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INFLUENCE OF EXTRUSION CONDITIONS ON FUNCTIONAL AND TEXTURAL PROPERTIES OF BROWN RICE-WATERMELON SEEDS EXTRUDED SNACKS

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This study aims to evaluate and model the effect of extrusion conditions on the functional and textural properties of brown rice-watermelon seeds extruded snacks. Taguchi was used in designing the experiment and Response Surface Methodology was used to evaluate and model the effect of exit barrel temperature (120 – 140 °C), barrel screw speed (300 – 420 rpm), and feed moisture content (16-18%) on water absorption index (WAI), water solubility index (WSI), hardness, chewiness, gumminess, and springiness of the extruded snacks. The Pareto plot was used to evaluate the significant extrusion parameters on the functional and textural properties. The WAI and WSI of the extruded snacks ranged between 2.09 and 2.87 (g/g), and 2.12 and 2.59% respectively. The hardness, chewiness, gumminess, and springiness of the extruded snacks ranged between 118.92 and 4054.40 N, 0.06 and 326.00 N, 2.41 and 1509.17 N, and 0.02 and 0.21, respectively. The Pareto plot showed that exit barrel temperature had the most significant influence on WAI and WSI whereas, the quadratic interaction effect of feed moisture content had the most significant influence on the hardness, chewiness, gumminess, and springiness of the extruded snacks. Polynomial regression models were developed for the functional and textural properties with an adequate coefficient of determination (R2) that ranged from 0.74 to 0.99, thus indicating their ability to predict the properties. Conclusively, a hybrid of Taguchi and Response Surface Methodology (RSM) technique was used to establish and predict the influence of extrusion conditions on the functional and textural properties of brown rice-watermelon seeds extruded snacks.

Keywords: Taguchi, Response Surface Methodology, extrusion, textural, functional properties.

INTRODUCTION

Extrusion cooking is a novel technology that has been adopted in many food processing industries due to its versatility, low cost, and efficiency. Extrusion technology can be used to produce different types of food products with varying shapes and sizes. Food products such as ready-to-eat snacks, breakfast cereals, and texturized vegetable protein are produced through mixing, continuous cooking, and forming processes (1). In the extrusion of raw materials, transformations such as protein denaturation, starch gelatinization, inactivation of anti-nutrients and enzymes, degradation of pigments and vitamins, and complex formation of amylose and lipids occur (2, 3). Functional and textural properties are among consumers' key indicators for product acceptability (3, 4). Extrusion cooking has been used to develop novel extruded products from blends of different raw materials and agricultural by-products. However, little has been reported in the literature about the utilization of broken

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brown rice and watermelon seeds to produce extruded snacks. Brown rice is a rich source of fibre, antioxidants, phytoestrogens, minerals (iron, phosphorus, magnesium, potassium, zinc, and copper) and B vitamins (5, 6). In addition, its protein content is higher than in white rice. Watermelon seeds are a rich source of protein, as well as phytochemicals (7). In developing countries, broken brown rice is believed to have a low market value, while watermelon seeds are usually discarded as a waste product. However whole brown rice and broken brown rice have the same nutritional composition and can be exploited as a starch-rich ingredient to produce extruded snacks. Also, watermelon seeds can be converted to flour and used as a protein source to enrich extruded snacks. Therefore, the effect of extrusion parameters on the blends of brown rice flour and watermelon seeds flour on the functional (water absorption index and water solubility index) and textural properties (hardness, springiness, chewiness, and gumminess) needed to be established. Oke et al. (8) and Sahu (9) reported that the final product quality, beside mixture composition, could be affected by extrusion parameters such as extruder screw speed, barrel temperature, feed moisture content, and diameter of the die. Thus, this suggests a proper adjustment of extrusion conditions to produce desired quality products is needed. Many researchers have found that feed moisture content, extruder temperature, and screw speed had a significant effect on the textural and functional properties of extrudates (3, 4, 8, 9). However, there is a paucity of information on the effect of extrusion parameters on the functional and textural properties of brown rice-watermelon seeds extruded snacks. Response Surface Methodology (RSM) and Taguchi design have been separately used to evaluate, model and optimize the effect of process parameters on product quality characteristics by several researchers (3, 4, 10-13). In spite of this, little has been reported about the integration of Taguchi design and response surface methodology to evaluate and model the effect of extrusion conditions on product quality parameters. Therefore, this study aimed to evaluate and model the effect of extrusion conditions on the functional and textural properties of brown rice-watermelon seeds extruded snacks using a hybrid of Taguchi design and response surface methodology approach.

