

PAPER 23 – MODIFICATION OF SOME QUALITY ATTRIBUTES OF BROWN RICE-BAMBARA NUTS-PINEAPPLE PEELS EXTRUDED SNACKS THROUGH EXTRUSION CONDITIONS

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ABSTRACT

This study aimed to create ready-to-eat extruded snacks using underutilized broken brown rice flour, Bambara nuts flour, and pineapple peel powder as primary ingredients in a 50:45:5 ratio. The effects of extrusion exit temperature, feed moisture content, and barrel screw speed on protein, total phenolic content, 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical scavenging activity, and vitamin C were assessed and modelled using polynomial regression. The Pareto chart showed that protein and vitamin C were significantly influenced by the quadratic effect of barrel screw speed, while total phenolic content was significantly influenced by barrel screw speed, and DPPH radical scavenging activity was significantly influenced by extrusion exit temperature. The extruded snacks had protein content ranging from 12.87 to 16.36%, total phenolic content ranging from 14.17 to 18.02 mg GAE/g, DPPH radical scavenging ranging from 14.57 to 16.25%, and vitamin C ranging from 12.05 to 14.25 mg/100g. The developed regression model predicted the quality attributes well, with a coefficient of determination ranging between 0.99 and 1. The optimum extrusion conditions for maximizing quality attributes differed, and the development of extruded snacks from brown rice, pineapple peels, and Bambara nuts would promote sustainable food production and reduce food waste.

KEYWORDS: Bambara nuts, Pineapple peels, Brown rice, Extrusion, Ready-to-eat extruded snacks

1. INTRODUCTION

There is a constant increase in the consumption of ready-to-eat extruded snacks by many individuals, especially children, which form a significant part of the daily diet (Ziena and Ziena, 2022). Children and adults are often captivated by numerous ready-to-eat products such as extruded snacks and noodles, credited for their pleasing smell, taste, texture, appearance, and ease of consumption. However, the raw materials commonly used in extrudates are cereals and grains, which are low in certain essential nutrients such as protein, antioxidants, and vitamins, consequently leading to malnutrition thus, there is a growing demand for healthier snacks.

Bambara nuts (*Vigna subterranean*) is a legume crop that has substantial socio-economic significance in emerging markets and is considered a "crop for the future," but is currently underutilized (Diedericks *et al.*, 2020; Muhammad *et al.*, 2020). The nuts consist of a high proportion of protein, ranging from 17 to 27%. They also contain a reasonable amount of carbohydrate and fat (Muhammad *et al.*, 2020). Fruit waste, such as pineapple peel, is an excellent source of low-cost proteins and antioxidants, such as polyphenol compounds and DPPH radical scavenging activity (Roda and Lambri, 2019). They are also rich in vitamins C, vitamin A, and vitamin B₆ (Franklyn *et al.*, 2018). Rice flour from brown rice has become a suitable and established material for numerous ready-to-eat extruded snacks due to its suitability, hypo-allergenicity, pleasing flavour, and good digestibility (Dalbhagat *et al.*, 2019; Sanusi and Akinoso, 2021). It is a good source of dietary fibre and antioxidants. Brown rice contains a higher protein content than hulled rice due to the presence of bran but is relatively low in vitamin C. Thus, it is necessary to enhance the protein, vitamin C, and antioxidant properties of products produced from rice. The chemical composition and antioxidant properties of extruded snacks could significantly influence the acceptability of the final product. The inclusion of Bambara nuts and pineapple peel into rice-based snacks could increase the quality attributes of the extruded snacks and provide a promising technique to improve product quality. However, there is a scarcity of information on the utilization of broken brown rice, Bambara nuts, and pineapple peel to develop extruded snacks.

Extrusion technology has revolutionized numerous traditional techniques for manufacturing snacks due to its high suitability, flexibility for different raw materials, and ability to modify the quality characteristics of raw materials through transformations such as starch gelatinization, protein denaturation, pigment degradation, and amylose formation (Offiah *et al.*, 2019; Dey *et al.*, 2021). Extrusion conditions significantly influence the overall compositions and quality of extruded products when they experience shear forces, extreme temperatures, and extreme pressure treatment, which have been widely studied in the literature (Sukumar and Athmaselvi, 2019;

Choton *et al.*, 2020; Sahu *et al.*, 2022; Sanusi *et al.*, 2023). However, a few research works focused on the effect of extrusion conditions on the quality attributes (protein, total phenolic content, DPPH radical scavenging activity, and vitamin C content) of brown rice-Bambara nuts-pineapple peel extruded snacks. Therefore, this study aims to examine the effect of extrusion conditions on the quality attributes of brown rice-Bambara nuts-pineapple peel extruded snacks.

