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Development and Optimization of the Physical and Functional Properties of Extruded Products

Leticia Amoakoah Twum[1*] and Akash Pare[2]

[1]Biotechnology and Nuclear Agriculture Research Institute (BNARI), Ghana Atomic Energy Commission, P.O.Box LG80 Legon, Kwabenya, Accra, Ghana.
[2]Indian Institute of Food Processing Technology, Thanjavur-613005, Tamil-Nadu, India.

Authors' contributions

This work was carried out in collaboration between both authors. Both authors designed the study, performed the statistical analysis, wrote the protocol, wrote the first draft of the manuscript and managed the analyses of the study and the literature searches. Both authors have read and approved the final manuscript.

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ABSTRACT

Aim: To optimize extruded products made from flour blends and studying the effect of ingredients on physical and functional properties of the extrudates.

Study Design: Design Expert mixture model.

Place and Duration of Study: Indian Institute of Food Processing Technology, Thanjavur, Tamil-Nadu - India. Nov, 2016- May, 2017.

Methodology: Yellow corn, brown rice, soybean and pineapple pomace were mixed to obtain 20 runs using the Stat-Ease (Design-Expert 10, 2016, Minneapolis, MN, USA) statistical software and extruded at a constant extruder parameter.

Results: Statistical analyses of the results showed that, the ingredients used for the study had an effect on the physical and functional properties of the final extruded products. The brown rice, yellow corn and pineapple pomace had effect on most of the physical and functional parameters

**Corresponding author: E-mail: amoakoahtwum@yahoo.com, amoakoahtwum@gmail.com;*

analyzed. The inclusion of soybean was seen to be significant in increasing the solubility of the final product

Conclusion: The study will help facilities the utilization of soybean in extrusion cooking and improve the uses of yellow corn, brown rice and pineapple pomace in the food industry.

Keywords: Extrusion cooking; soybean; yellow corn; brown rice pineapple pomace.

1. INTRODUCTION

Extrusion is one of the efficient food technology used in making snacks, breakfast cereals and pet food. Through high temperature and high pressure, many novel sensory characteristics of food have been developed. The thermomechanical cooking during extrusion creates some specific structural changes in the chemical structure of the food making them develop unique sensory and structural attributes [1]. The principle behind extrusion cooking yields significant functional and physicochemical changes in ingredients used for the process. The process included mixing, heating, shearing and drying at a preset manufacturing parameters [2, 3]. Extrusion technology allows for the production of various food products through a combination of process parameters and the use of variety of recipes and raw materials, to yield varying texture, shape, size, taste, etc. of food products [4,5,6]. Some extruded food products may include snacks, baby foods, breakfast/instant cereals, textured vegetable protein (Soybean protein) etc. Extrusion cooking has been reported to have little or no effect on the proximate composition of ingredients however the high temperature gelatinize starches and denatures protein which may cause changes in their pasting and functional properties [7]. Functional properties such as expansion ratio, bulk density, hardness and the water absorption index are mostly influenced by the process of extrusion technology. The expansion ratio mainly depends upon the temperature as an increase in temperature increases the screw speed with higher expansion ratio [8].

The effects of legumes on extruded product are more relevant on the nutritional rather than the physical properties [7,9,10]. Temperature and moisture had been reported to have an effect on starches. Extrusion cooking has been reported to have significant effect on physicochemical and functional properties of food that contain high carbohydrate content [11,12,13,14]. There are many research study on the effect of extruder parameters on extrudates but very sparse on the effect of ingredient on extrudates. This research study aimed at optimising extruded products made from flour blends and studying the effect of ingredients on physical and functional properties of the extrudates.

2. MATERIALS AND METHODS

2.1 Materials

2.1.1 Brown rice flour

Paddy brown rice (Nappillai Samba, a traditional rice variety from Tamil Nadu- India) was purchased from a local farm at Thanjavur, Tamil Nadu- India. The paddy rice was manually sorted to remove stones and other debris. The paddy was then de-husked using a Sheller (THU 35B 1999, Japan). The de-husked brown rice was milled using a commercial hammer mill into a 500 µm particle size. Brown rice flour was stored at 4°C until all analyses were performed.

