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Development and Process Optimization of a Ready-to-Eat Snack from Rice-Cowpea Composite by a Twin Extruder

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Abstract: A central composite rotatable design with four independent variables viz. blend ratio (broken rice flour and cowpea flour): 90:10–70:30, moisture content (10–18% wet basis), barrel temperature (110–150 °C), and screw speed (280–360 rpm) were varied in the development of ready-to-eat snacks using a twin extruder for a broken rice–cowpea product. The effects of the independent variables on specific mechanical energy, water absorption index, water solubility index, total color, hardness, bulk density, expansion ratio, and overall acceptability of the extruded snack were investigated using regression analysis. The results showed that the physical qualities of the ready-to-eat snacks were significantly affected by the extrusion parameters (i.e., blend ratio, barrel temperature, moisture content, and screw speed). From the findings, it was observed that screw speed and moisture contents affected hardness, while water absorption index was affected by all the extrusion parameters. However, the water solubility index and overall acceptance were majorly affected by the moisture content; extrudate produced with barrel ratio of 85:15, 12% moisture content, barrel temperature of 140 °C, and screw speed of 300 rpm was the most acceptable, at 6.73 on a 9 point hedonic scales. The blend ratio and barrel temperature influenced the expansion. Furthermore, the combination of cowpea and broken rice to produce nutritious ready-to-eat snacks has high acceptability and is a promising panacea for food security.

Keywords: broken rice; cowpea; extrusion; food security and ready-to-eat snacks

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1. Introduction

Extrusion technology involves the application of high temperature and shear pressures in a short time duration to develop ready-to-eat snacks (RTES) and there is increasing consumer demand for them due to the time-saving needs of the modern lifestyle [1]. Snack consumption is an important aspect of most eating habits of the populace, particularly the youth, as it plays a major role in their food intake [2]. Most snacks are produced from starchy ingredients including corn, oats, wheat, rice, potatoes, and other tuber crops, which have a high glycemic index (GI). Consumers, on the other hand, can enjoy snack foods with good taste, flavor, and pleasing textural mouth feel, but obtain more nutrients through the inclusion of legumes, fruits, and vegetables.

Extrusion cooking increases the digestibility of proteins and starch [3] as well as reducing the levels of some anti-nutrients in legumes, as they are heat liable [4–7] and has been employed by researchers to produce an array of RTES using different composites in both single- and twin-screw extruders [1,8,9]. Extrusion is very versatile, prolific, energy efficient, and environmentally friendly with no effluent and it is excellent in the development of RTES.

Rice is a cereal grain that is a staple food for a majority of the world's populace, especially in Asia and Africa [10]. Rice is one of the cheapest sources of food energy with a GI of 65 [11]. However, broken rice is rampant in rice milled in developing countries, ranging between 22 and 33% of the milled rice [12,13]; it contains the same nutrient profile as whole rice but is lower priced. [14–16]. Cowpea is a starch–protein legume with 25% protein content and is suitable to fortify RTES to improve dietary and nutritional values [9,17] Hence, broken rice was incorporated into cowpea so as to have desirable functional and nutritional qualities in this optimized RTES product. Jakkanwar et al. [9], using a single screw extruder, deduced that an increase in the feed moisture content (FMC) and a decrease in barrel temperature (BT) resulted in an increase of the bulk density (BD) and hardness (HD), but expansion ratio (ER), water absorption index (WAI), water solubility index (WSI), and overall acceptance (OA) were reduced.

Singh et al. [18] assessed the influence of moisture content (MC), screw speed (SS), and BT on a potato-based snack using a twin-screw extruder; he established that FMC influenced all product responses, although SS and BT had no effect on the specific mechanical energy (SME), WSI, and hardness (HD) of the product. An increase in FMC increases BD, WAI, and hardness, while it decreases SME and WSI. The BD, WAI, and hardness of the snacks reduce as the SS increases. However, the SME, BD, WAI, and HD decrease as the BT rises, but the WSI is on the increase. In the use of a twin-screw extruder, Danbaba et al. [8] observed that the mineral composition of the rice–cowpea extrudate affected the process variables of blend ratio (BR), barrel temperature (BT), and moisture content (MC). The physicochemical properties for the characterization of rice–cowpea composites using broken rice, which is of lower economic value, are required. Hence, the objective of this investigation is to characterize and optimize the extrusion parameters using a twin extruder in producing an acceptable and nutritious RTES from broken rice and cowpea.

2. Materials and Methods

2.1. Raw Materials Preparation

Broken rice (FARO 66) was collected from a double-pass rice mill and cowpea (IT97K-568-18) was obtained from the International Institute of Tropical Agriculture (IITA) in Ibadan, Nigeria. Prior to use, the materials were kept in desiccators at room temperature. Broken rice and the cowpea were winnowed to remove contaminants; the cowpea was soaked in water at 70 °C for 5 min to loosen the outer coat as suggested by Elina et al. [19] and de-hulled manually. The de-hulled cowpea was dried in a cabinet dryer (DC125 Genlab, Cheshire, UK) for 12 h at 60 °C, as suggested by Olaniran et al. [20]. A hammer mill (FT2-A, Armfield, UK) was used to grind broken rice and cowpea into flour, which was then sieved through a 1 mm sieve to ensure uniformity in size. The flours were wrapped in low-density polythene pouches and placed in separate desiccators at ambient temperature. Proximate analyses of the samples were determined before and after extrusion cooking using the AOAC (2005) method [21].

2.2. Extrusion Cooking

The experiment was performed with the use of an inter-meshing co-rotating twin-extruder (MPF-24,190U2F250CACAA215320-GADD, Baker Perkins, MI, USA) in the Department of Food Technology, University of Ibadan, Nigeria. The length-to-diameter (L/D) ratio was 25:1 and a die opening of 2 mm with four heating zones, and the first, second, and third were kept constant at Z_1 = 75 °C, Z_2 = 90 °C, and Z_3 = 90 °C, respectively, while the fourth Z_4 was varied within 110 to 150 °C, according to the experimental design in

Table 1. Before extrusion, the formulations were thoroughly mixed using the laboratory mixer (ES-315, EUROSONIC, GmbH, Germany) to be homogenized for 3 min. To each BR, salt, sugar, vegetable oil, and spice (Piper guineense) mix were added at 0.5, 4, 2, and 2.15% weight, respectively according to the experimental design (Table 1). The ingredients remained constant for all the experimental design runs derived by CCRD.

Table 1. Numerical optimization variables.

Name	Goal	Lower Limit	Upper Limit	Lower Weight	Upper Weight	Importance
BR	in range	70:30	90:10	1	1	3
MC	in range	10.00	18.00	1	1	3
BT	in range	110.00	150.00	1	1	3
SS	in range	280.00	360.00	1	1	3
SME	Minimize	47.10	102.27	1	1	3
BD	Minimize	251.30	593.30	1	1	3
ER	Maximize	2.26	3.06	1	1	3
HD	Minimize	1.99	3.46	1	1	3
WAI	in range	3.05	4.35	1	1	3
WSI	in range	2.80	20.00	1	1	3
TC	in range	36.85	45.89	1	1	3
OA	Maximize	5.20	8.10	1	1	3

Abbreviations: BR = blend ratio (% of gram), MC = moisture content (% wet basis), BT = barrel temperature (°C), SS = screw speed (rpm), SME = specific mechanical energy ($\frac{Wh}{kg}$), BD = bulk density ($\frac{kg}{m^3}$), ER = expansion ratio (mm), HD = hardness, WAI = water absorption index (g/g), WSI = water solubility index (%), TC = total color (ΔE), and OA = overall acceptance.

2.3. *Determination of Extrusion System Response*

Specific Mechanical Energy (SME)

The specific mechanical energy (SME) is utilized for gel formation of starch-based foods, and it controls the rate of starch conversion according to Hussain et al. [22]. SME was determined using Equation (1) [23].

$$\text{SME}\left(\frac{\text{Wh}}{\text{kg}}\right) = \frac{\text{Actual srcew speed (rpm)}}{\text{Rated screw speed (rpm)}} \times \frac{\%\ \text{motor torque}}{100} \times \frac{\text{motor power rating}}{\text{mass flow rate}\left(\frac{\text{kg}}{\text{h}}\right)} \times 1000 \quad (1)$$

2.4. *Properties of Extruded Products*

2.4.1. Bulk Density (BD)

The bulk density (BD) is the average ratio of mass to volume of ten samples of extrudates; BD was determined using a digital vernier caliper to measure axial dimensions (diameter, D; length, L) of 10 randomly selected products from each of the extrudate samples, according to Jakkanwar et al. [9]. An analytical balance (PA-214, OHAUS, NJ, USA) was used to determine the weight (m, g). The BD was calculated by the formula in Equation (2), given by Jakkanwar et al. [9].

$$\text{BD} = \frac{4 \times \text{m}}{\pi \times \text{D}^2 \times \text{L}}\left(\text{g/cm}^3\right) \quad (2)$$

2.4.2. Expansion Ratio (ER)

The expansion ratio (ER) is the degree of puffiness of an extrudate when exiting the die, determined by Equation (3), as described by Rathod and Annapure [24].

$$\text{ER} = \frac{\text{Extrudate diameter (mm)}}{\text{die diameter (mm)}} \quad (3)$$

2.4.3. Water Absorption Index and Water Solubility Index (WAI and WSI)

Extrudates were ground into a powder with a hammer mill (FT2-A, Armfield, UK) and passed through a sieve of mesh 60, and samples of 2.5 g suspended in 25 mL were centrifuged using the procedure described by Rathod and Annapure [24]. The WAI is the weight of gel obtained after removal of the supernatant per unit weight of original dry solids while WSI is the weight of dry solids in the supernatant expressed in percentage. The equations for WAI and WSI are represented in Equations (4) and (5).

$$\text{WAI}\left(\frac{\text{g}}{\text{g}}\right) = \frac{\text{weight of sediment}}{\text{weight of dry solids}} \tag{4}$$

$$\text{WSI}\ (\%) = \frac{\text{weight of dissolved solid in supernatent}}{\text{weight of dry solid}} \times 100 \tag{5}$$

where sediment represents the residual left over from decanting the liquid portion and supernatant stands for the liquid portion removed from the residue after centrifugation.

