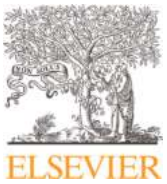
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# Composition, bioactive constituents and glycemic index of brown rice-watermelon seeds extruded snacks as stimulated by extrusion conditions



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ABSTRACT

Broken brown rice is usually categorised as raw material with low market value while watermelon seeds are discarded as waste. Therefore, this study aimed to develop brown rice-watermelon seeds extruded snacks by evaluating the effects of extrusion conditions (feed moisture content (12–16%), exit barrel temperature (120 - 140°C), and barrel screw speed (300 rpm - 420 rpm)) on its composition, bioactive constituents, and glycemic index. Polynomial regression was used to model the composition, bioactive constituents, and glycemic index while response optimizer was used to optimise the protein content of the extruded snacks. At a mixing ratio of 90% brown rice flour and 10% watermelon seeds powder, the effect of extrusion conditions on the moisture content of the extruded snacks ranged from 3.03 to 4.57%, protein content (11.24 to 16.20%), crude fat (0.77 to 1.08%), crude fibre (2.07 to 2.77%), ash (2.05 to 2.63%) and carbohydrate (73.66 to 79.36%). The total phenolic content of the extruded snacks ranged between 8.14 and 10.15 mg GAE/g, total flavonoid content (1.8 and 2.11 mg QE/100 g), DPPH radical scavenging activity (10.05% and 14.22%), and Glycemic index (60.00 and 67.24). The regression models showed the adequacy to predict the composition, bioactive constitutes and glycemic index of the snacks while the optimum conditions gave extruded snacks with 17.71% protein content. The glycemic index of the extruded snacks is intermediate. Conclusively, the developed extruded snacks served as an avenue to exploit the usage of underutilized broken brown rice and watermelon seeds to produce nutrient-rich value-added extruded product.

## 1. Introduction

Over the last few decades, the global demand for snacks with greater nutritional potential has risen (Lucas *et al.*, 2018). Snacks could be regularly consumed six times a day mostly with children (Shah *et al.*, 2017). Often, most developed snacks are categorized as junk owned to low nutrient contents such as higher calories, lower protein, minerals, and bioactive compounds (Neder-Su´arez *et al.*, 2021). Generally, extruded snacks are produced from a mixture of different ingredients which are obtained from crops that include cereals, pulses, and other important food crops (Wani & Kumar, 2018). Rice (*Oryza sativa L.*) is a major grain crop widely grown in the world next to wheat and corn (Sanusi & Akinoso, 2022). It is broadly used as a suitable raw material to produce cereal-based snacks, ready-to-eat foods, breakfast puffed rice, meat analogue, animal fodder, and nutritional foods due to its taste, aroma, colour, hypo-allergenicity, great functional and processing properties. Brown rice has been described to comprise an excess quantity of dietetic roughages, vitamins, and ferulic acid (Dalbhagat *et al.*, 2019). Brown rice is whole grain rice with the bran layer intact but without the inedible outer husk. The husk is removed from the whole rice grain or paddy in the first step of the milling process to yield the whole brown rice grain, which contains the outer bran layer with a common brown colour (Sanusi & Akinoso, 2021). The bran layer contains a substantial amount of nutrients and bioactive substances which are non-starch polysaccharides, flavonoids, phenolic acids, tocotrienols, tocopherols, proteins, carbohydrates, phytic acid, and c-oryzanol (Kaur *et al.*, 2016). Brown rice has moderately been utilized in the formulation of products including brown rice-based snacks (Samyor *et al.*, 2018), and brown rice paste (Wang *et al.*, 2016).

However, extruded snacks developed from a single ingredient do not accomplish all the essential nutritional requirements. Thus, several ingredients are supplemented with brown rice flour to enhance the nutritive, characteristics of the rice-built extruded snacks, satisfying consumers' demand as well as the provision of healthy and dietetically bal-

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anced products. Watermelon seeds have been identified as a significant source of food for human nutrition and a healthy diet (Addo *et al.*, 2018). Braide *et al.* (2012) acknowledged that watermelon seeds have a high quantity of vitamins B, protein, and minerals (such as magnesium, potassium, phosphorus, sodium, iron, zinc, copper, and manganese), and fats as well as phytochemicals. Watermelon seeds has been considered a waste as it is underutilized in our society because of the little attention and consideration regarding its nutritional value. Consequently, watermelon seeds are discarded wrongly, and the underutilization of watermelon seeds has brought about a low market value. Extrusion technology is one of the growing and most widely used food processing methods for the development of several food products from numerous ingredients (Yağcı *et al.*, 2020; Ascheri, 2023). This is due to its potential to create satisfactory flavour, texture, size, and form economically (Singh *et al.*, 2019). The production of extruded snacks from the extrusion process involves the techniques such as mixing, cooking, and shearing diverse mixtures of food ingredients under high pressure and temperature. The technology is very effective due to its high-temperature short-time (HTST) cooking. Thus, it is widely adopted by the food industries in the production of snacks (Nidhi *et al.*, 2019). Extrusion of food is a technique of producing a variety of products by forcing the material to flow through a die under various conditions using a combination of simultaneous mechanical and thermal treatment at a predetermined rate (Alam *et al.*, 2016). This procedure comes with the combination of various unit operations (compression, combining, shearing, kneading, and high-temperature heating) which are used to transform the food into a molten substance. The molten substance is then forced through a narrow die, yielding semi-cooked or fully cooked food with minimum nutritional loss.

The process of extrusion contains numerous parameters of consideration such as barrel temperature, barrel screw speed, and feed moisture content, which are important elements that must be greatly considered during extrusion cooking (Alam *et al.*, 2016). Extrusion cooking has been employed in the utilization of several ingredients to develop extruded snacks. Wang *et al.* (2016) researched the effects of extrusion conditions on the quality of brown rice pasta while Raja *et al.* (2019) worked on the production of extruded snacks by utilization of watermelon seed powder. O'Shea *et al.* (2014) also carried out a study on the effect of extrusion parameters such as screw speed and die temperature on apple pomace-corn-based extrudates while Sahu et al. (2022) studied the effect of controlled parameters in extrusion on the physical and functional qualities of snacks produced from soy protein-maize based. Despite the tremendous work done so far, there is sparse literature on the effect of the extrusion exit barrel temperature (EBT), barrel screw speed (BSS) and feed moisture content (FMC) on the composition, bioactive constituents and glycemic index of extruded snacks made from the blends of brown rice flour and watermelon seeds powder. This study is targeted toward optimizing the extrusion processing conditions to produce protein-rich extruded snacks from the blends of brown rice flour and watermelon seeds powder. The ingredients were carefully selected based on their nutrients and their levels of low utilization as this would be in line with United Nations sustainable development goal 12 (responsible consumption and production). Therefore, the objective of this study was to evaluate and model the effect of extrusion parameters on the composition, bioactive constituents and glycemic index of extruded snacks produced from blends of brown rice flour and watermelon seeds powder. The protein content of the extruded snacks is also optimised numerically.

## 2. Materials and methods

### 2.1. Materials

Watermelon seeds and broken brown rice were purchased from rice milling and watermelon juice companies in Nigeria. Broken brown rice of 25 kg was milled into brown rice flour with a particle size of 0.30 mm mesh size using a Hammer mill (Nukor, Model: SG 30, South Africa). Watermelon seeds of 5 kg were washed with portable water and dried using a forced-air dryer at 41 °C for 45 mins and then ground into powder using an electric blender (Geepas Mixer Grinder, Model: 550 w, India), and sieve to have an average particle size of 65 $\mu$m.

