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Full Length Research Paper

Some functional properties of extruded acha/soybean blends using response surface analysis

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The feed, comprising of acha flour and raw full fat soybean flour were mixed in ratios of 0:100, 12.5:87.5, 25:75, 37.5:62.5 and 50:50 of soybean flour to acha flour. The feed moisture content was adjusted to 15, 20, 25, 30 and 35% levels. Extrusion was carried out in a laboratory single screw extruder with variable screws and heaters following a 4K central composite (CCD) rotatable and nearly orthogonal design that required 36 extrusion runs. The extruder screw speed was varied at 90, 120, 150, 180 and 210 rpm while the extruder barrel temperature was adjusted to 100, 125, 150, 175 and 200°C. Effects of feed composition (FC), feed moisture content (FMC), extruder screw speed (SS) and extruder barrel temperature (TP) on extrudate bulk density (BD), browning index (BI) and expansion ratio (ER), were evaluated. Results showed that the BD ranged from 1.39 to 9.48 g/m^3 while the BI ranged from 0.60 to 5.72. Extrudate expansion ratio ranged from 2.75 to 6.80. The 2nd order polynomial was adequate in modeling the dependence of BD, ER and BI on the extrusion variables. The cross product effects of the process variables had significant ($P \leq 0.05$) effects on BD and BI, while the quadratic effect of feed composition had the greatest ($P \leq 0.00$) effect on the expansion ratio. Predicted values were very close to the experimental values, making the model ideal for prediction of the dependence of the extrudate functional properties on the extrusion variables.

Key words: Blends, acha, soybeans, response surface, extrusion.

INTRODUCTION

Increase in the cost of traditional sources of protein in many populations of the world today had necessitated the consumption of plant proteins as extenders or replacement for animal protein (Alabi and Anuonye, 2007). Several authors (Obatolu, 2002; Iwe, 2003; Jin and Xiao–lin., 1994a; Akinyele, 1987) had advocated for cereal/ legume blending in the face of deepening problems of hunger and malnutrition in the least developed countries (LDCs'). Several reports have shown that complementation could be achieved by mixing legumes and cereals, which abound in the tropics (Anuonye et al., 2007, 2008; Kieko et al., 1992; Delvalle et al., 1981).

Functional properties relate the ability of food to interact in a system in order to impart desirable properties to the food. According to Wilmot and Nelson (1998), foods are complex systems consisting of various components such as proteins, fats, carbohydrates minerals etc, which influence the behavior of foods in a system. Though the study of food functionality had remained complicated, Wilmot and Nelson (1998) insist that studies on functionality of individual food ingredients in simple systems are useful to predict control and eventually impart desirable characteristics to real food systems. In the extrusion environment (under high temperature and pressure), the interaction of food ingredients become more pronounced and complex. Understanding these complex behaviors in simple food systems aids in product development that involve real complex food systems.

Low cost extrusion cooking technology has been described as a process in which raw materials are heated and worked upon mechanically while passing through compression screws and is forced through a die or other restrictions (FAO, 1985; Iwe, 2003). According to Harper (1981), FAO (1985), IFT (1989), extrusion cooking is a high capacity sanitary, space and energy efficient capital cost saving technology. It is highly versatile manifested in its application as transporting, guiding, hydrating, shearing, homogenizing, mixing dispensing, expanding and forming instrument which is also used in destroying microorganisms, denaturing hydrolytic enzymes and inactivating anti-nutritional factors in food stuffs (FAO,1985).

Response surface methodology (RSM) basic principle is used to relate product properties (mechanical, functional, nutritional and sensory), and to process variables (geometry, raw material, operating variables). This is done by means of regression equations that describe inter-relations between input parameters and product properties; using a statistically designed multi-factor experiment for economy of experimental points (Tayeb et al., 1992; Iwe, 2001; Leslie and Dale, 1990; Aguilera and Kosikowshi, 1976; Frazier et al., 1983). Response surface methodology results are presented by response surface mapping to describe graphically the relation of one property versus two process parameters (Tayeb et al., 1992). According to Aguilera and Kosikowshi (1976), response surface methodology is a useful statistical tool for analyzing experimental data from plasticating extrusion. It is deemed appropriate for the evaluation of nutritional improvement of unheated defatted flakes known to be dependent on temperature, moisture, time etc (Liener, 1974).

Cereals such as maize, sorghum millet wheat oat barley and even rye have been extruded (FAO, 1985; Hoseney, 1986). Though there is dearth of information on the extrusion or extrusion blending of acha and legumes or oilseeds inspite of the nutritional potentials of acha, Anuonye (2006), Anuonye et al. (2007a, b, c) and Anuonye and Ekwu (2011) have reported on the extrusion and blending of acha and soybeans. This present work reports some functional properties of the extruded blends.

MATERIALS AND METHODS

The materials used in this study were soybean (*Glycine max* L Merrill) TGX 1448 – 2E and acha (*Digitaria exilis).* Soybean was obtained from the seed store of the National Cereals Research Institute, Bida, Niger State, Nigeria. Acha was purchased from Vom Local Market in Plateau State, Nigeria.

Soybean was cleaned to remove immature grains, and other foreign materials. The sorted grains were washed in clean tap water. The washed grains were sun dried for 3 to 4 h at 34 to 40°C, cracked in a commercial attrition mill, winnowed manually to remove hulls. The grits were further milled in attrition mill into flour.

