

Optimization of extrusion variables for the production of extruded snacks from mung bean (*Vigna radiata*) flour

Azih, S. S.^{1*}, Kajihausa, O. E.¹, Adebowale, A. A.¹ and Adegunwa, M. O.²

¹Department of Food Science and Technology, Federal University of Agriculture, P. M. B 2240, Abeokuta, Ogun State, Nigeria.

²Department of Hospitality and Tourism, Federal University of Agriculture, P. M. B 2240, Abeokuta, Ogun State, Nigeria.

*Corresponding author. Email: azihsoftchukwusandra@gmail.com; Tel: +2347033099209; ORCID: 0000-0003-0659-9002.

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Received 5th February 2024; Accepted 24th February 2024

ABSTRACT: This study investigated the effects of temperature (70, 75 and 80°C), screw speed (130, 140 and 150 rpm) and feed moisture content (55, 60 and 65%) on the protein, expansion ratio, bulk density, water absorption capacity, lightness and hardness of mungbean extruded snacks. The Box Behnken design of Response Surface Methodology was used to generate seventeen experimental runs having different combinations of the process variables. Standard laboratory procedures were used to evaluate the six responses. The regression coefficients and the 3D surface plot that explored the relationship between the extrusion variables and the responses were developed. The extrusion variables were optimized by choosing the desired goal for the responses. The amino acid contents of the optimized snack were analyzed and the sensory acceptability was rated using a 9-point hedonic scale. The values of protein, expansion ratio, water absorption capacity, bulk density, lightness and hardness ranged from 16.27 - 17.08%, 1.55-1.90, 5.29-6.52 g/g, 0.19-0.40 g/ml, 22.59-30.70 and 199.93-256.64 N, respectively. An increase in temperature and screw speed significantly ($p < 0.05$) increased the expansion ratio and water absorption capacity of the snack while the bulk density, lightness and hardness of the snacks decreased. An increase in feed moisture significantly ($p < 0.05$) increased the hardness, bulk density and lightness of the snack while the expansion ratio of the snacks decreased. The optimal processing condition obtained was temperature (75.59°C), screw speed (142.41 rpm) and feed moisture (55.74%). The optimized snack contained all the essential amino acids. The highest sensory score for the optimized snack was the taste (7.33) while the lowest was the colour (5.17). In conclusion, an organoleptically acceptable extruded snack was produced from mung bean using the optimized process condition.

Keywords: Expansion ratio, extrusion, functional properties, Response Surface Methodology (RSM),

INTRODUCTION

Snacks such as cookies, cakes, pies and popcorn, among others are relied upon in developing countries to meet the physiological needs of the populace, particularly children, therefore, they contribute an important part of the consumers' daily nutrient and calorie intake (Hunter and Mattes, 2020; Almoraie *et al.*, 2021). The contemporary snacks that are regularly consumed are produced from cereals; they are high in carbohydrates and fat, therefore they have dense energy content but are nutritionally poor in terms of protein, vitamins and mineral content (Patil *et*

al., 2017). The poor nutritional quality of snacks can be improved upon by adding animal protein (which could be beyond the income of the poor) or adding cheaper and more available plant protein sources, such as legumes which could improve the nutritional profile of snacks (Patil *et al.*, 2017)

Mung bean (*Vigna radiata*) is a legume considered one of the lesser-known and underutilized legumes in Nigeria (Onwurafor *et al.*, 2014). According to Nair *et al.* (2013), mung bean has great potential for becoming an industrial

food raw material. This is because mung bean is an excellent source of vitamins, minerals, protein and essential amino acids (Ganesan and Xu, 2018; Zou *et al.*, 2019). Also, the high starch content of mungbean qualifies it as a good raw material for the production of noodles and extruded snacks due to its acceptable functional properties (Zou *et al.*, 2019; Wang *et al.*, 2021; Sahu *et al.*, 2022)

Snacks can be processed by different methods and techniques such as toasting, flaking, roasting, extruding, and baking. According to Gulati *et al.* (2015) and Pardhi *et al.* (2019), extrusion is one of the commonly adopted processing techniques by the food industry to develop novel snack products. Extrusion combines mixing, cooking, kneading, shearing, shaping and forming of dough at high temperatures and short time to obtain a desired product (Singh *et al.*, 2017). These processes lead to the denaturation of protein, gelatinization of starch and the inactivation of enzymes and anti-nutrients (Amer and Rizk, 2022), thereby improving the organoleptic properties, functional properties and shelf life of the snack, whilst retaining the heat-sensitive nutrients, natural colours and flavours of extruded snacks.

Convenience, good quality and other physical characteristics of snacks, such as expansion, hardness and bulk density, are important parameters that affect the consumption and acceptability of snack products (Devi *et al.*, 2013; Omwamba and Mahungu, 2014; Prabhakar *et al.*, 2017). These physical parameters are dependent on the processing variables maintained during processing. For extruded snacks, the temperature of the barrel, the feed moisture and the screw speed used during extrusion are among the important extrusion variables (Mesquita *et al.*, 2013; Oke *et al.*, 2013; Chiu *et al.*, 2013). Response surface methodology (RSM) which is a statistical-mathematical tool that uses quantitative data in an experimental design to determine and solve multivariate equations (Selvarathi *et al.*, 2019), has been successfully used for developing, improving and optimizing food production processes. Therefore, studying the effects of varying the levels of extrusion parameters (barrel temperature, screw speed and feed moisture) on the functional property of mung bean extruded snacks using RSM will ensure that the optimal extrusion variables required for the production of a convenient ready-to-eat extruded snack with improved nutritional values and desirable functional properties are obtained (Charunuch *et al.*, 2014).

MATERIALS AND METHODS

Source of raw materials

Mung bean (*Vigna radiata*) seeds (brown variety) were purchased from Ogbete market in Enugu State, Nigeria while other ingredients such as salt, sugar and margarine

were purchased from a local market in Abeokuta, Ogun State, Nigeria.

Preparation of mung bean flour

Mung bean flour was produced by modifying the method described by Offia-Olua and Madubuike (2015). The mung bean seeds were cleaned (to remove stones, twigs and debris), then it was soaked in water at 25°C for 12 hours. The water was drained and the seeds were dried in an oven (Model DHG 9101-S.N) at 65°C for 5 hours. The seeds were dry milled into flour which was sieved using a 50 mesh size sieve and packaged in airtight and water proof nylon packaging materials.