**Table 1**
Effect of mixing ratio of brown rice flour and watermelon seeds powder on crude protein.

| Sample code | Brown rice flour (%) | Watermelon seeds powder (%) | Crude protein (%) |
|---|---|---|---|
| 1 | 80 | 20 | 10.88 |
| 2 | 100 | 0 | 11.89 |
| 3 | 90 | 10 | 12.00 |
| 4 | 85 | 15 | 10.07 |
| 5 | 95 | 5 | 10.71 |

### 2.2. Blends preparation

A preliminary experiment was carried out to study the effect of different mixing ratios of the blends of brown rice flour and watermelon seeds powder using a mixture design in Minitab statistical software version 20.3 on the crude protein content (Table 1). The mixing combination ratio of 90% brown rice flour and 10% watermelon seeds powder was observed to have the highest protein content (12%) and thus was selected for this study.

### 2.3. Experimental design

Taguchi experimental design was used to interact the effect of feed moisture content, barrel screw speed and exit barrel temperature. The effect of the feed moisture content (FMC) (16%, 17%, and 18%), barrel screw speed (BSS) (300 rpm, 360 rpm and 420 rpm) and exit barrel temperature (EBT) (120, 130 and 140 °C) on composition, bioactive constituents and glycemic index of the brown rice-water melon seeds extruded snacks were analysed using Response Surface Methodology (RSM) in Minitab statistical software version 20.3. The composition, bioactive constituents and glycemic index were related to EBT, BSS and FMC by the second-order polynomial regression model of RSM that has linear, quadratic and interaction relationships as shown in Eq. (1) (Sanusi & Akinoso, 2020).

$$Y = \beta_o + \sum_{i=1}^{3} \beta_i X_i + \sum_{j=1}^{3} \beta_{ii} X_i^2 + \sum_{i=1}^{2} \sum_{j=1}^{3} \beta_{ij} X_i X_j + \varepsilon \quad (1)$$

where $\beta_o$ is the coefficients of the model constant, $\beta_i X_i$ are the linear terms, $\beta_{ii} X_i^2$ is the quadratic terms and $\beta_{ij} X_i X_j$ is the interaction terms, Y is the responses (compositional (moisture content, crude fat, ash content, crude fibre, crude protein, carbohydrates), bioactive constitutes (DPPH radical scavenging activity, flavonoid, total phenol content), and glycemic index), $X_i$and $X_j$ are the independent variables (EBT, BSS and FMC). The fitness of the models for the responses were determined by using the coefficient of determination $R^2$, $R^2_{adjusted}$ and $R^2_{predicted}$. Analysis of variance (ANOVA) was used to determine the significant effect using p-values at 95%, 99% and 99.9% confidence levels and Fischer values (F-value).

### 2.4. Production of brown rice-watermelon seeds extruded snacks

Fig. 1 shows the flow chart of the production of brown rice-watermelon seeds extrudate snacks and Fig. 2 shows the schematic of a typical co-rotating twin-screw extruder**.** A co-rotating twin-screw extruder (Model: HN-65, Zhuoheng Product, Jinan City, Shandong Province, China) was used to extrude the mixture blend of brown rice

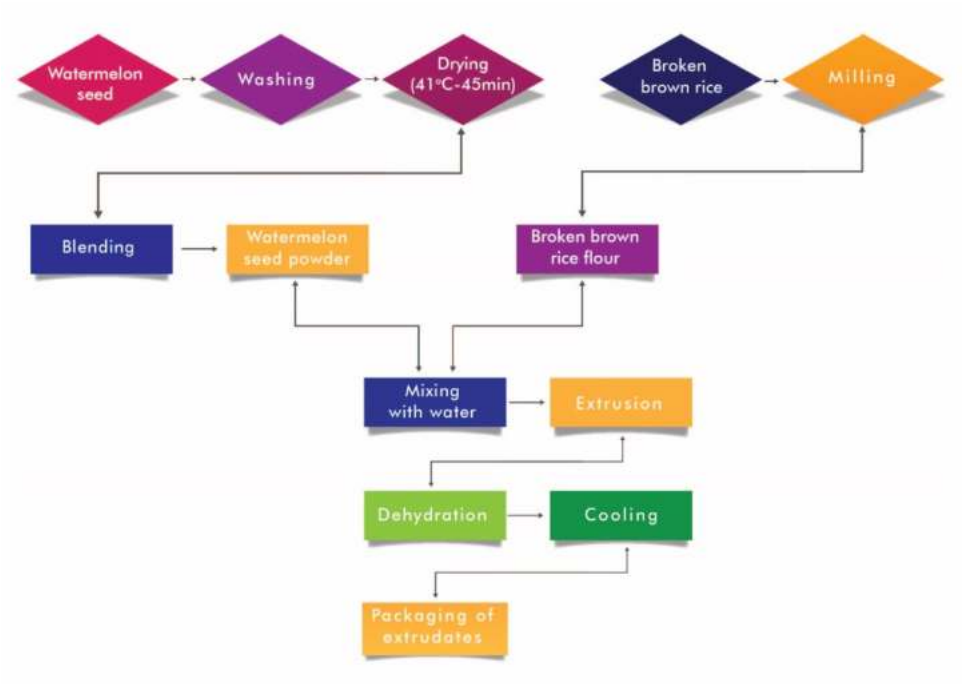



**Fig. 1.** Flow chart for the production of brown rice-watermelon seeds extruded snacks.

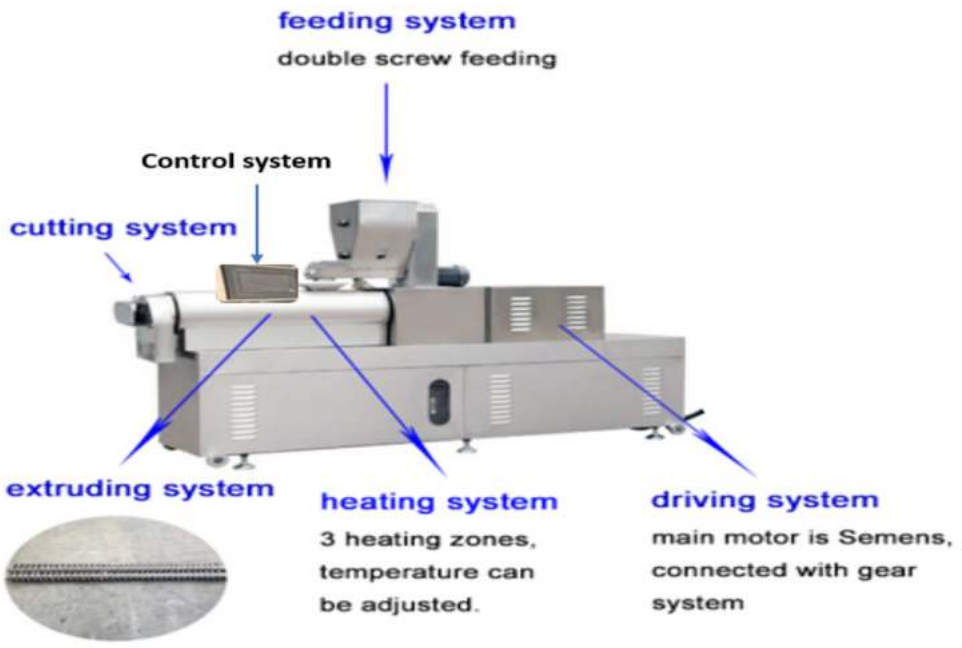



**Fig. 2.** Schematic of a typical co-rotating twin-screw extruder.

flour and watermelon seeds powder in a ratio of 90:10. The blends were mixed with potable water at 16%, 17% and 18% feed moisture content of the entire mixture mass (3 kg) using a mixer (Sokany Stand Mixer, Model: Cx-6612, China) per sample. The first and second heating bands of the extruder were set at a temperature of 80 °C and 100 °C, while the last heating band temperature was varied between 120, 130 and 140 °C. The samples were fed through the hopper at a constant speed of 120 rpm which was conveyed into the barrel where the cooking takes place. From the barrel, the samples passed through the heating zones at various barrel screw speeds of 300, 360 and 420 rpm. The cooked sample within the barrel then passed through the orifice die of 4 mm and the extrudates were cut at a speed of 1500 rpm. The extrudates were collected, dried using a forced-air dryer and packed in a zip-lock container at room temperature for proper storage.

