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Optimization of extrusion conditions for production of breakfast cereal from sorghum–soybean blends using sensory evaluation

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Abstract

Central Composite Face-Centered Design (CCFC) and sensory evaluation were used to optimize the extrusion conditions for production of breakfast cereal from sorghum–soybean flour mixes. Sorghum flour was blended with soybean flour in varying proportions of 90:10, 80:20 and 70:30 respectively and extruded at 20%, 22.5% and 25% moisture levels and 120ºC, 140ºC and 160ºC extrusion temperatures. The most acceptable extrudate was from the mix with 10% soybean flour, 22.5% feed moisture and 140ºC barrel temperature. The optimum values for all the sensory attributes assessed were established at 11 to 24% feed composition, 20% feed moisture and 120ºC extrusion temperature. The colour, flavour, grittiness, stickiness and overall acceptability had optimum values of 9.76 (brown), 5.04 (low cooked cereal flavour), 5.5 (low grittiness), 4.52 (low stickiness) and 10.45 (high overall acceptability) respectively. The coefficients of determination (R^2) were 0.80 for colour, 0.83 for flavour, 0.76 for grittiness, 0.93 for stickiness and 0.84 for overall acceptability. Graphical residual analyses showed a good fit for the empirical models suggesting that they could be used to estimate these sensory properties of the extrudates.

Keywords: Optimization, extrusion, acceptability, sorghum, soybean, response surface

1. Introduction

The primary consideration for selecting and eating a food commodity is the product's palatability or eating quality. Other quality parameters such as nutrition and wholesomeness are secondary (Meiselman and MacFie, 1996, Lawless and Heymann, 1998) [1, 2]. Thus, if we accept that food quality is that "which the consumer likes best" and that the grades of quality are understood more by degree of desirable attributes and absence of undesirable characteristics which are primarily detected by the consumer's sensory organs, then a good method of deciding quality of food is through sensory evaluation. Sensory evaluation has been defined by Sidel and Stone (1993) [3] as a scientific discipline used to evoke, measure, analyze and interpret those responses to products as perceived through the senses of sight, smell, touch, taste and hearing. When consumer needs and company requirements on the other hand are not addressed in the development or optimization of a product, it is unlikely that the new product will be successful if launched. This is where sensory science reduces the risk of product failure (Singh-Ackbarali and Maharaj, 2014) [4]. Since there is no one instrument that can replicate or replace the human psychological and emotional response, the sensory evaluation component of any food study is essential and the importance of good experimental design cannot be overemphasized in sensory experiments (Lawless and Klein, 1989, Meiselman *et al.*, 1999) [5, 6]. Sensory analysis is applicable to a variety of areas such as; inspection of raw materials, product development, product improvement, cost reduction, quality control, selection of packaging material, shelf life/storage studies, establishing analytical/instrument/sensory relationship and process development (Singh-Ackbarali and Maharaj, 2014) [4].

For all sensory assessment methods, humans are the measuring instrument. In order for a sensory assessment to provide reliable and valid results, the sensory panel must be treated as a scientific instrument; that is, members of the panel must be screened, calibrated and validated (Meilgaard *et al.*, 1999) [7]. There are many types of sensory analysis methods, the most popular being difference tests, descriptive analysis and consumer acceptance testing (Lawless and Heymann, 1998) [2]. Descriptive sensory analysis uses several techniques that seek to discriminate between a ranges of products based on their sensory characteristics and also to determine a quantitative description of the sensory differences that can be identified, not just the defects. No judgment of "good" or "bad" is made as in traditional quality judging methods because this is not the purpose of the evaluation (Singh-Ackbarali and Maharaj, 2014) [4].

True food security will be hard to achieve in those countries with comparative advantage in sorghum production; and are located in harsh climatic conditions, without a significant improvement in the production, utilization and marketing of this major staple cereal (Dicko *et al.*, 2006) [8]. In West Africa, ungerminated sorghum grains are generally used for the preparation of 'to' porridge and couscous while malted sorghum is used in the process of local beer 'dolo' (reddish, cloudy or opaque), infant porridge and non-fermented beverages (Dicko *et al.*, 2006) [8]. *Ogi* is an example of traditional fermented sorghum food used as weaning food in Nigeria, which has been upgraded to semi-industrial scale (Achi, 2005) [9]. *Injera* is a local fermented pancake-like bread prepared in Ethiopia from sorghum (Yetneberk *et al.*, 2004) [10] while *Kibra* is a traditional bread prepared from fermented sorghum dough (Mahgoub *et al.*, 1999) [11]. Sorghum is now industrially used for the production of lager beer in Nigeria. It is the predominant cereal for industrial scale malting and brewing of beer, following legislation banning the importation of barley and wheat.

In the United States and Japan, sorghum utilization as human food is increasing because of its use in snacks and cookies (Rooney and Wansika, 2004) [10, 12]. The future promise of sorghum in the developed world is wheat substitution for people allergic to gluten (Fenster, 2003) [13]. Pasta products such as spaghetti and macaroni made from semolina or wheat could be made with mixtures of composite flours consisting of 30 – 50% sorghum in wheat (Hugo *et al*., 2000, 2003) [14, 15]. Pre-cooked sorghum flours mixed with vitamins and exogenous sources of protein are commercially available in many African countries for the preparation of instant soft porridges for infants. Sorghum can be puffed, popped, shredded and flaked to produce ready-to-eat breakfast cereals.