2.4.4. Hardness

Hardness (HD) is a subjective perception of a material's textural structure that determines the product's cell structure and puffiness. The hardness was determined from the 30 mm length of extruded product using a universal testo metric machine (Texture Analyzer, M500-100AT, Testrometric, UK) at the National Centre for Agricultural Mechanization (NCAM), Ilorin, Nigeria. A 3-point flexural test was performed with a 100 kg load cell. Three randomly selected samples of each of the extrudates were used for the hardness test and the mean values of the readings were calculated according to Jakkanwar et al. [9]. The compression probe was used to determine the amount of compression force necessary to break the samples, according to Hussain and Singh's method [15]. The testing conditions were 90 mm/min test speed; the preload was set at off and the span at 50 mm.

2.4.5. Color

The total color change ΔE are values of L* (luminosity), a* (red-green chromaticity), and b (yellow/blue chromaticity) and was determined by a Chroma Meter (CR-400 & CR-410-Konica Minolta, Europe). The total color change (ΔE) of the RTES was calculated using Equation (6) [25].

$$\Delta\text{E} = \left\{\left\{ (\text{L}^*{}_1 - \text{L}^*{}_0)^2 + (\text{b}^*{}_1 - \text{b}^*{}_0)^2 + (\text{a}^*{}_1 - \text{a}^*{}_0)^2 \right\}^{\frac{1}{2}}\right\} \tag{6}$$

2.4.6. Sensory Evaluation

Overall acceptability (OA) is important in the food processing sector because it enables the producer to ascertain the acceptability of the product and enhance improvements for food product development. A trained panel of fifty, which comprised staff and students of Landmark University, were asked to evaluate the RTES using the 9-point hedonic scale (from 1 = 'extremely dislike' to 9 = 'extremely like') for appearance, color, crunchiness, crispiness, taste, mouth-feel, and OA [18,26]. Thirty coded samples were served to the panelists in batches of six samples daily for five (5) days. The panelists were provided with distilled water that was used to rinse the mouth to neutralize the taste buds and had a 5 min break between sample sets for each day.

2.4.7. Numerical Optimization

The optimal levels of the four independent variables were determined via numerical optimization. This was performed using the Design Expert 11.1.0.1 software [27], ranging with minimum and maximum values. All response parameters were assigned a main goal. ER and OA were set to the maximum; WAI and WSI were set in range; SME, BD, and hardness were set to the minimum, respectively, [28,29] as shown in Table 1.

2.5. Statistical Analysis and Experimental Design

The proximate and mineral analysis data were analyzed statistically with the use of Statistical Package for Social Sciences (SPSS) software version 21 [30]. The experiments were replicated thrice, and the data were analyzed using a design factorial in a Complete Randomized Design (CRD). Duncan's Multiple Range Test (DMRT) was performed to determine the statistical difference in a one-way ANOVA at a 5% level of significance.

The independent variables considered using CCRD of RSM were BR for rice and cowpea (90:10 and 70:30)—A; MC (10–18%)—B; BT (110–150 °C)–C; and SS (280–360 rpm) –D. With the use of CCRD of RSM in Design Expert 11.1.0.1 software [27], 30 experimental runs were generated for extrusion cooking. All experimental runs were analyzed for their responses to SME, WAI, WSI, TC, BD, ER, OA, and hardness. The multiple regression models were used to analyze the results from the experimental data, which illustrated the effects of variables in the derived models. The experimental data were fitted to the chosen models, and the regression coefficients were obtained.

The regression analysis was used for the experimental conditions (independent variables) and represented by BR, MC, BT, and SS, respectively. They were compared to the responses/dependent variables, SME, BD, WAI, WSI, total color, hardness, ER, and OA of the extrudates for the assessment and interactive effects. The lack of fit test of the models was used to judge the adequacy of model fit. Three-dimensional (3D) plots were generated on RSM to assess the changes in the responses with respect to the processing factor.

3. Results and Discussion

3.1. Effect of Blend Ratio, Moisture Content, Barrel Temperature, and Screw Speed on the Extrudates

The process parameters of the input data of the response surface analysis are presented in Table 2.

Table 2. Experimental data of ready-to-eat snacks for response surface analysis.

Run	BR (%)	MC (%)	BT (°C)	SS (rpm)	SME (Wh/kg)	WAI (g/g)	WSI (%)	TC	HD (N)	BD (Kg/m^3)	ER (mm)	OA
1	80:20	10	130	320	92.16	3.63	8.4	40.48	1.99	266.8	2.93	7.55
2	75:25	16	140	340	84.86	4.06	6.8	41.58	3.02	354.3	2.47	5.3
3	80:20	14	130	280	66.3	3.71	10	40.62	2.14	396.9	2.58	6.7
4	85:15	16	120	340	84.86	4.03	7.6	40.02	3.23	541.4	2.49	5.2
5	80:20	14	130	360	82.94	4.33	4.8	41.16	2.89	309.8	2.48	6.25
6	85:15	16	140	340	73.98	4.26	4.4	41.38	3.46	413.3	2.69	6.45
7	80:20	14	130	320	77.82	3.97	3.6	40.2	2.31	498.4	2.38	6.9
8	85:15	16	140	300	65.28	4.35	2.8	39.1	2.14	443.2	2.56	6.9
9	80:20	14	130	320	75.78	3.78	3.6	40.71	2.31	489.3	2.43	6.65
10	75:25	16	140	300	74.88	3.34	2.8	45.72	2.86	481.5	2.27	5.85
11	85:15	12	120	300	84.48	3.38	7.6	44.5	3.08	441.4	2.54	5.65
12	75:25	16	120	300	65.28	3.39	10	37.85	2.05	508.4	2.41	7.45
13	80:20	14	130	320	77.82	4.17	5.2	39.77	2.32	521.5	2.38	7.05
14	75:25	12	120	300	80.64	3.33	10	45.89	2.55	506.5	2.47	7.35
15	80:20	18	130	320	55.3	4.05	4.4	37.42	2.96	541	2.61	5.45
16	85:15	12	140	340	84.86	3.05	16.8	40.43	2.82	434.6	2.56	6.3
17	75:25	12	120	340	87.04	3.58	9.6	39.08	2.76	536.1	2.4	6.1
18	70:30	14	130	320	77.82	3.21	20	39.39	3.03	593.3	2.26	6.9
19	80:20	14	130	320	77.82	3.64	14.4	42.12	2.13	481	2.42	7.4
20	75:25	12	140	300	65.28	3.76	10.4	36.85	2.94	513.2	2.39	7.15
21	80:20	14	130	320	77.82	4.29	6.4	40.62	2.45	489.2	2.42	7.7
22	80:20	14	150	320	65.28	4.07	6	42.73	2.23	416.9	2.32	7.5
23	85:15	12	140	300	84.48	3.95	12	44.52	2.98	361.3	2.78	8.1
24	90:10	14	130	320	88.06	3.61	8	39.96	2.73	437.3	2.86	7.5
25	80:20	14	110	320	47.1	3.3	11.6	44.54	2.6	251.3	3.06	7.45
26	85:15	16	120	300	71.04	3.61	5.2	39	2.54	554.2	2.68	5.75

Table 2. *Cont.*

Run	BR (%)	MC (%)	BT (°C)	SS (rpm)	SME (Wh/kg)	WAI (g/g)	WSI (%)	TC	HD (N)	BD (Kg/m^3)	ER (mm)	OA
27	80:20	14	130	320	77.82	4.14	6.8	37.64	2.17	487.7	2.28	6.9
28	75:25	16	120	340	76.16	3.75	6.8	41.56	2.9	581.5	2.31	5.8
29	85:15	12	120	340	97.92	3.37	7.6	40.1	3.01	449.8	2.46	7.6
30	75:25	12	140	340	102.27	4.19	8.4	44.3	2.29	386.3	2.47	7.05

3.1.1. Specific Mechanical Energy (SME)

Starch conversion occurs more quickly with a high SME, leading to better expanded product, as observed by Singh et al. [18]. From Table 2, the SME values for the extrusion conditions of the experimental runs ranged between 47.10 and 102.27 Wh/kg. The low SME range observed is desirable and was because of the 2% vegetable oil added in the extrusion process, which is in agreement with the observations made by Yu [31] and Dogan [32]. Equation (7) shows the SME expressed as a linear equation.

$$\text{SME} = 77.44 - 2.58\text{BR} - 13.70\text{MC} + 2.07\text{BT} + 11.16\text{SS} \tag{7}$$

Equation (7) depicts that regression terms of BR and MC had a negative effect on SME while BT and SS had positive effect. The ANOVA (Table 3) showed that MC and SS were the significant linear regression terms for the model ($p < 0.05$). Response surface plots for SME in Figure 1a show a decrease in SME with an increase in the cowpea proportion of the BR and increase in MC, while SME increased with an increase in BT and SS, as shown in Figure 1b,c. The SME decreases when there is an increase in the cowpea proportion of the BR due to the effect of easier flow for the melt at a high mass flow during extrusion. This was in agreement with the observation of Zhang et al. [33] using soy protein isolate and Rivera. The decrease in SME because of an increase in MC could be attributed to the fact that high MC acts as a softening agent and lubricant according to Yu [31], Matysiak et al. [34], and Reshi et al. [23].

Table 3. ANOVA for response surface models for specific mechanical energy of extruded RTE snack.