2.1.2 Full fat soybean flour

Soybean (white variety) was purchased from a local supermarket in Thanjavur, Tamil Nadu- India. The soybean was sorted to remove all debris and washed under running water. The soybean samples were blanched for 30 mins to remove the beany flavour and bitterness from the bean. After blanching, the soybean samples were drained and put under running water to allow for easy dehulling and cooling. Dehulled samples were dried in a mechanical dryer (Everflow hot air oven, India) at 60ºC overnight. Dried soybean samples were milled into 500 µm particle size flour using an industrial hammer mill. Milled soybean flour was stored at 4ºC till all analyses were performed.

2.1.3 Pineapple pomace flour

Ripe pineapples were purchase from a local fruit shop at Thanjavur, Tamil Nadu- India. The pineapples were washed, peel using a sharp knife and cut into pieces. Using a Colloids Mill (KWSC, India), the cut pineapples were made into a liquid (smoothly). The liquid was passed through muslin to separate the pineapple juice from the pomace (Pulp). The pineapple pomace was tinny spread on a tray and dried using a conventional hot air oven dryer (Everflow hot air oven, India) at 40°C overnight. The dried pineapple pomace was milled into 500 µm particle size using an industrial hammer mill. Milled pineapple pomace flour was stored at 4°C until all analyse were performed.

2.1.4 Yellow corn flour

Commercial yellow corn flour was bought from a local supermarket at Thanjavur, Tamil Nadu-India and stored at 4°C until all analyse were performed.

2.2 Methodology

2.2.1 Formulation of the flour blends from the individual flour samples

Using the Stat-Ease (Design-Expert 10, 2016, Minneapolis, MN, USA) statistical software, 20 different blends were generated with the D-optimal mixture model. The maximum and minimum limits of the individual flour samples used for the blends are represented in Table 1. The individual runs for the flour blends are represented in Table 2.

Table 1. Composition limits of individual flour samples

Individual flour samples	Limits (%)	
	Maximum	Minimum
Yellow corn	60	40
Brown rice	40	20
Full fat soybean	30	20
Pineapple pomace	10	0

2.2.2 Extrusion cooking of the 20 blends

Twenty flour blends of yellow corn, brown rice, white soybean and pineapple pomace were used for the extrusion cooking according to the experimental design described in Tables 1 and 2. A co-rotation double screw extruder (KK lifestyle SLG 30, India) was used for the extrusion cooking. The extruder's set-up is as follows: 4 temperature zone barrels, screw length of 500 mm, and screw diameter of 30 mm with a die diameter of 3 mm. The temperatures of the barrels during extrusion were 30°C, 60°C, 90°C and 120°C. The temperature profile of the extruder was set up in order to reach these temperatures. Screw speeds used was 180 rpm. The die pressure was set at 20 MPa. The extruder was operated with a constant feed rate of about 12 kg h^{-1}. For every 1 kg of sample, 3% water was added. After extrusion, the extrudate was dried in an oven at 40 ± 3°C to reach a moisture content of about 7%.

2.2.3 Physical analyses of soybean based extruded product

2.2.3.1 Colour determination

A Hunter Lab colorimeter (Colour Flex EX Model, India) was used to determine colour values of the extruded product in terms of L*, *a** and *b** parameters. The extruded product was ground in a laboratory grinder and sieved to about 500 µm particle size prior to colour analysis.

2.2.3.2 Expansion ratio

The ratio of diameter of extrudate and the diameter of die was used to express the expansion of extrudate by the method described by [15].

$$\text{Expansion ratio} = \frac{\text{Diameter of the product} - \text{Diameter of die hole}}{\text{Diameter of die hole}} \times 100$$

2.2.3.3 Density

Twenty replicates of extrudate were randomly selected. The mass, length and diameter were taken and used to calculate the density [15,16]

$$\text{Density} = \frac{4 \times M}{\pi \times D^2 \times L}$$

Where M = mass, L= length and D= diameter of the cooled extrudate.

