0.03b | 3.24 ± 0.02b | 3.94 ± 0.06c | 1.48 ± 0.02c | 4.30 ± 0.07b | 2.27 ± 0.05b | 2.04 ± 0.08b | 3.27 ± 0.09c |
| Formulation 4 | 5.60 ± 0.07c | 3.14 ± 0.02c | 3.10 ± 0.01b | 3.14 ± 0.02c | 3.14 ± 0.02c | 1.48 ± 0.02c | 4.30 ± 0.07b | 2.27 ± 0.05b | 2.04 ± 0.08b | 3.27 ± 0.09c |
| Control (extruded rice) | 2.93 ± 0.14b | 1.52 ± 0.07a | 0.66 ± 0.13d | 2.30 ± 0.05a | 0.72 ± 0.03a | 2.78 ± 0.09a | 0.72 ± 0.03a | 0.72 ± 0.03a | 2.78 ± 0.09a | 0.72 ± 0.03a |

Note: Values are presented as mean ± standard deviation, and values with different superscripts on the same column are significantly different at $p < 0.05$. 
acid content in extruded acha–soybean blends. Thus, based on the essential amino acids, the formulated rice–pigeon pea flour blends show a great potential for utilization in developing different products made from conventional flour sources that could meet the nutrient requirements of vulnerable population.

4 | CONCLUSION

The effect of different factors affecting extrusion of rice–pigeon pea flour blends was studied using FCCCD. The optimum independent variables were established at screw speed of 220 rpm, feed moisture content of 30% and feed blend composition of 25%, which resulted in maximum EI of 9.98 ± 0.15, BD of 0.12 ± 0.01 g/mL and WAI of 6.41 ± 0.07. Out of the four formulations prepared for validation experiments, Formulation 3 was found to be better in terms of physical properties, mineral and essential amino acid contents. Based on this, different complementary foods can be produced from rice–pigeon pea flour blend using extrusion method. The use of these locally available raw materials could help in management of some malnutrition-related cases in developing countries where these raw materials are found in abundance.

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CONFLICT OF INTEREST

No conflict of Interest during the research and preparation of the manuscript.

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AUTHOR CONTRIBUTION

Ndaliman, Salihu, Muhammad and Bala contributed in the conceptualization and design of the study. Ndaliman and Salihu carried out the experimentation and analysis of data. All the four authors contributed equally in the interpretation and revision of the contents of the manuscript, and their approval was sought before submission.

ETHICAL APPROVAL

Ethical principles for research were adhered to, and for food characterization-based study like this, institutional ethical committee of Ahmadu Bello University, Zaria, ensures that hygienic/safety measures have been taken into consideration. I wish to declare that human subjects/animal models have not been used in this study and the two samples (rice and pigeon pea) are commonly used as staple foods in Nigeria and no reported toxicity on any one of them has been documented.

DATA AVAILABILITY STATEMENT

The authors wish to state that the data obtained that supported the findings reported in this study are available upon reasonable request from the corresponding author.

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