Soybean is an important source of high quality but inexpensive protein (about 40%) and 20% of highly digestible and cholesterol-free oil and also a source of superior amino acid profile. Soybean protein has great potential as a major source of dietary protein. Soybean products are used in hospitals for bio-fortified feeding of sick people and malnourished children (Coulibaly *et al*., 2009) [16]. Leading infant food manufacturers in Nigeria use soybeans because of its high nutritional value (USDA, 2008) [17]. Soybeans are now widely consumed and are readily used in the production of soymilk, soy cake, soy yoghurt and the fortification of local carbohydrate-based Nigerian foods. *Daddawa*, a local food seasoning is also produced from soybeans. Government sources estimate that about 25 per cent of Nigeria's domestic production is consumed directly in rural area as human food (USDA, 2008) [17].

A breakfast cereal (or just cereal) is a food made from processed grains that is often eaten with the first meal of the day. It is often eaten cold, usually mixed with milk (e.g. cow's milk, soy milk, rice milk, almond milk), juice, water, or yogurt, and sometimes fruit, but may be eaten dry. Some products are produced from high fibre cereals. Cereals may be fortified with vitamins while others are made with high sugar content. Many breakfast cereals are produced via extrusion cooking. The traditional breakfast cereals in Nigeria are *Ogi* or *Akamu* from maize, millet and sorghum, *kunun-gyada* from rice, *masa* from rice and porridge (*Iber*-Tiv), from millet or sorghum flour. Commercially processed breakfast cereals presented in modern packages in the Nigerian market include Golden morn, Corn Flakes and Fast-O-Meal; all from maize.

The production of breakfast cereals in Nigeria currently gives less attention to extrusion technology and sorghum. This work was intended to produce breakfast cereals from red sorghum (*Chakalari red)*, and also consider supplementation of the breakfast cereal with soybean flour to improve the present low protein content of sorghum products, create variety and also increase the utilization of sorghum in the Nigerian diet. The specific objective of this work was to optimize the production of breakfast cereals from red sorghum (*Chakalari red*) by extrusion cooking using sensory evaluation and response surface methodology (RSM).

2. Materials and Methods

2.1 Procurement of raw materials

The red sorghum variety (*Chakalari red)*, was obtained from Maiduguri Monday market. Soybean was purchased from the Mubi main market.

2.2 Preparation of sorghum flour

Sorghum grains were cleaned using a laboratory aspirator (Vegvari Ferenc Type OB125) to remove stalks, chaff, leaves and other foreign matter. They were then washed with clean water and sun dried. This was then dehulled using a commercial rice dehuller and milled using an attrition mill. The flour was packed in polythene bags and stored for further use.

2.3 Preparation of soybean flour

The soybean (*Glycine max* (L) Merr.) was steam cooked for 30 min, dehulled by lightly crushing with a pestle and mortar. The hulls were separated and the beans oven dried to 12% moisture content. This was milled, packed in polythene bags and stored for further use (Filli, 2010) [18].

2.4 Blending of sorghum flour with soybean flour and moisture adjustment

Sorghum flour was blended with soybean flour in varying proportions (90:10, 80:20 and 70:30 respectively). The individual moisture contents of the soybean and sorghum flours were determined (on dry weight basis) using the hot air oven method (Egan *et al*., 1981) and then the total moisture of the blends adjusted to the desired level according to Zasypkin and Tung-Ching (1998) [20], using the formula below. The blends were mixed using a laboratory mixer (Hobert, Model: A200) and the moisture allowed to equilibrate for one hour before extrusion.

$$C_{sbf} = [r_{sbf} \text{ x } M \text{ x } (100-w)] / [100 \text{ x } (100-W_{sbf})]$$
$$C_{sf} = [r_{sf} \text{ x } M \text{ x } (100-w)] / [100 \text{ x } (100-W_{sf})]$$
$$W_x = M - C_{sbf} - C_{sf}$$

Where Csb_f is the mass of soybean flour (g); $C_{sf,}$ the mass of sorghum flour (g); $S_{f,}$ and Csb_f are sorghum flour and soybean flour respectively; r_{sbf} and r_{sf} are the soybean flour (%) and sorghum flour (%) respectively; M, the total mass of the blend (g); w is the moisture content of final blend (%); W_x is weight of water added (g); $Wsb_{f,}$ the moisture content of soybean flour (%); while W_{sf} is the moisture content of sorghum flour (%).

2.5 The extrusion process

Extrusion cooking was done in a single screw extruder (Model: Brabender Duisburg DCE-330), equipped with a variable speed DC drive unit and strain gauge type torque meter. The extruder was fed manually through a screw operated conical hopper. The hopper which is mounted vertically above the end of the extruder is equipped with a screw rotated at variable speed. Extrudates were kept on stainless steel work benches overnight. They were then packaged in polythene bags prior to analysis. Experimental samples were collected when steady state was achieved. Variables considered were feed composition, feed moisture content and temperature of extrusion. Extrudates were kept on stainless work benches overnight to dry. They were then packaged in polythene bags prior to analysis.

2.6 Sensory evaluation

2.6.1 Descriptive analysis

Descriptive analysis with scaling (Larmond, 1977) [21] was used. This analysis involves the rating of specific attributes defined by the test objective. The subjects were trained to use a line scale (Stone *et al*., 1974) [22], an unstructured horizontal line 15 cm in length for the evaluation of intensity of each attribute.