2.3 Functional and Physicochemical analyses of the Extruded Product

2.3.1 Moisture content

Briefly, about 2 g (M_o) of extruded product was weighed into a weighed dish previously heated to 130°C and cooled. The dish with the extruded sample was placed in the air-oven (Everflow, India) for 1 h at 130°C. The dish with the dried extruded samples was covered while still in the oven and then transferred into a desiccator to equilibrate. The cooled extruded sample was then weighed (M_1) and the moisture content calculated as follows [17]:

$$Moisture\ (\%) = \frac{M_0 - M_1}{M_0} \times 100$$

Table 2. Blends for the optimization of the extruded product

Samples code (run)	Yellow corn flour	Brown rice flour	Full fat soybean flour	Pineapple pomace powder
1	60	20	20	0
2	48	28	24	0
3	48	29	20	3
4	51	20	23	6
5	44	24	28	4
6	49	20	30	1
7	41	34	25	0
8	40	25	25	10
9	40	30	30	0
10	40	30	24	6
11	46	34	20	0
12	40	20	30	10
13	51	20	23	6
14	60	20	20	0
15	48	28	24	0
16	44	26	20	10
17	41	35	20	4
18	48	28	21	3
19	40	31	24	6
20	40	40	20	0

The figures were based on 100 g calculation. 1 % salt was added to each sample for taste

2.3.2 Bulk density

A calibrated centrifuge tube was weighed (W1) and filled with extruded product samples to the 5 ml mark by constant tapping until there was no further change in volume. The extruded product was weighed (W2) and the differences in weight were recorded. The bulk density of the extruded product was calculated by dividing the differences in weight by the volume [7].

2.3.3 Swelling and solubility index

The swelling power and solubility determinations were carried out based on method described by [18] with slight modifications. One gram of extruded product was weighed (on dry matter basis) into a previously weighed 40 ml capacity centrifuge tube and 40 ml of distilled water added. The suspension was stirred uniformly and gently to avoid excess force that might rapture the granules. The suspension was heated in a thermostatically controlled water bath (Everflow, India) at 85°C for 30 mins, with constant stirring. The tubes were removed from the water bath, wiped and allowed to dry and cool to room temperature. The tubes were centrifuged (Rota 4R-V/Fm, India) at 2200 rpm for 15 mins. The supernatants were poured into a weighed crucible and evaporated to dryness in an oven at 105ºC. The dried supernatant was weighed after cooling and the weight was used to calculate the solubility. The sedimented paste was weighed and the value used to calculate the swelling power.

2.3.4 Water absorption capacity (WAC)

WAC of the extruded product was determined using the method described [19] as modified by [20]. About 1.0 grams of the sample was dispersed in 10 ml distilled water and the suspension stirred using a magnetic stirrer for 5 mins. The suspension was centrifuged (Rota 4R-V/Fm, India) at 3500 rpm for 30 mins and the supernatant measured in a 10 ml graduated cylinder. The density of the water is taken as 1.0 g/cm^3. The WAC (%) was calculated as the difference between the initial volume of water added to the sample and the volume of the supernatant expressed in percentage.

2.3.5 pH

Two grams of the sample was mixed with 40 ml of distill water and allowed to stand for some time and stirred intermittently. The pH of the sample was determined using a pH meter (Everflow, India).

2.4 Statistical Analysis

Stat-Ease, (Design-Expert 10, 2016, Minneapolis, MN, USA) statistical software was used to generate the optimization runs for the experiment and data analysis of the extruded products.

3. RESULTS AND DISCUSSION

The results of the mean values of the 20 runs of the extruded product are presented in tables and figures below.

3.1 Physical Analyses of Extruded Product

The physical analyses of the extruded products made from different composition of the four flour blends are presented in Table 3 and Figs. 1- 7. The result show values at central point of the mixture model design.

The mean value for expansion ratio ranged between 1.16 and 2.87. Analyses of the mean values for the expansion ratio showed a non significant p-value for both ANOVA and LOF.