Acha was also sorted and winnowed manually. Cleaned grain was milled using the attrition mill. The flours (soybean and acha) were sieved to pass a laboratory sieve mesh of 0.75 to 1 mm. The moisture content of the flours were determined and adjusted as shown in Table 1.

Extrusion of acha and soybean blends

Extrusion was carried out using a Branbender Laboratory single screw extruder (DUISBURG DCE – 330 Model, Germany). It was powered by a decoder drive (Type 832, 500) and driven by a 5.94 kw motor. The grooved band had a length/diameter ratio of 20:1. The extruder had variable screws and heaters with a fixed die diameter of 2 mm and length of 40 mm. A feed hopper mounted vertically above the end of the extruder and equipped with a screw that rotated at a constant speed of 80 rpm on a vertical axis takes feed into the extruder. The blends were mixed according to the experimental design (Table 1).

Experimental design

The experimental design was a 4-factor (central composite rotatable design nearly orthogonal) involving 4 independent variables: Feed composition (FC), feed moisture content (FMC), screw speed (SS) and barrel temperature (TP), tested at 5 levels of – 2 to +2 (Meyers, 1976; Iwe, 2003). The experimental design required 36 experiments of which 16 were to be performed at the factorial point, 8 at the axial point and 12 at the center point. The feed, comprising of acha flour and raw full fat soybean flour were mixed in ratios of 0:100, 12.5:87.5, 25:75, 37.5:62.5 and 50:50 of soybean flour to acha flour.

Extrusion runs were conducted as shown in Table 1. The extruder was stabilized using acha flour. The bulk density, browning index and expansion ratio of extrudates were evaluated.

Functional analysis of extruded blends

Expansion ratio (ER)

This was evaluated following the procedure described by Iwe and Ngoddy (1998).

Bulk density

Bulk density (BD) of extruded a*cha* and soybean samples was determined as described by Okezie and Bello (1988).

Browning index

The browning index (BI) was evaluated for extrudate samples according to the method reported by Harvey et al. (1982).

Statistical analysis

All results were subjected to standard statistical analysis. The generalized regression model fitted was $Y = b_0+b_1x_1 + b_2x_2 + \varepsilon$ where Y = objective response X_1 = feed composition X_2 = feed moisture content X_3 = extruder screw speed and X_4 = extruder barrel temperature and ε = random error in which the linear, quadratic and interaction effects were involved. A computer programmme SPSSWIN (11.0) SPSS INC. (2003), USA was used in fitting the regression models. The resulting models were tested for significance using analysis of variance (ANOVA) and coefficient of determination (R^2). Significant terms were accepted at $P \leq 0.05$ (Jin et al., 1994b; Howard, 1983). The R^2 of 0.6 was accepted for predictive purposes .The terms that were not significant were deleted from the model equations. For each significant model equation, response surfaces in three dimensional plots were generated on a computer programme STATISTICA (STAT SOFT INC. USA) version 5.0 (1984 to 1995) by holding the two variables with the least and second least effects on the response, constant (center points) and changing the other two variables.

RESULTS AND DISCUSSION

The results of the extrudate bulk density (BD) are presented in Table 2. Analysis of variance of extrudate

Table 1. Matrix transformation of the experimental design runs and extrusion conditions.

No.	Feed composition (g)	Feed moisture content (%)	Screw speed (rpm)	Barrel Temperature (°C)		
				1	2	Die temp
1	125	20	120	125	125	125
2	125	20	120	125	125	175
3	125	20	180	125	125	125
4	125	20	180	125	125	175
5	125	30	120	125	125	125
6	125	30	120	125	125	175
7	125	30	180	125	125	125
8	125	30	180	125	125	175
9	375	20	120	125	125	125
10	375	20	120	125	125	175
11	375	20	180	125	125	125
12	375	20	180	125	125	175
13	375	30	120	125	125	125
14	375	30	120	125	125	175
15	375	30	180	125	125	125
16	375	30	180	125	125	175
17	500	25	150	125	125	150
18	0	25	150	125	125	150
19	250	15	150	125	125	150
20	250	35	150	125	125	150
21	250	25	90	125	125	150
22	250	25	210	125	125	150
23	250	25	150	125	125	100
24	250	25	150	125	125	200
25	250	25	150	125	125	150
26	250	25	150	125	125	150
27	250	25	150	125	125	150
28	250	25	150	125	125	150
29	250	25	150	125	125	150
30	250	25	150	125	125	150
31	250	25	150	125	125	150
32	250	25	150	125	125	150
33	250	25	150	125	125	150
34	250	25	150	125	125	150
35	250	25	150	125	125	150
36	250	25	150	125	125	150

parameters showed that there was significant ($P \leq 0.01$) model difference. With coefficient of determination (R^2) high at (0.70) the results showed that the model greatly fitted the linear regression. Removing the non-significant terms, the model equation became:

$$BD = -145.49 + 3.0FC*FMC*SS*BT + 1.762\ FC^2 - 1.76\ FC*BT - 1.72\ FC*SS + 9.97SS$$

The values of BD ranged from 1.39 to 9.48 g/m^3. This range was higher than the values reported by Iwe (2001) and Rampersad et al (2003) but lower than the values reported by Almieda–Domingues et al. (1993) Bhatnagar and Hanna (1994). Differences in reported values were dependent on extruder configuration and nature of extruded materials.