2.6.2 Procedure

Fifteen panelists made up of staff and students of the Department of Food Science and Technology and the Department of Nutrition and Dietetics were selected for sensory evaluation of the products. Selection was based on availability and interest in participation. All panel members had previous experience in evaluation of sensory attributes of foods. The questionnaires were distributed to all the potential panelists and during the training sessions, questions were allowed and answers provided on areas that were not well understood by the panelists. The nature of the samples to be tasted was explained to all the potential panel members. Water was provided for the panelists to rinse their mouth before tasting the next sample. The panel members agreed on the sensory properties to be evaluated. Panel members were seated in individual booths. Samples were coded with three digit numbers (from the table of random numbers) and served in tea cups along with teaspoons. The order of serving was randomized for each session. The scale used was an interval scale consisting of a horizontal line (15 cm) long with anchor points (1.3 cm) from the each end and usually, having a mid-point. Each anchor point was labeled with a word or expression. Each judge recorded his evaluation by making a vertical line across the horizontal line at the point that best reflects his perception of the magnitude of the property. After the panelists had completed their judgments, a rule was used to measure the rating by each of panelist. Results were subjected to multiple regression analysis and response surface methodology.

2.7 Experimental design

The Central Composite Face-Centered Design (CCFC) used in this work was produced using MINITAB 14 statistical software (MINITAB 14, 2003). The process variables and their levels used in the design are shown in Table 1. The experimental matrix used in the study, based on central composite face-centered design, is as shown in Table 2. The experimental space had fourteen star points and six central points, making a total of twenty runs. The data obtained from the study was fitted to the second-order polynomial regression model (Annor *et al.*, 2009) of the form:

$$Y = b_o + b_1X_1 + b_2X_2 + b_3X_3 + b_{11}(X_1)_2 + b_{22}(X_2)_2 + b_{33}(X_3)_2 + b_{12}X_1X_2 + b_{13}X_1X_3 + b_{23}X_2X_3 + \varepsilon$$

Where X_1, X_2 and X_3 are feed composition (per cent soybean flour), feed moisture and barrel temperature, respectively; b_o is the regression constant; b_1, b_2 and b_3 are linear regression terms; b_{11}, b_{22} and b_{33} are quadratic regression terms; b_{12}, b_{13} and b_{23} are the cross-product regression terms; ε is the error term. MINITAB Version 14 was used in the design of the experiment as presented in Table 2.

Table 1: Independent variables and their levels of replication

Parameters code	Levels of replication		
	-1	0	+1
Soybean flour (%) X1	10	20	30
Feed moisture (%) X2	20	22.5	25
Temperature (°C) X3	120	140	160

Table 2: Central composite face centered (CCF) design matrix and the independent variables in their natural forms

Runs	X1	X2	X3	Soybean flour (%)	Feed moisture (%)	Extrusion temp.(°C)
1.	-1	-1	-1	10	20	120
2.	+1	-1	-1	30	20	120
3.	-1	+1	-1	10	25	120
4.	+	+1	-1	30	25	120
5.	-1	-1	+1	10	20	160
6.	+1	-1	+1	30	20	160
7.	-1	+1	+1	10	25	160
8.	+1	+1	+1	30	25	160
9.	-1	0	0	10	22.5	140
10.	+1	0	0	30	22.5	140
11.	0	-1	0	20	20	140
12.	0	+1	0	20	25	140
13.	0	0	-1	20	22.5	120
14.	0	0	+1	20	22.5	160
15.	0	0	0	20	22.5	140
16.	0	0	0	20	22.5	140
17.	0	0	0	20	22.5	140
18.	0	0	0	20	22.5	140
19.	0	0	0	20	22.5	140
20.	0	0	0	20	22.5	140

Key: X_1 = soybean flour, X_2 = feed moisture, X_3 = extrusion temperature

Central composite face-centered designs provide relatively high quality predictions over the entire design space and do not require using points outside the original factor range. However, they give poor precision for estimating pure quadratic coefficients. (http://www.itl.nist.gov/div898/handbook).

2.8 Statistical analysis

MINITAB version 14 statistical analysis software was used in the statistical analysis of data. Analysis of variance (ANOVA) was used to establish statistical significance of the model and various responses. Numerical optimization and interactive graphs were used to optimize the various input variables and responses. Graphical residual analysis (NIST/SEMATECH, 2006) [26]. was used to establish the validity of the empirical models.

3. Results and Discussion

3.1 Effect of extrusion conditions on the sorghum-soybean extrudates

3.1.1 Colour

Sensory evaluation is the scientific measurement of food product properties as are perceived through the five human senses of sight, smell, taste, touch, and hearing (Oliveira, 2011) [27]. Sensory evaluation is used to evaluate quality, improve quality, provide inputs for decision making in product development, ingredient substitution in product formulation, determine storage conditions and compare products with those of competitors (Oliveira, 2011) [27]. Colour is one of the most important attributes used to determine the acceptability of foods. This is because no matter how nutritious, flavoured or well textured a food is, it is unlikely to be accepted unless it has the right colour and appearance (Serna-Sardivar *et al.*, 1990) [28]. The colour of the extrudates varied from 4.79 (cream) to 10.04 (brown) (Table not shown). Run 9 showed the least value for colour intensity while Run 14 had the highest colour intensity. The response surface plots for colour of sorghum-soybean extrudates are presented in Figure 1(a). The colour of the extrudates was affected by both the feed moisture and amount of soybean flour in the extrudates. Increase in feed moisture and the soybean flour caused an increase in the colour intensity of the extrudates. Feed composition and extrusion temperature had the most effect on the colour of extrudates.