Experimental design

A Box Behnken design of Response Surface Methodology (RSM) was used in this study. Three independent variables (extrusion temperature, screw speed and feed moisture) with three levels each were used. The three independent variables in the process were extruder temperature (70, 75 and 80°C), screw speed (130, 140 and 150 rpm) and feed moisture (55, 60 and 65%). The range of these variables was established by preliminary tests. A total of seventeen combinations as shown in Table 1 were generated for the three independent variables with five center points (the level of combination in which the value of the un-coded variable was zero). The data were analyzed by analyzing the regression coefficients, applying the coefficient of determination (R^2) and response plots.

Preliminary study

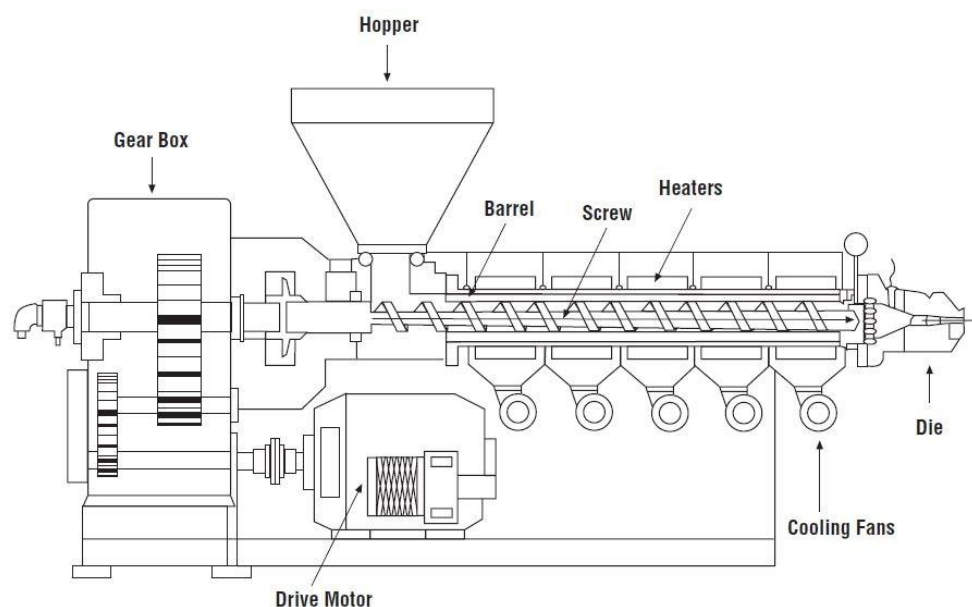
Extrusion trials were carried out using the mung bean flour at a range of extruder conditions. Temperature ranged from 70 to 120°C, screw speed ranged from 100 to 160 rpm while feed moisture ranged from 40 to 70%. Based on the products with the most desirable attributes and expansion, the extrusion conditions were selected. Temperature was set at 70 to 80°C, feed moisture was set at 55 to 65% while screw speed was set at 130 to 150 rpm. The schematic of the extruder used is shown in Figure 1.

Extruded snacks production

The extruded snack was prepared using a modified method as described by Ogunmuyiwa *et al.* (2016). Approximately 200 g of mung bean flour was mixed with 1 g of salt, 30 g of sugar and varied amounts of water. The dough obtained was kneaded for 2 minutes before the

Table 1. Experimental design combinations for extrusion variables.

Experimental runs	Barrel Temp (°C)	Screw speed (rpm)	Feed moisture (%)
1	70	150	60
2	75	140	60
3	75	140	60
4	75	140	60
5	75	140	60
6	80	130	60
7	75	130	65
8	80	140	55
9	75	140	60
10	75	150	65
11	80	150	60
12	80	140	65
13	70	140	55
14	75	130	55
15	70	140	65
16	70	130	60
17	75	150	55

**Figure 1.** Schematic of the single screw extruder used.

dough was fed into a single screw extruder with a screw length of 37 cm and screw diameter of 1.85 cm. The extruder composed of two sections, the transmission and the die zones. The barrel zone was heated with band heater. The dough was fed into the hopper for extrusion to be carried out. The extrusion variable for the seventeen samples was set as shown in Table 1. The extrudates were cut into pieces of approximately 2 cm each and then oven-dried (Model DHG 9101-S.N) at 60°C for 1 hour. The

snacks was cooled to room temperature after drying before being packaged in an air-tight and water-proof packaging material and then kept for further analysis. The pictures of the samples produced are shown in Figure 2.

Determination of crude protein

The crude protein content of the flour and the extruded



Figure 2. Pictures of mung bean flour and extruded snacks samples.

snack sample was determined using semi-micro Kjeldahl technique as described by AOAC (2019). Approximately 1 g of the samples was put into a Kjeldahl flask and 3 g of hydrated cupric sulphate (catalyst) was added into the flask. Then, 20 ml of anhydrous sodium sulphate and 1 g of concentrated sulphuric acid (H₂SO₄) was added to digest the sample. The flask and its content were swirled occasionally until the liquid was clear and free from black or brown colour. The clear solution was cooled and made up to 100 ml after which an aliquot of 5 ml was collected for distillation. Five (5) ml of 60% sodium hydroxide solution was distilled using a distillation flask. Boric acid indicator absorbed the ammonia which was distilled off and this was titrated with 0.1 ml hydrochloric acid (HCl). The titre value or the end point at which the colour changes from green to pink was taken. The crude protein was calculated thus:

$$\text{Percentage crude protein} = \frac{0.001410 \times 6.25 \times 25 \times T \times 100}{W \times 5} \dots\dots (1)$$

Where: W = Weight of sample and T = Titre value.

Determination of expansion ratio (ER)

The method described by Sahu *et al.* (2022) was used to determine the expansion ratio. A vernier calliper was used to measure the cross-sectional diameter of the extrudates. The expansion ratio was calculated as the cross-sectional diameter of the extrudate divided by the cross-sectional diameter of the die opening. The expansion ratio values were obtained from 10 random samples for each extrusion condition.

$$\text{Expansion ratio} = \frac{\text{Extrudate diameter}}{\text{die diameter}} \dots\dots\dots (2)$$

Determination of hardness

The hardness was determined using a universal texture analyzer with a 50 kg load cell and a probe. The test speed was 102 mm/min and for each treatment ten extrudates were assayed (Mesquita, 2013). Hardness of the extruded

snacks was examined by using a Texture Analyzer (TMS-PRO, Food Technology Corporation, USA). The compression probe (38 mm diameter aluminum cylinder) was applied to measure the compression force required for samples breakage which indicates hardness. Hardness of extruded snacks was expressed in Newton (1 N = 101.97 g force).