Specific Mechanical Energy (Linear)						
Source	**SS**	**Df**	**MS**	**F-Value**	***p*-Value**	
Model	1937.82	4	484.46	6.01	0.0016	significant
A-BR	39.96	1	39.96	0.4957	0.4879	
B-MC	1125.46	1	1125.46	13.96	0.0010	
C-BT	25.69	1	25.69	0.3186	0.5775	
D-SS	746.72	1	746.72	9.26	0.0054	
Residual	2015.54	25	80.62			
Lack of Fit	159.56	24	6.65	3.06	0.1081	not significant
Pure Error	3.47	5	0.6936			
Cor Total	3953.37	29				

Abbreviations: BR = blend ratio (% of gram), MC = moisture content (% dry basis), BT = barrel temperature (°C), SS = screw speed (rpm).

The positive linear effect of BT that resulted in an increase in SME was not affirmative to the finding of Reshi et al. [23]; however, the reason for this could be because of differences in the crop used, method of sample preparation, extrusion conditions, and configuration of the extruder. The positive linear SS coefficients indicated that SME increases as SS increase due to the increasing shearing force within the screws. According to Meng et al. [35], hydrogen bonds within starch granules are ruptured by significant mechanical stress, hence allowing gelatinization to occur.

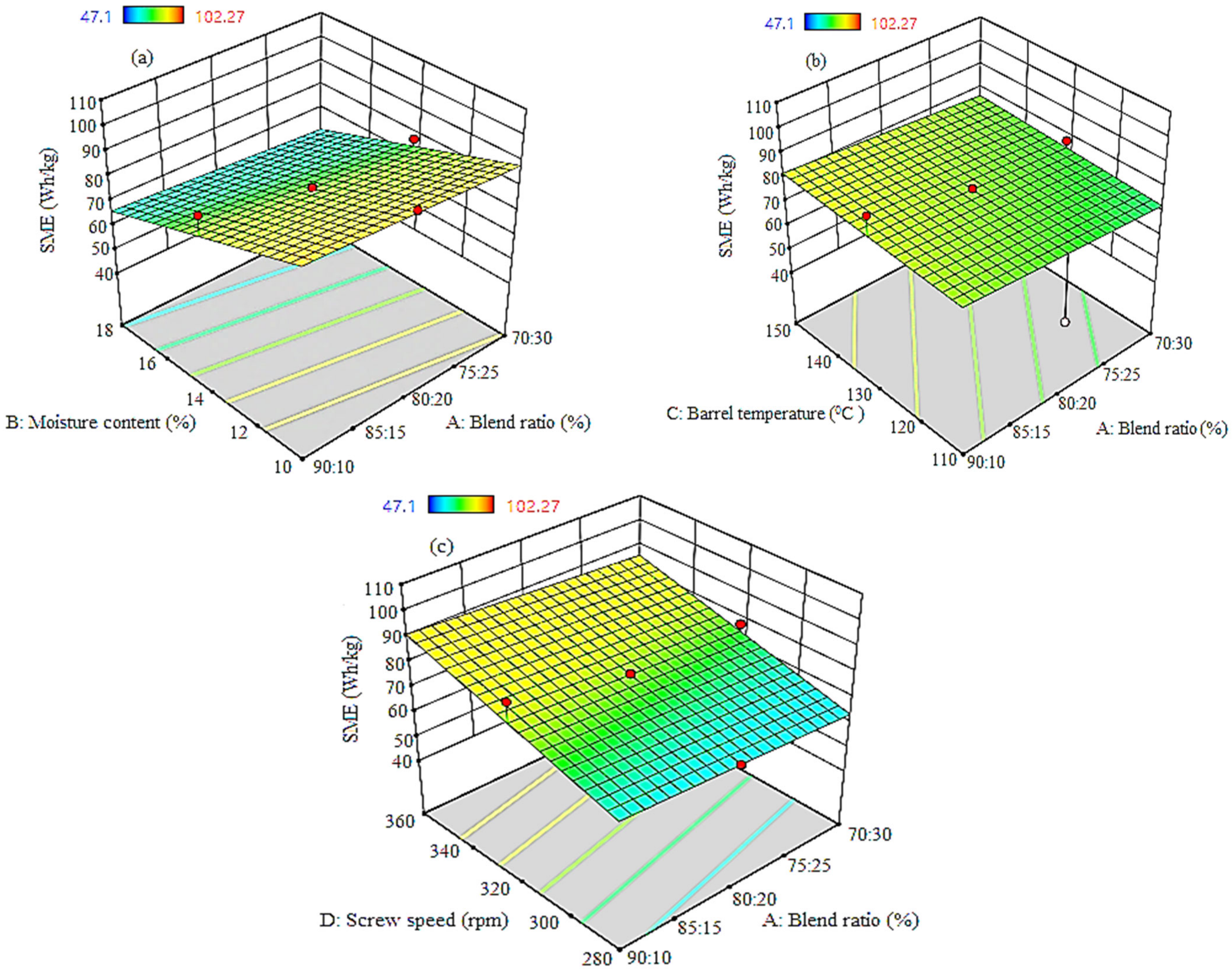

Figure 1. 3D response surface plot of specific mechanical energy (SME) against (**a**) blend ratio versus moisture content, (**b**) blend ratio and barrel temperature, (**c**) blend ratio versus screw speed.

3.1.2. Water Absorption Index (WAI)

WAI refers to the weight of the gel generated after the starch has swelled in excess water, as well as the amount of polysaccharide obtained from the starch polymer when excess water is added to it [36]. The starch granules went through transformation during extrusion cooking in the presence of heat energy [37]. The WAI values ranged from 3.05 to 4.35 g/g (Table 2). The fitted quadratic equation for WAI is shown in Equation (8).

$$\begin{aligned} \mathrm{WAI} = \; & 4.00 - 0.1167\mathrm{BR} + 0.2517\mathrm{MC} + 0.3383\mathrm{BT} + 0.2017\mathrm{SS} - 0.7050\mathrm{BR} * \mathrm{MC} + 0.0200\mathrm{BR} * \mathrm{BT} \\ & + 0.5850\mathrm{BR} * \mathrm{SS} - 0.0150\mathrm{MC} * \mathrm{BT} + 0.4100\mathrm{MC} * \mathrm{SS} - 0.2150\mathrm{BT} * \mathrm{SS} - 0.6058\mathrm{BR}^2 \\ & - 0.1758\mathrm{MC}^2 - 0.3308\mathrm{BT}^2 + 0.0042\mathrm{SS}^2 \end{aligned} \quad (8)$$

The quadratic regression Equation (8) depicts that BR had a negative effect on WAI, whereas MC, BT, and SS had a positive effect on WAI. The ANOVA (Table 4) showed that MC, BT, BR × MC, BR × SS, and BR^2 were the significant quadratic regression terms ($p < 0.05$) for the model. The response surface plots for WAI in Figure 2a showed an increase in WAI with an increase in cowpea proportion of the BR up to 80:20 at the lowest MC, though it has the highest value of 4.35 g/g at an MC of 18 and BR of 90:10. Generally, WAI increased with an increase in MC, BT, and SS, as shown in WAI Figure 2b,c. From Equation (8), the interactive effect of the increase in BR × BT, BR × SS, and MC × SS resulted in an increase in WAI. However, WAI decreased with an increase in BR × MC, MC × BT, and BT × SS. The increase in the cowpea proportion in the BR led to a decrease in WAI at the lowest SS. At a constant BR of 90:10, an increase in MC increases the WAI. Jakkanwar [9] observed that WAI increases along with BT and FMC up to a point and then decreases as a result of increased dextrinization.

Table 4. ANOVA for response surface models for water absorption index of extruded RTE snack.

Water Absorption Index (Quadratic)						
Source	**SS**	**Df**	**MS**	**F-Value**	***p*-Value**	
Model	3.22	14	0.2297	4.18	0.0047	significant
A-BR	0.0817	1	0.0817	1.48	0.2418	
B-MC	0.3800	1	0.3800	6.91	0.0190	
C-BT	0.6868	1	0.6868	12.49	0.0030	
D-SS	0.2440	1	0.2440	4.440	0.0524	
AB	0.4970	1	0.4970	9.04	0.0089	
AC	0.0004	1	0.0004	0.0073	0.9332	
AD	0.3422	1	0.3422	6.22	0.0248	
BC	0.0002	1	0.0002	0.0041	0.9498	
BD	0.1681	1	0.1681	3.06	0.1009	
CD	0.0462	1	0.0462	0.8405	0.3738	
A^2	0.6292	1	0.6292	11.44	0.0041	
B^2	0.0530	1	0.0530	0.9637	0.3418	
C^2	0.1876	1	0.1876	3.14	0.0846	
D^2	0.000	1	0.000	0.0005	0.9817	
Residual	0.8250	15	0.0550			
Lack of Fit	0.5135	10	0.0514	0.8243	0.6296	not significant
Pure Error	0.3115	5	0.0623			
Cor Total	4.04	29				

Abbreviations: BR = blend ratio (% of gram), MC = moisture content (% dry basis), BT = barrel temperature (°C), SS = screw speed (rpm), AB = BR × MC, AC = BR × BT, AD = BR × SS, BC = MC × BT, BD = MC × SS, CD = BT × SS.

It was observed that with an increase in MC from 10 to 12%, WAI was low. However, with a further increase in MC from 12 to 18%, an increase in WAI occurred. According to Reshi et al. [23], a high MC has a plasticizing effect on starch and hence has a large control over starch breakdown. The increase in BT increases WAI (2.86–3.5 g/g). This is most likely due to a higher temperature, which enhanced dextrinization, which is in agreement with the observation of Jakkanwar et al. [9]. This result was comparable to the findings of Yousf et al. [38] who used a BT of 120 to 150 °C on rice carrot RTES. Higher SS caused starch granules to break apart, allowing more water molecules to reach the hydrophilic regions, therefore reducing WAI.