2. MATERIALS AND METHODS

2.1 Materials

Broken brown rice and Bambara nuts were purchased from a local market in Ilorin, Nigeria, while pineapple peels were obtained from a fruit store in Ilorin, Nigeria. The broken brown rice was weighed and milled into flour using a hammer mill (Nukor, Model: SG 30, South Africa). Bambara nuts were soaked in lukewarm water (40°C) for 12 h, the hull removed, and dried using a fabricated forced-air dryer at 60°C for 12 h. The dried Bambara nuts were then milled into flour using a hammer mill. The pineapple peels were washed and blanched at 55°C for 30 min to reduce microbial contamination. The blanched pineapple peels were drained, dried at 45°C in a fabricated forced-air dryer, and then milled into a fine powder using an electric grinder (Grinder GR708HA, China).

2.2 Blends Preparation

A preliminary assessment was conducted using the mixture design feature in Minitab Statistical Software version 20.3 to determine the optimal combination of brown rice flour, Bambara nuts flour, and pineapple peel powder that can provide the highest protein content. Based on the results of the preliminary experiment, the mixture consisting of 50% brown rice flour, 45% bambara nut flour, and 5% pineapple peel powder was selected due to maximum protein content of 13%.

2.3. Experimental design

The study utilized an integration of Taguchi and response surface methodology (RSM) to investigate how extrusion conditions; extrusion exit temperature (120°C, 130°C, and 140°C), barrel screw speed (300 rpm, 360 rpm and 420 rpm) and feed moisture content (16%, 17% and 18%) affect the protein, total phenolic content, DPPH radical scavenging activity, and vitamin C content of the brown rice-bambara nut-pineapple peels extruded snacks. The Taguchi design results were analyzed by the second-order polynomial model of RSM, where the linear, quadratic, and interaction relationships of EET, BSS, and FMC were related to the protein, total phenolic content, DPPH radical scavenging activity, and vitamin C contents, as shown in Equation 1:

$$Y = C + \beta_1x_1 + \beta_2x_2 + \beta_3x_3 + \beta_1x_1^2 + \beta_2x_2^2 + \beta_3x_3^2 + \beta_{12}x_1x_2 + \beta_{13}x_1x_3 \quad (1)$$

Here, C represents the model constant coefficients, β_1x_1 , β_2x_2 , and β_3x_3 are the linear terms, $\beta_1x_1^2$, $\beta_2x_2^2$, and $\beta_3x_3^2$ are the quadratic terms, and $\beta_{12}x_1x_2$ and $\beta_{13}x_1x_3$ are the interaction terms. The responses (protein, total phenolic content, DPPH radical scavenging activity, and vitamin C) are represented by Y, while x_1 , x_2 , and x_3 denote the extrusion exit temperature (EET), barrel screw speed (BSS), and feed moisture content (FMC), respectively. The models' fitness for the quality attributes was evaluated using the coefficient of determinations (R^2 , R^2_{adj} , and R^2_{pred}). The study also employed analysis of variance (ANOVA) to determine the p-values at a 95% confidence level and Fischer values (F-value) of the quality attributes. The significant extrusion parameter based on their linear, quadratic and interaction effects were determined using the Pareto chart in Minitab software version 20.3, with a reference line indicating the p=0.05 threshold for statistically significant effects.