### 2.5. Optimization validation

The optimization of protein content was maximized using the approach described by Sanusi and Akinoso (2021). The performance of the predicted optimum conditions was validated by experiment in the laboratory. Response optimizer in Minitab software version 20.3 was used for the numerical optimization. The optimum validation error (OVE) was calculated to determine the fitness of the optimum condition using

Eq. (2).

$$OVE = \frac{V_e - V_p}{V_e} \times 100 \quad (2)$$

where Ve is the experimental value and Vp is the predicted value.

### 2.6. Compositional analysis

The composition (ash content, protein content, moisture content, crude fibre and crude fat) of the extruded snacks were carried out by the methods recommended by the Association of Analytical Chemists AOAC (2000) while the total carbohydrates were calculated by difference.

### 2.7. Bioactive constituents' analysis

#### 2.7.1. Total phenolic content

500 mg of finely ground extrudates were extracted in 12.5 ml of acetone/ water (4:1, v/ v). The mixture was stirred using a magnetic stirrer for 2 h and then centrifuged at 3000 rpm in a centrifuge (Laboratory centrifuge Model 800, China) for 10 mins. The supernatant was collected and used for analysis. Total phenolic content was determined in the extracts by the method of Hegazy *et al.* (2017). 0.2 ml of extract was added to 1.5 ml of freshly diluted 10-fold Folin Cioculteau reagent. The mixture was allowed to stand for 5 mins before adding 1.5 ml of sodium carbonate (60 g/L). The mixture was then incubated for 90 mins in the dark and the absorbence read at 725 nm. Acetone water (4:1, v / v) was used as a blank and gallic acid was used as the standard. The results were expressed as mg gallic acid equivalent per 1 g sample.

### 2.8. DPPH (2,2 -DIPHENYL-1- PICRYLHYDRAZYL) radical scavenging activity

Antioxidant activity of the extrudates was determined with a stable radical 2,2-diphenyl-1- picrylhydrazyl (DPPH) as described by Anton *et al.* (2009). 200 µl of the sample extract was reacted with 3.8 ml of 63 mm DPPH. The decreasing absorbance was monitored at 517 nm with a UV–visible spectrophotometer (UNICO spectrophotometer, Model No. 2802 PC, USA) after 30 mins reaction at room temperature in the dark against a methanol blank. The control consisted of 200 µl of acetone/ water (4:1, v/ v) in 3.8 ml of DPPH solution. The results were obtained as a per cent of discolouration according to Eq. (3).

$$\text{DPPHScavenged}(\%) = \frac{\text{Absorbance sample}}{\text{Absorbance control}} \times 100 \quad (3)$$

### 2.9. Total flavonoid content

The total flavonoid content (TFC) of each extrudate was determined using the aluminium chloride colourimetry method described by Chang *et al.* (2002). The extracted sample was diluted with methanol of 100 µg/mL. The calibration curve was prepared by diluting quercetin in methanol (0–100 µg/mL). The diluted extract or quercetin (2.0 mL) was mixed with 0.1 mL of 0.1 mM potassium acetate solution. The mixture was kept at room temperature for 30 mins. Then the maximum absorbence of the mixture was measured at 450 nm using a UV–VIS spectrophotometer. TFC was expressed as milligram quercetin equivalent per gram defatted L. *aromatic* (mg QCE/g DFLA).

### 2.10. Glycemic index

The approach reported by Wani et al. (2021) was adopted using rapid in vitro procedure of the international Diabetic Institute, Melbourne, Australia. 50 g of each extrudate was homogenised based on a standard amount of available starch. Hexokinase enzymatic spectrophotometer method was used to determine the available glucose.

### 2.11. Statistical analysis

The experiments were conducted in replicates and an analysis of variance (ANOVA) of the data was performed using the SPSS package (SPSS 20.0, SPSS Inc., and Chicago, IL, USA). Duncan multiple tests with a confidence interval of 95% were used to determine significant differences between means.

## 3. Results and discussion

### 3.1. Composition of brown rice-watermelon seeds extruded snacks

Table 2 shows the effect of extrusion conditions on the composition of brown rice-watermelon seeds extruded snacks. The moisture content of the extruded snacks varied between 3.03 and 5.06%, protein content (11.24 and 16.25%), crude fat (0.77 and 1.08%), crude fibre (2.07 and 2.77%), ash (2.05 and 2.63%) and carbohydrate (73.66 and 79.36%), respectively. The extruded snacks observed the minimum moisture content at 18% FMC, 120 EBT and 360 rpm BSS, whereas the maximum moisture content was recorded in the snacks at 18% FMC, 130 °C EBT and 300 rpm BSS. Moisture content is a key determinant of product shelf life and texture acceptability. According to Rico et al. (2020), products with a higher moisture content of more than 10% would require further processing to enhance their shelf stability. However, the moisture contents of the extruded snacks obtained are within the safe moisture content that can extend their shelf stability. The negative interaction effect of EBT and BSS exhibited a negative influence on the moisture content of the extruded snacks (Table 3).

The contour plot in Fig. 3a similarly displayed a negative effect between EBT and BSS on the extrudates' moisture content, in which at higher BSS and EBT, a lower extrudates' moisture content was achieved. The quadratic interaction of EBT, BSS, and FMC had a negative impact on the moisture content. However, the positive interaction effect of EBT and FMC showed a positive influence on the moisture content (Table 3). An increase in EBT and FMC, consequently, increases the moisture content of the extruded snack (Fig. 3b). The positive linear coefficients of FMC, EBT and BSS, had a positive effect on the moisture content of the snacks. This means that an increase in FMC, EBT and BSS would result in an increase in the snacks' moisture content. This could be attributed to lower moisture loss at higher FMC, EBT and BSS during extrusion cooking. Furthermore, the linear effect, quadratic effect, and interaction effect of extrusion parameters (FMC, EBT, BSS) were observed to be significant at 95%, 99%, and 99.9% confidence levels. The quadratic regression model developed for moisture content (MC) has a high F-value (4004.82) and a non-significant lack-of-fit. The high value of the coefficient of determination $R^2$ (0.99) demonstrates the adequacy of the model. The predicted $R^2$ (0.99) of the model agrees with the adjusted $R^2$ (0.99) which further reveals that the models could be effectively used to navigate the design space and predict the effect of extrusion parameters on the moisture content of the extruded snacks with considerable accuracy.

The optimum protein content of 16.25% was achieved for the brown rice-watermelon seeds extruded snacks at 16% FMC, 120 °C EBT and 420 rpm BSS, whereas, the least (11.24%) was achieved at 17% FMC, 140 °C and 360 rpm. The optimum protein content of the extruded snacks is greater than 12% of the non-extruded blends of 90% brown rice flour and 10% watermelon seeds powder. An increase in the protein content after extrusion cooking was also reported for chickpea-based extrudates (Yagci et al., 2020). The recommended basic protein requirement to curb protein malnutrition in complementary food products according to Gbenyi *et al.* (2016) is 15%. The optimum protein obtained for the brown-rice watermelon extruded snacks showed that it is above the recommended basic protein requirement. The negative linear coefficients of EBT and FMC in Table 3 showed that EBT and FMC have a negative influence on the protein content. Similarly, the interaction effect of EBT and FMC negatively affects the protein content. This is