3.1.3. Water Solubility Index (WSI)

WSI of the extrudates ranged between 2.8 and 20% (Table 5). The linear equation for WSI is shown in Equation (9).

$$WSI = 8.07 + 2.07BR - 3.67MC - 0.9333BT - 0.2667SS \quad (9)$$

WSI indicates starch breakdown through dextrinization, and is associated with the presence of water-soluble molecules [15]. The WSI of the extrudates ranged from 2.8% to 20% (Table 5). The linear regression in Equation (9) shows that BR had a positive effect on WSI, while MC, BT, and SS had a negative effect on WSI. The ANOVA showed that MC was the significant linear regression term ($p < 0.05$) for the model. The response surface plots of WSI in Figure 3a show an increase in WSI with an increase in cowpea proportion of the BR, while WSI decreased with an increase in MC, BT, and SS, as shown in WSI Figure 3b,c. At a constant MC, an increase in cowpea proportion in BR (90:10 and 70:30) increased WSI from 9.6 to 13.7%. This can be attributed to the fibrous and higher protein content in the feed combination, which is in agreement with the observation of Yousf et al. [38]. Whereas, at a constant BR, the increase in MC from 10 to 18% decreased WSI from 9.6 to 2.5%, due to a greater gelatinization of starch and plasticizing effect. Lower MC led to an increase in WSI, likely due to higher starch degradations, as observed by Reshi et al. [23] and Sibel and Fahrettin [39].

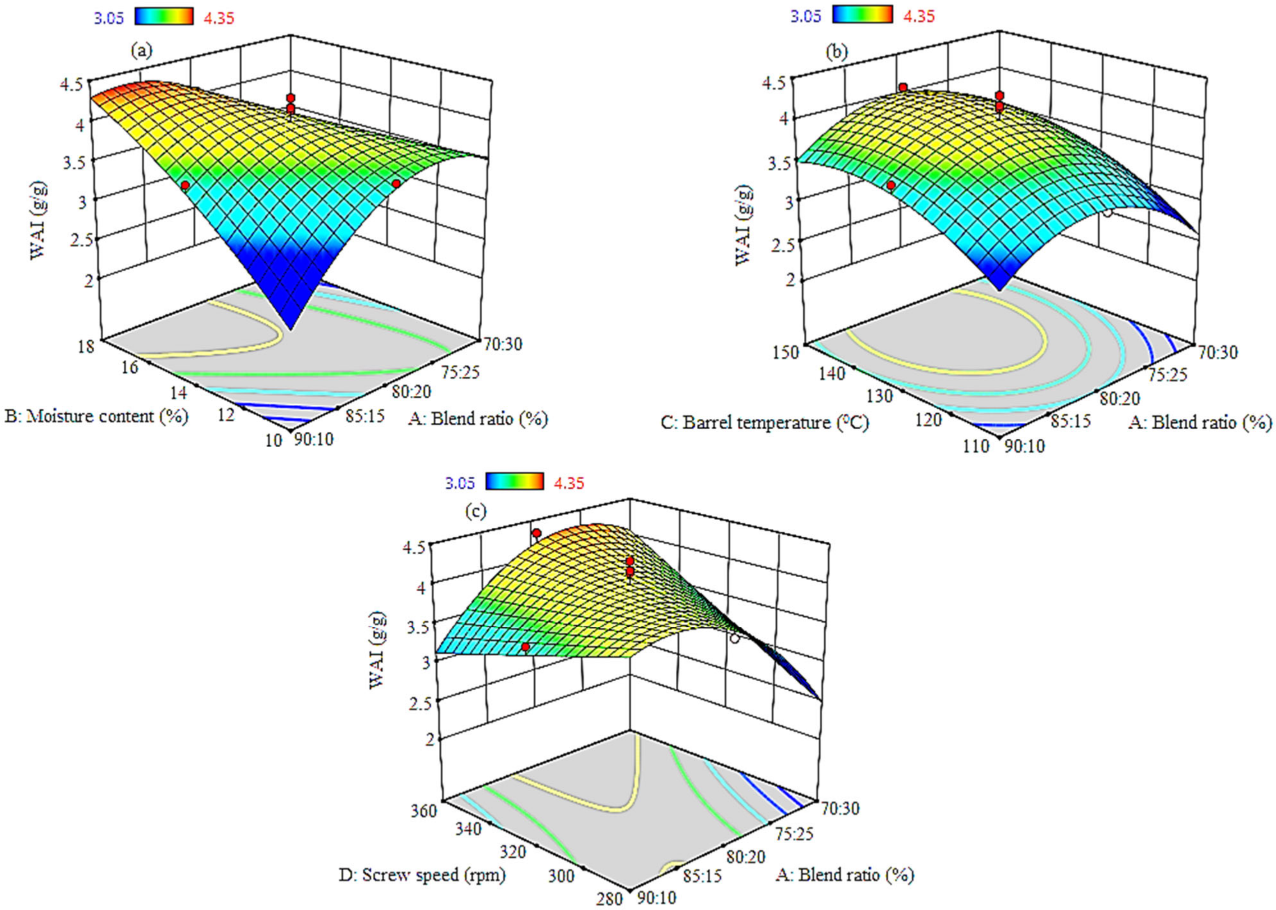

Figure 2. 3D response surface plot of water absorption index as against (**a**) blend ratio versus moisture content, (**b**) blend ratio versus barrel temperature, (**c**) blend ratio versus screw speed.

Table 5. ANOVA for response surface models for water solubility index of extruded RTE snack.

Water Solubility Index (Linear)						
Source	**SS**	**Df**	**MS**	**F-Value**	***p*-Value**	
Model	111.95	4	27.99	1.97	0.01308	significant
A-BR	25.63	1	25.63	1.80	0.1918	
B-MC	80.67	1	80.67	5.67	0.0252	
C-BT	5.23	1	5.23	0.3671	0.5500	
D-SS	0.4267	1	0.4267	0.0300	0.864	
Residual	355.92	25	14.24			
Lack of Fit	275.07	20	13.75	0.8505	0.6444	not significant
Pure Error	80.85	5	16.17			
Cor Total	467.87					

Abbreviations: BR = blend ratio (% of gram), MC = moisture content (% wet basis), BT = barrel temperature (°C), SS = screw speed (rpm).

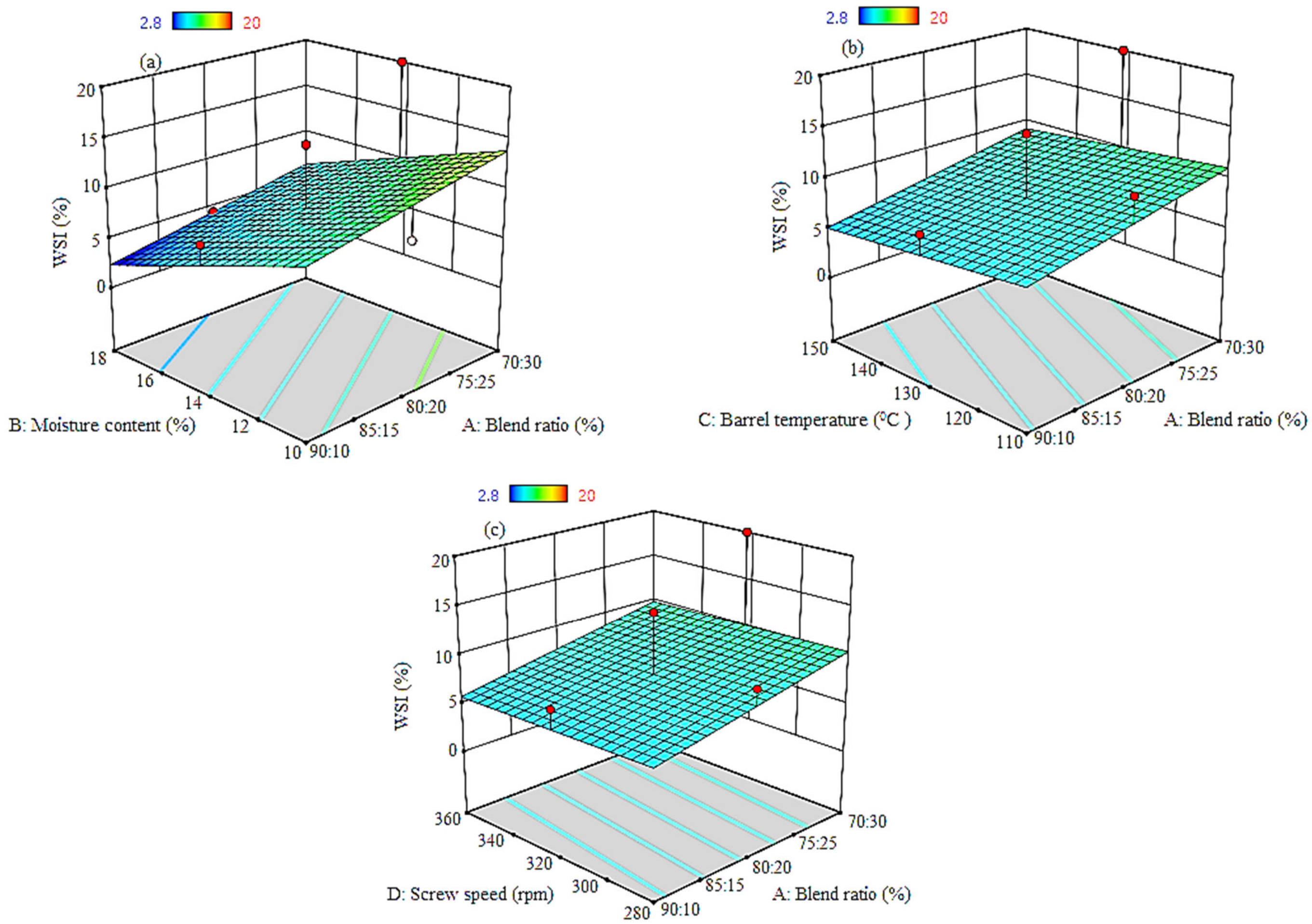

Figure 3. 3D response surface plot of water solubility index against (**a**) blend ratio versus moisture content, (**b**) blend ratio versus barrel temperature, (**c**) blend ratio versus screw speed.