R^2 *value = 0.141* Final equation was *Y= 1.86*A +2.37*B +2.18*C +1.68*D*

(Where A= yellow corn, B= brown rice, C= full fat soybean flour D= pineapple pomace flour). Even though the R^2 is low the LOF value shows that the linear mixture model could be used as a good predictor. From the equation it could be deduced that the brown rice had influence on the expansion ratio at the central point of the

Table 3. The coefficient table of the physical properties of the extruded product for the mixture model with p-values

Response	Yellow corn (A)	Brown rice (B)	Full fat soybean (C)	Pineapple pomace (D)	AVOVA p-value	Lack of fit (LOF)	R^2
Expansion ration	1.86	2.37	2.18	1.68	N/S	N/S	0.141
Density	0.45	0.27	0.31	0.29	N/S	N/S	0.1541
Colour L value	67.56	62.24	66.16	57.97	S	NS	0.4132
Colour *a** value	7.22	7.94	8.22	12.01	S	N/S	0.4795
Colour *b** value	26.99	23.20	24.28	28.50	S	N/S	0.5266
pH value	6.59	6.59	6.46	5.60	S	N/S	0.7924
Hardness (Texture)	529.18	526.77	515.49	518.42	S	S	0.839

Mean values are coefficient values from the linear mixture model at the central point. N/S- not significant, S- significant where P=0.05

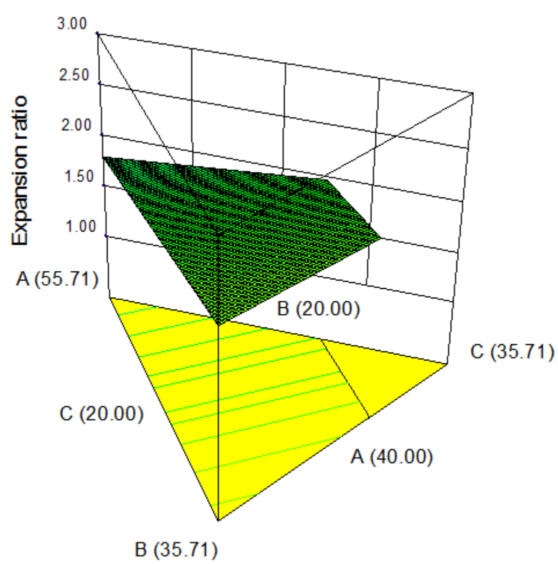

Fig. 1. Expansion ratio of extruded product made from four different flour samples at different composition ratio

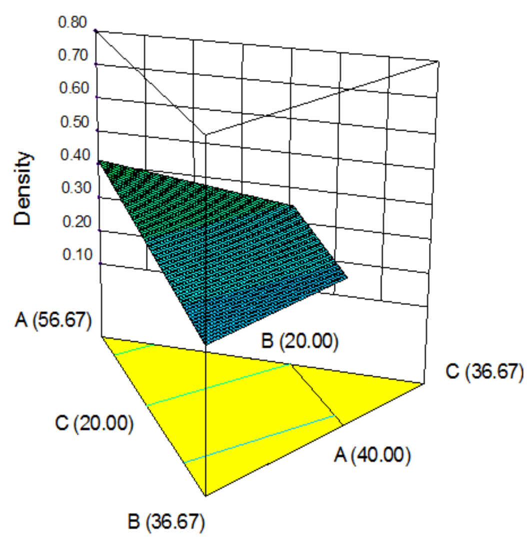

Fig. 2. Density of extruded product made from four different flour samples at different composition ratio

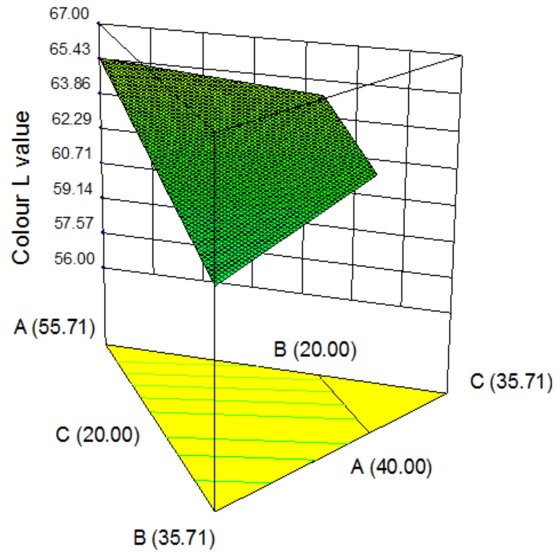

Fig. 3. L colour value of extruded product made from four different flour samples at different composition ratio