2.4 Brown rice-Bambara nuts-pineapple peels extruded snacks production

A twin-screw extruder (Model: HN-65, Zhouheng Product, Jinan City, China) was used for producing the brown rice-bambara nuts-pineapple peel extruded snacks. The flour blends were fed into a co-rotating twin-screw extruder that contains a barrel, three electric band heaters, and a standard co-rotating screw. Water of 16%, 17%, and 18% of the entire mass (3 kg) blends were added and mixed using a mixer (Sokany Stand Mixer, Model: Cx-6612, China). The set temperature of the first and second heating bands of the extruder was 80°C and 100°C, respectively while the last heating band was varied between 120°C, 130°C and 140°C. A constant feed speed of 120 rpm was used to feed the samples into the barrel through the hopper, where proper cooking took place. The fed blends passed through the three heating barrel zones at different barrel screw speeds of 300, 360, and 420 rpm during the extrusion cooking. The cooked samples passed through a die orifice with a diameter of 4 mm in the

barrel. The extruded products were cut at a speed of 1500 rpm. The final extruded products were collected, dried using a forced-air dryer at $80 \pm 5^\circ\text{C}$ and packed in a zip-lock nylon at room temperature for storage.

e. Quality attributes

The protein content was evaluated using the standard method of Association of Analytical Chemists (AOAC) (2010). The total phenolic content and 2,2 -Diphenyl-1- Picrylhydrazyl (DPPH) radical scavenging activity were evaluated based on the procedures described by Sanusi *et al.* (2023). The method described by Gumul *et al.* (2013) was used to determine the Vitamin C.

2.6 Statistical analysis

The experiments were replicated, and the data were analyzed using the SPSS package (SPSS 20.0, SPSS Inc., Chicago, IL, USA) through one-way analysis of variance (ANOVA). Significant differences between means were determined using Duncan's multiple tests with a confidence interval of 95%.

3. RESULTS AND DISCUSSION

3.1 Influence of extrusion conditions on protein content

The protein content of the extruded snacks under the influence of extrusion conditions ranged between 12.87 and 16.36%. The highest crude protein content (16.36%) was attained at 130°C EET, 16% FMC, and 420 rpm BSS. According to Gbenyi *et al.* (2016), a food product with 15% crude protein content is recommended as the basic protein requirement to arrest protein malnutrition and to also supplement low-protein foods. The protein content obtained in the extruded snacks is higher than the 13% protein content from the blends of 50% brown rice flour, 45% Bambara nuts flour, and 5% pineapple peel powder. This could be attributed to the high temperature and high-pressure processing that occurs during extrusion. This process denatures the protein in the flour blend, making it more available for digestion and increasing its concentration in the final product. Sanusi *et al.* (2023) reported similar findings in the production of brown rice-watermelon seeds extruded snacks. The quadratic effect of BSS showed the most significant influence on the protein content as shown in Figure 1a of the Pareto chart. The BSS significantly affects the residence time of the products, which consequently influences the disruption and denaturation of the proteins of extruded products. Alam *et al.* (2016) reported similar findings. The quadratic effect of EET also had a significant effect on the protein content as shown in the Pareto chart. The protein content of the extruded snacks can increase at high BSS and low EET or at higher EET and lower BSS (Figure 1b). From Figure 1c, the protein content increased with an increase in FMC at a lower EET. The linear, quadratic, interaction effect of EET, BSS, and FMC were significant at $p < 0.05$ on the protein content of the extruded snacks with an F-value of 21624.77. Equation 2 shows the polynomial regression model developed for predicting the protein content. The R^2 , R^2_{pred} and R^2_{adj} of the model measure the degree of fitness and had high values of 1.0. This shows that the model is perfectly sufficient to predict the protein content. A model fitness with R^2 close to unity (1) is the best (Sukumar and Athmaselvi, 2019; Sanusi and Akinoso, 2021).

$$Y_{\text{protein}} = -133.82 - 1.28x_1 - 0.15x_2 + 30.59x_3 + 0.0087x_1^2 + 0.00048x_2^2 - 0.795x_3^2 + 0.0014x_1x_2 + 0.028x_1x_3 \quad 2$$

Table 1. Effects of extrusion conditions on quality attributes of rice-bambara nuts-pineapple peel extruded snacks