**Table 2**
Effect of extrusion conditions on the composition of brown rice-watermelon seeds extruded snacks.

| Sample | FMC (%) | EBT ( °C) | BSS (rpm) | Moisture (%) | Crude fat (%) | Ash (%) | Crude fibre (%) | Protein content (%) | Carbohydrate (%) |
|---|---|---|---|---|---|---|---|---|---|
| AA1 | 17 | 120 | 300 | $3.25^{h}$ | $1.08^{a}$ | $2.11^{f}$ | $2.77^{a}$ | $12.56^{f}$ | $78.24^{c}$ |
| AA2 | 18 | 120 | 360 | $3.03^{i}$ | 0.88 g | $2.48^{b}$ | $2.66^{ab}$ | $14.35^{c}$ | $76.59^{e}$ |
| AA3 | 16 | 120 | 420 | $4.02^{e}$ | $1.02^{d}$ | $2.44^{c}$ | $2.62^{ab}$ | $16.25^{a}$ | $73.66^{h}$ |
| BB1 | 18 | 130 | 300 | $5.06^{a}$ | $0.89^{f}$ | $2.05^{h}$ | $2.54^{bc}$ | $15.07^{b}$ | 74.38 g |
| BB2 | 16 | 130 | 360 | 3.53 g | $0.77^{h}$ | $2.22^{d}$ | $2.11^{ef}$ | $13.25^{e}$ | $78.11^{c}$ |
| BB3 | 17 | 130 | 420 | $4.21^{c}$ | $1.04^{c}$ | 2.07 g | $2.08^{f}$ | $11.24^{h}$ | $79.36^{a}$ |
| CC1 | 16 | 140 | 300 | $3.58^{f}$ | $1.06^{b}$ | $2.14^{e}$ | $2.07^{f}$ | 12.12 g | $79.03^{b}$ |
| CC2 | 17 | 140 | 360 | $4.54^{b}$ | $1.08^{a}$ | $2.63^{a}$ | $2.26^{de}$ | 12.07 g | $77.42^{d}$ |
| CC3 | 18 | 140 | 420 | $4.07^{d}$ | $0.97^{e}$ | $2.47^{b}$ | $2.41^{cd}$ | $14.06^{d}$ | $76.02^{f}$ |

Mean values and superscript with dissimilar letters along the same column are significantly different at $p$ <0.05. FMC is the feed moisture content, EBT is the exit barrel temperature and BSS is the barrel screw speed.

**Table 3**
Polynomial regression coefficients and extrusion parameters for the composition of the brown rice-watermelon seeds extruded snacks.

| Source | Regression coefficients<br>Moisture | Crude fat | Ash | Crude fibre | Protein content | Carbohydrate |
|---|---|---|---|---|---|---|
| $X_0$ | $-134.50^{***}$ | $-27.34^{***}$ | $49.83^{***}$ | $85.3^{**}$ | $855.52^{***}$ | $-728.8^{***}$ |
| $X_1$ | $0.36^{***}$ | $-0.26^{**}$ | $0.87^{***}$ | $-0.92^{***}$ | $-3.59^{***}$ | $5.28^{***}$ |
| $X_2$ | $0.22^{***}$ | $-0.0070$ | $0.084^{***}$ | $0.013^{**}$ | $0.37^{***}$ | $-0.68^{***}$ |
| $X_3$ | $8.25^{***}$ | $5.41^{**}$ | $0.88^{***}$ | $-2.95^{**}$ | $-79.55^{***}$ | $69.71^{***}$ |
| $X_1^2$ | $-0.0052^{***}$ | $0.0011^{***}$ | $0.0027^{***}$ | $0.0022^{**}$ | $0.0038^{***}$ | $-0.00046^{***}$ |
| $X_2^2$ | $-0.000039^{***}$ | $0.000027^{***}$ | $-0.000084^{***}$ | 0.000009 | $-0.00017^{***}$ | $0.00028^{***}$ |
| $X_3^2$ | $-0.58^{***}$ | $-0.16^{***}$ | $-0.026^{***}$ | 0.014 | $1.64^{***}$ | $-0.89^{***}$ |
| $X_1 X_2$ | $-0.0015^{***}$ | $-0.000098^{***}$ | $-0.00018^{***}$ | $-0.000074$ | $-0.0020^{***}$ | $0.0038^{***}$ |
| $X_1 X_3$ | $0.093^{***}$ | $-0.00043$ | $0.014^{***}$ | $0.020^{**}$ | $-0.19^{***}$ | $-0.32^{***}$ |
| $R^2$ | 0.99 | 0.99 | 0.99 | 0.96 | 0.99 | 0.99 |
| $R^2$adj | 0.99 | 0.99 | 0.99 | 0.92 | 0.99 | 0.99 |
| $R^2$ pred | 0.99 | 0.99 | 0.99 | 0.84 | 0.99 | 0.99 |
| F-value | 4004.82 | 542.65 | 2126.76 | 27.25 | 5099.28 | 2053.14 |
| P-value | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |

*Significant at 95% level.
**Significant at 99% level.
***Significant at 99.9% level, $X_0$ – Model, $X_1$ - Barrel temperature. $X_2$ - Screw speed, $X_3$ - Feed moisture content.

apparent in Fig. 3d, in which lower EBT and FMC increase the protein content. This explains that higher moisture content increases protein content. However, the positive linear coefficient in BSS indicates that an increase in BSS increased the protein content. This is affirmed in Fig. 3c where higher BSS and lower EBT gave higher protein content. This result could be due to the mild thermal treatment and high shear stress during the extrusion cooking which resulted in mild denaturation of the protein. This result corroborates with the findings of Yusuf *et al.* (2018) and Dalbhagat *et al.* (2019) that at lower barrel temperatures there is an increase in the crude protein content of the extruded snacks. The linear effects of extrusion parameters had significant effects on the crude protein of the extruded snacks at ($p$<0.001). The quadratic and interaction effects were also significant at $p$<0.001. The crude protein's model was observed to be significant at $p$<0.001 with a higher F-value (5099.28) (Table 3). Furthermore, $R^2$, adjusted $R^2$, and predicted $R^2$ were 0.99, 0.99,0.99 respectively, which display their strong adequacy to predict the relationship.

The snacks recorded the maximum fat content (1.08%) at 17% FMC, 120 EBT and 300 rpm BSS, and 17% FMC, 140 EBT and 360 rpm BSS with no significant difference at $p$>0.05. The linear effect of EBT and BSS indicates a negative influence on the fat content, followed by the interaction effect of EBT and BSS. This is apparent from Fig. 3i that the fat content of the extruded snacks increases either at lower EBT and higher BSS, or at lower BSS and higher EBT. The interaction effect of EBT and FMC had a negative effect on the fat, and indicated that increased EBT and FMC resulted in lower fat content in the extruded snacks. However, the contour plot of Fig. 3j showed that the crude fat content increased at FMC within the range of 16.8–17.5% and at EBT within the range of 125–135 °C. This could be attributed to the fact that at higher extrusion temperatures, oils released from the extruded snacks are consumed by heat thus, produced snacks with lower fat content. However, the positive linear coefficient of FMC demonstrates a positive influence on the extrudate fat content (Table 3). This result agreed with the findings of Danbaba *et al.* (2016) that crude fat decreased from rice-cowpea blend as a result of high extrusion cooking. The generated fat content's regression model with an F-value of 542.65, was significant at $p$<0.001. The coefficient of determination expressed in $R^2$, $R^2$ adjusted, and $R^2$ predicted are 0.99. This shows the model's sufficiency to predict the effect of extrusion parameters on the fat content.