The response surface relationship of the independent variables and the dependent variable (BD) showed that increasing the soybean flour concentration of the feedstock and increasing the extruder screw speed (SS) caused decreases in extrudate bulk densities (Figure 1). Several reasons could be adduced for this. Firstly, increase in soybean content increased the lipid content of the feed leading to greater amylase complexing.

Table 2. Estimated regression coefficients and ANOVA for extrudate BD.

Regression on constants	Coefficients -145.49	Standard error	P-values	R^2
FMC	8.26	3.80	0.138	0.70
SS	9.97	0.62	0.072	
TP	5.25	0.66	0.269	
FC*FC	1.76	7.20	0.014	
FMC*FMC	-0.47	0.02	0.689	
SS*SS	-0.49	4.58	0.680	
TP*TP	0.98	6.59	0.492	
FC*FMC	-1.44	3.51	0.104	
FC*SS	-1.76	5.86	0.054	
FC*TP	-10.64	5.86	0.048	
FMC*SS	-7.64	0.02	0.132	
FMC*TP	-9.91	0.02	0.244	
SS*TP	-9.58	0.04	0.142	
FMC*SS*TP	8.81	1.52	0.266	
FC*FMC*SS*TP	3.00	1.55	0.003	
ANOVA	**DF**	**SS**	**MS**	
Regression	15	206.51894	13.7679 3	
Residual	20	96.67515	4.83376	
F 2.84829	Sign. F.0.0152			

Bhatnagar and Hanna (1994a) observed that as the amount of complexed amylose decreased, the expansion ratio increases and percentage of water-soluble carbohydrate decrease leading to decreased bulkiness. Also under normal circumstances, increase in oil content should contribute to lowering of extruder shear (Iwe, 2000) and thus increase BD. Feed addition beyond 50% of soybean substitution resulted in significant increases ($P \leq 0.02$) in bulk densities which was expected. Optimal extruder combination for screw speed (SS) and feed composition (FC) was located between 120 to 150 rpm and 12.5 to 37.5% soybean flour addition. Increasing the FC and barrel temperature (TP) (Figure 2) showed a similar trend. Increasing the soybean flour content up to 60% and barrel temperature up to 160°C led to significant ($P < 0.05$) reductions in BD. As already observed higher temperatures beyond 140°C led to starch degradation that resulted to more plugging. This ultimately lowered the extruder shear and hence increased bulkiness.

The results showed that BD was more than linearly related to the process parameters; hence the model could not explain all the changes in the measured parameters. The extrudate maximum BD was located at 125 FC; 20% Feed moisture content (FMC); 120 SS and 125°C TP while the minimum was located at 250 FC, 25% FMC, 150 SS and 210°C TP.

Browning index

The results of the effect of process variables (FC, FMC SS and extruder TP) on extrudate browning index (BI) are shown in Table 3. The results showed that the linear, cross products and quadratic effects of the variables had significant ($P \leq 0.05$) effect on the browning index. Analysis of variance showed that there was significant ($P \leq 0.05$) model difference showing the goodness of fit of the model to the linear regression. The coefficient of determination (R^2) was high at (0.70) showing that about 70% of the extrudate variability was explained by the model. Removing the non-significant terms, the model equation became:

$$BI = -100.105 + 3.129\ FC{*}FMC{*}SS{*}TP - 16.599FMCSS + 10.882TP + 11.770SS - 13.613SS{*}TP + 11.209FMC + 15413FMC{*}SS{*}TP - 2.789TP^2 - 1.627FC{*}TP$$

The BI index ranged from 0.60 to 5.72. The results showed that SS played a more significant role in extrudate BI, yielding minimal values at the lowest SS of 90 rpm and maximal values at SS of 210 rpm at the same moisture content (Figure 3). Increase in SS and FMC resulted in both increases and decreases in BI showing a quadratic relationship.

The response surface relationship between BI, and TP and SS (Figure 4) indicated that combining high TP and high SS would have minimal browning effects on extrudates. This is because at high TP and high SS, residence time is greatly reduced resulting in decreased browning. This trend of results again indicated that SS remained a dominant factor in extrudate BI.