Sample	FMC (%)	EET (°C)	BSS (rpm)	CP (%)	TPC mg GAE/g	DPPH (%)	Vitamin C (mg/100g)
A	16	120	300	16.23±.00 ^b	16.28±.00 ^c	14.57±.00 ^g	12.08±.01 ^f
B	17	120	360	14.24±.01 ^c	16.21±.00 ^d	14.86±.00 ^f	12.28±.01 ^c
C	18	120	420	14.08±.01 ^d	14.17±.00 ^e	15.21±.00 ^c	14.25±.01 ^a
D	17	130	300	15.35±.01 ^d	18.02±.01 ^a	16.25±.00 ^a	14.03±.00 ^c
E	18	130	360	14.04±.01 ^g	15.74±.00 ^c	15.25±.00 ^b	12.05±.01 ^g
F	16	130	420	16.36±.01 ^a	16.21±.00 ^d	16.25±.00 ^a	12.07±.01 ^{fg}
G	18	140	300	14.26±.01 ^c	18.02±.00 ^a	16.24±.00 ^a	14.02±.01 ^c
H	16	140	360	12.87±.00 ^h	16.58±.00 ^b	15.02±.00 ^c	12.66±.01 ^d
I	17	140	420	15.43±.01 ^c	15.27±.00 ^f	15.11±.00 ^d	14.21±.01 ^b

Mean values and superscripts with dissimilar letters along the same column are significantly different at $p < 0.05$. CP- Crude Protein, TPC- Total Phenol Content, 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical scavenging activity

3.2 Influence of extrusion conditions on vitamin C content

The vitamin C content of the extruded snacks ranged between 12.05 and 14.25 mg/100g (Table 1). All values are significantly different at $p < 0.05$. The highest vitamin C content was attained at 18% FMC, 420 rpm BSS, and 120°C EET whereas the least vitamin C content was attained at 18% FMC, 360 rpm BSS, and 130°C EET. The linear, quadratic, interaction effect of EET, BSS, and FMC were significant at $p < 0.05$ on the vitamin C content of the extruded snacks. The quadratic effect of BSS and EET was observed to have a significant effect on the vitamin C content (Figure 1d). The vitamin C content of the extruded snacks increased with an increase in BSS at higher temperature or lower EET at lower BSS (Figure 1e). Also, high FMC and moderate EET increased vitamin C content (Figure 1f). This result corroborates with the findings of Choton *et al.* (2020) that lower feed moisture and higher extrusion temperature could lead to loss of vitamin C and that short barrel screw speed has a higher retention rate of water-soluble vitamins such as vitamin C compared to long barrel screw extruders which will take longer for the extruded products to leave the barrel chamber. The regression model generated for predicting the vitamin C content in Equation 3 showed that the F-value, R^2 , R^2_{adj} and R^2_{pre} were 3334.61, 1.0, 0.99, and 0.99 respectively, which demonstrated its high accuracy for predicting the model relationship.

$$Y_{\text{vitamin c}} = -88.19 + 1.66x_1 - 0.14x_2 + 7.56x_3 + 0.0084x_1^2 + 0.00031x_2^2 - 0.22x_3^2 + 0.0014x_1x_2 + 0.0008x_1x_3 \quad 3$$