The brown rice watermelon seeds snacks observed the maximum ash content (2.63%) at 17% FMC, 140 EBT and BSS 360 rpm. The regression analysis for ash content is presented in Table 3. The linear effect of EBT, BSS, and FMC are significant at $p$<0.001. Similarly, the quadratic, and interaction effects of EBT, BSS, and FMC significantly impacted the ash content of the extruded snacks at $p$<0.001. The developed ash content quadratic model had a high F-value (2126.76), with an $R^2$ value of 0.99, which explains that the model could adequately predict the relationship within the experiment range. The predicted $R^2$ (0.99) closely agrees with the adjusted $R^2$ (0.99) and further supports its competency

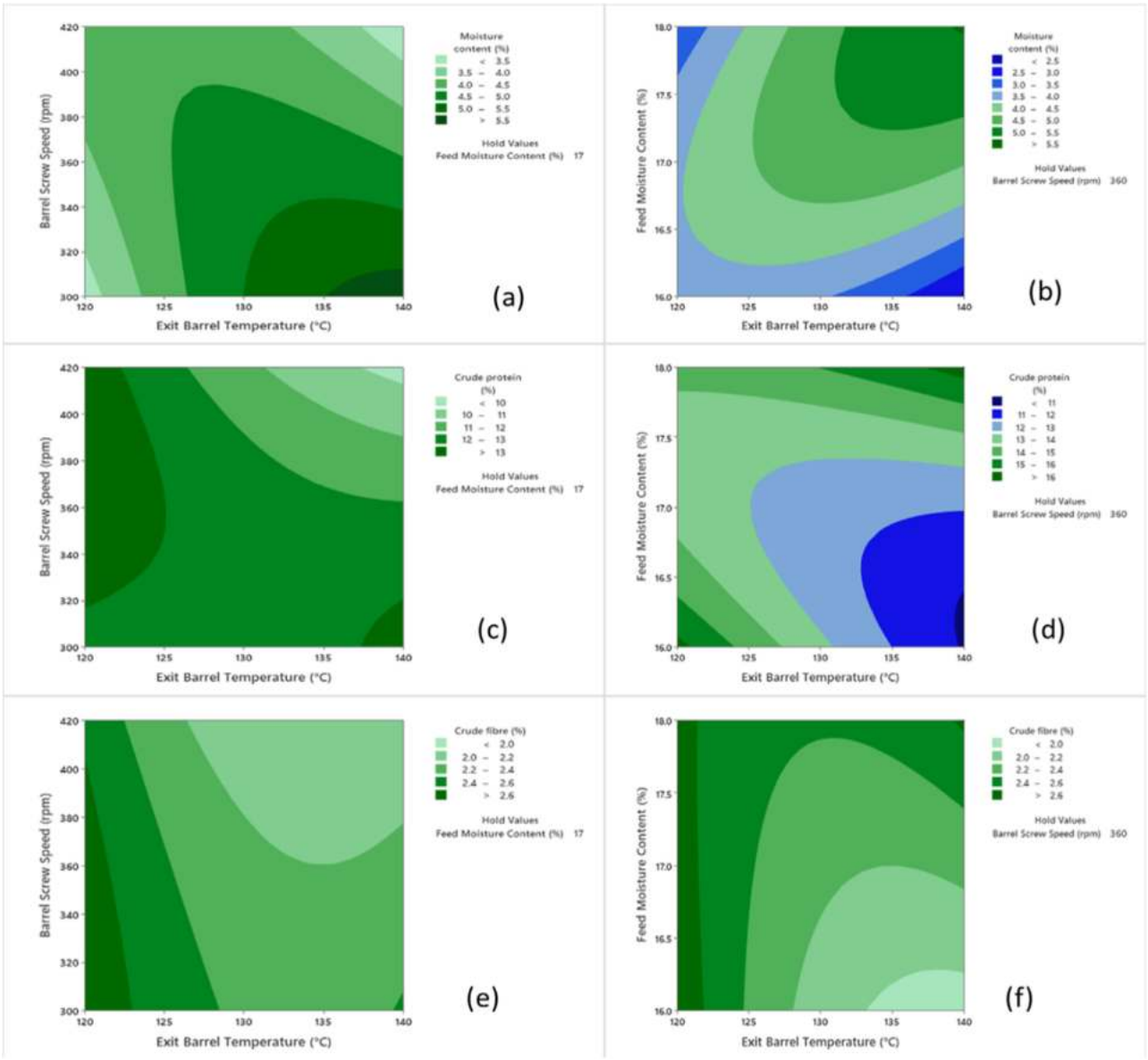



**Fig. 3.** Effect of extrusion parameters on moisture content (a&b), crude protein content (c&d), crude fibre (e&f), ash content (g&h), crude fat content (i&j) and carbohydrate (k&j) of brown rice-water melon seeds extruded snacks.

for prediction. The high positive linear coefficient of FMC (0.88), followed by EBT (0.87), and BSS (0.084) presented a positive influence on the extrudates ash content. This is evident, as the ash content of the extrudates increased with an increase in EBT and BSS (Fig. 3 g). A similar trend was observed between FMC and EBT, where the ash content increased with an increase in FMC and EBT (Fig. 3h). The ash contents obtained could be ascribed to extrusion temperature as high barrel temperature is described to favour the ash content of snacks (Omohimi *et al.*, 2013).

The snacks observed the maximum crude fibre (2.77%) at 17%FMC, 120 ˚C EBT and 300 rpm BSS. Table 3 showed that the fibre content model was significant at $p<0.01$. The linear effect of FMC, EBT and BSS were significant at $p<0.001$. However, amongst the quadratic effect, only $X_1$ significantly influence the fibre content while the double interaction of $X_2$ and $X_3$ had a non-significant effect on the fibre content. The interaction effect of EBT and FMC significantly affect the fibre content at $p<0.01$ while the interaction effect of EBT and BSS showed no effect on the fibre content. The developed quadratic model for fibre content has an F-value of 27.25, and $R^2$ value of 0.96, which supports that the model could sufficiently predict the relationship within the experiment range. The predicted $R^2$ (0.84) accords with the adjusted $R^2$ (0.92) and further show its fitness for prediction. The negative linear coefficients of EBT and FMC indicated that crude fibre decreased as a result of the increase in EBT and FMC, while an increase in BSS increases the crude fibre (Table 3). Contour plots of Fig. 3e&f displayed that at lower EBT and as the FMC and BSS raises, the crude fibre content consequently increased in the extrudates. The reason why lower EBT favoured high crude fibre content could be traced to the absence of any significant structural changes in fibres which cause the insoluble dietary fibres to change into soluble dietary fibres. In addition, the soluble and insoluble fibres re-allocate thereby generating non-appearing mechanical and thermal transformation (Omohimi *et al.*, 2013). Yusuf *et al.* (2018) reported similar findings that lower extrusion temperature aid higher crude fibre content.

The highest carbohydrate content (79.36%) of brown rice-watermelon seeds snacks was obtained at 17% FMC, 130 ˚C EBT and 420 rpm BSS. The polynomial regression analysis depicted that the linear effect of EBT, BSS, and FMC had a significant effect on the carbo-