Determination of lightness (L*)

The lightness of the mung bean flour and mung bean extruded snacks samples were determined by using a colorimeter as described by Mesquita *et al.* (2013). The images of the 17 extruded snack samples were captured, processed and their results were displayed on the colorimeter (Minolta Co. Ltd., Osaka, Japan). The lightness of the samples were quantified using the L*a*b* (CIELAB scale, D50/2- light D50, viewing angle 2). The L* value which measured the lightness/brightness of the samples, from 100 indicating perfect white to 0 for black.

Determination of bulk density

The bulk density of the extruded snack samples were determined by the method described by Obadina *et al.* (2013). A measuring cylinder which had been weighed previously was filled to the 100 ml mark with the sample. The bottom of the cylinder was tapped gently but repeatedly on a laboratory bench until there was no further reduction of the sample level. The cylinder with the sample was weighed. The formula underneath was used to calculate the bulk density of the samples:

$$BD \text{ (g/cm}^3\text{)} = \frac{W_2 - W_1}{V} \times 100 \dots\dots\dots (3)$$

Where: BD = bulk density in g/cm³, W₁ = weight of empty cylinder (g), W₂ = weight of cylinder + sample (g), and V = Volume of cylinder occupied by the sample (cm³)

Determination of water absorption capacity (WAC)

The water absorption capacity of the extruded snack sample was determined using the method described by Chandra *et al.* (2014). One (1) gram of the sample was dispensed into a weighed centrifuge tube with 10 ml of distilled water and mixed thoroughly. Then the mixture was allowed to stand for 1 hour before being centrifuged at 3500 rpm for 30 minutes. The unabsorbed water was decanted and then the tube was inverted over an adsorbent paper to drain the sample dry. The water absorption capacity was calculated as:

$$WAC = \frac{\text{Volume of water used} - \text{volume of free water}}{\text{weight of sample used}} \times 100 \dots\dots (4)$$

Optimization of extrusion variables

Response surface methodology (RSM) was employed to investigate the effect of extrusion conditions on the functional properties of mung bean flour extruded snack (Shahmohammadi *et al.*, 2016). Extruder temperature (70, 75 and 80 °C), screw speed (130, 140 and 150 rpm) and feed moisture (55, 60 and 65%) were the independent variables while expansion ratio (ER), bulk density (BD), hardness (H), protein content (PC), water absorption capacity (WAC) and lightness (L*) of the extruded snacks were the dependent variables/responses that was used to select the optimal conditions that gave the mung bean flour extruded snacks with desirable quality attributes. The responses obtained were presented graphically as overlaid contour maps where the curves of the required responses were plotted while other variables were fixed (Charunuch *et al.*, 2014). The optimization of the extrusion processes aimed at finding the barrel temperature, screw speed and feed moisture that will maximize the expansion ratio, protein content, water absorption capacity and lightness of the snacks while minimizing its bulk density and hardness of the snacks.

Amino acid profile of mung bean extruded snacks

This was determined using the method described by Benitez (1989). The sample was dried to constant weight, defatted, hydrolyzed, evaporated in a rotary evaporator and loaded into the Applied Biosystems PTH Amino Acid Analyzer as follows:

Sample preparation (defatting) for amino acid analysis

The method of AOAC (2010) was used for amino acid analysis. About 500 mg of the sample was put in extraction thimble and extracted for 15 hours in soxhlet extraction apparatus.

Nitrogen determination

A small amount (115 mg) of sample was weighed, wrapped in whatman filter paper (No.1) and put in the Kjeldahl digestion flask. Concentrated sulphuric acid (10 ml) was added. Catalyst mixture (0.5 g) containing sodium sulphate (Na₂SO₄), copper sulphate (CuSO₄) and selenium oxide (SeO₂) in the ratio of 10:5:1 was added into the flask to facilitate digestion. Six pieces of anti-bumping granules were added. The flask was then put in Kjeldahl digestion apparatus for 3 hours until the liquid turned light green. The digested sample was cooled and diluted with distilled water to 100 ml mark in standard volumetric flask. Aliquot (10 ml) of the diluted solution with 10 ml of 45%

sodium hydroxide was put into the Markham distillation apparatus and distilled into 10 ml of 2% boric acid containing 4 drops of bromocresol green/methyl red indicator until about 70 ml of distillate was collected. The distillate was then titrated with standardized 0.01 N hydrochloric acid to grey coloured end point.

$$\% \text{ Nitrogen} = \frac{(a-b) \times 0.01 \times 14 \times V \times 100}{W \times C} \dots\dots\dots(5)$$

Where: a = Titre value of the digested sample, b = Titre value of blank sample, v = Volume after dilution (100ml), W = Weight of dried sample (mg), C = Aliquot of the sample used (10 ml), 14 = Nitrogen constant in mg.

Hydrolysis of samples

Thirty (30) mg of the defatted sample was weighed into glass ampoules. About 7 mls of 6 mol/L HCL was added and oxygen expelled by passing nitrogen gas into the samples. The glass ampoules was sealed with a Bunsen flame and placed in an oven at 105±5°C for 22hours, and then allowed to cool. The content was filtered and the filtrate evaporated to dryness at 40°C under vacuum in a rotary evaporator. Each residue was dissolved with 5 ml of acetate buffer (pH 2.0) and stored in a plastic specimen bottle kept in the deep freezer.

Loading of the hydrolysate into analyzer

The amount loaded was 60 microlitre. This was dispensed into the cartridge of the analyzer. The analyzer is designed to separate and analyze free acidic, neutral and basic amino acids of the hydrolysate.

Method of calculating amino acid values

An integrator attached to the Analyzer calculated the peak area proportional to the concentration of each of the amino acids.

Sensory evaluation

The optimized extruded snack samples was served to 30 trained panelists; all graduate students of the Department of Food Science and Technology, Federal University of Agriculture, Abeokuta. The sample was coded with a random letter and number and the panelists were provided with a questionnaire and asked to rate the samples for appearance, taste, aroma, texture (chewiness) and over all acceptability. A 9-point Hedonic scale was used where 1 represents extremely dislike and 9 represents extremely liked.