Increasing the level of soybean flour in the FC and TP

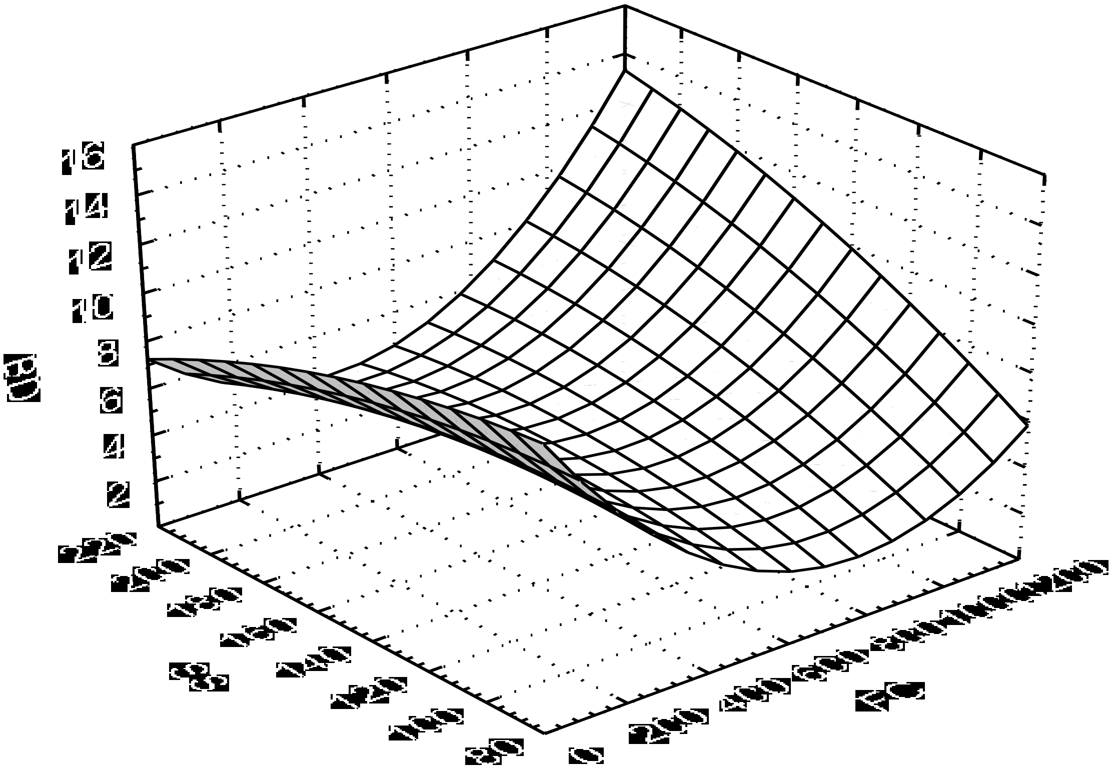

Figure 1. Response surface plot of the effect of screw speed and feed composition on extrudate bulk density.

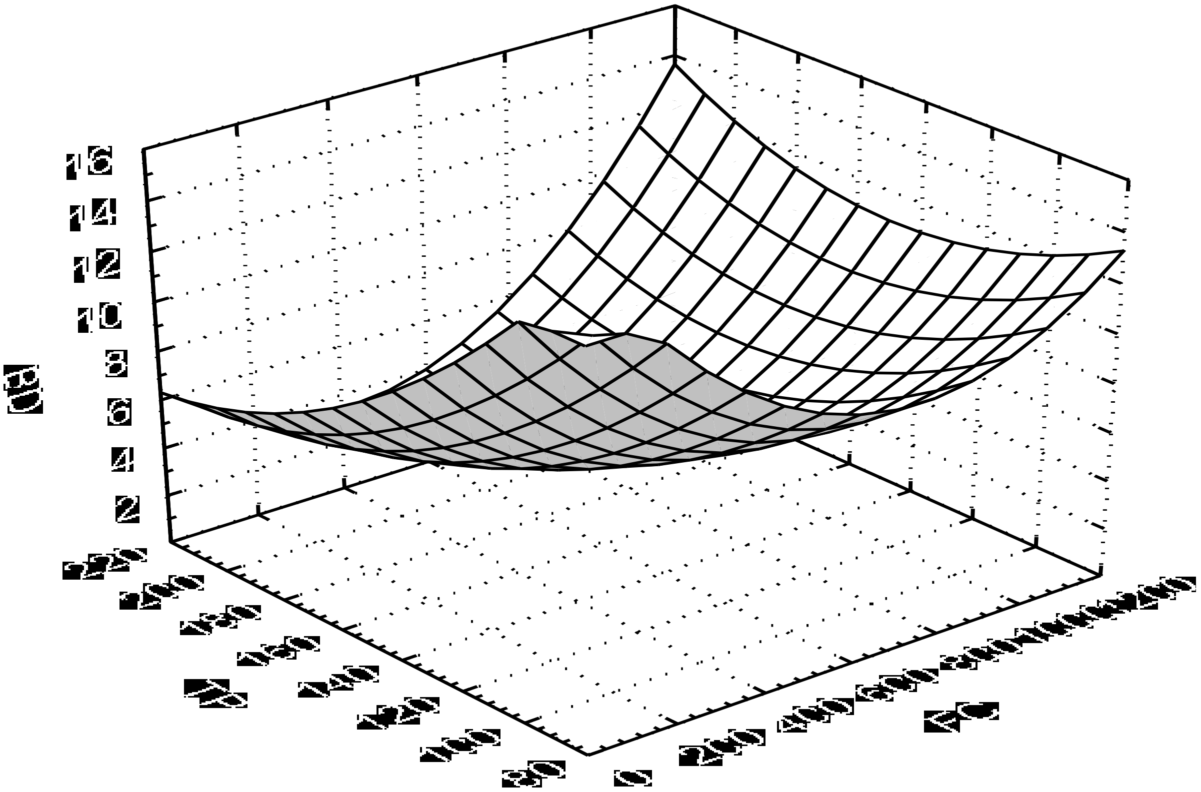

Figure 2. Response surface plot of the effect of barrel temperature and feed composition on extrudate bulk density.

Table 3. Estimated regression coefficients and ANOVA for Browning index.