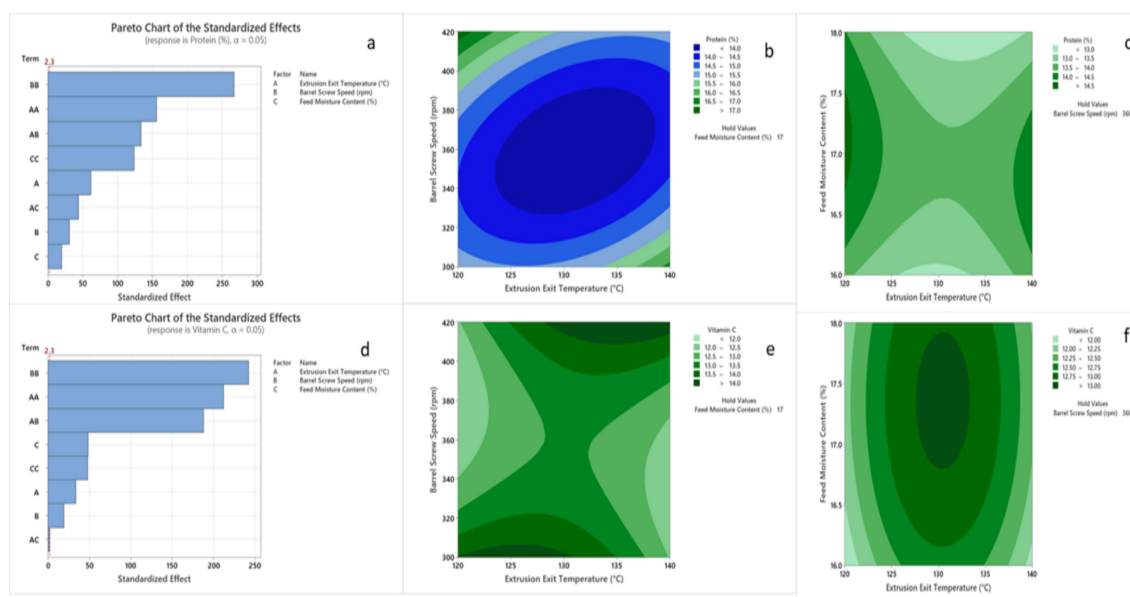


Figure 1. Pareto charts and Contour plots of protein content and vitamin C content of rice-bambara nut-pineapple peels based extrudates snacks. (a) Pareto chat of protein content, (b) Contour plot of BSS and EET of protein content, (c) Contour plot of FMC and EET of protein content, (d) Pareto chat of vitamin C content, (e) Contour plot of BSS and EET of vitamin C content (f) Contour plot of FMC and EET of vitamin C content.

3.3 Influence of extrusion conditions on total phenolic content

The measurement of total phenolic content in food products is important because it can help to determine the potential health benefits of consuming that food. Foods with higher total phenolic content are generally considered to be healthier options. The total phenolic content of the extruded snacks under the effect of extrusion conditions ranged from 14.17 - 18.02 mg GAE/g (Table 1). The highest TPC was found at 17% FMC, 130°C EET, 300 rpm BSS and 18% FMC, 140°C EET, 300 rpm BSS while the lowest was found at 18% FMC, 120°C EET, and 420 rpm BSS. The linear effect of barrel screw speed had the most impactful effect on the total phenolic content (Figure 2a) and this could be attributed to the high shear forces generated by the screw which can break down cell walls and release phenolic compounds from the food matrix, thereby increasing their availability. The total phenolic content of the extruded snack increased at higher EET and lower BSS (Figure 2b). At lower FMC, the total phenolic content of the extruded snacks increased significantly (Figure 2c). This result also supports the findings of Samyor *et al.* (2018) in the production of red rice and passion fruit powder-based extrudates. The linear, quadratic, interaction effect of EET, BSS, and FMC were significant at $p < 0.05$ on the total phenolic content of the extruded snacks. Equation 4 shows the polynomial regression model developed for predicting the total

phenolic content. Furthermore, the high F-value (272390.7), and the R^2 , R^2_{adj} , and R^2_{pred} of the model are 1 thus affirming its high precision for the prediction of total phenolic content.

$$Y_{TPC} = -56.68 - 0.15x_1 + 0.17x_2 + 7.25x_3 - 0.0051x_1^2 - 0.00010x_2^2 - 0.61x_3^2 - 0.00092x_1x_2 + 0.0108x_1x_3 \quad 4$$

3.4 Influence of extrusion conditions on DPPH radical scavenging activity

The influence of extrusion conditions on the DPPH radical scavenging activity of the extruded snacks ranged from 14.57 - 16.25% (Table 1). The rice-bambara nut-pineapple peels extruded snacks attained an optimum DPPH radical scavenging activity in sample D and sample F with extrusion conditions of 17% FMC, 130°C EET, and 300 rpm BSS, and 16% FMC, 130°C EET, and 420 rpm BSS respectively. The least DPPH radical scavenging activity was attained at 17% FMC, 120°C EET, and 360 rpm BSS. There is a non-significant difference at $p > 0.05$ in the DPPH radical scavenging activity of sample D and sample F. The DPPH radical scavenging activity of a food sample depends directly on the food's total phenolic content (Samyori *et al.*, 2018). The linear effect of EET had the most significant influence on the DPPH radical scavenging activity of the extruded snacks (Figure 2d). Lower BSS and moderate EET increases the DPPH radical scavenging activity of the extruded snacks (Figure 2e) while lower FMC and EET increase the DPPH radical scavenging activity (Figure 2f). These results corroborate the findings of Samyori *et al.* (2018) that the DPPH radical scavenging activity of the rice-passion fruit powder blend extrudates decreased with an increase in barrel speed and extrusion temperature. The high DPPH radical scavenging activity observed in this study might be a result of the linear relationship between TPC and DPPH radical scavenging activity, while the decrease in DPPH radical scavenging activity could also be credited to the reduction in TPC during high extrusion temperature. Basilio-Atencio *et al.* (2020) also reported similar observations in the DPPH radical scavenging activity of kiwicha extrudates. Equation 5 shows the polynomial regression model developed for predicting the DPPH radical scavenging activity with a high F-value of 272390.7, and the R^2 , R^2_{adj} and R^2_{pred} of the model is 1 thus affirming its high precision for the prediction of DPPH radical scavenging activity.