3.1.4. Total Color (TC)

An increase in BR, MC, BT, and SS had no significant effect ($p > 0.05$) on TC, as seen in Equation (10), and Figure 4a–c depicts that BR, BT, and SS had a negative effect on TC while MC had a positive effect. The minimum and maximum TC 36.85 and 45.89 were obtained at the same BR of 75:25, 12% MC, and SS of 300 rpm but BT of 140 and 120 °C, respectively, as shown in Table 2. The no significant difference ($p > 0.05$) in TC was observed across the processing variables, which was inconsistent with the finding of Cuj-Laines et al. [40], who recorded a significant rise in ΔE with a temperature increase from 110 to 190 °C due to Maillard reactions on carbohydrates and protein at higher temperatures resulting in darkening of products.

$$TC = 273 - 0.24BR + 1.09MC - 2.51BT - 0.462SS + 0.017BR^2 - 0.05MC^2 + 0.00970BT^2 + 0.00071SS^2 \quad (10)$$

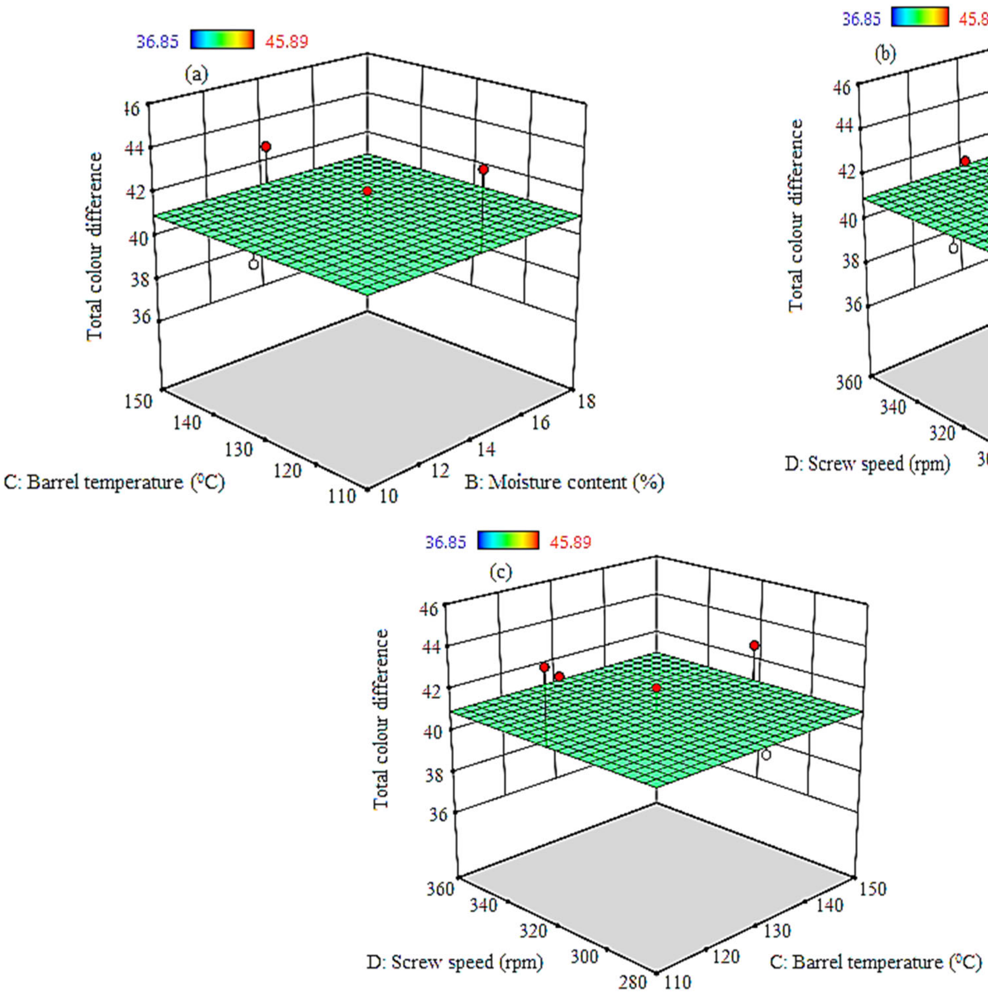

Figure 4. 3D response surface plot of total colour against (**a**) moisture content versus barrel temperature, (**b**) moisture content versus screw speed, (**c**) barrel temperature versus screw speed.

3.1.5. Hardness (HD)

HD values for the extrudates ranged between 1.987 N and 3.46 N (Table 2). Equation (11) shows the significant fitted quadratic equation of HD.

$$\begin{aligned} HD = \; & 2.31 - 0.1084BR + 0.1411MC - 0.0194BT + 0.3209SS + 0.2053BR * MC + 0.3293BR * BT \\ & -0.3027BR * SS + 0.2827MC * BT + 0.9208MC * SS - 0.2522BT * SS + 0.7086BR^2 \\ & +0.3036MC^2 + 0.2671BT^2 + 0.3481SS^2 \end{aligned} \quad (11)$$

The quadratic Equation (11) depicts that BR and BT had a negative effect on HD, but MC and SS had a positive effect on HD. The ANOVA (Table 6) showed that the interaction of MC × SS was significant in the quadratic regression ($p < 0.05$) terms for the model. The response surface plots of the HD in Figure 5a,b showed a decrease in HD with an increase in cowpea proportion of the BR up to 20% and an increase in BT. HD equally increased with an increase in MC and SS, as shown in HD Figure 5a,c. At a constant MC, an increase in the cowpea proportion of the BR resulted in a gradual decrease from 90:10 to 80:20 of the HD. However, with a further increase in the cowpea proportion to 25%, there was a steep increase in HD. At a constant BR, an increase in MC increased HD. This was because of the reduction in expansion caused by the high MC. This observation was the same for a chickpea-based extrudate, according to Meng et al. [35].

Table 6. ANOVA for response surface models for hardness of extruded RTE snack.

Hardness (Quadratic)						
Source	**SS**	**DF**	**MF**	**F-Value**	***p*-Value**	
Model	3.09	14	0.2206	2.48	0.0459	significant
A-BR	0.0705	1	0.0705	0.7933	0.3872	
B-MC	0.1194	1	0.1194	1.34	0.2646	
C-BT	0.0023	1	0.0023	0.0254	0.8754	
D-SS	0.6179	1	0.6179	6.95	0.0187	
AB	0.0421	1	0.0421	0.473	0.507	
AC	0.1084	1	0.108	1.220	0.2869	
AD	0.0917	1	0.091	1.030	0.326	
BC	0.0799	1	0.079	0.899	0.358	
BD	0.8478	1	0.847	9.540	0.007	
CD	0.0636	1	0.063	0.715	0.410	
A^2	0.8608	1	0.860	9.680	0.007	
B^2	0.1580	1	0.158	1.780	0.202	
C^2	0.1223	1	0.122	1.381	0.259	
D^2	0.2078	1	0.207	2.34	0.147	
Residual	1.33	15	0.0889			
Lack of Fit	1.54	10	0.1543	2.71	0.1416	not significant
Pure Error	0.0384	5	0.0077			
Cor Total	4.42	29				

Abbreviations: BR = blend ratio (% of gram), MC = moisture content (% wet basis), BT = barrel temperature (°C), SS = screw speed (rpm).