Regression on constants	**Coefficients -100.105**	**Standard error**	**P-values**	**R^2**
FMC	11.21	1.78	0.056	0.70
SS	11.74	0.29	0.043	
TP	10.88	0.31	0.034	
FC*FC	0.82	3.37	0.239	
FMC*FMC	-014	0.00	0.910	
SS*SS	1.36	2.14	0.272	
TP*TP	-2.79	3.08	0.068	
FC*FMC	-0.85	1.64	0.342	
FC*SS	-1.21	2.74	0.181	
FC*TP	-1.63	2.74	0.075	
FMC*SS	-16.60	0.01	0.028	
FMC*TP	-11.71	0.01	0.101	
SS*TP	-13.61	0.00	0.049	
FMC*SS*TP	15.41	7.11	0.069	
FC*FMC*SS*TP	3.13	7.27	0.003	
ANOVA	**DF**	**SS**	**MS**	
Regression	15	40.90879	2.72725	
Residual	20	21.18867	1.05943	
F 2.57426	Sign. F.0.0249			

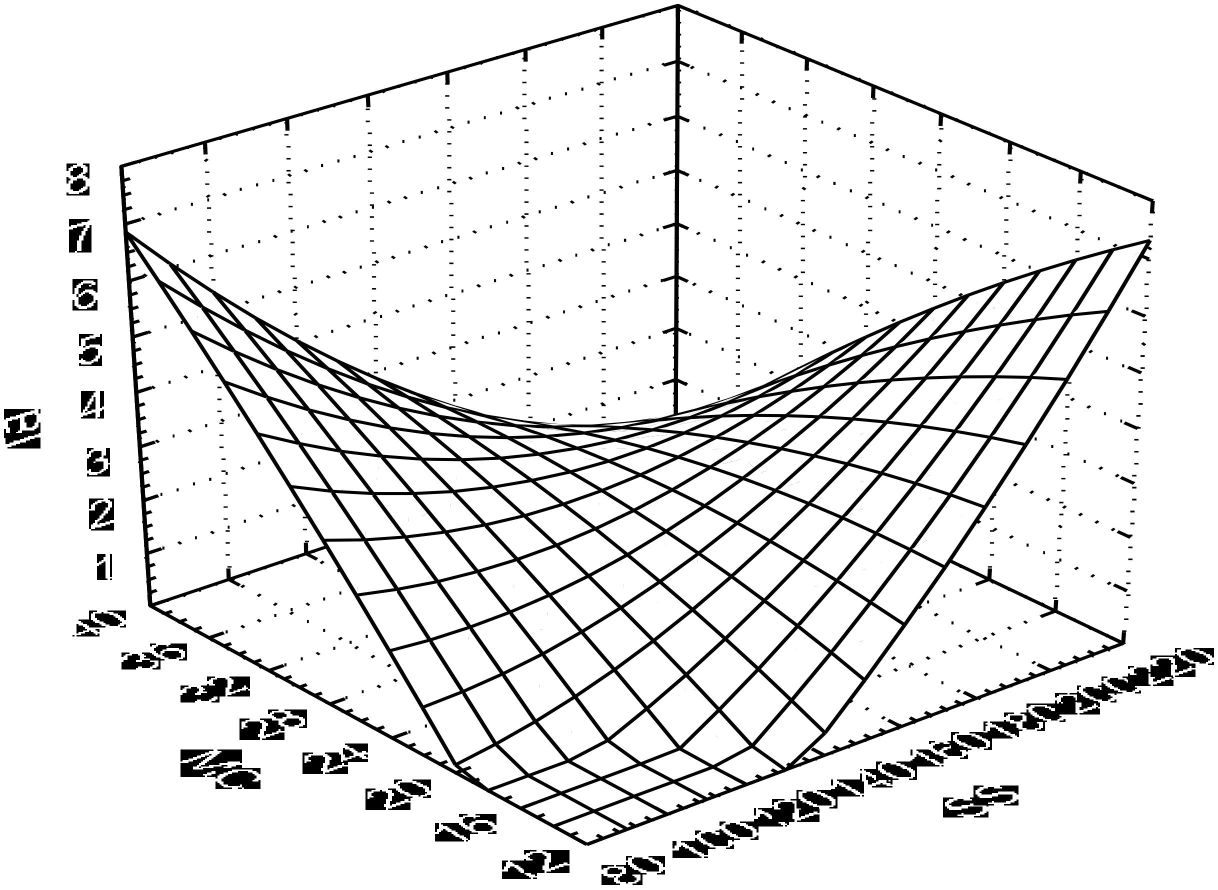

Figure 3. Response surface plot of the effect of moisture content, and screw speed on extrudate browning index.