Statistical analysis

Data generated were subjected to statistical analysis using a one-way analysis of variance (ANOVA), the processing conditions were optimized using response surface methodology from design expert version 8. Duncan Multiple Range Test from SPSS (statistical package for social sciences) version 17.0 was used to separate the means of the quality attributes as scored by the sensory panelists at 0.05 significance level.

RESULTS AND DISCUSSION

The protein content of the extruded snacks ranged from 16.27 to 17.08% as shown in Table 2. According to Table 3, barrel temperature (A) and screw speed (B) had a significant negative linear effect on the protein content of the samples while feed moisture had a significant positive linear effect on the protein content of the samples. The interaction between temperature and feed moisture (AC) and temperature and screw speed (AB) also had a significant negative effect on the protein content of the samples. All three factors were significant for protein content for both the linear (A, B, C) and quadratic model (A², B², C²). The R² of 0.9870 indicates that the regression predictions fit the data. According to 3D contour plots in Figure 3, increase in temperature and screw speed led to a decrease in protein content of the samples; while an increase in feed moisture led to an increase in protein content. The reduction in protein content as temperature and screw speed increased is due to Malliards/non-enzymic browning which is a complex reaction between the carbonyl group of reducing sugars and free amino groups to yield melanoidins (brown nitrogenous polymers) (Xiang *et al.*, 2021; Liu *et al.*, 2022). High temperatures and low feed moisture favours Malliards reaction (Semedo and Silveira, 2022).

The expansion ratio of the extruded snacks ranged from 1.55 to 1.90 as shown in Table 2. The minimum value of the expansion ratio (1.55) was observed at sample 15 with the combination of 70°C, 140 rpm and 65% feed moisture while the maximum value of expansion ratio (1.90) was observed at sample 8 with the combination of 80°C, 140 rpm and 55% moisture. According to Table 3, Barrel temperature (A) and screw speed (B) had a significant positive linear effect on the expansion ratio of the samples while feed moisture had a significant negative linear effect on the expansion ratio of the samples. All three factors were significant for expansion ratio for the linear (A, B, C) model while for the quadratic model (A²) was significant. The R² of 0.9495 indicates that the regression predictions fit the data. According to 3D contour plots in Figure 4, increase in temperature and screw speed led to an increase in expansion ratio of the samples; while an increase in feed moisture reduced the expansion ratio. The

Table 2. Protein content and functional properties of mung bean extruded snacks.

S/No	Temp (%)	S.S (rpm)	F.M (%)	Protein Content	B.D (g/ml)	E.R	WAC (g/g)	L*	Hardness (N)
1	70	150	60	17.02	0.36	1.66	6.03	30.25	235.08
2	75	140	60	16.62	0.27	1.75	5.92	28.09	214.74
3	75	140	60	16.65	0.27	1.75	5.92	28.09	214.78
4	75	140	60	16.63	0.27	1.75	5.92	28.09	214.78
5	75	140	60	16.62	0.25	1.75	5.91	28.09	214.74
6	80	130	60	16.48	0.28	1.73	5.44	23.43	219.70
7	75	130	65	16.91	0.31	1.64	6.00	29.42	237.18
8	80	140	55	16.27	0.19	1.90	5.29	22.59	199.93
9	75	140	60	16.62	0.27	1.75	5.92	28.09	214.76
10	75	150	65	16.66	0.30	1.71	5.81	26.69	218.15
11	80	150	60	16.32	0.20	1.86	5.22	23.02	200.01
12	80	140	65	16.46	0.23	1.80	5.43	24.13	215.43
13	70	140	55	17.03	0.33	1.64	5.82	30.12	238.18
14	75	130	55	16.56	0.28	1.71	5.99	28.99	224.95
15	70	140	65	17.08	0.40	1.55	6.50	30.02	244.58
16	70	130	60	17.05	0.39	1.56	6.51	30.70	256.64
17	75	150	55	16.48	0.25	1.72	5.49	25.69	219.37

Table 3. Regression coefficients for protein content and functional properties of mung bean extruded snacks.

Parameters	Protein	ER	BD	WAC	L*	Hardness
Intercept	16.62	1.75	0.27	5.918	28.09	214.76
A	-0.331*	0.11*	-0.073*	-0.438*	-3.550*	-17.43*
B	-0.064*	0.039*	-0.02*	-0.174*	-0.840*	-8.23*
C	0.095*	-0.034*	0.023*	0.146*	0.440	4.11*
A ²	0.078*	0.01*	0.02*	-0.0876	-1.050*	-6.36*
B ²	0.018*	0.038	0.02*	-0.0302	-0.240	6.74*
C ²	0.010*	-0.017	-	-0.0653	-0.160	3.41*
AB	-0.033*	-	-0.01*	0.065*	-0.035	-0.47*
AC	-0.035	-	-	-0.14*	0.240	2.27
BC	0.04	0.015	-	0.0775	0.140	-3.36*
Mean	16.67	1.72	0.29	5.83	27.41	222.53
R ²	0.9870	0.9495	0.9835	0.9810	0.9689	0.9858

Values with * are significantly different at $p < 0.05$. **Key:** A = Temperature, B = Screw speed, C = Feed moisture, ER = Expansion ratio, B.D = Bulk density, WAC = Water Absorption Capacity, L* = Lightness.

expansion ratio of an extruded snack is related to the extent of puffing of a snack. For expansion to occur during extrusion, the pressure differential between the extruder die and atmosphere must be high in order to cause flash evaporation of water from the dough as it exits the die and subsequently expansion of the product (Mesquita *et al.*, 2013). The expansion ratio of the mung bean extruded snack samples increased with increasing temperature and screw speed; this is due to the high temperature and shear which increased the super heating of water in the dough which therefore increased the puffing/expansion of the

snacks (Korkerd *et al.*, 2016). Also, lower feed moisture increased the expansion ratio of the mung bean extruded snacks. This could be due to lower moisture content of the dough which made it more viscous therefore leading to a higher difference in pressure as the extruded dough exited the die; this higher difference in pressure is what caused better expansion of the dough as it exited the die (Singh *et al.*, 2007). Tumwine and Asiimwe (2019) indicated that the expansion ratio of extruded cassava snacks increased with an increase in temperature.