$$Y_{DPPH} = 134.67 - 1.10x_1 + 0.024x_2 - 5.86x_3 - 0.000591x_1^2 + 0.00004x_2^2 - 0.13x_3^2 - 0.00042x_1x_2 + 0.081x_1x_3 \quad 5$$

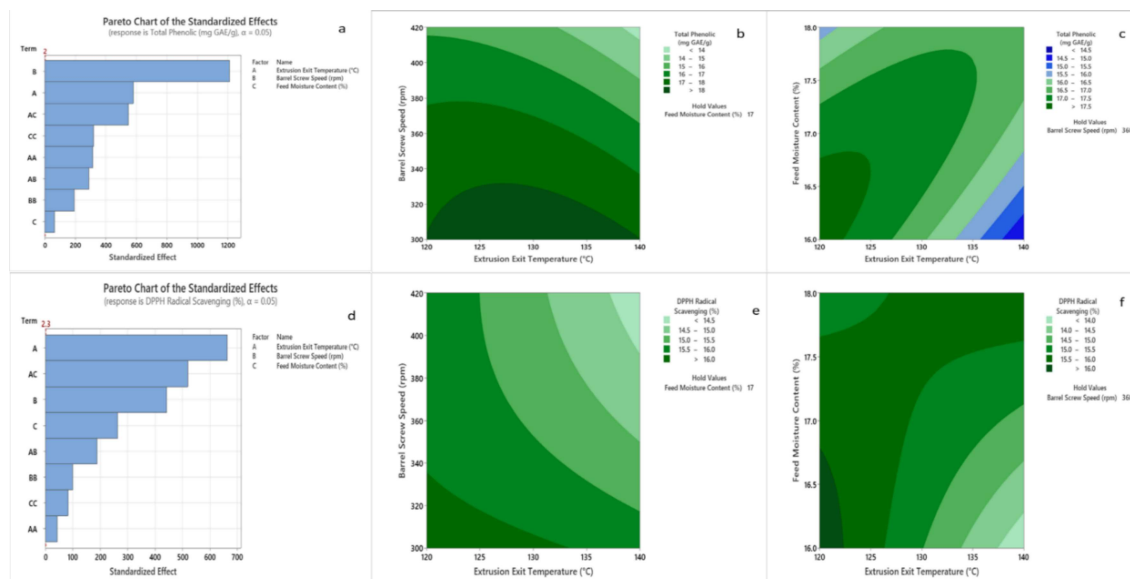


Figure 2. Pareto charts and Contour plots of total phenolic content and DPPH content of rice-bambara nut-pineapple peels based extrudates snacks. (a) Pareto chart of total phenolic content, (b) Contour plot of BSS and EET of total phenolic content, (c) Contour plot of FMC and EET of total phenolic content, (d) Pareto chart of DPPH radical scavenging activity, (e) Contour plot of BSS and EET of DPPH radical scavenging activity (f) Contour plot of FMC and EET of DPPH radical scavenging activity.

4. CONCLUSIONS

Blends of broken brown rice flour, Bambara nut flour, and pineapple peel powder were used to produce ready-to-eat extruded snacks at a ratio of 50:45:5. The extrusion exit temperature, feed moisture content, and barrel screw speed significantly affected the protein, total phenolic content, DPPH radical scavenging activity, and vitamin C

contents of the snacks. Polynomial regression models were developed to predict the influence of extrusion conditions on quality attributes, with R^2 , R^2_{adj} , and R^2_{pred} ranging between 0.99 and 1.0, indicating high adequacy. Optimum extrusion conditions for maximizing quality attributes differed, and the developed models could aid in optimizing the quality attributes of extruded snacks, leading to improved product development. Furthermore, the development of extruded snacks from brown rice, pineapple peels, and Bambara nuts would promote sustainable food production and reduce food waste.

ACKNOWLEDGEMENT

The authors appreciate the Department of Food Engineering, University of Ilorin for supporting this study with facilities.

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