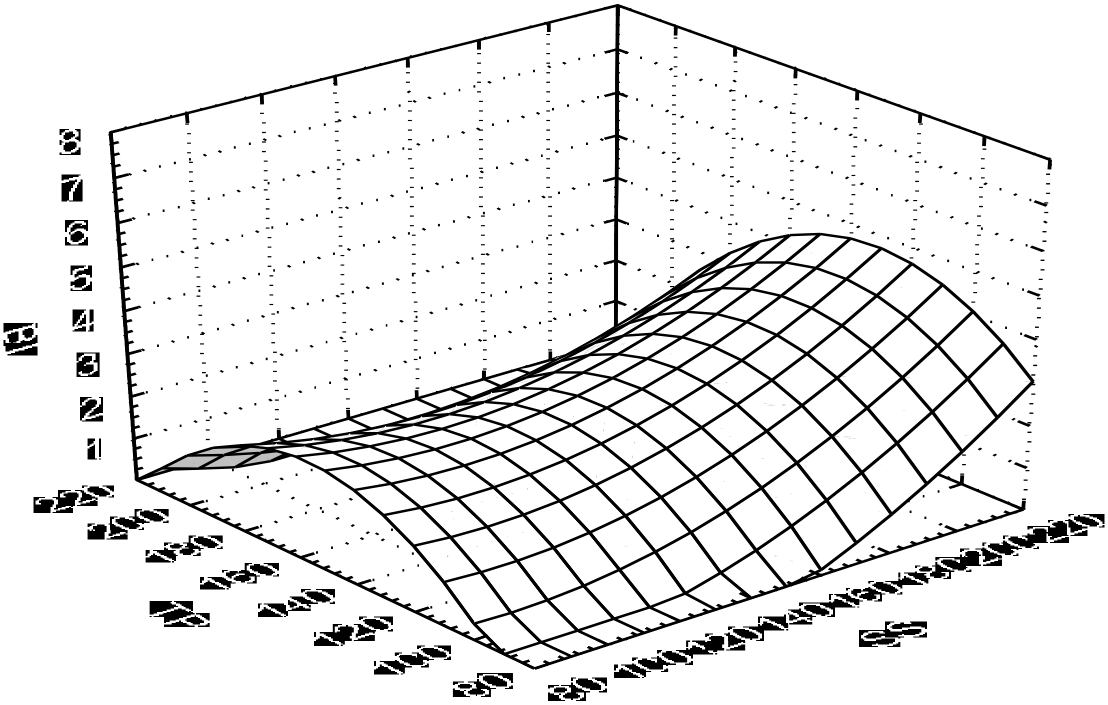

Figure 4. Response surface plot of the effect of barrel temperature and screw speed on extrudate browning index.

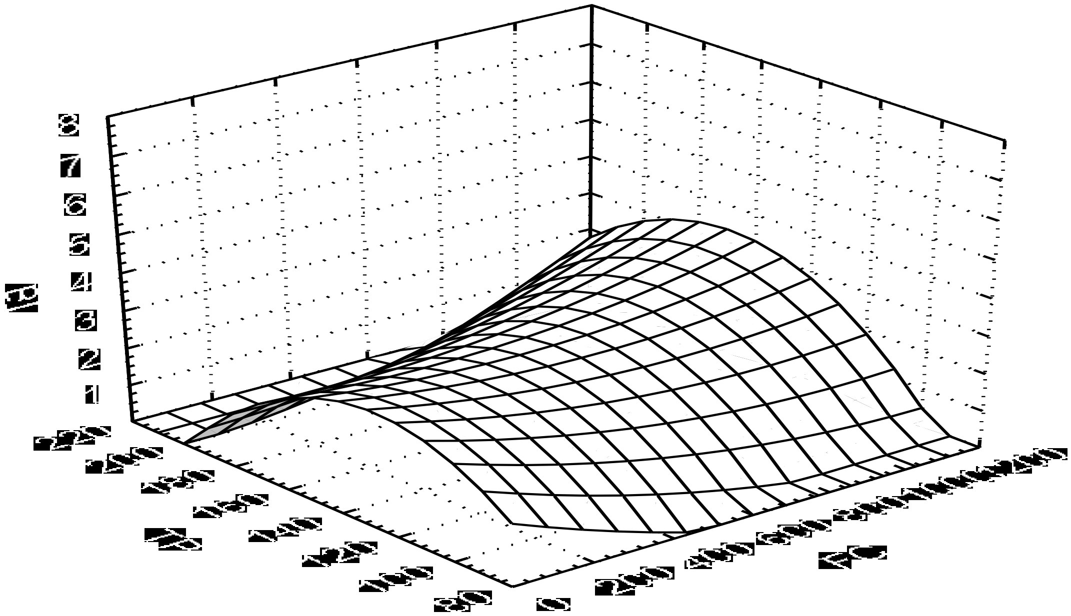

Figure 5. Response surface plot of the effect of barrel temperature and feed composition on extrudate browning index.

(Figure 5) showed that beyond 40% level of soybean flour supplementation, BI of extrudates would increase irrespective of the extrusion temperature combination. This was expected because of the high lysine content of soybean containing ε - amino group resulting in production of reducing sugars by increased barrel

Table 4. Estimated regression coefficients and annova for etxrudate expansion ratio.

Regression on constants	Coefficients 42.46	Standard error	P-values	R^2
FMC	7-7.46	0.95	0.1066	0.78
SS	-7.11	0.16	0.1165	
TP	4.41	0.16	0.2608	
FC*FC	2.12	1.81	0.0000	
FMC*FMC	1.25	0.00	0.2608	
SS*SS	0.67	1.15	0.4964	
TP*TP	-0.32	1.65	0.7856	
FC*FMC	-1.57	8.79	0.0366	
FC*SS	-1.17	1.47	0.1081	
FC*TP	-2.66	1.47	0.0010	
FMC*SS	8.93	0.01	0.1260	
FMC*TP	7.80	0.01	0.1673	
SS*TP	8.48	9.82	0.11690.	
FMC*SS*TP	-11.02	3.81	0.0987	
FC*FMC*SS*TP	2.30	3.89	0.0053	
ANNOVA	**DF**	**SS**	**MS**	
Regression	15	21.85226	1.45682	
Residual	20	6.07717	0.30386	
F 4.79439	Sign. F.0.0007			

temperature. Extrusion of soybean/acha flour was therefore expected to favour Maillard reactions and production of non-enzymatic polymerization products.

