Response Surface Optimization of Extrusion Conditions for the Texture and Aroma of Extrudates from Blended Aerial Yam and Soybean Flours

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Abstract
This study was conducted with the aim of modeling and optimizing the extrusion process conditions for the texture and aroma characteristics of extruded snacks from blends of aerial yam and soybean flours. Blends of aerial yam and soybean flours were extruded using a laboratory-scale single-screw extruder in a ratio of 25% aerial yam to 75% soybean. Twenty runs of response surface methodology based on Box-Behnken design were conducted at five levels of barrel temperature (95, 100, 105, 110, and 115 °C), screw speed (85, 100, 115, 130, and 145 rpm), and feed moisture (31, 33, 35, 37, and 39%). Significant ($p < 0.05$) regression models, describing the effects of process parameters on the product quality attributes, were employed. Results obtained showed that texture and aroma characteristics scores ranged from 4.38 to 6.02 for texture; and 4.45 to 7.00 for aroma. The models can be used to navigate the design space, as evidenced by the high regression coefficient, $R^2 \geq 0.9$. According to optimization results based on the desirability concept, extrudates with desired texture and aroma characteristics would be produced at a barrel temperature of 114.12 °C, a screw speed of 100.56 rpm, and 38.02% feed moisture.

Keywords: *Numerical optimization, Extrusion process, Response surface, Extruded snacks, Regression analysis.*

Introduction

Optimization is crucial in order to formulate and manufacture acceptable food products from neglected food crops, and to manage process conditions or variables to produce extrudates with the appropriate quality (Umoh *et al*., 2024b; Umoh *et al*., 2024c).

Extrusion offers the potential to alter the functional characteristics of food ingredients and/or texturize them, in addition to the typical advantages of these procedures.

According to Yagci and Gogus (2009), ready-to-eat (RTE) cereals, salty and sweet snacks, co-extruded snacks, indirect expanded products, croutons for soups and salads, an increasing variety of dry pet foods and fish foods, textured meat-like materials from defatted high-protein flours, nutritious precooked food mixtures for infant feeding, and confectionery products are just a few of the many uses for the process. The extrusion process is an efficient, continuous process, which uniquely combines several unit operations, namely: mixing, shearing, heating, pumping,

forming, and sizing. The food industry is increasingly using extrusion cooking technology, a high-temperature-short-time (HTST) process, to create new cereal-based snacks, such as breakfast cereals, baby foods, high dietary fiber foods, and modified starch from cereals (Sebio and Chang, 2000; Pardeshi and Chattopadhyay, 2014; Pawar *et al*., 2014; Navale *et al*, 2015).
The drawbacks of this procedure include the loss of heat-labile vitamins and the Maillard reaction, which lowers the protein's nutritional value. For an extruded product to be nutritionally balanced, production factors must be controlled (Nikmaram *et al*., 2015).
One of the lesser-known sweet potato types is the aerial yam (*Dioscorea bulbifera*), which is known as "flying/air potatoes" because it produces bulbils that resemble potatoes instead of regular sweet potatoes. South and Central America, West Africa, and Southeast Asia are the regions where it is grown. It is rarely eaten and usually ignored at both the home and commercial levels due to a number of factors, such as its overall obscurity and a noticeably more severe delayed flavor impression in comparison to other sweet potato species. However, *Dioscorea bulbifera* has a lot of potential uses, including the creation of new industrial goods and its economic significance (Umoh *et al*., 2024a). Soybeans (*Glycine max*), a significant oilseed in the *Leguminosae* family, are typically cultivated for food. Iwe (2003) reported that soybeans are so adaptable that they can be turned into a wide range of food products.
The texture and appearance of soybeans can be treated to resemble those of many other foods. Soybean flour can replace wheat flour up to 25% in extruded food products to improve their nutritional value, diversity, and affordability (Omeire *et al*., 2014; Umoh *et al*., 2024a).
Extrusion is still a complex process that needs to be tailored for certain uses depending on the type of raw materials and intended finished product, even with its growing utilization. Even within a given extrusion process, small variations in processing conditions affect process variables as well as product quality (Umoh and Ekanem, 2024).
This study is aimed at modeling and optimizing the extrusion process conditions for the texture and aroma characteristics of extruded snacks from aerial yam and soybean flours blend using Response surface methodology.

Materials and Methods

Acquisition of soybean seeds and aerial yam bulbs

The Uyo Urban Market in Uyo Local Government Area, Akwa Ibom State, Nigeria, provided the aerial yam bulbs and soybean seeds used in this investigation.

Aerial Yam Flour Preparation

The procedure outlined by Olurin *et al*. (2006) was used to manufacture aerial yam flour. After cleaning and sorting the aerial yam bulbs to get rid of undesired elements, they were peeled with a knife, cleansed with clean water, and then cut to a thickness of 10 mm. After that, the slices (chips) were dried for 12 hours at 60°C in an oven. After being dried, the slices (chips) were ground in an Italian MF120 Hammer mill and sieved through a 600µm aperture laboratory sieve. For later usage, the flour was placed in a polyethene bag.