METHODOLOGY

MATERIALS

Broken brown rice and watermelon seeds were obtained from Saris-Sodiq rice mill and Fruits glow store, Ilorin, Nigeria and were both processed into brown rice flour (0.30 mm) and watermelon seed flour (65 μm) using a Hammer mill (Nukor, Model: SG 30, South Africa) and an electric blender (Geepas Mixer Grinder, Model: 550w, India), respectively.

BLENDS PREPARATION

A preliminary experiment was conducted to select the best blends of brown rice flour and watermelon seed flour using mixture design in Minitab Statistical Software version 20.3. Mixture of brown rice flour (90%) and watermelon seeds flour (10%) was selected based on the highest protein content (12%) obtained from the preliminary experiment as shown in Figure 1.

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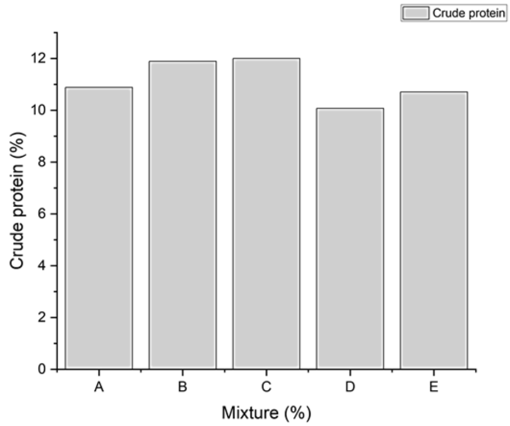

Figure 1. Effect of different mixture of brown rice flour and watermelon seeds flour on crude protein

where A is the mixture of 80% brown rice flour and 20% watermelon seeds flour, B is 100% brown rice, C is 90% brown rice flour and 10% watermelon seeds flour, D is 85% brown rice flour and 15% watermelon seeds flour, and E is 95% brown rice flour and 5% watermelon seeds flour.

EXPERIMENTAL DESIGN

A hybrid of Taguchi and response surface methodology was used to design and evaluate the effect of extrusion parameters on functional and textural properties of brown rice-watermelon seeds extruded snacks. Taguchi Orthogonal Array Design which is $L_9(^{3**3})$ was generated using Minitab Software Version 20 UK. The L_9 implies nine runs, while 3**3 implies 3 factors with 3 levels. The factors are Exit Barrel Temperature (EBT), Barrel Screw Speed (BSS) and Feed Moisture Content (FMC) while the levels ranged from 16-18%, 300– 420 rpm and 120 - 140 °C, respectively as shown in Table 1. Response surface methodology (RSM) was used to analyze the results obtained from the Taguchi design by using the second-order polynomial regression model of RSM that has linear, quadratic, and interaction relationships as shown in Equation [1].

$$Y = \beta_o + \sum_{i=1}^{3} \beta_i X_i + \sum_{j=1}^{3} \beta_{ii} X_i^2 + \sum_{i=1}^{2} \sum_{j=1}^{3} \beta_{ij} X_i X_j + \varepsilon \qquad [1]$$

where β_o is the coefficients of the model constant, $\beta_i X_i$ is 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 (water absorption index, water solubility index, hardness, springiness, chewiness and gumminess), X_i and X_j are the independent variables (exit barrel temperature, barrel screw speed and feed moisture content). The fitness of the models for water absorption index, water solubility index, hardness, springiness, chewiness, and gumminess were determined by the coefficient of determination R^2, $R^2_{adjusted}$ and $R^2_{predicted}$. Analysis of variance (ANOVA) was used to determine

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the p-values at 95% confidence level and Fischer values (F value) of water absorption index, water solubility index, hardness, springiness, chewiness, and gumminess. Pareto plot in Minitab software version 20.3 was used to determine the most significant extrusion parameters. In the Pareto plot, a reference line is drawn on the chart to indicate the P=0.05 threshold for a statistically significant effect.