The effect of extrusion conditions on the sensory responses of sorghum-soybean extrudates are presented in Table 3**.** The colour of sorghum-soybean extrudates was significantly ($p<0.05$) influenced by the linear and quadratic effects of feed composition and the extrusion temperature. The coefficient of determination (R^2) was 0.98 while the adjusted R^2 was 0.95 for colour; this implies that 98% of the total variations in colour could be explained by the model. There was a non-significant lack of fit. A high R^2 value does not necessarily guarantee that the model fits the data well. The primary tool for most process modeling applications is graphical residual analysis (NIST/SEMATECH, 2006) [26]. The normal probability plot of the residuals for colour (Figure 1b) shows an approximately straight line, indicating a good fit. The second-order model was therefore used to predict these sensory responses. Since the fitted second-order model provides a good fit, it was used to locate the optimum levels of feed composition, feed moisture and extrusion temperature for the extrusion process. Moskowitz (1977) [29]. suggested response surface methodology (RSM) as an optimization procedure in sensory evaluation. Henika (1982) [30] described the application of RSM to sensory data to guide product formulation and to help bridge the gap between sensory evaluation, product development, and marketing. Meyers (1984) [31] pointed out that, RSM is useful in optimizing the sensory properties of a new product.

Table 3: Regression coefficients for the sensory evaluation of sorghum- soybean extrudates

Coefficients		**Colour**	**Flavour**	**Grittiness**	**Stickiness**	**Ovaccept**
Linear	b_o	22.1466	24.26416	-2.98548	-137.036	7.61946
	b_1	0.83213*	-0.40560*	1.32406*	0.373	0.89754*
	b_2	1.01689	-2.03259	-0.78523	8.3270**	2.05096
	b_3	0.51218*	0.012065	0.02576	0.6460**	0.20527*
Quadratic	b_{11}	0.01757*	0.02404*	-0.02061*	-0.0070*	0.00773*
	b_{22}	0.02789	0.03829	0.02313	-0.1690**	0.04665*
	b_{33}	0.00171*	-0.00030	0.00020	-0.0020*	0.00066
Interaction	b_{12}	0.00235	-0.00785*	0.00335	------	0.00463
	b_{13}	0.00018	-0.000113	-0.00131*	-0.0010	0.00171*
	b_{23}	0.00150	0.00373*	-0.00228	-0.0040	0.02100
	R_2	0.975	0.996	0.997	0.925	0.992
Adjusted R^2		0.953	0.993	0.995	0.858	0.986
Lack of Fit		NS	NS	NS	*	NS

$Y = b_o + b_1X_1 + b_2X_2 + b_3X_3 + b_{11}(X_1)^2 + b_{22}(X_2)^2 + b_{33}(X_3)^2 + b_{12}X_1X_2 + b_{13}X_1X_3 + b_{23}X_2X_3 + \varepsilon$

X_1 = Feed composition, X_2 = Feed moisture, X_3 = Extrusion temperature;

* Significant at $p \le 0.05$, and **$p \le 0.01$ respectively, NS = not significant.

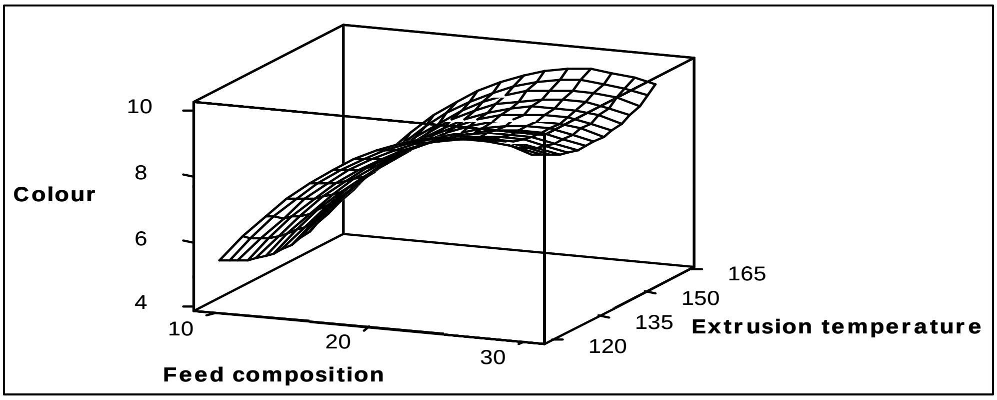

Fig 1(a): Surface plot of effect of feed composition and extrusion temperature on colour of soybean extrudates

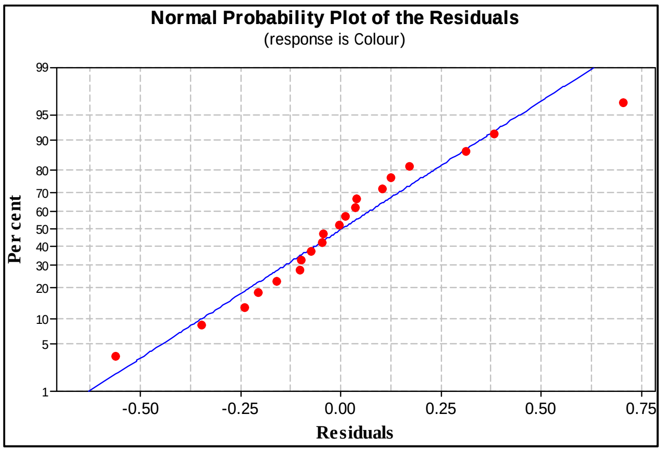

Fig 1(b): Normal probability plots of the residuals for colour of soybean extrudates