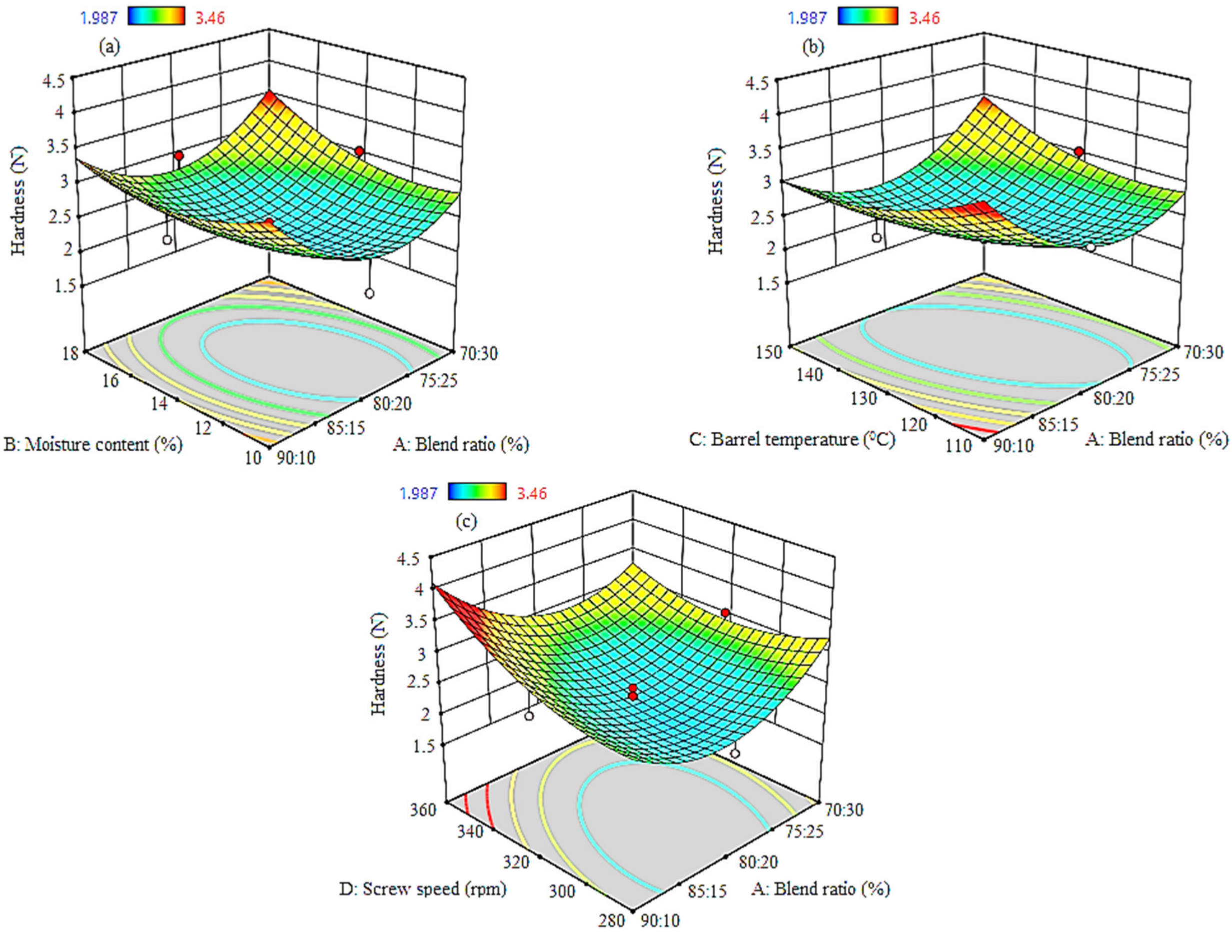

Figure 5. 3D response surface plot of hardness against (**a**) blend ratio versus moisture content, (**b**) blend ratio versus barrel temperature, (**c**) blend ratio versus screw speed.

At a constant BR, an increase in SS resulted in a gradual increase in hardness from 2.8 to 4.1 N, as shown in HD Figure 5c. This observation was against the result obtained by Reshi et al. [23] and Meng et al. [35]. They observed that an increase in SS reduced hardness because increased SS favors starch depolymerization and bubble generation; thus, the hardness of the extrudate decreases with increased SS. The interactive effect of the increase in BR × MC, BR × BT, MC × BT, and MC × SS resulted in an increase in hardness, while BT × SS and BR × SS decreased hardness, as shown in the regression Equation (11).

3.1.6. Bulk Density (BD)

The BD is crucial in the quality control of food products, especially RTES. It shows the volumetric expansion of the products and is used in the food sector to determine the design of packaging materials for food products [23,41]. The BD values for the extrudates ranged between 0.251 and 0.593 g/cm^3 (Table 2). The linear equation for BD is shown in Equation (12).

$$\text{Bulk density} = 456.25 + 45.05\text{BR} + 66.42\text{MC} - 33.37\text{BT} - 23.88\text{SS} \tag{12}$$

The linear regression Equation (12) shows that BR and MC had a positive effect on BD, while BT and SS had a negative effect. The ANOVA (Table 7) showed that there was no significant linear regression ($p > 0.05$) term in the model equation. The response surface plots of BD in Figure 6a showed an increase in BD with an increase in the cowpea proportion of the BR and MC, while a decrease in BD was observed due to the increase in SS and BT, as shown in BD Figure 6b,c. The increase of cowpea proportion in the BR led to an increase in the BD because cowpea is denser than rice. Cowpea contains higher protein and fiber content and therefore, an increase in cowpea resulted in an increase in B. A similar observation was reported by Altaf et al. [42] using rice and chickpea as base products. An increase in MC at a constant BR increases the BD because there is an increase in FMC during extrusion resulting in a reduction of the elastic property of the dough by condition of the melt. This reduced gel formation and decreased the expansion, thereby resulting in an increase in the BD of extrudates. Hagenimana et al. [43] observed that an increase in the MC of RTES increases the BD. The BD decreases when BT is increased due to the high stored energy for the flash-off of highly heated water provided by high temperature as extrudates exit the die. The rise in BT resulted in moisture loss at the exit which caused the extrudate to become lighter in weight, as reported by Köksel [44].

Table 7. ANOVA for response surface models for bulk density of extruded RTE snack.

Bulk density (Linear)						
Source	**SS**	**Df**	**MS**	**F-Value**	***p*-Value**	
Model	48746.54	4	12186.64	1.83	0.15584	not significant
A-BR	12177.02	1	12177.02	1.82	0.1889	
B-MC	26467.04	1	26467.04	3.96	0.0575	
C-BT	6680.01	1	6680.01	1.00	0.3267	
D-SS	3422.48	1	3422.48	0.5127	0.4806	
Residual	1.669×10^5	25	6675.52			
Lack of Fit	1.659×10^5	20	8293.01	40.34	0.0003	significant
Pure Error	1027.83	5	205.57			
Cor Total	2.156×10^5	29				

Abbreviations: BR = blend ratio (% of gram), MC = moisture content (% wet basis), BT = barrel temperature (°C), SS = screw speed (rpm).

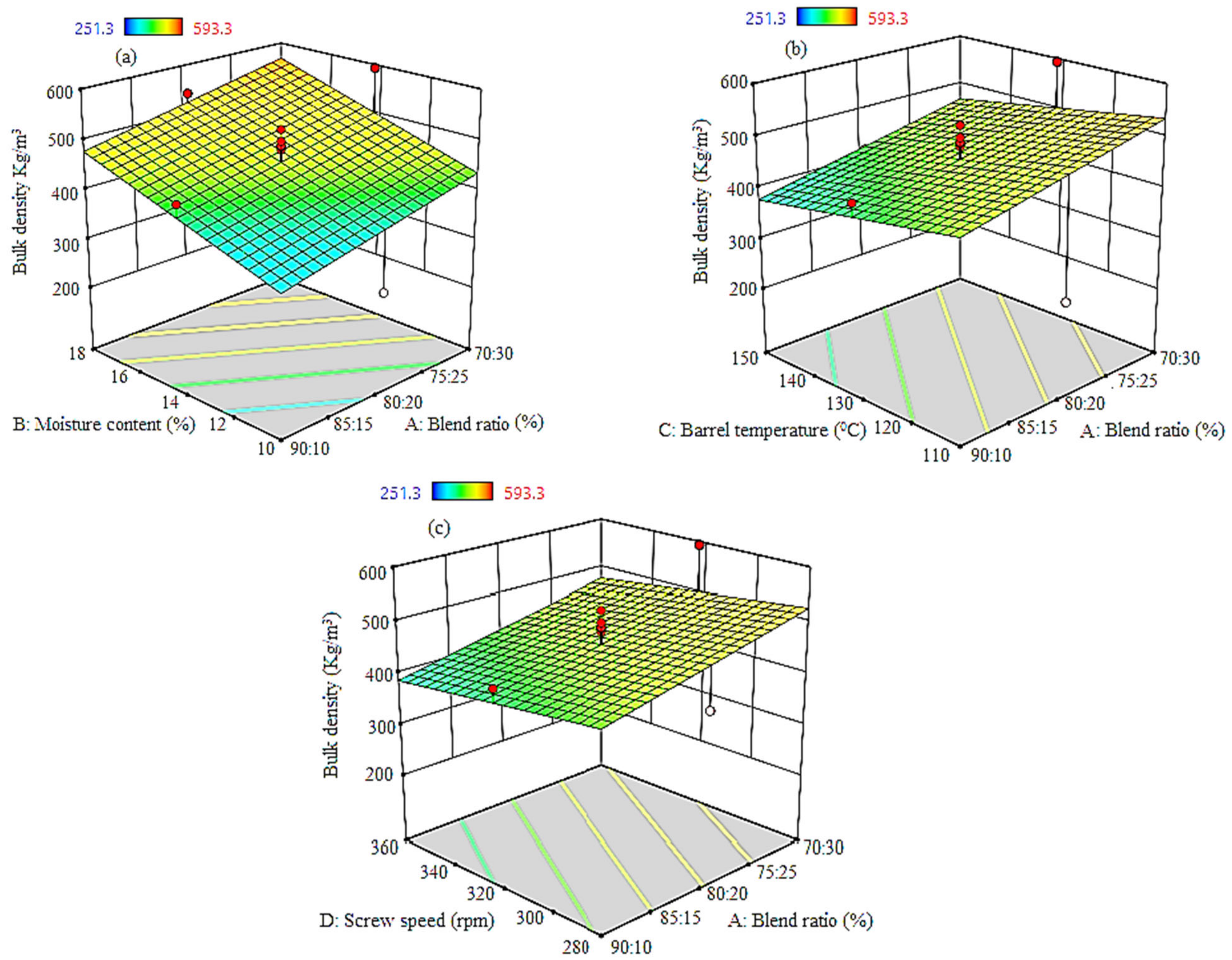

Figure 6. 3D response surface plot of bulk density against (**a**) blend ratio versus moisture content, (**b**) blend ratio versus barrel temperature, (**c**) blend ratio versus screw speed.