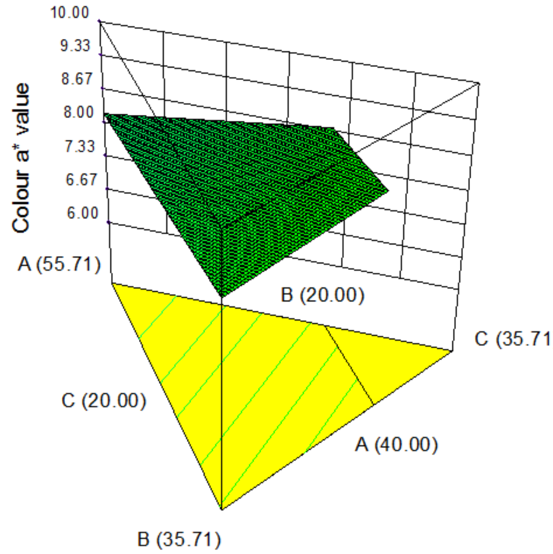

Fig. 4. a* colour value of extruded product made from four different flour samples at different composition ratio

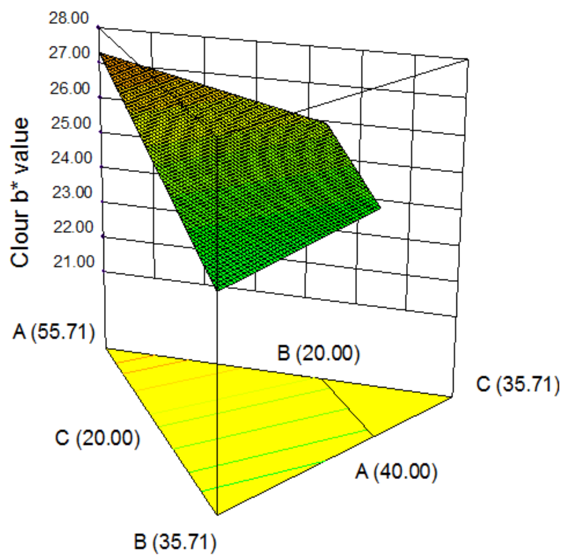

Fig. 5. b* colour value of extruded product made from four different flour samples at different composition ratio

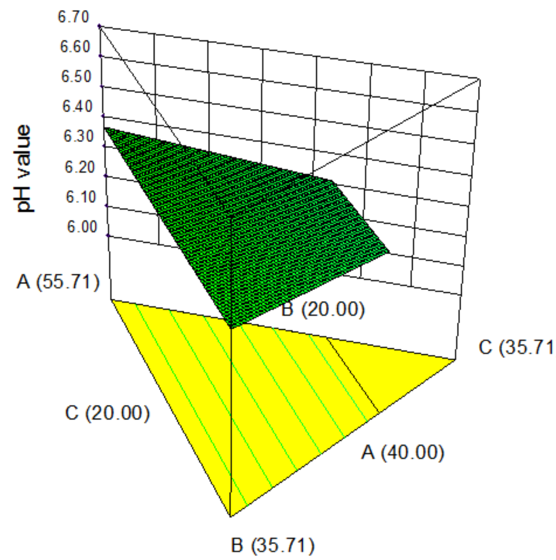

Fig. 6. pH value of extruded product made from four different flour samples at different composition ratio

D-optimal mixture model. The mean value for the density of the extruded product ranged from 0.05 to 0.18. The linear mixture model shows that at the central point, the individual flour had insignificant influence on the density of the extruded product however, the model is a good predictor since its LOF was insignificant.

R^2 value = 0.1541 Final equation was *Y = 0.11*A + 2.37*B +2.18*C + 1.68*D*

From the equation that can be observed that brown rice (B) influenced the density of the extruded product. The L *a** *b** colour values range from 69.34 to 56.52, 11.12 to 6.57 and 27.96 to 21.70 respectively. The mean colour values (L *a** *b**) of the extruded product gave a significant p-value for ANOVA analyses but a non significant LOF p-value. The model is therefore a good predictor.