3.1.2 Flavour

The rating for flavour intensity of extrudates varied from 1.5 (low cooked cereal flavour) to 9.63 (high cooked cereal flavour) (Table not shown). Run 6 had the highest flavour intensity. The response surface plots for flavour of the extrudates are presented in Figure 2(a). Feed composition and feed moisture showed significant effect on the flavour intensity of the products. Increase in the feed composition and feed moisture caused a significant increase in the flavour intensity of the extrudates. This may be due to the beany flavour observed in soybean. The flavour of the sorghum-soybean extrudates was significantly ($p<0.05$) affected by the negative linear and quadratic effects of feed composition and the negative interaction effect of feed composition and feed moisture and the combined positive interaction effects of feed moisture and the extrusion temperature. The coefficient of determination (R^2) was 0.83 while the adjusted R^2 was 0.99 for flavour with a non-significant lack of fit. This implies that 83% of the total variation in flavour could be explained by the model. The normal probability plot of the residuals for flavour (Figure 2b) shows an approximately straight line, indicating a good fit. A straight line suggests that the errors are randomly distributed. The second-order model was therefore used to predict these sensory responses. Feed composition had the most effect on extrudates followed by feed moisture and extrusion temperature.

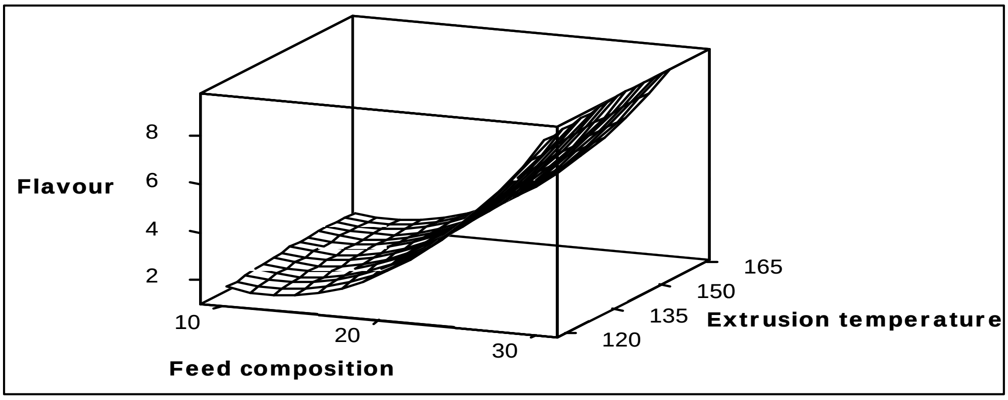

Fig 2(a): Surface plot of effect of feed composition and extrusion temperature on flavour of soybean extrudates

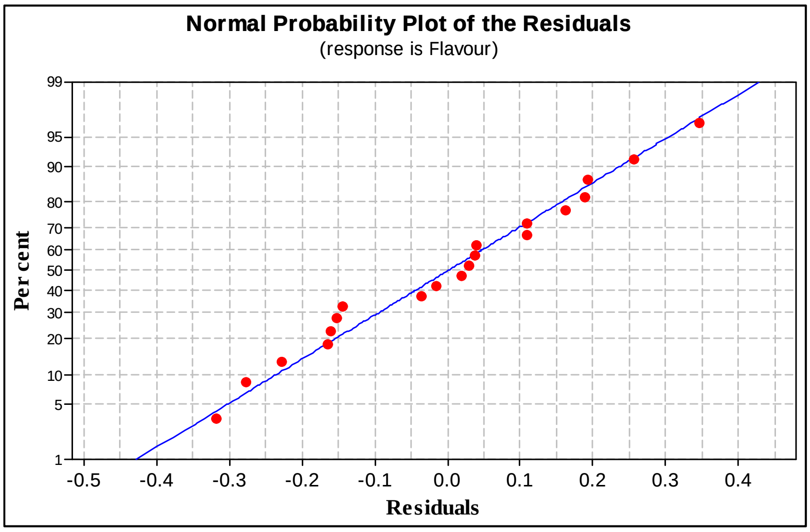

Fig 2(b): Normal probability plots of the residuals for flavour of soybean extrudates

3.1.3 Grittiness

Grittiness is a geometrical characteristic which is closely related to the particle size of the food material (Fellows, 2000). Grittiness in this work defines the size and degree of hardness of the food particles in question. Grittiness of the extrudates ranged from 1.29 (very low) to 10.4 (high) (Table not shown).