The results of this work showed that increased substitution of soybean flour in the feedstock resulted in increased browning. Optimal processing condition for browning from this study was located at 25% FC, 25% FMC, 120 SS and 150 TP.

Expansion ratio

The results of effects of processing variables on extrudate expansion ratio are shown in Table 4. The quadratic effect of FC had the greatest effect ($P \leq 0.000$) on expansion ratio. The cross product effects of all the variables also significantly ($P \leq 0.01$) affected the expansion ratio. Analysis of variance was significant ($P \leq 0.001$). Coefficient of determination was high (0.78) indicating that about 80% of the total variables of the process were adequately estimated.

The resultant polynomial after removal of insignificant variables became:

$$ER = 42.458 + 2.924FC^2 - 2.662FC*TP + 2.303 FC*FMC*SS*TP - 1.567FC*FMC - 11.024FMC*SS*TP$$

Extrudate expansion ratio values ranged from 2.75 to 6.80. The results indicated that the linear effects of the FM, SS and TP were negatively related to the expansion of extrudate while the FC was positively associated with ER. Lower FMC and higher FC (Figure 6) led to decreases in the expansion ratio. Decreasing the percentage of soybean flour in the mixture and increasing the FMC led to increases in the extrudate expansion ratio. These results are in line with established extrusion trends (Bhattacharya et al., 1986; Bhatnagar and Hanna, 1994a; Kokini et al., 1992; Tomas et al., 1994; Antila et al., 1983; Iwe and Ngoddy, 1988; El–dash et al., 1984). Lower moisture content encourages higher shearing and higher extruder internal temperature leading to reduced residence time. This resulted in highly expanded extrudates. Nevertheless, higher levels of soybean flour substitution encouraged greater lipid–amlyose complexing resulting in decreased expansion. Bhatnargar and Hanna (1994b) reported that lipid amylose complexion reduces extrudate expansion ratio. However, increasing the FMC encourages greater starch degradation and hence greater extrudate expansion. The results showed that maximum level of feed substitution for maximum expansion was at 40% soybean addition.

The relationship between ER, TP and SS showed that increasing the TP and SS led to increase in ER (Figure 7). This is in agreement with observed trends of cereal extrusion (Hoseney, 1986). Higher temperatures had been reported to enhance extrudate expansion (Alverez–Martinez et al., 1988).

From this study, it was observed that the lowest SS for

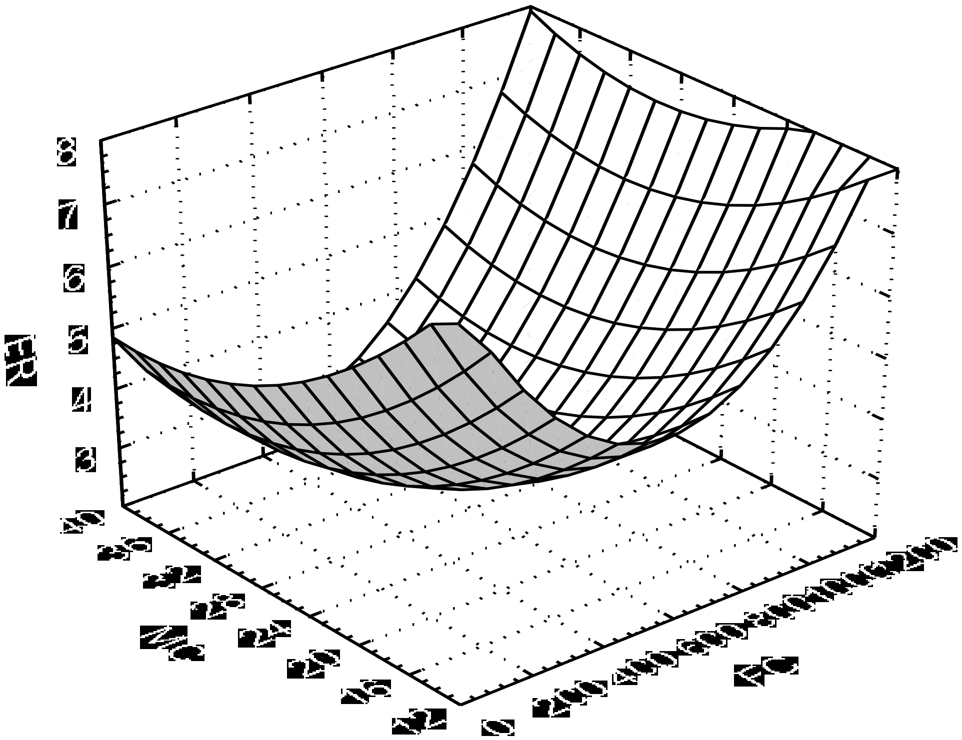

Figure 6. Response surface plot of the effect of feed moisture content and feed composition on extrudate expansion ratio.