3.1.7. Expansion Ratio (ER)

The expansion ratio (ER) is the degree of puffiness of an extrudate when exiting the die due to the presence of the atmospheric air which leads to a quick flash-off of internal moisture [23,41]. ER ranged between 2.26 and 3.06 mm (Table 2). Equation (13) shows the linear equation of ER.

$$ER = 2.51 - 0.2308BR - 0.0692MC + 0.1592BT - 0.0375SS \quad (13)$$

The linear regression Equation (13) depicts that BR, MC, and SS had a negative effect on ER, whereas BT had a positive effect. The ANOVA (Table 8) showed that BR and BT were the significant linear ($p < 0.05$) regression terms for the model. The response surface plots for the expansion ratio in Figure 7a show a decrease in ER with an increase in cowpea proportion in the BR and an increase in MC. An increase in BT increased ER whereas an increase in SS led to a decrease in ER, as shown in Equation (13). An increase in the cowpea proportion of the BR reduces the ER (2.8–2.3 mm). An increase in the cowpea proportion of the BR increased the protein content, which influences the expansion of the starch polymer due to the generation of starch–protein complexes. As a result, the number of accessible molecules present in water for the creation of bubbles is reduced, and expansion is restricted, as observed by de Mesa et al. [45], with Pandey et al. [37] and Robin et al. [46] also confirming this finding. At a constant BR, an increase in MC reduced the ER because cowpea has a high water-holding capacity, which hinders moisture loss at the exit and suppressed bubble formation, resulting in a denser product with less puffiness, which is in agreement with Reshi et al. [23]. The increase in SS, on the other hand, led to a drop in the ER. The negative effect of increased SS on ER is ascribed to shorter residence time and inadequate temperature increase in the molten mix, as observed by Rathod and Annapure [24]. This obstructs expansion by flash vaporization at the die according to Kaur et al. [47].

Table 8. ANOVA for response surface models for expansion ratio of extruded RTES.

Expansion Ratio (Linear)						
Source	**SS**	**Df**	**MS**	**F-Value**	***p*-Value**	
Model	0.5088	4	0.1272	5.32	0.0031	significant
A-BR	0.3197	1	0.3197	13.36	0.0012	
B-MC	0.0287	1	0.0287	1.20	0.2838	
C-BT	0.1520	1	0.1520	6.35	0.0185	
D-SS	0.0084	1	0.0084	0.3527	0.5579	
Residual	0.5980	25	0.0239			
Lack of Fit	26.01	20	1.30	1.55	0.3314	not significant
Pure Error	0.0156	5	0.0031			
Cor Total	2.156×10^5	29				

Abbreviations: BR = blend ratio (% of gram), MC = moisture content (% wet basis), BT = barrel temperature (°C), SS = screw speed (rpm).

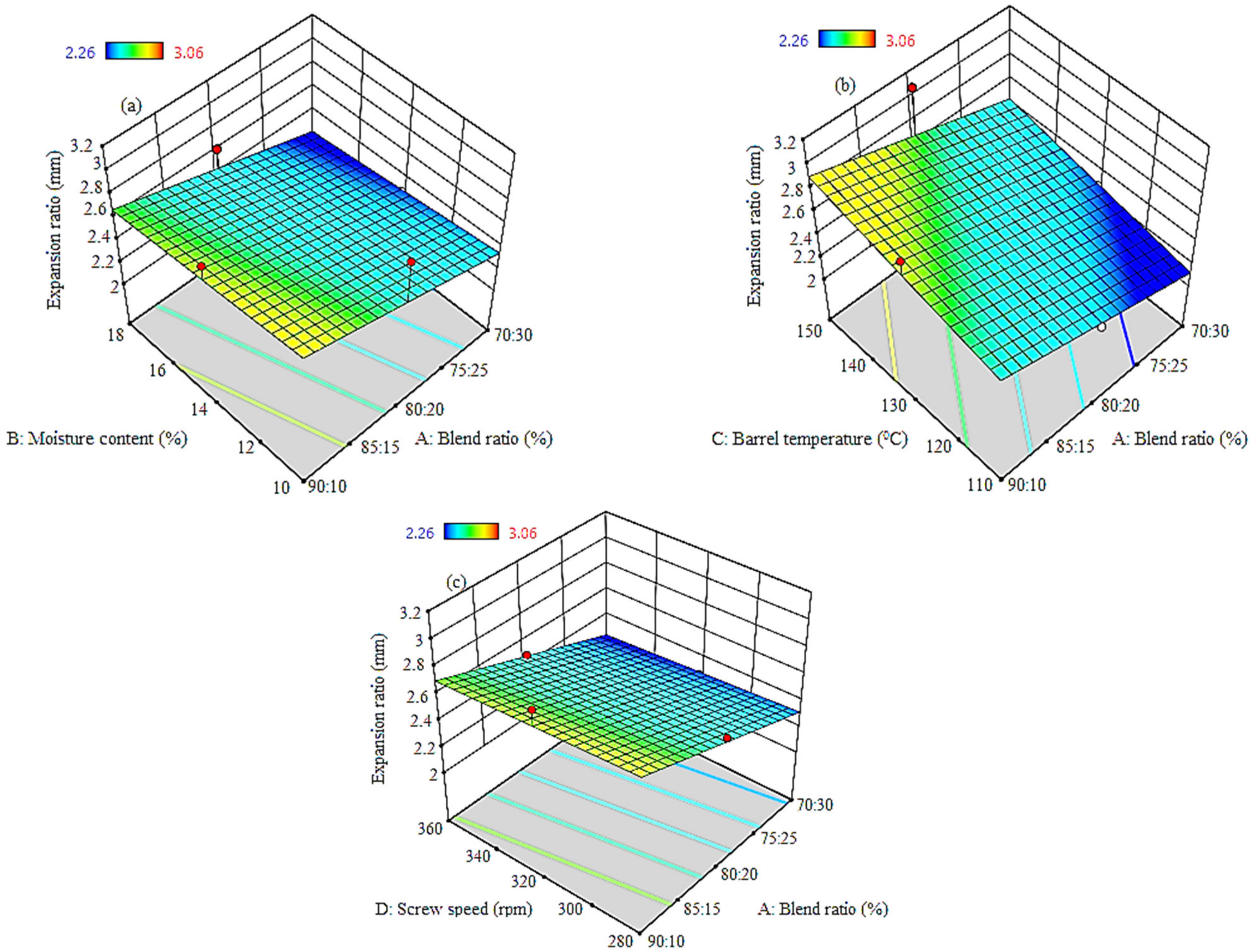

Figure 7. 3D response surface plot of expansion ratio against (**a**) blend ratio versus moisture content, (**b**) blend ratio versus barrel temperature, (**c**) blend ratio versus screw speed.

3.1.8. Overall Acceptance (OA)

The value for OA ranged between 5.2 and 8.1 for runs 4 to 23, respectively (Table 2). The linear equation for sensory property (OA) is given in Equation (14).

$$OA = 6.73 - 0.0917BR - 0.900MC + 0.19197BT - 0.4417SS \quad (14)$$

From Equation (14), it is shown that BR, MC, and SS had a negative effect on the OA of the extrudates, while only BT had a positive effect. The ANOVA (Table 9) shows that MC was the significant linear ($p < 0.05$) regression term for the model. The response surface plot for OA in Figure 8a,c showed that an increase in cowpea proportion of the BR resulted in an increase in MC. An increase in SS resulted in a decrease in OA. This is because an increase in the cowpea proportion of the BR reduced the expansion of the extrudates, thereby resulting in a reduction in OA. However, the increase in BT increased the OA of the extrudates by the panelist assessment, as shown in Figure 8b. This is because higher temperature increases the expansion of the extrudates and the consumer's preference is for a puffier snack. From the results, it was obvious that extrudates can be produced by using a rice–cowpea composite with good sensory acceptability. The extrudate with the BR 85:15, MC 12%, BT 140 °C, and SS 300 rpm had the most acceptable performance according to the panelists.

Table 9. ANOVA for response surface models for overall acceptance of extruded RTES.

Overall Acceptance (Linear)						
Source	**SS**	**Df**	**MS**	**F-Value**	***p*-Value**	
Model	6.30	4	1.58	3.23	0.0287	significant
A-BR	0.0504	1	0.0504	0.1034	0.7504	
B-MC	4.86	1	4.86	9.97	0.0041	
C-BT	0.2204	1	0.2204	0.4522	0.5075	
D-SS	1.17	1	1.17	2.40	0.1338	
Residual	12.19	25	0.4875			
Lack of Fit	11.45	20	0.5726	3.90	0.0687	not significant
Pure Error	0.7350	5	0.1470			
Cor Total	18.49	29				

Abbreviations: BR = blend ratio (% of gram), MC = moisture content (% wet basis), BT = barrel temperature (°C), SS = screw speed (rpm).

3.2. Optimization

The numerical optimization produces desirable physical qualities with improved nutritional properties of the RTES. The optimum values for the responses were obtained using the Design Expert 11.1.0.1 software [27]. The values were set at 83:17 BR, 10.3% MC, 150 °C BT, and 307.1 rpm SS, with a desirability index of 0.737 on a scale of 0 to 1. (Figure 9).

The significance difference between the proximate and mineral composition of the RTES and raw materials was evaluated. The results of the proximate composition and mineral composition of the raw materials (broken rice and cowpea flour) and the optimized RTES are presented in Tables 10 and 11. From the results presented in Table 11, it was revealed that sodium increased significantly ($p < 0.05$) for the optimized snack, mainly due to the introduction of salt (NaCl), while the iron, phosphorus, manganese, and copper of the optimized RTES were decreased. This may be due to the variety of materials used, the MC, and the BT range. Table 12 shows the regression values of all the process parameters with WAI having the highest value of 0.706.