Run 1 showed the least value while Run 4 was rated highest in grittiness. The response surface plots for the grittiness of the extrudates is shown in Figure 3(a). Increases in feed moisture along with temperature produced an increase in the grittiness of the extrudates. Increase in the per cent soybean flour and feed moisture of samples produced similar results. In like manner, increases in the feed composition and extrusion temperature caused an increase in the grittiness of the products. The grittiness of extrudates was significantly influenced by the linear and negative quadratic effects of feed composition and the negative interaction effects of feed composition and extrusion temperature. The coefficient of determination (R^2) and adjusted R^2 were 0.99 and 0.99 respectively for grittiness. There was a non-significant lack of fit. The normal probability plot of the residuals for grittiness (Figure 3b) shows that most of the points fall on the straight line, suggesting a good fit. The second-order model was therefore used to predict these sensory responses. Feed composition showed the most effect on grittiness followed by extrusion temperature.

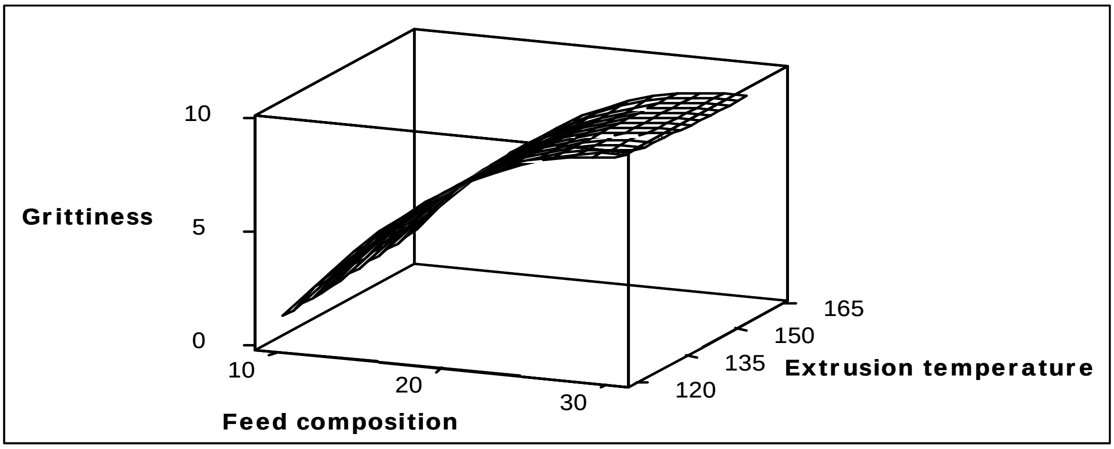

Fig 3(a): Surface plot of effect of feed composition and extrusion temperature on grittiness of soybean extrudates

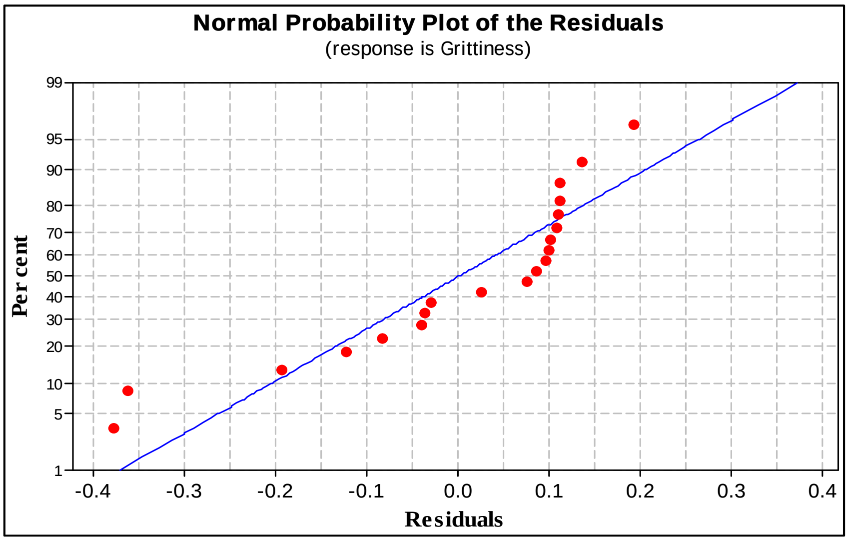

Fig 3(b): Normal probability plots of the residuals for grittiness of soybean extrudates

3.1.4 Stickiness

The rating for stickiness ranged from 3.55 (low) to 4.9 (low) (Table not shown). The lowest rating was from Run 3 while the highest was from Run 9 (10: 22.5: 140). The response surface plots for the stickiness of sorghum-soybean extrudate samples are presented in Figure 4(a). The stickiness of extrudates increased as the feed moisture was increased. It could also be observed from the plots that the combined effects of feed composition and extrusion temperature caused a marginal increase from 5.0 to 5.25 and then declined to 4.25. The interaction between feed composition and feed moisture gave similar results as observed in the interaction between feed composition and extrusion temperature. The stickiness was significantly (p<0.01) influenced by the linear effects of feed moisture and extrusion temperature. It was also affected by the negative quadratic effects of feed composition, feed moisture and extrusion temperature. The coefficient of determination (R^2) was 0.93 while the adjusted R^2 was 0.86 for stickiness. There was a significant lack of fit. The normal probability plot of the residuals for stickiness (Figure 4b) shows that most of the points fall on the straight line, suggesting a normal distribution of the random error. The second-order model was therefore used to predict these sensory responses. Feed moisture had the effect on the stickiness of extrudates followed by extrusion temperature.