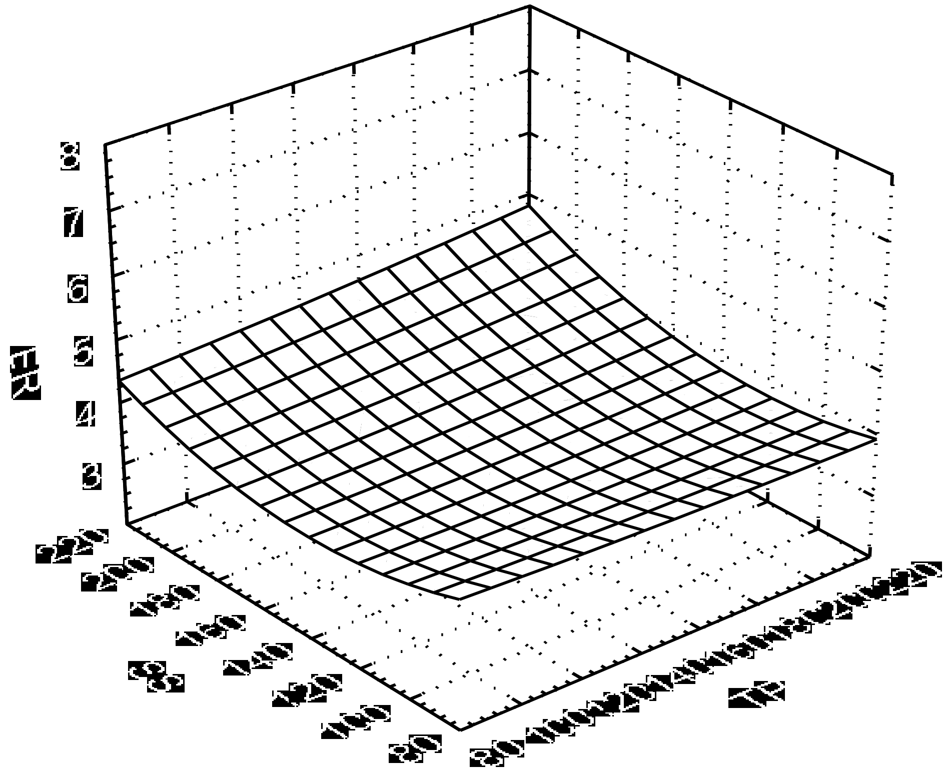

Figure 7. Response surface plot of the effect of screw speed and barrel temperature on extrudate expansion ratio.

optimum extruder function was 135 rpm. Optimum SS and TP combination was located at SS 135 rpm and TP of 120°C. Similar reports have been given for corn starch (25% amylose content) by Owusu–Ansa et al. (1984), Chinnaswamy and Hanna (1988), and Iwe (2000).

Conclusion

The effect of processing variables on blends of acha/soybeans did not show any significant variation from other cereal/legume-extruded blends. The feed composition had greater influence over other process variables. This is indicative that soybean addition to acha had significant modifying effect on the functional properties of the extruded products. The experimental results were close to the predicted values (Appendix 1) showing that response surface application would be a good tool in development of products from acha/soybean blends.

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APPENDIX 1

Summary of experimental values calculated from the experiment compared to predicted values by the equations generated from the models.

Extrusion runs	Expansion ratio		Bulk density		Browning index	
	Exp. value	Pred. value	Exp. value	Pred. value	Exp. value	Pred. value
1	5.30	5.200	8.83	9.05	1.2	1.00
2	5.60	5.200	7.33	7.56	1.44	1.00
3	4.90	5.200	13.00	9.05	1.88	1.00
4	6.80	5.200	7.17	7.56	1.68	2.00
5	3.69	4.16	12.45	7.37	2.6	2.00
6	4.10	4.16	7.52	5.21	2.28	2.30
7	3.95	4.16	4.32	2.37	0.92	2.00
8	3.50	3.82	1.39	5.21	2.88	1.00
9	3.25	3.82	13.93	8.29	1.8	1.00
10	3.05	3.82	7.29	6.51	1.36	1.40
11	3.70	3.82	5.95	8.29	2.76	1.30
12	2.90	2.78	3.90	6.51	1.28	2.70
13	3.15	2.78	4.98	6.62	2.88	1.00
14	3.10	2.78	4.89	4.16	2.44	2.98
15	3.60	5.20	6.53	6.63	1.08	2.40
16	3.00	3.07	2.66	4.15	3.36	2.00
17	4.80	4.56	9.48	4.13	3.12	3.00
18	3.00	2.48	2.59	5.94	2.68	2.80
19	5.25	3.52	2.86	7.705	0.96	1.00
20	2.85	3.52	4.84	3.03	3.76	2.56
21	3.00	3.52	3.20	5.04	0.92	1.32
22	4.60	3.52	4.46	5.04	5.72	5.00
23	3.35	3.52	7.23	7.62	0.96	1.00
24	3.45	3.52	4.11	2.46	0.96	1.00
25	3.65	3.52	3.74	5.04	2.92	2.0
26	3.35	3.52	3.74	5.04	1.60	1.50
27	3.00	3.52	6.48	5.04	1.20	1.01
28	3.35	3.52	5.03	5.04	1.60	1.75
29	3.35	3.52	6.64	5.04	1.58	1.59
30	3.70	3.52	2.80	5.04	2.92	3.00
31	3.35	3.52	3.51	5.04	1.40	1.70
32	3.20	3.52	5.16	5.04	3.36	3.04
33	3.70	3.52	6.03	5.04	2.60	2.83
34	4.10	3.52	8.28	5.04	2.92	3.00
35	3.60	3.52	3.74	5.04	2.92	3.00
36	3.50	3.52	4.14	5.04	2.92	3.00