Table 1. Taguchi experimental design

Extrusion Parameters	Units	Low	Medium	High
Exit Barrel Temperature (EBT)	°C	120	130	140
Barrel Screw Speed (BSS)	rpm	300	360	420
Feed Moisture Content (FMC)	%	16	17	18

EXTRUSION PROCEDURE

Figure 2 shows the schematic illustration of the extrusion of brown rice-watermelon seed blends using a twin-screw extruder. The co-rotating twin-screw extruder (Model: HN-65, Zhuoheng Product, Jinan City, Shandong Province, China) was used to extrude the mixture of brown rice flour and watermelon seeds flour in a ratio of 90:10. The blend was mixed with potable water at 16%, 17%, and 18% moisture content of the entire mixture mass using a mixer (Sokany Stand Mixer, Model: Cx-6612, China). The extruder was set at a temperature of 80 °C and 100 °C in the first and second heating bands, while the last heating band temperature was varied from 120 °C, 130 °C, 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 took place. From the barrel, the samples passed through the three heating zones at various barrel screw speeds of 300, 360 and 420 rpm. The cooked sample within the barrel was 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 fabricated forced-air dryer and packed in a zip-lock container at room temperature for proper storage.

WATER ABSORPTION INDEX (WAI) AND WATER SOLUBILITY INDEX (WSI)

The determination of WAI and WSI was performed by employing the approach outlined by Stojceska et al. (14) and Sahu and Patel (15). Three samples of each run were analyzed where extrudate of 2 g of powdered form from each run was poured into a centrifuge tube where 20 ml of distilled water was also added to dissolve the products for 30 mins under room temperature, and gently stirred for 5 mins. Centrifugation was completed by rotating at a very high speed of 3000 rpm for 15 mins. Equations [2] and [3] were used for the evaluation of the WAI and WSI.

$$\text{WAI (g/g)} = \frac{WS}{WDS} \quad [2]$$

$$\text{WSI (\%)} = \frac{WDSS}{WDS} \times 100 \quad [3]$$

where WS is the weight of sediment, WDS is the weight of dry solids, WDSS is the weight of dissolved solids in the supernatant.

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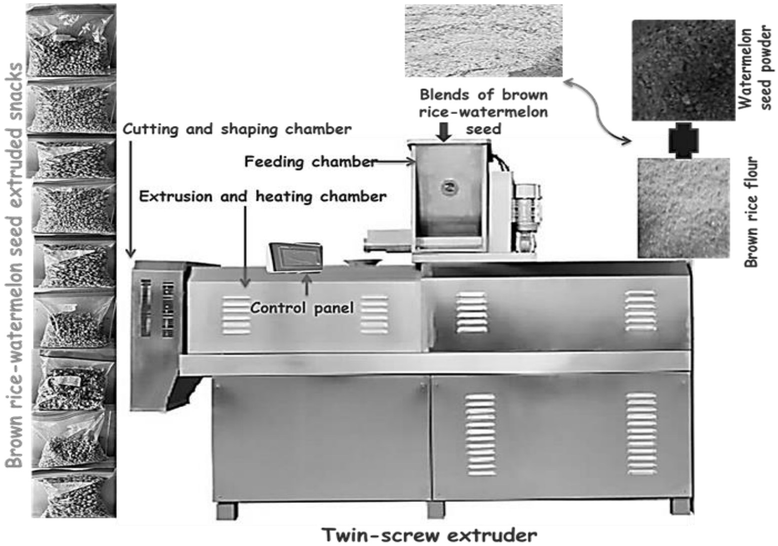

Figure 2. Schematic illustration of extrusion of brown rice-watermelon seeds blends using a twin-screw extruder

TEXTURAL PROFILE ANALYSIS

Texture profile analysis (TPA) of the extruded snacks samples was conducted with a texture analyser (Stable Micro Systems, England, UK). For the TPA, a 36 mm cylindrical aluminium probe and 30 kg load capacity were used in two compression cycles. The test speed was 200 mm/min, compression was at 50% and the recovery period between the strokes was 5 s. The recorded parameters were hardness, chewiness, gumminess, and springiness. Measurements were done in triplicates per sample.

STATISTICAL ANALYSIS

The experiments were conducted in triplicate and 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.

RESULTS AND DISCUSSION

WATER ABSORPTION INDEX (WAI)

WAI is a measure of the degree of gelatinization index and dextrinization of starch by determination of water absorption and retention by starch (16, 17). The WAI of the brown rice-watermelon seeds extruded snacks ranged between 2.09 and 2.87 (g/g) as shown in