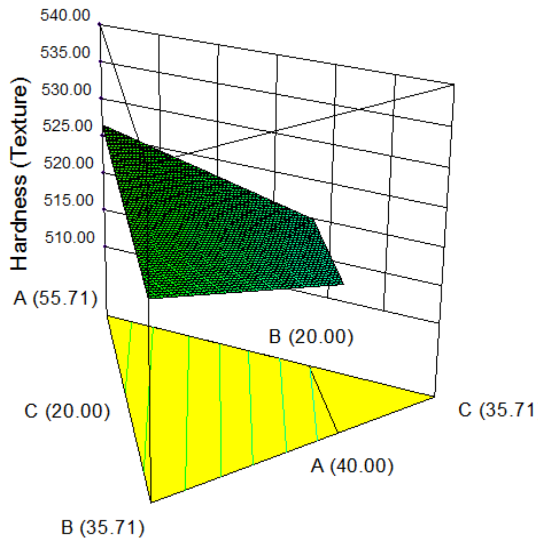

Fig. 7. Hardness (texture) value of extruded product made from four different flour samples at different composition ratio

The final equations for the model after colour analyses were:

Y_1 = *67.56*A +62.24*B +66.16*C +57.97*D* with R^2 *value = 0.4132*

Y_2= *7.22*A + 7.94*B + 8.22*C + 12.01*D* with R^2 *value = 0.4795*

Y_3= *26.99*A + 23.20* B + 24.28 *C +28.50*D* with R^2 *value = 0.5266*

for L *a** *b** colour values respectively. From the equation it was observed that the L colour values were influenced by yellow corn whilst the *a** and *b** values were influenced by the pineapple pomace flour at the central point of the linear mixture model used.

R^2 *value = 0.7924*. The final equation was *Y= 6.59*A +6.59*B +6.46*C +5.60*D*.

The p-values for ANOVA were significant whilst LOF had a non significant value. The model can therefore be used as a good predictor. The hardness of the extruded product had a non significant p-value for ANOVA but a significant LOF, therefore the model cannot be used as a good predictor for hardness.

The R^2 *value = 0.1839* Final equation was *Y=529.18*A+528.77*B+515.49*C +518.42*D*

Extrusion cooking is said to have significant effect on physical properties of extruded products [21,11,14,12,13]. The present study shows that physical parameters were affected by ingredients used in the flour blends. There have been reports that addition of legume to flour for extrusion increases nutritional properties rather than physical attributes [22,15,23,9]. Addition of soybean did not influence the extruded products physical qualities. The colour, density and hardness of the extruded product were mainly affected by the addition of the corn flour.

3.2 Functional Properties of Extruded Product

The result of the functional analyses of the extruded product made with different composition ratio of the four different flour samples are presented in the Table 4 and Figs. 8- 12.

The Swelling power for the extruded product had mean values ranging from 5.68- 6.49 %. The ANOVA table gave a significant p-value but a non significant LOF. The Model is therefore a good predictor.

R^2 *value = 0.8167* Final equation was *Y=6.34*A +6.48*B +5.74*C +5.47*D*.

The swelling power was mainly influenced by the brown rice and yellow corn. The mean values for solubility of the extruded product ranged from 15.01- 28.50 %. ANOVA table showed a non significant p-value whilst LOF was significant. This model is not a good predictor solubility of the extruded product.

Table 4. The coefficient table of the functional of the extruded product for the mixture model with p-values

Responds	Yellow corn (A)	Brown rice (B)	Full Fat soybean (C)	Pineapple pomace (D)	AVOVA p-value	Lack of fit (LOF)	R^2
Swelling power	6.34	6.48	5.74	5.47	S	N/S	0.8167
Solubility	16.01	19.21	23.33	19.07	N/S	S	0.1763
WAC	34.75	36.76	33.28	28.25	N/S	N/S	0.3214
Bulk density	94.47	81.53	84.92	81.54	N/S	S	0.3495
Moisture content	7.52	8.23	9.56	8.56	N/S	N/S	0.1608