As shown in Table 2, the bulk density of the extruded

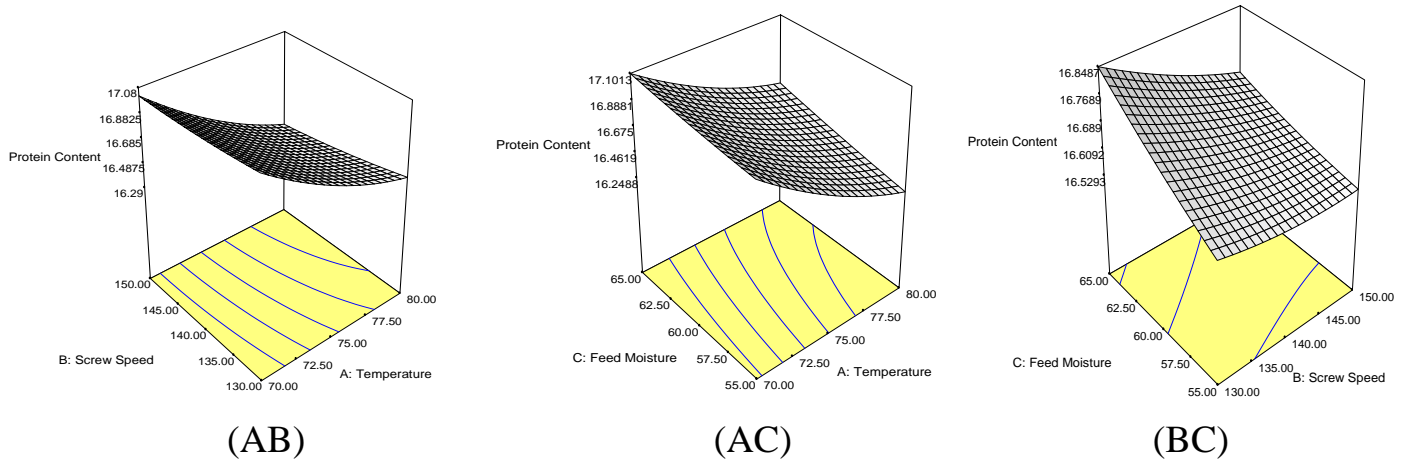


Figure 3. (AB)- Effect of barrel temperature and screw speed on the protein content of samples; **(AC)-** Effect of barrel temperature and feed moisture on the protein content of samples; **(BC)-** Effect of screw speed and feed moisture on the protein content of samples.

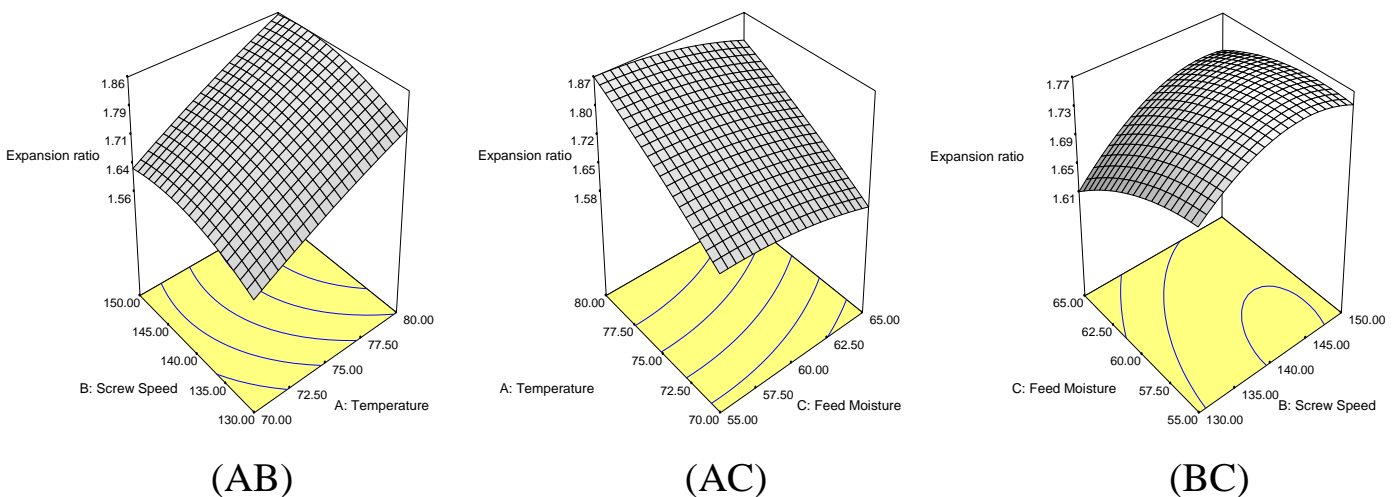


Figure 4. (AB)- Effect of barrel temperature and screw speed on the expansion ratio of samples; **(AC)-** Effect of barrel temperature and feed moisture on the expansion ratio of samples; **(BC)-** Effect of screw speed and feed moisture on the expansion ratio of samples.

snacks ranged from 0.19 to 0.40 g/ml. The minimum value of the bulk density (0.19 g/ml) was observed at sample 8 with the combination of 80°C, 140 rpm and 55% feed moisture while the maximum value (0.40 g/ml) of bulk density was observed at sample 15 with the combination of 70°C, 140 rpm and 65% moisture. According to Table 3, barrel temperature (A) and screw speed (B) had a significant negative linear effect on the bulk density of the samples while feed moisture had a significant positive linear effect on the bulk density of the samples. All three factors (temperature, screw speed and feed moisture) were significant for the linear (A, B, C) model while for the quadratic model (A^2 and B^2) were significant. For the interactions, temperature and screw speed (AB) was

significant. The R^2 of 0.9835 indicates that the regression predictions fit the data. According to 3D contour plots in Figure 5, increase in temperature and screw speed led to a decrease in bulk density of the samples; while an increase in feed moisture increased the bulk density of the extruded snacks. The increase in bulk density as moisture increased could be attributed to the plasticizing effect that moisture has on the dough. When the feed moisture is high, the elasticity of the dough is reduced thereby reducing the expansion and increasing the bulk density of the snack (Sahu *et al.*, 2022). A snack with a high bulk density indicates that the inner layer of the product is dense because it has less air pockets or pores due to lower expansion (Filli *et al.*, 2013). An increase in temperature