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Table 2. The snacks' maximum WAI was recorded at 17% FMC, 120°C EBT and 300 rpm BSS whereas, the minimum was recorded at 18% FMC, 140°C EBT and 420 rpm BSS. It was observed that all the linear, quadratic, and interaction effects of the extrusion parameters have a significant influence on the WAI (Figure 3a). However, it was observed that EBT had the most significant influence on the WAI of the snacks. The developed model is significant for WAI prediction and is presented in Table 3. The R^2 presents its close adequacy. The predicted R^2 of the model strongly agrees with the adjusted R^2 and shows its adequacy to predict the effect of extrusion parameters on WAI. The negative linear coefficient of EBT, BSS, and FMC implies that an increase in WAI would occur as a result of a decrease in EBT, BSS, and FMC. Figure 3c&d showed that lower EBT, BSS and FMC lead to an increase in WAI of the extrudates. These results could be traced to the extrusion process as lower FMC led to excess shearing by the barrel screw which ultimately maximizes the WAI retained (18, 19). Also, Samyor et al. (20) similarly reported an inverse relationship between BSS and WSI from passion fruit-rice flour-based extrudates, which was traced to the reduction in the polymeric chain length from high screw speed. Likewise, the negative coefficient of EBT indicated dextrinization of starch takes place at lower EBT and thus increased the WAI. This could be attributed to the decomposition of starch at a lower temperature. Our results have a relative connection with the study of Beigh *et al.* (17) and Sahu *et al.* (3) on the production of extrudates from barley and chestnut flour and soy protein enriched maize-based extruded snacks.

WATER SOLUBILITY INDEX (WSI)

The WSI defines the water-soluble components liberated during extrusion which is the measure of starch degradation and digestibility (16, 17). The WSI of brown rice-water melon seeds snacks ranged between 2.12 and 2.59% as shown in Table 2.

Table 2. Effect of extrusion conditions on functional and textural properties of brown rice-watermelon seeds extruded snacks

Samples	FMC (%)	EBT (°C)	BSS (rpm)	WAI	WSI	Hardness (N)	Chewiness (N)	Gumminess (N)	Springiness
AA1	17	120	300	2.87[a]	2.56[a]	136.05[a]	0.07[a]	3.68[a]	0.02[a]
AA2	18	120	360	2.45[b]	2.59[b]	193.53[a]	0.07[a]	6.25[a]	0.03[a]
AA3	16	120	420	2.38[c]	2.14[f]	167.58[a]	0.26[a]	6.64[a]	0.07[a]
BB1	18	130	300	2.16[d]	2.15[f]	158.12[a]	0.46[a]	10.61[a]	0.06[a]
BB2	16	130	360	2.54[e]	2.30[c]	118.92[a]	0.56[a]	4.35[a]	0.03[a]
BB3	17	130	420	2.14[f]	2.12[g]	184.94[a]	0.16[a]	14.45[a]	0.04[a]
CC1	16	140	300	2.32[g]	2.23[d]	135.98[a]	0.41[a]	2.69[a]	0.02[a]
CC2	17	140	360	2.21[h]	2.22[e]	133.15[a]	0.06[a]	2.41[a]	0.02[a]
CC3	18	140	420	2.09[i]	2.21[e]	4054.40[b]	326.00[b]	1509.17[b]	0.21[b]

Means value and superscript with dissimilar letters along the same column are significantly different at P <0.05.

The snacks maximum WSI was recorded at 18% FMC, 120 °C EBT and 360 rpm BSS whereas, the minimum was recorded at 17% FMC, 130 °C EBT and 420 rpm BSS. It was observed that the linear, quadratic and interaction effects of the extrusion parameters have a significant influence on the WSI (Figure 3b). However, it was observed that EBT had the most significant influence on the WSI of the extrudates. Table 3 showed the developed regression model for WSI with a high F-value. The value of R^2 presents its close adequacy.

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The predicted R^2 of the model strongly agrees with the adjusted R^2 showing the adequacy to predict the effect of extrusion parameters on WSI. Figures 4a&b showed that higher EBT and lower BSS are desirable for lower WSI while higher EBT and FMC lead to a decrease in WSI of the extrudates.

Table 3. Regression equations and statistical analysis for the responses of brown rice-watermelon seeds extruded snacks