Mean values are coefficient values from the linear mixture model at the central point. N/S- not significant, S- significant where P=0.05

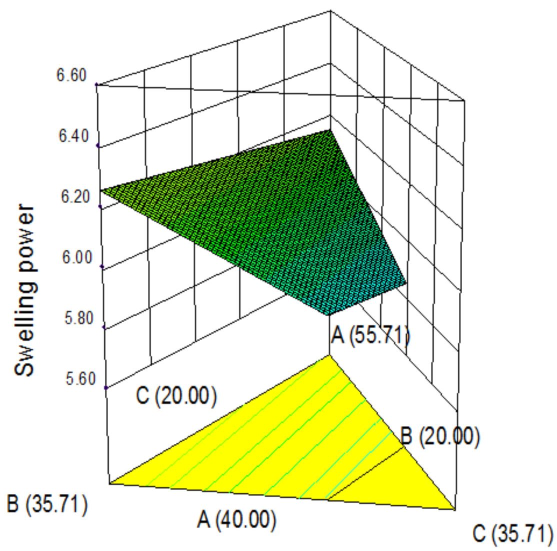

Fig. 8. Effect of different composition ratio of the individual flour on the swelling power of the extruded product at central

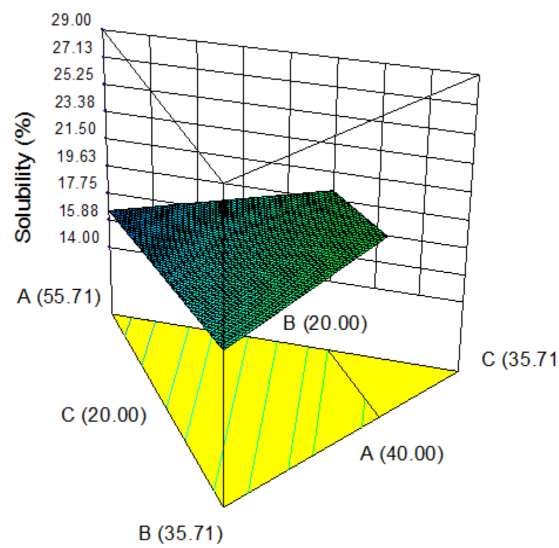

Fig. 9. Effect of different composition ratio of the individual flour on the % solubility of the extruded product at central

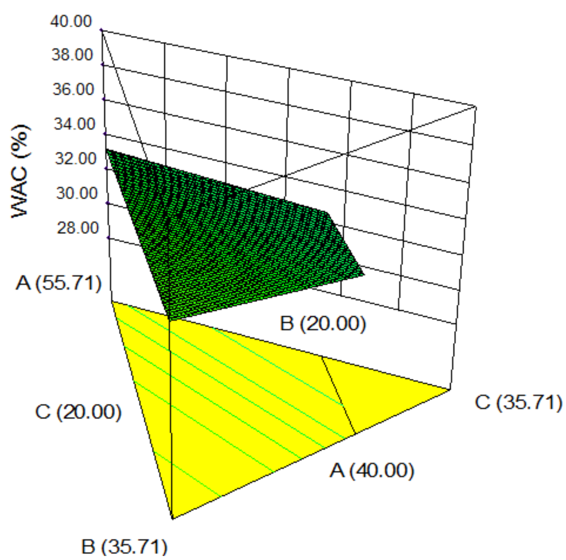

Fig. 10. Effect of different composition ratio of the individual flour on the % WAC of the extruded product at central

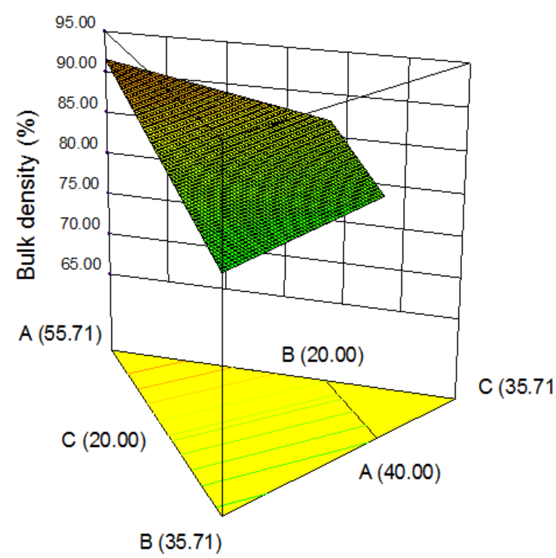

Fig. 11. Effect of different composition ratio of the individual flour on the % Bulk density of the flour blends at central