Soybean Flour Preparation

The process outlined by Umoh and Abasiekong (2024) was used to make soybean flour. To get rid of splits, extraneous objects, and damaged beans, seeds were inspected. Washing and roll boiling at 100 °C for 30 minutes came next. After being oven-dried for 12 hours at 70 °C, it was ground in a disc attrition mill. A normal 100-mesh sieve was used to filter the ground full-fat soybean. After that, the flour was kept at room temperature in an airtight polyethene bag for later use.

Extrusion Processing

The extrusion process was executed sing a single-screw laboratory scale extruder, in accordance with the procedure outlined by Umoh *et al*. (2024b). As indicated in the experimental design structure, two hundred grams (200 g) of the flour blend (25% aerial yam flour, 75% soybean flour) were precisely measured and preconditioned in accordance with the required moisture levels. The extruder was turned on, and its screw speeds and barrel temperatures were adjusted in accordance with the experimental design. The hopper was used to feed the raw material into the extruder.

For additional examination, the extrudates were gathered as they came out of the die, oven-dried, and sealed in airtight zip-lock polyethylene bags. According to the experimental design, a total of twenty runs were made during the extrusion process.

Determination of Texture and Aroma characteristics

According to Omeire *et al*. (2014), a 9-point Hedonic scale was used to determine these, with 1 denoting "extremely dislike," 5 denoting "neither like nor dislike," and 9 representing "extremely liked." Fifteen members of a semi-trained panel assessed the samples and assigned scores based on the extruded snacks' texture (measured as hardness) and aroma.

Design of Experiment/Data Analysis

The statistical computer application software package, Design Expert (version 11.0.1) was utilized for the layout and design of the experiment. Barrel temperature (X_1), screw speed (X_2), and feed moisture levels (X_3) were the independent factors in a three-factor experimental setup with five levels each using Central Composite Randomized Design (CCRD) (Table 1). The impacts of the independent variables or factors on the dependent variables (the responses) were examined using Response Surface Methodology (RSM).The independent variables that were employed had coded values of -2, -1, 0, 1, and 2, where -2 denotes the lowest levels, 0 the median (mid-point), and 2 the highest levels.

Table 1: Coded and Actual values of different Experimental variables

Factors	Units	Codes	Levels					Interval of Variation
			-2	-1	0	1	2	
Barrel temp.	°C	X_1	95	100	105	110	115	5.0
Screw speed	rpm	X_2	85	100	115	130	145	15.0
Feed moisture	%	X_3	31	33	35	37	39	2.0

The empirical expression for the responses is represented in Equation below as:

$$Y = \beta_0 + \sum_{i=1}^{2} \beta_i X_i + \sum_{i=1}^{2} \beta_{ii} X_i^2 + \sum_{i=1}^{2} \sum_{j=i+1}^{2} \beta_{ij} X_i X_j (3.1)$$

Where Y = Response, β_0 = Constant term, $\sum_{i=1}^{2} \beta_i$ = Summation of coefficient of linear terms, $\sum_{i=1}^{2} \beta_{ii}$ = summation of quadratic terms, $\sum_{i=1}^{2} \sum_{j=i+1}^{2} \beta_{ij}$ = summation of coefficient of interaction terms, and $X_i X_j$ = independent variables.

Model selection for optimization of extrusion process parameters

Design Expert (version 11.0.1), a statistical software program for experimental design was utilized to create and analyze the model equations for the responses (texture and aroma characteristics). The highest order polynomial, where the additional terms are significant and the model is not aliased, insignificant lack-of-fit, and the maximization of the adjusted and predicted correlation coefficients (Adjusted R^2 and Predicted R^2) were taken into consideration when choosing an appropriate model for the extrusion process parameters of the responses. Lower standard deviation figures and greater coefficient of determination (R^2) were also taken into account.

The Response surface methodology (RSM) numerical method was used to optimize the extrusion process parameters (barrel temperature, screw speed, and feed moisture). The optimization goals were to maximize the barrel temperature and screw speed, followed by a potential range for the feed moisture. All three extrusion process parameters and the responses were given equal weight of three in order to optimize the extrusion process parameters using a numerical algorithm that determines a point that maximizes the desirability function.

Table 2 shows the primary criteria, the intended outcomes, and the response for texture and aroma characteristics for each process parameter.

Table 2: Criteria for numerical Optimization of Extrusion process parameters for Texture and Aroma characteristics

Extrusion criteria	Unit	Lower limit	Upper limit	Optimization Goal	Relative Importance
Barrel Temperature	℃	95.00	115.00	Maximize	3
Screw Speed	rpm	85.00	145.00	Maximize	3
Feed Moisture	%	31.00	39.00	Range	3
Texture		4.38	6.02	Range	3
Aroma		4.45	7.00	Range	3
Desirability					

Results and Discussions

The results of the texture and aroma characteristics of the extruded aerial yam and soybean flour blends are presented in Table 3.

Table 3: Texture and Aroma characteristics of extruded aerial yam and soybean flour blends.