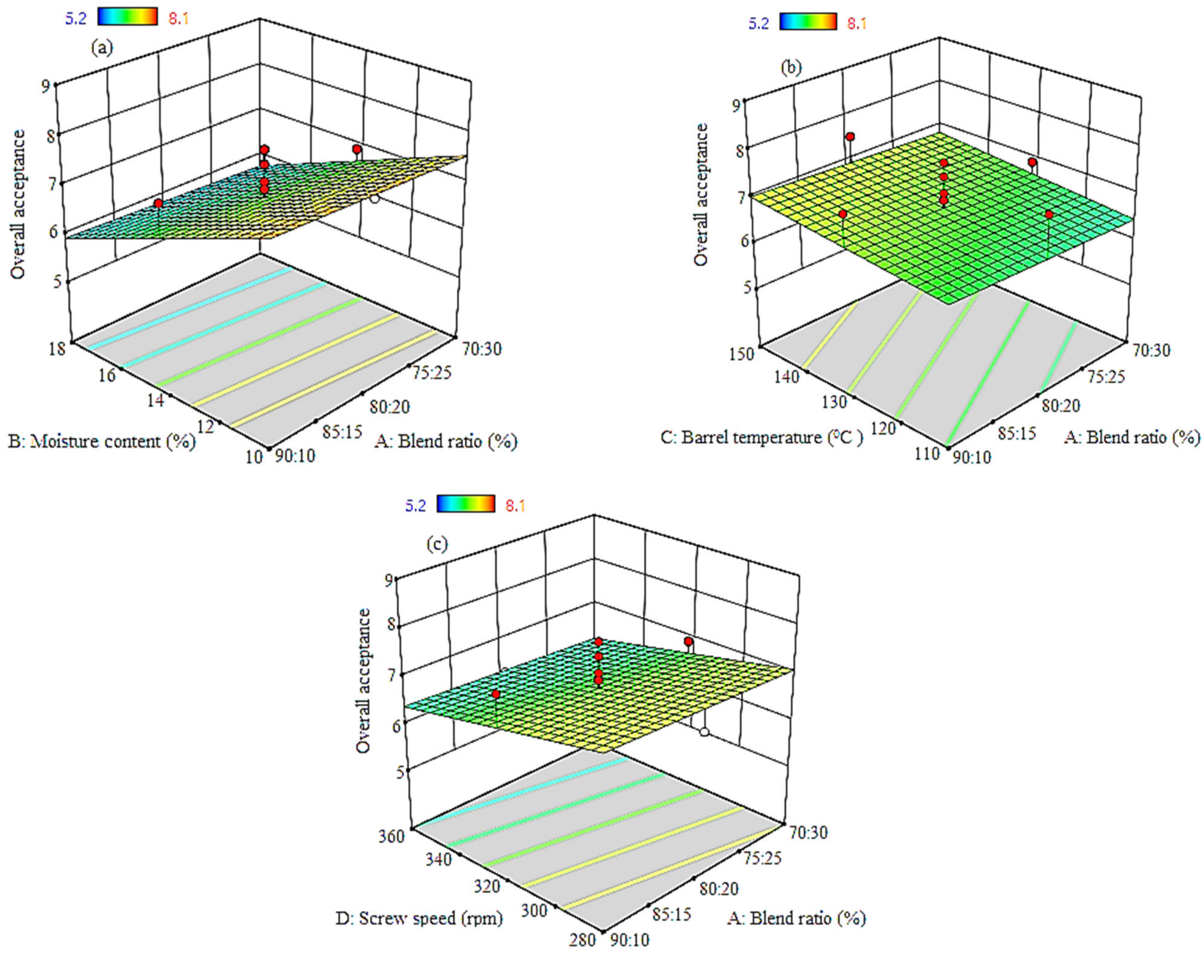

Figure 8. 3D response surface plot of overall acceptance against (**a**) blend ratio versus moisture content, (**b**) blend ratio versus barrel temperature, (**c**) blend ratio versus screw speed.

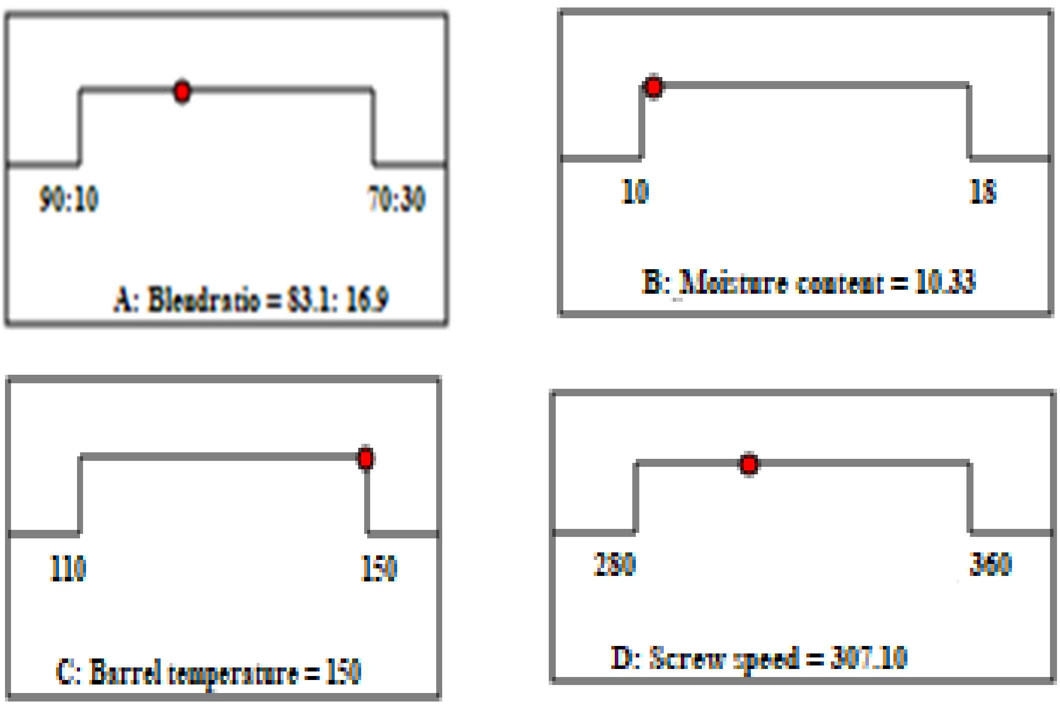

Figure 9. Proximate and minerals of the raw materials and optimized snack.

Table 10. Proximate composition of optimized snack and the raw materials.

Samples	MC (%)	CP (%)	TA (%)	CF (%)	CFAT (%)	CHO (%)
Rice flour	10.1 ± 0.02 [c]	13.11 ± 0.01 [b]	4.68 ± 0.01 [c]	2.96 ± 0.06 [b]	8.56 ± 0.01 [c]	60.54 ± 0.10 [b]
Cowpea flour	7.98 ± 0.01 [b]	24.48 ± 0.03 [c]	4.01 ± 0.01 [b]	2.49 ± 0.01 [a]	7.94 ± 0.03 [b]	53.11 ± 0.05 [a]
Optimized extrudate	5.99 ± 0.04 [a]	6.73 ± 0.01 [a]	0.96 ± 0.02 [a]	3.04 ± 0.02 [b]	2.60 ± 0.04 [a]	80.70 ± 0.01 [c]

MC = moisture content, CP = crude protein, TA = total ash, CF = crude fiber, CFAT = crude fat, CHO = carbohydrate. Values are given as mean ± standard deviation. Values with different superscripts are significantly different at ($p < 0.05$).

Table 11. Mineral composition of optimized snack and the raw materials before extrusion.

Samples	Fe (mg/100kg)	P (mg/100kg)	Mn (mg/100kg)	Cu (mg/100kg)	Na (mg/100kg)
Rice flour	0.46 ± 0.012 [b]	110.89 ± 0.19 [c]	0.07 ± 0.00 [b]	0.078 ± 0.00 [a]	0.02 ± 0.00 [a]
Cowpea flour	0.53 ± 0.042 [c]	106.57 ± 1.27 [b]	0.06 ± 0.00 [b]	0.8 ± 0.00 [b]	0.02 ± 0.00 [a]
Optimized extrudate	0.41 ± 0.07 [a]	16.21 ± 0.03 [a]	0.02 ± 0.00 [a]	0.06 ± 0.01 [a]	23.44 ± 0.04 [b]

Fe = iron, P = phosphorus, Mn = manganese, Cu = copper, Na = sodium. Values are given as mean ± standard deviation. Values with different superscripts are significantly different at ($p < 0.05$).

Table 12. Regression table.

Regression	SME	WAI	WSI	TC	HD	BD	ER	OA
SD	8.90	2.2345	3.77	2.42	0.2982	81.70	0.1547	0.6982
R^2	0.4902	0.7958	0.2393	0.4216	0.6984	0.2261	0.2497	0.3408
Mean	77.44	3.78	8.07	40.97	2.64	456.25	2.51	6.73
Adj. R^2	0.4086	0.6053	0.1176	0.0000	0.4169	0.1022	0.3733	0.2354
C.V %	11.59	6.21	46.77	5.92	11.31	17.91	6.16	10.37
Pred. R^2	0.2038	0.1570	−0.0912	−0.0702	−0.6999	−0.1869	0.2058	0.0115
PRESS	3147.57	3.41	510.53	182.37	7.52	2.556E + 05	0.8791	18.28
Adeq.prec.	8.0482	7.2765	4.7607	NA	5.1122	5.0581	7.8659	6.3150

Abbreviations: SME = specific mechanical energy ($\frac{Wh}{kg}$), BD = bulk density ($\frac{kg}{m^3}$), ER = expansion ratio (mm), HD = hardness, WAI = water absorption index (g/g), WSI = water solubility index (%), TC = total color (ΔE) and OA = overall acceptance.

4. Conclusions

The physicochemical qualities of twin-screw extruded cereal-based snacks were affected by the extrusion parameters studied (BR, BT, MC, and SS). The results obtained suggested that SS and MC affect SME. BR, SS, and MC affect HD, while WSI is affected by BR, MC, BT, and SS; only BR and BT influence ER and only MC influences OA. The optimal conditions were BR (83:17), MC (10.3%), BT (150 °C), and SS (307.1 rpm) with a combined desirability of 0.737 on a scale of 0–1. The addition of cowpea into the broken rice mix for the development of RTES improved the dietary fiber and overall acceptability, with a value of 6.73 on a 9-point hedonic scale. The MC was observed to have the highest impact on the response parameters and should be kept between the range of 10.3 and 12%. Further investigation should be conducted into the quality of the developed RTES, and shelf-life studies should be conducted.

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