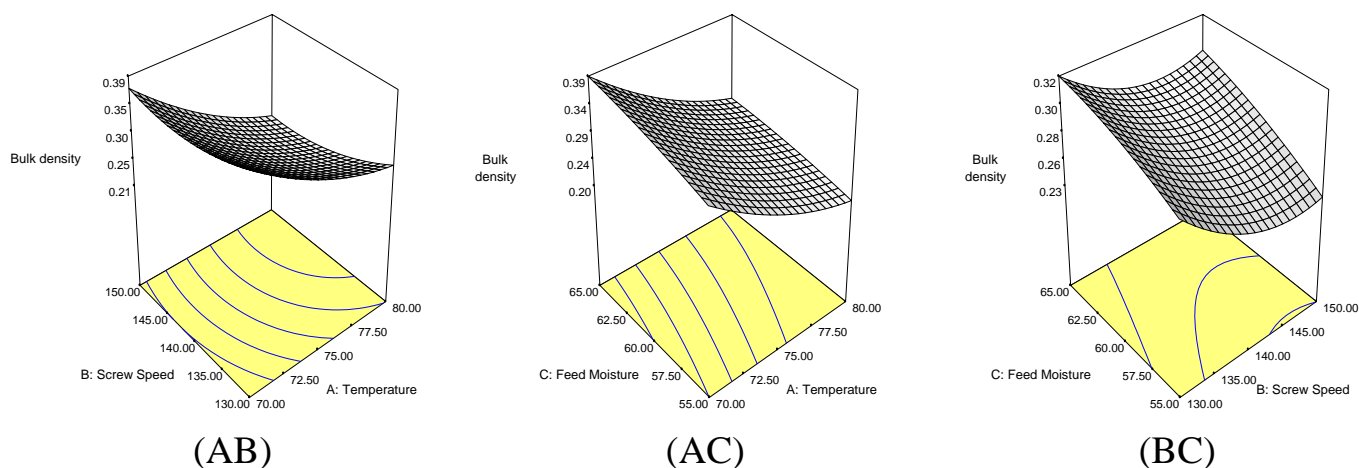


Figure 5. (AB)- Effect of barrel temperature and screw speed on the bulk density of samples; **(AC)-** Effect of barrel temperature and feed moisture on the bulk density of samples; **(BC)-** Effect of screw speed and feed moisture on the bulk density of samples.

led to a decrease in bulk density. This reduction in bulk density could be attributed to the high temperature increasing the expansion of the snack and therefore leading to low bulk density (Kaur *et al.*, 2013). Structural breakdown of protein and starch in the high shear environment could also lower the bulk density of extruded snacks (Wani and Kumar 2016). Obradović *et al.* (2018) explained that lower temperatures led to an increase in the bulk density of extruded snacks made from corn and carrot powder blends.

The water absorption capacity (WAC) of the extruded snacks ranged from 5.22 to 6.51 g/g. The minimum value of the water absorption capacity (5.22 g/g) was observed at sample 11 with the combination of 80°C, 150 rpm and 60% feed moisture while the maximum value of water absorption capacity (6.51 g/g) was observed at sample 16 with the combination of 70°C, 130 rpm and 60% moisture as shown in Table 2. According to Table 3, the barrel temperature (A) and screw speed (B) had a significant negative linear effect on the water absorption capacity of the samples while feed moisture had a significant positive linear effect on the water absorption capacity of the samples. The interaction between temperature and feed moisture also had a significant negative effect on the water absorption capacity of the samples. For the linear models, temperature, screw speed and feed moisture (A,B,C) were significant. Also the interactions between temperature and screw speed (AB), and temperature and feed moisture (AC) was significant. The R^2 of 0.9810 indicates that the regression predictions fit the data. According to 3D contour plots in Figure 6, increase in temperature and screw speed led to a decrease in the water absorption capacity of the samples; while an increase in feed moisture increased the water absorption capacity. Water absorption capacity (WAC) measures the amount of water that starch can

absorb or the measure of the volume occupied by the starch of the extrudate after swelling in excess water (Filli *et al.*, 2013). When the water absorption capacity of a snack sample is high, then it indicates the presence of larger hydrophilic molecules that bind water particles (Pardhi *et al.*, 2019). The water absorption capacity of the extruded snacks decreased as the temperature and screw speed increased. This can be attributed to the enhanced degradation of starch which reduces its water holding capacity. However when the temperature and screw speed is lower, there is more undamaged polymer chains and a greater availability of hydrophilic groups for binding more water thereby resulting in higher water absorption capacity (Ding *et al.*, 2005). The water absorption capacity of the snack also reduced as the feed moisture reduced. This reduction could be attributed to the high shearing of the elastic dough in the barrel therefore causing more mechanical damage to the dough, more starch breakdown and subsequently low water absorption index (Sobukola *et al.*, 2012). However when the feed moisture is increased, the dough is less elastic and softer, the dough is therefore not subjected to extreme shearing thereby leading to less mechanical damage, less starch breakdown and a higher water absorption capacity (Pardhi *et al.*, 2019).

The colour of extruded snack sample plays a significant role in its appearance and consumers' acceptability of the product (Idowu and Aworh, 2017). The lightness of the extruded snacks ranged from 22.59 to 30.70 as shown in Table 2. The minimum value of the lightness (22.59) was observed at sample 8 with the combination of 80°C, 140 rpm and 55% feed moisture while the maximum value of lightness (30.70) was observed at sample 16 with the combination of 70°C, 130 rpm and 60% moisture. According to Table 3, barrel temperature (A) and screw speed (B) had a significant negative linear effect on the