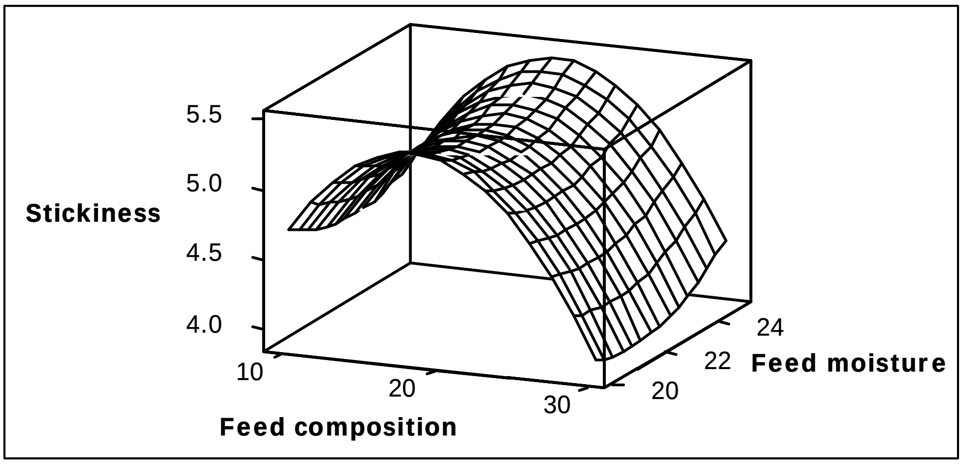

Fig 4(a): Surface plot of effect of feed composition and feed moisture on stickiness of soybean extrudates

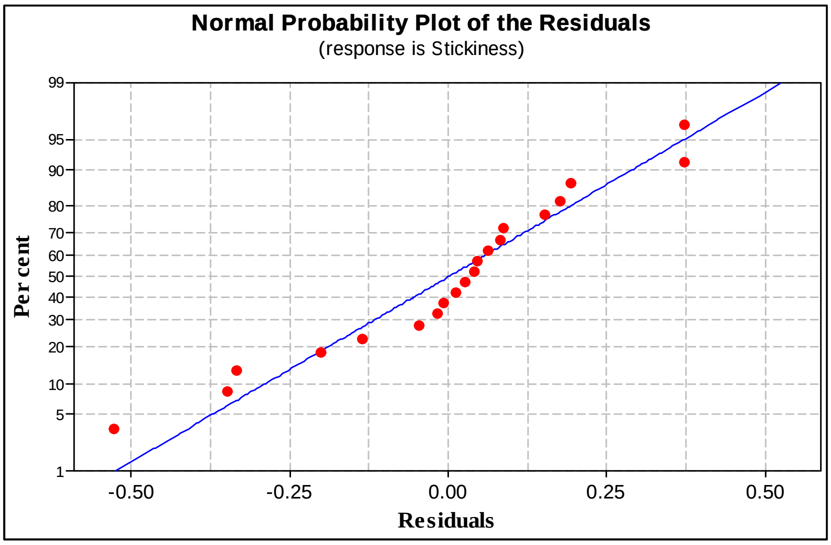

Fig 4(b): Normal probability plots of the residuals for stickiness of soybean extrudates

3.1.5 Overall acceptability

The overall acceptability of a product is a reflection of the various individual attributes that altogether make the product attractive and acceptable to the consumer. The rating of overall acceptability of the extrudates varied from 3.9 ((low) to 11.8 (high) (Table not shown). The least acceptable extrudate was from Run 2 while the most acceptable extrudate was from Run 9 (10: 22.5: 140). The overall acceptability of the products as influenced by the amount of soy-flour and feed moisture of the extrudates showed a steep downward slope, indicating a decrease in the overall acceptability of the products. Increase in the soybean flour content led to a slight increase in the overall acceptability of samples up to a maximum and then dropped as evidenced by the downward slopes. From the response surface plots, optimum conditions for the production of an acceptable sorghum-soybean breakfast cereal were: feed composition 15.38%, feed moisture 20% and extrusion temperature of 120ºC. The predicted response for the overall acceptability was 10.46 on a 15 point scale. The overall acceptability of the sorghum-soybean extrudates was significantly ($p<0.05$) influenced by the linear effects of feed composition and extrusion temperature, the quadratic effects of feed composition and feed moisture and the interaction effects of feed composition and extrusion temperature. The coefficient of determination (R^2) was 0.99 and R^2 was 0.99 for grittiness. There was a non-significant lack of fit. The normal probability plot of the residuals for overall acceptability (Figure 3b) shows that most of the points fall on the straight line, suggesting a normal distribution of the random error. The second-order model was therefore used to predict these sensory responses. Feed composition had the most influence on the overall acceptability extrudates followed by extrusion temperature and feed moisture.