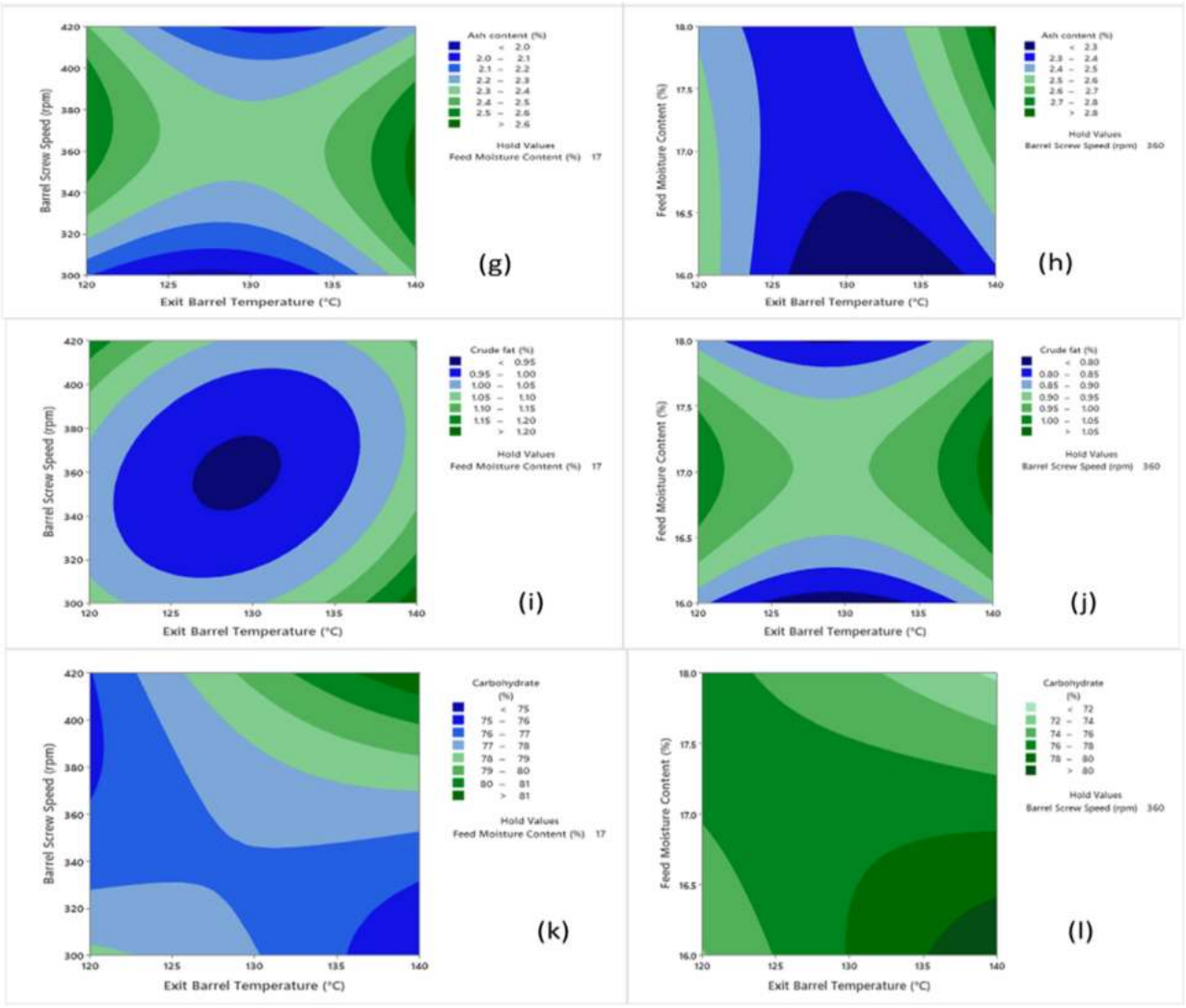



**Fig. 3.** Continued

hydrate content at $p<0.01$ significant level. The quadratic effect of EBT, BSS and FMC, and the interaction effect of EBT and BSS, and EBT and FMC were similarly significant at $p<0.01$ level. The coefficient of determination in terms of $R^2$, adjusted $R^2$, and predicted $R^2$ had high values of 0.99, 0.99, 0.99, respectively. Their high values and close range showed that the developed carbohydrate model can adequately predict the carbohydrate content. The high positive linear coefficients of FMC (69.71) and EBT (5.28) in Table 3 indicated an increase in carbohydrate content as a result of an increase in EBT and FMC, while a decrease in BSS increases the carbohydrate content due to negative coefficient of BSS (−0.68). The carbohydrate content of the developed extrudates was showed to increase as the EBT increases, and BSS decreases (Fig. 3k). The negative coefficient of the interaction effect of EBT and FMC presented a negative influence on the carbohydrate content. This is affirmed in Fig. 3l of the contour plot. The carbohydrate content was displayed to increase at higher EBT and lower FMC. The increase in the carbohydrate content could be attributed to the high mechanical shearing, extrusion temperature and pressure which led to an increase in the rate of starch gelatinization thereby making carbohydrate to be more available. The starch degradation during the gelatinization process leads to the formation of dextrin and simple sugars such as glucose and pre-digestion of starch.

### 3.2. Bioactive constituents of brown rice watermelon seed extruded snacks

#### 3.2.1. Total phenolic content (TPC)

The TPC of the extruded snacks varied between 8.14 and 10.15 mg GAE/g. The snacks' minimum TPC was recorded at 18% FMC, 140 EBT and 420 BSS while the maximum was recorded at 16% FMC, 140 EBT and 300 BSS. The TPC of all samples differs significantly ($p < 0.05$) (Table 4). From the ANOVA Table 5, it can be deduced that the linear, quadratic, and interaction effects of extrusion parameters significantly influence the TPC at 95%, 99.0%, and 99.9% significant confidence levels. The regression model for TPC has an F-value of 2126.76 and was significant at $p<0.001$. The value of $R^2$, adjusted $R^2$, and predicted $R^2$ are 1 and it expresses perfect suitability to predict the effect of extrusion parameters on TPC. The positive linear coefficients in EBT (0.622) and BSS (0.28) in Table 5, indicated that an increase in TPC was due to an increased EBT and BSS. In addition, the positive coefficient of the interaction effect of EBT and BSS had a similar positive influence on the TPC. This is also apparent in Fig. 4a. It can be deduced that higher EBT and moderate BSS lead to an increase in the TPC of the extrudates. From Table 5, the positive coefficient of the interaction effect of EBT and FMC favours the extrudates' phenolic content. It was deduced from Fig. 4b that at higher EBT and FMC, TPC

**Table 4**
Effect of extrusion conditions on DPPH, TFV, TPC, and GI of brown rice-watermelon seeds extruded snacks.

| Samples | FMC(%) | EBT( °C) | BSS (rpm) | DPPH(%) | TFV (mg/100 g) | TPC(mg GAE/g) | GI |
|---|---|---|---|---|---|---|---|
| AA1 | 17 | 120 | 300 | $10.05^{i}$ | $2.05^{b}$ | 8.25 g | $67.24^{a}$ |
| AA2 | 18 | 120 | 360 | $11.51^{f}$ | $1.89^{e}$ | $10.02^{c}$ | $60.78^{b}$ |
| AA3 | 16 | 120 | 420 | $12.11^{b}$ | $2.02^{c}$ | $8.32^{f}$ | $61.48^{c}$ |
| BB1 | 18 | 130 | 300 | $10.55^{h}$ | $1.89^{e}$ | $10.05^{b}$ | $62.14^{d}$ |
| BB2 | 16 | 130 | 360 | $12.06^{d}$ | $2.01^{c}$ | $8.66^{e}$ | $64.24^{e}$ |
| BB3 | 17 | 130 | 420 | $14.22^{a}$ | $2.02^{c}$ | $8.19^{h}$ | $65.13^{f}$ |
| CC1 | 16 | 140 | 300 | $12.09^{c}$ | $1.88^{f}$ | $10.15^{a}$ | 60.00 g |
| CC2 | 17 | 140 | 360 | 11.02 g | $2.11^{a}$ | $9.49^{d}$ | $63.06^{h}$ |
| CC3 | 18 | 140 | 420 | $12.02^{e}$ | $1.98^{d}$ | $8.14^{i}$ | $62.16^{i}$ |

Means value and superscript with dissimilar letters along the same column are significantly different at $p$ <0.05 DPPH- Diphenyl-1- picrylhydrazyl, TFC- Total flavonoid content, TPC- Total phenolic content, GI- Glycemic index. FMC is the feed moisture content, EBT is the exit barrel temperature and BSS is the barrel screw speed.