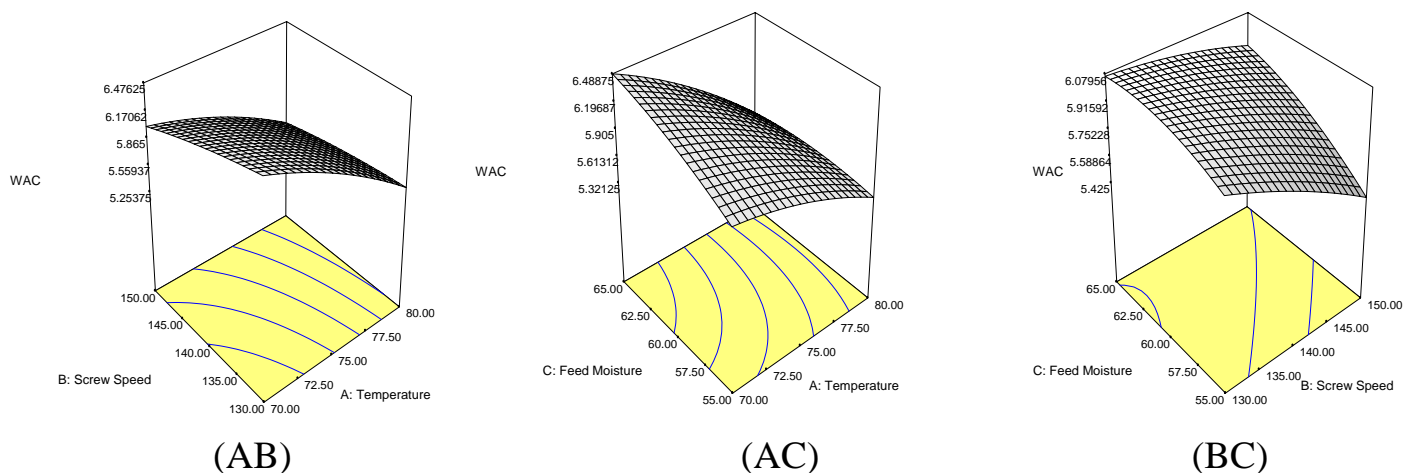


Figure 6. (AB)- Effect of barrel temperature and screw speed on the water absorption capacity; **(AC)-** Effect of barrel temperature and feed moisture on the water absorption capacity; **(BC)-** Effect of screw speed and moisture on the water absorption capacity.

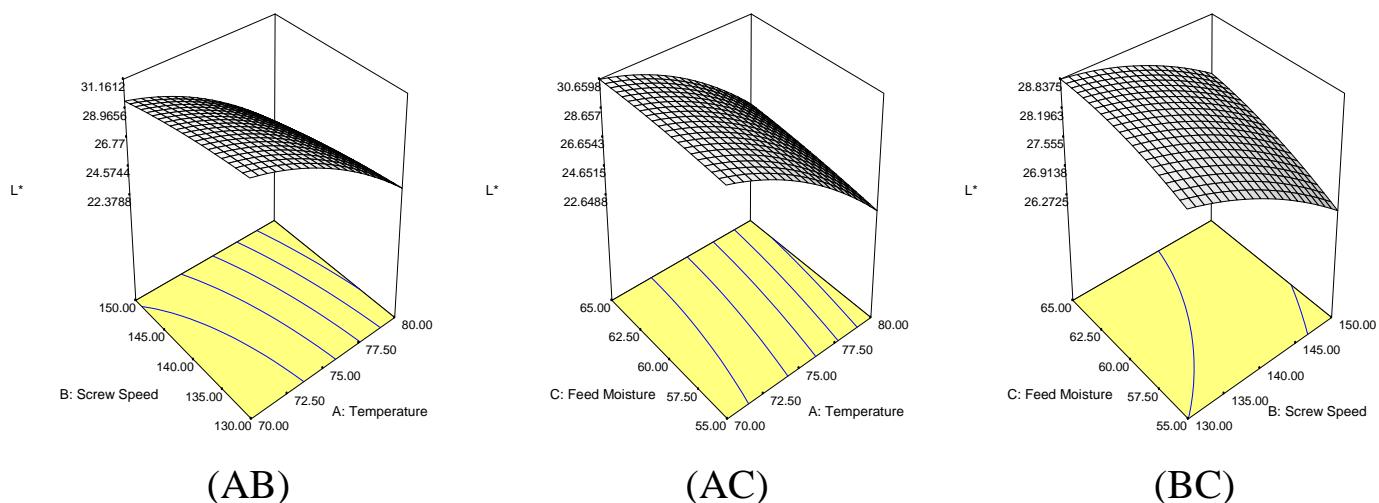


Figure 7. (AB)- Effect of barrel temperature and screw speed on the L* of samples; **(AC)-** Effect of barrel temperature and feed moisture on the L* of samples; **(BC)-** Effect of screw speed and moisture on the L* of samples.

lightness of the samples while feed moisture had a significant positive linear effect on the lightness of the samples. The interaction between temperature and feed moisture, temperature and screw speed also had a significant negative effect on the lightness of the samples. For the linear models, temperature and screw speed (A and B) were significant while A² was significant for the quadratic model. The interaction between temperature and feed moisture was also significant for lightness. The R² of 0.9689 indicates that the regression predictions fit the data. According to 3D contour plots in Figure 7, increase in temperature and screw speed led to an decrease in lightness of the samples. The darker colour of the products

was due to malliarids browning. Lysine and other reactive amino acids which are present in the mung bean reacted with reducing sugars and favoured by a high temperature and screw speed led to the darkening of the products thereby reducing its lightness (Kaur, 2013). Lower moisture content also favoured malliarids browning which reduced the lightness of the extruded snacks. do Carmo *et al.* (2019) also reported a reduction in lightness with a high temperature and lower feed moisture in pea and oat meal extruded snacks.

The hardness of a snack is the average force required for the probe to penetrate into the sample (Boakye *et al.*, 2023). The higher the value of the maximum force applied,