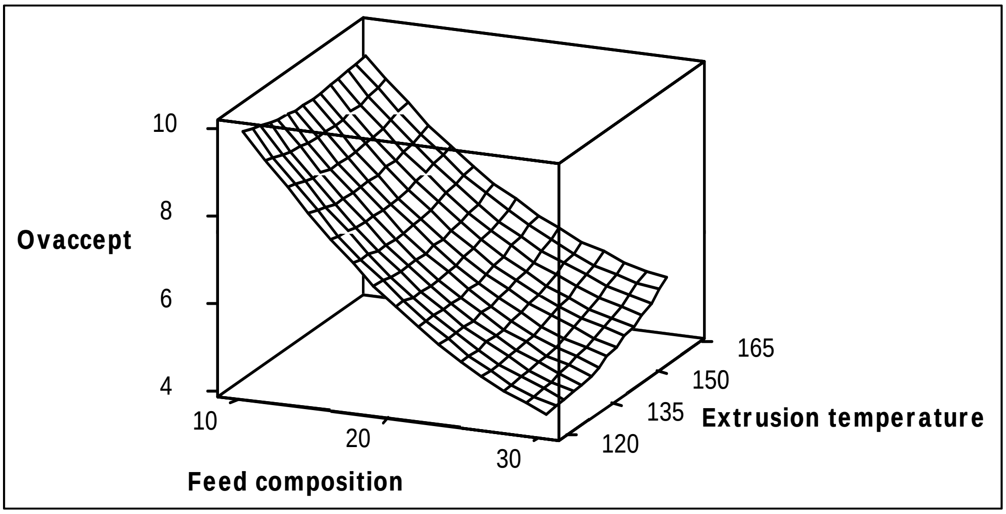

Fig 5(a): Surface plot of effect of feed composition and extrusion temperature on overall acceptability of soybean extrudates

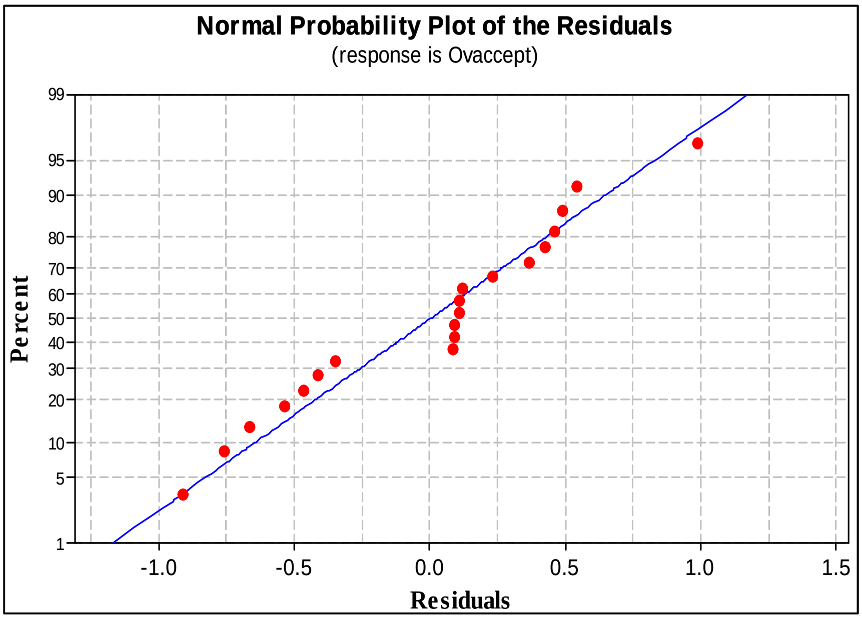

Fig 5(b): Normal probability plots of the residuals for overall acceptability of soybean extrudates

3.7 Optimization

Numerical optimization and interactive graphs were used to optimize the various input variables and responses. The factor levels were adjusted from the interactive optimization plots until the highest desirability value possible (maximum is 100%) was obtained for the particular response in question. The value of such a response at this point was considered the optimum. The colour, flavour, grittiness, stickiness and overall acceptability had optimum values of 9.76 (brown), 5.04 (low cooked cereal flavour), 5.5 (low in grittiness), 4.52 (low in stickiness) and 10.45 (high in overall acceptability) respectively.

Table 4: Optimization of sensory properties of sorghum-soybean extrudates

Responses	Feed composition (%)	Feed moisture (%)	Extrusion temperature (°C)	Optimum
Colour	19.0	20	120	9.76
Flavour	24.0	20	120	5.04
Grittiness	16.5	20	120	5.5
Stickiness	11.0	20.5	142	4.52
Overall acceptability	15.38	20	120	10.45

Plate 1: Photographic responses of sorghum-soybean extrudates

The photographic responses of the various sorghum-soybean extrudates are presented in plates S1 to S15. Plate S1 (10% Soybean, 20% moisture at 120ºC) showed the highest expansion and was closely followed by plates S12 (10% Soybean, 25% moisture at 160ºC), S7 (20% Soybean, 20% moisture at 140ºC) and S4 (30% Soybean, 20% moisture at 120ºC). The lowest expansion was shown by S3 (20% Soybean, 22.5% moisture at 120ºC) followed by plate S2 (10% Soybean, 25% moisture at 120ºC), S8 (20% Soybean, 22.5% moisture at 140ºC), S6 (10% Soybean, 22.5% moisture at 140ºC) and S15 (30% Soybean, 25% moisture at 160ºC) respectively.

4. Conclusion

The sorghum-soybean breakfast cereals were rated “low” in cooked cereal flavour, grittiness, stickiness but had “good” overall acceptability with optimum value of 10.46 on a 15 point scale. In the sensory evaluation of product attributes, the second-order model was found to sufficiently describe the colour, flavour, grittiness, and the overall acceptability of the sorghum-cowpea extrudates. The model also significantly described the colour, flavour, grittiness and overall acceptability of the sorghum-soybean extrudates. The model was found sufficient in predicting the colour, flavour, texture and the overall acceptability of the extrudates. Sensory evaluation in combination with response surface methodology can be used to optimize the degree of acceptability of extruded sorghum soybean breakfast cereals.

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