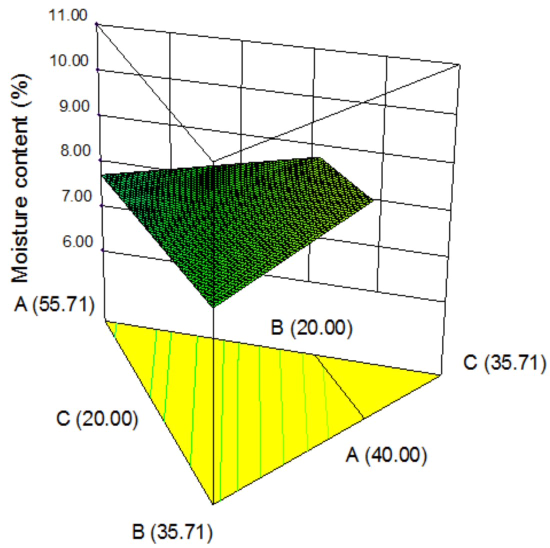

Fig. 12. Effect of different composition ratio of the individual flour on the % Moisture content of the flour blends at central

R^2 *value= 0.1763* Final equation was *Y=16.01*A +19.21*B +23.33*C +19.07*D.*

WAC ranged from 29- 39 %. There was a non significant p-value for ANOVA and LOF.

R^2 value= *0.3214* Final equation *Y= 34.75*A +36.76*B +33.28*C +28.25*D.*

The model could be a good predictor for the WAC of the linear mixture model. Bulk density of the mixture model ranged from 69.38 to 95.83 %. The ANOVA table gave a non significant p-value however LOF was significant. The model is therefore not a good predictor for bulk density.

R^2 value= *0.3495* Final equation *Y= +94.47*A +81.53*B +84.00*C +81.54*D.*

The Moisture content mean values were between 6.484 and 10.015 %. The p-values for both the ANOVA and LOF were not significant.

R^2 *value= 0.1608* Final equation *Y= 7.52*A +8.23*B +9.56*C+8.56*D.*

The model could be used as a good predictor for the moisture content of the extruded product. Increased starch content in a blend is said to increase viscosity, which are directly correlated with WAC [21]. WAC is usually dependant on the protein content. The ability of flour to absorb water is reported to have a significant correlation with its starch content [24,25,26,27]. From the result obtain it was realized that corn and brown rice influence the WAC of the extruded product. The amount of lipid in a starch sample can affect its swelling power and solubility index. Lipids establish connection with amylose and increase its molecular mass which causes the blocking of the binding water molecules, preventing the swelling of granule and distribution of the amylase [28,25,29]. The present study shows swelling power was affected by the yellow corn and brown rice while solubility was affected by the full fat soybean. According to [30,31,32] as gelatinization increases, the volume of extruded products increases and bulk density decreases. The bulk density of the present study was greatly affected by yellow corn. A similar trend was observed [32]. The moisture content of the extruded product was low which can make it shelf stable.

4. CONCLUSION

Each Ingredient had an effect on the functional and physical properties of the final extruded products. The high temperature in extrusion cooking gelatinizes starches and denatures protein altering the physical and functional properties of extruded food products. The extinct to which these occurred was dependant on the composition ratio of each of the four individual flours used for the flour blends before the extrusion cooking. This study has shown that ingredient have effect on extrudate depending on their composition ratio. The use of flour blends from yellow corn, brown rice, soybean and pineapple pomace in extrusion snacks is very viable. This study can facilitate the use of underutilized brown rice and yellow corn as well as by-product of pineapple in the food industry and improve the consumption of soybean. The effect of extrusion parameter on the physical, nutritional and physicochemical properties of the blends needs to be investigated.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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