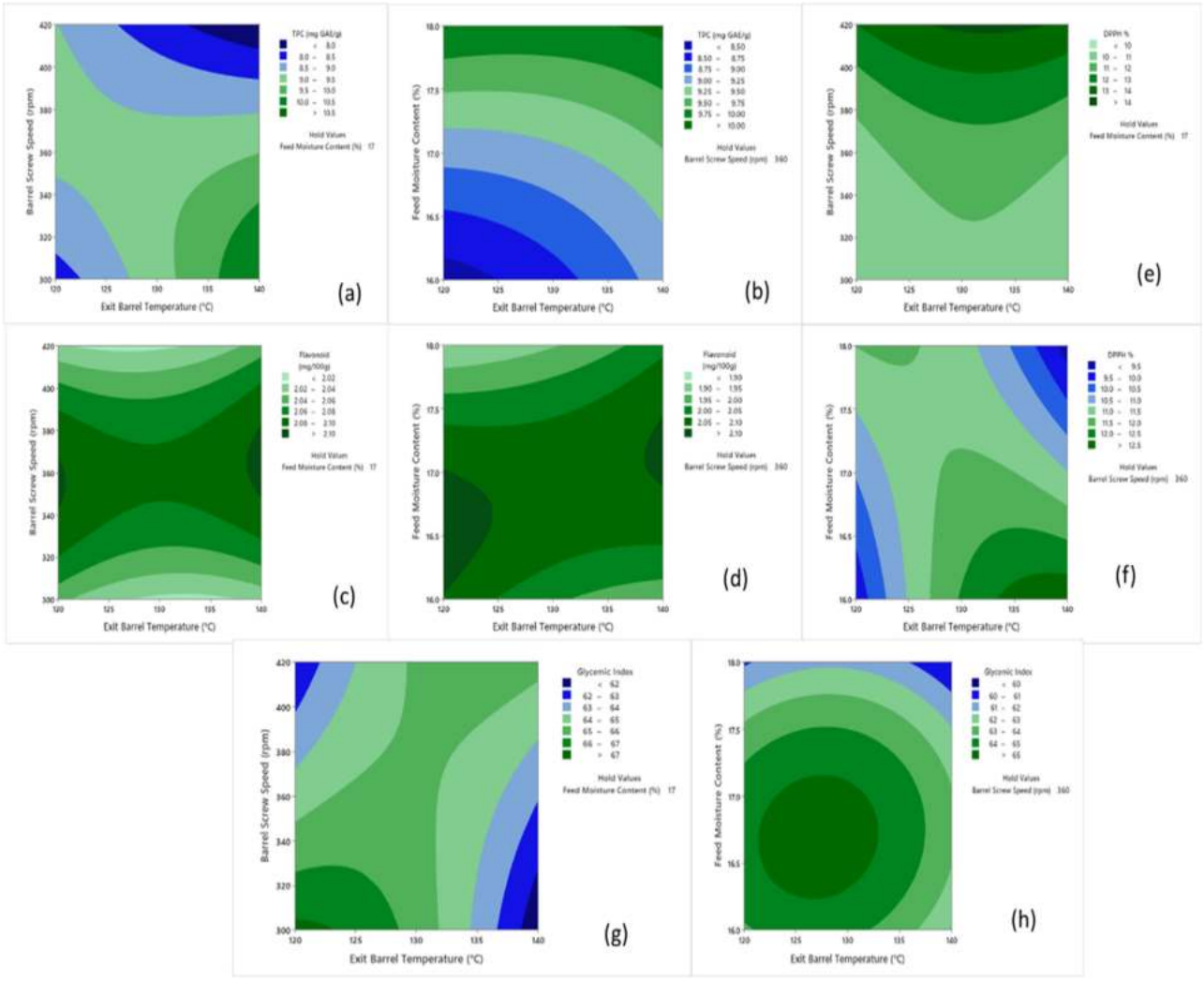



**Fig. 4.** Effect of extrusion parameters on Total Phenolic Content (a&b), Total Flavonoid Content (c&d), DPPH (e&f) and Glycemic index (g&h) of brown rice-water melon seeds extruded snack products.

was also observed to increase significantly. The quadratic effect of EBT, BSS, and FMC were also observed to favour the total phenolic content of the extruded snacks. This could be attributed to the damage of the cell tissue of the extrudates which aid or ease of liberation of bioactive materials at higher extrusion temperature and shearing of the barrel screw speed. The result corroborates with the findings of Wani and Kumar (2016) that EBT influences the TPC. Samyor *et al.* (2018) and Singha *et al.* (2018) reported a similar trend in the production of red rice and passion fruit-powder based extrudates and pomace-enriched extrudates.

### 3.3. DPPH (Diphenyl-1- picrylhydrazyl) radical scavenging

DPPH was employed to measure the antioxidant activities (AA) of the brown rice-watermelon seeds extruded snacks. The DPPH of the snacks ranged between 10.05% and 14.22% (Table 3). The highest DPPH radi-

**Table 5**
Polynomial regression coefficients and extrusion parameters for the DPPH, TFV, TPC, and GI of the brown rice-watermelon seeds extruded snacks.

| Source | Regression coefficients | | | |
|---|---|---|---|---|
| | DPPH | TFC (mg/100 g) | TPC | GI |
| $X_0$ | −377.55*** | −11.34*** | −79.54*** | −523.31** |
| $X_1$ | 4.38*** | 0.18 | 0.622*** | 1.70*** |
| $X_2$ | −0.21*** | −0.011 | 0.28*** | −0.55*** |
| $X_3$ | 16.31*** | −2.72** | −0.95*** | 69.64** |
| $X_1^2$ | −0.0081*** | 0.00021*** | 0.95*** | −0.0.14*** |
| $X_2^2$ | 0.00028*** | −0.000019*** | 0.00093*** | 0.000056*** |
| $X_3^2$ | 0.036*** | −0.11*** | 0.11*** | −2.18*** |
| $X_1$ $X_2$ | 0.00025*** | 0.000020*** | 0.0016*** | 0.0039*** |
| $X_1$ $X_3$ | 0.14*** | 0.0068 | 0.017*** | 0.026*** |
| $R^2$ | 1.0 | 0.99 | 1.0 | 1.0 |
| $R^2$ adj | 1.0 | 0.99 | 1.0 | 1.0 |
| $R^2$ pred | 1.0 | 0.98 | 1.0 | 1.0 |
| F-value | 2,052,275.56 | 252.39 | 2126.76 | 457,306.87 |
| P-value | 0.000 | 0.000 | 0.000 | 0.000 |

*Significant at 95% confidence level, **Significant at 99% confidence level, ***Significant at 99.9% confidence, $X_0$ – Model, $X_1$ - Barrel temperature. $X_2$ - Screw speed, $X_3$ - Feed moisture content.

cal scavenging was recorded at 17% FMC, 130 °C EBT and 420 BSS. The ANOVA for DPPH is shown in Table 5 showed that the linear, quadratic and interaction effects of extrusion parameters have a significant influence on the DPPH radical scavenging of the extruded snacks at $p<0.01$. The DPPH radical scavenging model was affirmed to be significant at $p<0.001$, along with a higher F-value of 2,052,275.56. The $R^2$, adjusted $R^2$, and predicted $R^2$ were observed to be 1 and this presents its perfect capability to predict the effect of extrusion parameters on the DPPH radical scavenging content of the extrudates. The positive linear coefficients in EBT and FMC shown in Table 5 imply that DPPH increased due to an increase in EBT and FMC. Also, the positive coefficient of the interaction effect of EBT and FMC had an analogous positive effect on the DPPH. The DPPH increased with an increase in feed moisture content and barrel temperature during extrusion (Fig. 4f). Whereas the positive coefficient in BSS as well as the interaction effect of EBT and BSS showed a profound positive impact on the extrudates' DPPH. A significant increase in BSS and EBT increases the DPPH radical scavenging content. This could be attributed to the low shearing action of the barrel screw at higher extrusion temperature which resulted into the release of cellular components from the cell matrix during cell lysis adding to the DPPH radical scavenging of the extrudates. It might also result from the action of Maillard on the antioxidants from pigment browning formation that occurred in the snacks. This result corroborates the findings of Hegazy *et al.* (2017) and Samyor *et al.* (2018).