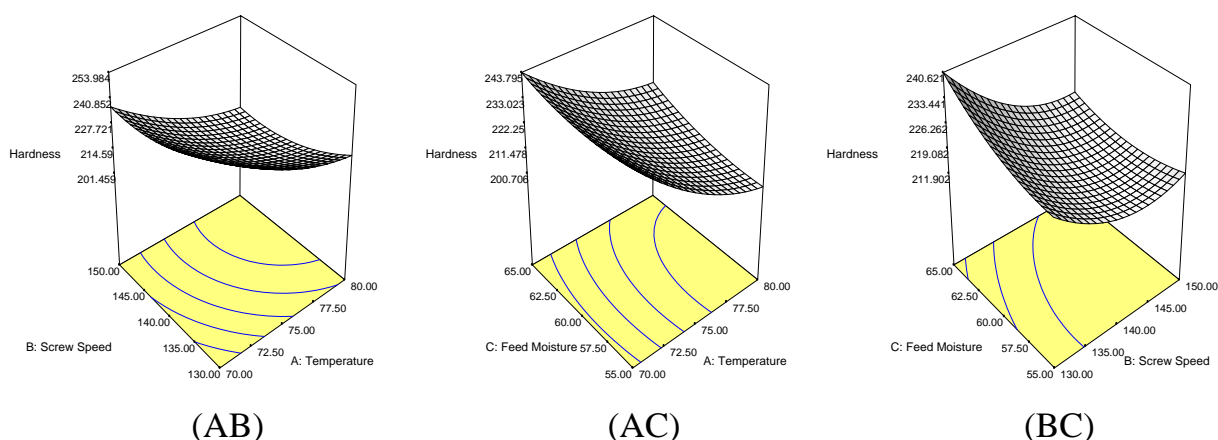


Figure 8. (AB)- Effect of barrel temperature and screw speed on the hardness of samples; (AC)- Effect of barrel temperature and feed moisture on the hardness of samples; (BC)- Effect of screw speed and moisture on the hardness of samples.

the harder the product (Ogunmuyiwa *et al.*, 2016). According to Table 2, the hardness of the extruded snacks ranged from 199.93 to 256.64 N. The minimum value of hardness (199.93 N) was observed at the combination of 80°C, 140 rpm and 55% feed moisture while the maximum value of hardness (256.64 N) was observed at the combination of 70°C, 130 rpm and 60% feed moisture. Barrel temperature (A) and screw speed (B) had a significant negative linear effect on the hardness of the samples while feed moisture had a significant positive linear effect on the hardness of the samples. Temperature, screw speed and feed moisture were significant for the linear and for the quadratic models. The interaction between feed moisture and screw speed (BC) was significant for hardness. The R^2 of 0.9858 indicates that the regression predictions fit the data. According to 3D contour plots in Figure 8, increase in temperature and screw speed led to a decrease in hardness of the samples; while an increase in feed moisture increased the hardness of the extruded snack; this could be attributed to the plasticizing effect of high feed moisture which limits expansion of the snacks and subsequently increases the bulk density and hardness of the extruded snack sample (Boakye *et al.*, 2022). Seth *et al.* (2015) reported that increased moisture increased the hardness of the extruded snack developed from blends of yam-corn-rice. Amer and Rizk (2022) also reported that higher feed moisture reduced expansion, thereby making their ginger fortified corn extrudate harder than other samples. However, when temperature and screw speed is increased and the feed moisture was decreased, there was a reduction in the hardness of the samples due to a higher expansion ratio of the snack which reduced its bulk density and subsequently reduced the hardness of the snack density (Sahu *et al.*, 2022). Also, there is a high correlation

between bulk density and hardness of extruded snacks; a product with a lower bulk density means that the product will be less hard while a high density product means that the product will be harder (Meng *et al.*, 2010).

Optimization of the extrusion variables

For optimization of the extrusion variables, the hardness and bulk density were minimized while the water absorption capacity, protein content, lightness and expansion ratio were maximized in order to generate a set of extrusion variables that will yield a crisp and highly proteineous snack. Three sets of extrusion conditions with their desirability were generated by the RSM software. The conditions with the highest desirability of 0.702 were selected for producing the optimized sample. Therefore, the extrusion conditions selected for the production of the extruded snacks is (temperature- 75.59°C, screw speed- 142.41 rpm, feed moisture- 55.74%) (Table 4).

The optimised mung bean extruded snacks contained all the essential amino acids leucine (6.48 g/100g), lysine (4.24 g/100g), Iso-leucine (3.99 g/100g), phenylalanine (3.81 g/100g), tryptophan (0.87 g/100g), valine (4.80 g/100g), methionine (1.18 g/100g), histidine (2.11 g/100g) and threonine (3.86 g/100g) as shown in Table 5.

The sensory evaluation scores for the optimized samples of the mung bean extruded snacks is shown in Table 6. The mean of the scores of 30 panelists showed that the optimized snack sample was rated 6.45 for appearance, 5.17 for colour, 5.87 for texture, 7.33 for taste and 6.77 for overall acceptability. The taste had the highest score while the colour had the lowest score. The lower scores for colour could be attributed to the deep brown colour of the samples which many panelists disliked while

Table 4. Barrel temperature, screw speed and feed moisture generated after optimization.

Parameters	1 (Selected)	2	3
Temperature	75.59	75.82	75.54
Screw speed	142.41	141.03	139.40
Feed moisture	55.74	56.48	55.00
Protein content	16.50	16.50	16.50
Bulk density	0.23	0.24	0.24
Expansion ratio	1.80	1.80	1.79
Water Absorption capacity	5.95	5.93	5.90
Hardness	210.647	210.093	21.304
L*	26.90	26.96	27.12
Desirability	0.702	0.699	0.695

Table 5. Amino acid profile of mung bean extruded snacks.

Amino acid	Mung bean extruded snacks (g/100g protein)
Leucine*	6.48
Lysine*	4.24
Iso-leucine*	3.99
Phenylalanine*	3.81
Norleucine	-
Tryptophan*	0.87
Valine*	4.80
Methionine*	1.18
Proline	3.55
Arginine	6.19
Tyrosine	3.27
Histidine*	2.11
Cystine	0.91
Alanine	4.17
Glutamic acid	10.75
Glycine	3.56
Threonine*	3.86
Serine	3.98
Aspartic acid	9.56

*Indicates essential amino acids.

Table 6. Sensory analysis of mung bean extruded snacks (optimized sample).

Optimized sample	Score
Appearance	6.45±0.86
Colour	5.17±1.15
Texture	5.87±1.31
Taste	7.33±0.96
Overall acceptability	6.77±0.77

the low score for texture could be attributed to the hardness of the sample. The overall acceptability indicated that the snacks were slightly liked by the panelists.

Conclusion

In conclusion, increasing temperature and screw speed significantly reduced the protein content, bulk density, hardness, water absorption capacity and lightness of the samples while expansion ratio of the samples increased. Higher feed moisture significantly reduced the expansion ratio of the snacks thereby increasing its bulk density and hardness. The optimum extrusion variables obtained were temperature of 75.59°C, Screw speed of 142 rpm and feed moisture of 55.74%. The optimized samples contained all the essential amino acids and were moderately liked by the sensory panelists.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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