Response	Model	R^2	R^2 Adj	R^2 Pred	F-value
WAI	$3.06 - 0.3439X_1 - 0.0455X_2 - 0.8198X_3 + 0.0010X_1^2 - 0.0001X_2^2 + 0.0383X_3^2 - 0.0004X_1X_2 - 0.0053X_1X_3$	0.99	0.99	0.99	6018.65
WSI	$26.173 - 0.223X_1 - 0.028X_2 - 0.375X_3 + 0.0013X_1^2 - 0.0001X_2^2 + 0.0641X_3^2 - 0.0003X_1X_2 - 0.0143X_1X_3$	0.99	0.99	0.99	2933.25
Hardness	$59022 - 2363X_1 - 400.3X_2 + 6.495X_1^2 + 0.185X_2^2 + 1295X_3^2 + 2.139X_1X_2$	0.97	0.96	0.94	94.20
Chewiness	$49831 - 200.5X_1 - 33.5X_2 + 108.6X_3^2 + 0.1807X_1X_2$	0.74	0.62	0.42	6.44
Springiness	$26.83 - 0.0958X_1 - 0.0133X_2 + 0.0001X_2^2 + 0.0576X_3^2 + 0.00001X_1X_2$	0.83	0.76	0.62	11.09
Gumminess	$228292 - 910X_1 - 154.8X_2 + 2.45X_1^2 + 499X_3^2 + 0.832X_1X_2$	0.82	0.74	0.60	10.41

where WAI is the water absorption index and WSI is the water solubility index, X_1 is the exit barrel temperature (EBT), X_2 is the Barrel Screw Speed (BSS) and X_3 is the Feed Moisture Content.

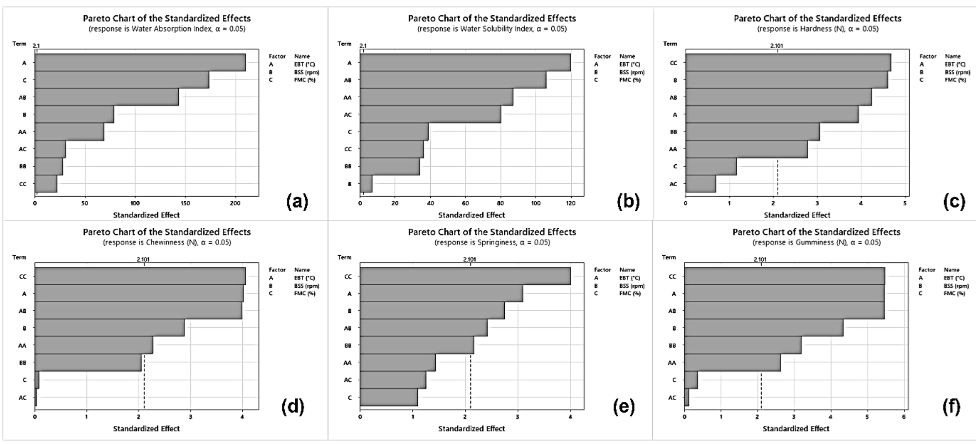

Figure 3. Influence of extrusion parameters on (a) water absorption index (b) water solubility index (c) hardness (d), chewiness (e) gumminess and (f) springiness content of brown rice-water melon seeds extruded snacks. EBT- Exit barrel temperature, BSS- Barrel screw speed, FMC- Feed moisture content

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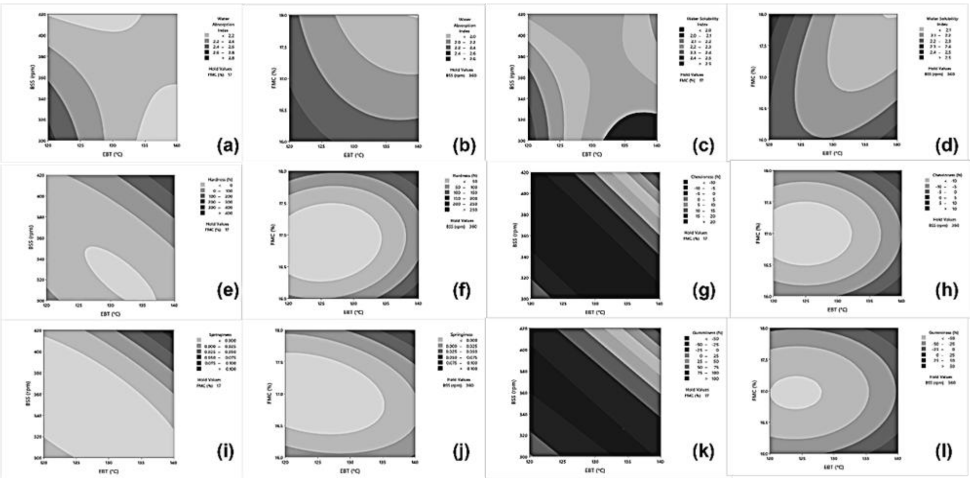

Figure 4. Effect of extrusion parameters on water solubility index (a&b), water absorption index (c&d), hardness (e&f), chewiness (g&h), springiness (i&j) and gumminess (k&j) of brown rice-watermelon seeds extruded snacks.