### 3.4. Total flavonoid content (TFC)

The TFC of the extruded snacks ranged between 1.8 and 2.11 mg QE/100 g as shown in Table 3. The highest TFC was recorded at 17% FMC, 130 °C EBT and 420 rpm BSS. The regression analysis was performed to understand the effect of extrusion on TFC, which the result was presented Table 5. It can be understood that the linear effect of FMC significantly affects the TFC at $P<0.01$ significant level, while EBT and BSS appeared to be non-significant extrusion parameters. Only the interaction of EBT and BSS amongst has a significant effect on the response. However, all quadratic effects are significant at $p<0.01$. The developed regression model for TFC in Table 5 was significant at $p<0.001$ having F-value of 252.39. The $R^2$, adjusted $R^2$, and predicted $R^2$ were 0.99, 0.99 and 0.98, respectively. These values present perfect competency to describe the effect of extrusion parameters on the TFC of the extruded snacks. The positive coefficient of the linear effect of EBT (0.18) and BSS (0.011) indicated that an increase in EBT and BSS benefited an increase in the flavonoid content of the snacks. Fig. 4c showed that the flavonoid content of the extrudates increases at intermediate BSS (340–380 rpm), and as the EBT increases. However, the negative coefficient of the interaction effect of EBT and FMC had a negative influence on the TPC, in which lower EBT and lower FMC, or higher EBT and intermediate FMC favoured higher flavonoid content (Fig. 4d). This result is in good agreement with those previously reported by Patil et al. (2016), that feed moisture content had a significant effect on TFC. Although, the amount of TFC obtained from brown rice-watermelon seeds extruded snacks were generally low compared to ones reported by Patil et al. (2016) on Sorghum extrudates. This could be traced to the difference in the composition of the snacks. Also, high extrusion temperature had been reported to cause degradation of TFC. Flavonoids are regarded to be heat sensitive and prone to thermal destruction (Igual *et al.*, 2021).

### 3.5. Glycemic index (GI)

The GI of the brown rice-watermelon seeds extruded snacks ranged between 60.00 and 67.24 (Table 3). The maximum GI was recorded at 17% FMC, 120 °C EBT and 300 rpm BSS while the minimum GI was recorded at 16% FMC, 140 °C EBT and 300 rpm BSS. GI is a measure of food nutritional quality, and a product with a low or intermediate GI is preferable to enhance the control of blood sugar in diabetic patients (Gujral et al., 2019). The polynomial regression in Table 5 showed that the linear effect in terms of EBT, BSS, FMC on the extrusion parameters had a significant effect on the GI content at $p<0.01$ significant level, and the quadratic effect ($EBT^2$, $BSS^2$, $FMC^2$) had a similar significant at $P<0.05$. Furthermore, all interaction effects in terms of EBT and BSS, and EBT and FMC significantly affect the GI. The developed regression model was significant at $p< 0.001$ with F-value of 457,306.87. The $R^2$, adjusted $R^2$ and predicted $R^2$ of the model is exactly 1 (unity) and this reveals its accuracy to describe the effect of extrusion parameters on the GI. However, the positive linear coefficients of EBT and FMC imply that an increase in GI could occur due to an increase in EBT and FMC. This effect is also shown in Fig. 4 g&h of the contour plots in which, at higher EBT, FMC and BSS, GI of the extrudates reduced. Similarly, the interaction effect of EBT and BSS, and EBT and FMC, showed a positive effect on the glycemic index of the developed extrudates. These findings are in accordance with the report of Yang et al. (2020), that high GI could be attributed to the influence of high extrusion temperature and feed moisture applied during cooking. The glycemic index obtained in the study could be categorised as intermediate GI. Oosthuizen et al. (2005) categorized GI as low (GI below 56), intermediate GI (between 56 and 70) and high (GI more than 70). The intermediate GI obtained in this study could be attributed to the effect of extrusion that leads to partial gelatinization of the starch, thus causing the intermediate GI in the snacks. In addition, extrusion cooking involves transformation of protein and starch into texturized and restructured convenience foods which causes large starch molecules to be dextrinised and which then affect the glycemic index.

### 3.6. Numerical optimization

The EBT, FMC and BSS were numerically optimized as shown in Fig. 5. During the optimization, the assumption was done to develop a product with maximum protein content. The other responses, moisture content, crude fibre, ash, carbohydrate, TPC, DPPH, TFC and glycemic index were kept in range. The optimization analysis result showed that at 18.0% FMC; 140 °C EBT and 300 rpm BSS, an optimized product with a predicted protein content of 17.71% could be achieved. The optimum desirability of 1 was obtained and this indicates the accuracy of the optimization. According to Sanusi and Akinoso (2021), the closer the optimum desirability is to unity, the better the accuracy of the optimum conditions. The experimented value for the validation gave a protein content of 17.80% with an optimum validation error of 0.51%. These optimum conditions can be used to produce protein-rich brown rice-watermelon seeds extruded snacks.

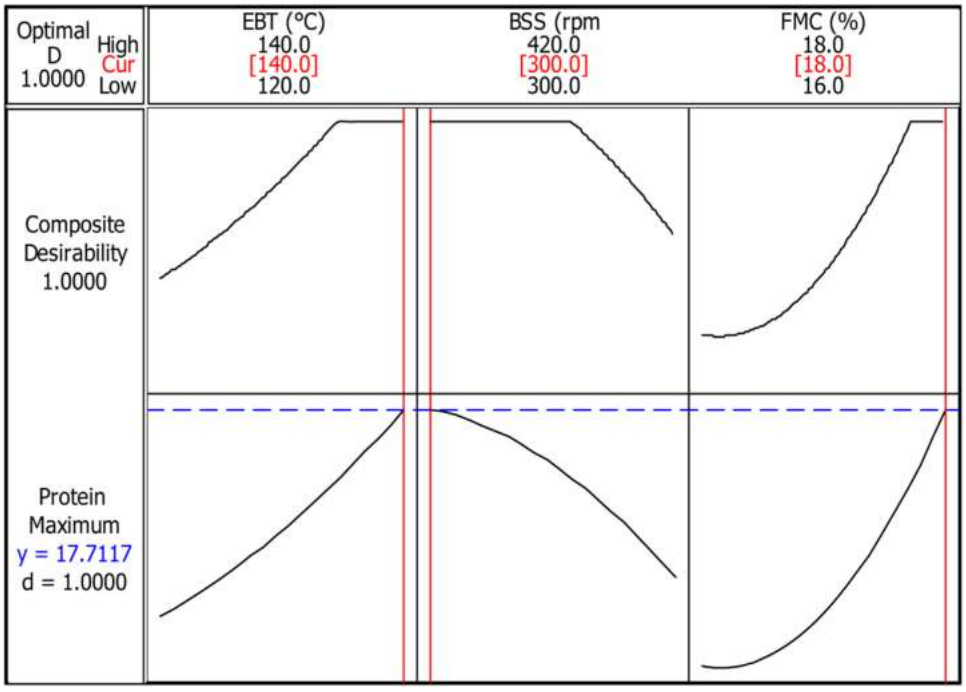



**Fig. 5.** Numerical optimization of extrusion parameters for protein-rich brown rice-water melon seeds extruded snacks.

## 4. Conclusions

In the present work, extruded snacks from blends of 90% broken brown rice flour and 10% watermelon seeds powder were produced. The exit barrel temperature, feed moisture content and barrel screw speed significantly affected the composition, total phenolic content, DPPH radical scavenger, total flavonoid content and glycemic index of the brown rice-water melon seeds extruded snacks. However, the extent of the effect of the extrusion parameters differs significantly at 95%, 99% and 99.9% confidence levels for the composition, bioactive constituents and glycemic index. The regression models developed for the composition, bioactive constituents and glycemic index were significant and have $R^2$, $R^2_{adj}$ and predicted $R^2$ that ranged from 0.96 to 1.00, 0.93–1.00 and 0.84–1.00, respectively. Protein-rich brown rice-watermelon seeds extruded snacks were obtained at optimum conditions of 18.0% FMC, 140 °C EBT and 300 rpm BSS with optimum validation error of 0.51%. This study has proven the potentiality of using broken brown rice and watermelon seeds that are regarded as raw materials with low market value and or waste to produce brown rice-water melon seeds extruded snacks with greater nutritional contents. Additionally, the developed extruded snacks served as an avenue to exploit the usage of underutilized broken brown rice and watermelon seeds in our society and convert it into wealth.

## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Data availability

Data will be made available on request.

## Funding Declaration

The authors declared that no funding was received for this study.

## Ethical Statement - Studies in humans and animals

This study does not involve the use of humans and animals.

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