This supports the report by Gopirajah and Muthukumarappan (21), as the increase in temperature decreased the water solubility due to the release of numerous soluble materials from c. The negative linear coefficient of EBT, BSS and FMC imply that an increase in WSI would occur as a result of a decrease in EBT, BSS and FMC. The reduction in the WSI with an increase in feed moisture content could be due to a reduction in lateral expansion of starch because of the plasticization. An increase in EBT with a decrease in water solubility may also be due to the lateral expansion of the extrudates as a result of incomplete starch gelatinization. This study agrees with Kebede *et al.* (22) and Nargis *et al.* (23) findings during the production of extruded products from rice and carrot blend.

TEXTURAL ANALYSIS

The hardness, chewiness, gumminess, and springiness of the brown rice-water melon seeds extruded snacks ranged between 118.92 and 4054.40 (N), 0.06 and 326.00 (N), 2.41 and 1509.17 (N), and 0.02 and 0.21, respectively (Table 2). The hardness measured the highest penetration force required to collapse an extrudate and has a direct implication on product expansion and its structure (24). Chewiness defined how extrudates behave through the process of biting. Gumminess is a sensory property of snacks that defines the energy needed to crumble a semi-solid food material into a condition prepared for consumption, while springiness is a sensory property of snacks that defines their ability to leap back after initial distortion. This property is lower in crispy snacks (24). The quadratic effect of FMC was observed to have the most significant influence on the hardness, chewiness, gumminess and springiness of the extruded snacks as shown in Figures 3 c, d, e & f. At higher FMC, the dough elasticity reduces through plasticization which invariably affected the hardness, chewiness, gumminess and springiness (Yağcı *et al.* (25); Sahu *et al.* (3)). Table 3 showed the developed regression models for hardness, chewiness, gumminess and springiness. All

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the models were significant at $P<0.05$ with F-values ranging from 10.41 - 94.20 (Table 3). The combined values of R^2, adjusted R^2 and predicted R^2 present strong adequacy for the prediction of the hardness of the extruded snacks under different extrusion parameters. For chewiness, the values of R^2, adjusted R^2, and predicted R^2 also present strong sufficiency for its prediction. The R^2 of gumminess presents close adequacy with adjusted and predicted values. The model strongly agrees with adjusted showing its adequacy for the prediction of gumminess. The predictive model between springiness and extrusion parameters gave an R^2 close to unity while the adjusted R^2 and predicted R^2 also showed a close agreement. The springiness, chewiness and gumminess of the extruded snacks were observed to increase as the EBT and FMC increased (Figures 4 f, g, h, i, j & k). Inversely, the hardness increased with lowered barrel screw speed and increased barrel temperature (Figures 4 e). The results corroborate with the findings of Yağcı *et al.* (25) that low barrel screw speed and high extrusion temperature and extrusion temperature increase the hardness of chickpea extrudates while Neder-Su´arez *et al.* (26) also reported that increasing feed moisture content and barrel screw speed increases the hardness of extrudates. Wang *et al.* (27) reported that chewiness reduces at lower screw speed and extrusion temperature which thus correlates with the obtained result. This could be attributed to the destruction of starch network continuity at lower screw speed and extrusion temperature, and at high pressure and thus causing lower chewiness.

CONCLUSIONS

A hybrid of Taguchi and response surface methodology technique was successfully used to depict the effect of extrusion conditions on the functional and textural properties of brown rice-watermelon seeds extruded snacks. Extrusion process parameters significantly influenced the functional and textural properties of the extruded snacks. Pareto plot showed that exit barrel temperature had the most significant effect on water absorption index and water solubility index, whereas quadratic interaction of feed moisture content had the most significant effect on hardness, chewiness, gumminess and springiness of the extruded snacks. The exit barrel temperature negatively influenced the water absorption index and water solubility index, whereas the quadratic interaction of feed moisture content positively influences hardness, chewiness, gumminess, and springiness. The second-order polynomial regression models developed for functional and textural properties showed their adequacy to predict the effect of extrusion conditions on the functional and textural properties with the coefficient of determination (R^2) that ranged between 0.74 and 0.99. Therefore, with minimum experimental runs using Taguchi design, the effect and model of extrusion conditions on functional and textural properties of brown rice-watermelon seeds extruded snacks can be established using response surface methodology. Also, blends of broken brown rice flour and watermelon seeds flour can also be used to produce an extruded product with good functional and textural properties, thus valorize by-products.

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