S/N	BT (^{0}C)	SS (rpm)	FM (%)	Texture	Aroma
1	105	115	31	5.72±0.021	6.30±0.034
2	105	115	35	5.91±0.042	6.95±0.111
3	105	115	35	5.96±0.042	6.90±0.111
4	105	85	35	4.79±0.003	6.00±0.001
5	100	130	33	5.79±0.124	6.00±0.421
6	110	100	37	5.55±0.004	7.00±0.011
7	100	100	37	5.88±0.014	6.30±0.004

8	110	130	33	5.86±0.002	5.90±0.006
9	105	115	35	5.90±0.042	6.83±0.111
10	115	115	35	4.98±0.007	5.00±0.021
11	95	115	35	5.57±0.011	4.45±0.011
12	105	115	39	5.89±0.044	6.20±0.001
13	105	115	35	5.95±0.042	6.89±0.111
14	100	100	33	5.47±0.004	4.76±0.006
15	110	130	37	6.02±0.001	5.01±0.001
16	110	100	33	4.38±0.004	6.01±0.312
17	105	145	35	4.89±0.002	5.02±0.006
18	100	130	37	5.10±0.004	5.85±0.001
19	105	115	35	5.93±0.042	6.93±0.111
20	105	115	35	5.99±0.042	6.91±0.111

Note: Values are mean ± standard deviation of triplicate determination.
BT=Barrel temperature, SS= Screw speed, FM= Feed moisture

Texture

Texture values ranged from 4.38 to 6.02 (Table 3). This range of values is consistent with the previous results that Umoh *et al*. (2024a) published. However, as previously observed by Tadesse et al. (2019), it is higher than 1.96 and 4.64 for sorghum-based extruded product supplemented with defatted soy meal flour, but lower than 7.22 to 8.44 for pulse-based snacks (Alemayehu *et al*., 2019). The extrudate generated at 110 °C barrel temperature, 130 rpm screw speed, and 37% feed moisture had the greatest texture score (6.02), whereas the extrudate produced at 110 °C barrel temperature, 100 rpm screw speed, and 33% feed moisture received the lowest score (4.38).

Aroma

Table 3 displays the aroma scores that were recorded. The numbers ranged from 4.45 to 7.00, according to the results. Although this range of values is consistent with the previous study by Umoh *et al*. (2024a), it is marginally higher than the 4.88 and 6.80 for the sorghum-based extruded product enriched with defatted soy meal flour previously reported by Tadesse *et al*. (2019). Nonetheless, it is similar to 5.3 and 7.4 for root and tuber composite flour noodles, as Akonor *et al*. (2017) previously found. Extrudate produced at 110 °C barrel temperature, 100 rpm screw speed, and 37% feed moisture received the maximum aroma score of 7.00, whereas extrudate generated at 95 °C barrel temperature, 115 rpm screw speed, and 35% feed moisture received the lowest aroma score of 4.45.

Table 4: Coefficient of Regression/ANOVA for Texture and Aroma characteristics

	Texture		**Aroma**	
	Coeff.	**p-values**	**Coeff.**	**p-values**
X_0	-3.99		-482.80	
Linear				
X_1	0.1786	0.0142	5.71	0.0051
X_2	0.1703	0.0111	1.37	0.0003
X_3	-0.5336	0.0285	6.28	0.0541
Interaction				
X_1X_2	0.00402	< 0.0001	-0.00482	< 0.0001
X_1X_3	0.0201	0.0019	-0.0161	0.0116
X_2X_3	-0.00879	0.0003	-0.0149	< 0.0001
Quadratic				
${X_1}^2$	-0.00650	0.0001	-0.0217	< 0.0001
${X_2}^2$	-0.00121	< 0.0001	-0.00154	< 0.0001
${X_3}^2$	-0.00750	0.2943	-0.0406	0.0003
Test for model adequacy				
R^2	0.9585		0.9831	
Pred. R^2	0.6617		0.8634	
Model F-value	25.65		64.68	
Lack of fit	31.98		24.77	

Note: X_o = intercept, X_1 = Barrel temperature, X_2 = Screw speed, X_3 = Feed moisture. Significance at $p < 0.005$.

Table 4 displays the findings of the models' Regression Analysis/ANOVA for optimizing the extrusion process parameters of the extruded aerial yam and soybean flour blend's texture and aroma characteristics.

Model selection for optimization of extrusion process parameters for texture

The quadratic model was selected for the optimization of extrusion process parameters for texture, taking into account the model with the lowest standard deviation (0.1359) and the highest coefficient of determination, R^2 (0.9585), Adjusted R^2 (0.9211), and projected R^2 (0.6617). Equation 1 provides the final texture regression model as follows:

$$\boldsymbol{T_X = -3.99 + 0.1786BT + 0.1703SS - 0.5336FM + 0.00402BTSS + 0.0201BTFM - 0.00879SSFM - 0.00650BT^2 - 0.00121SS^2 - 0.00750FM^2} \quad (1)$$

Where: T_X = Texture, BT = Barrel temperature (^{0}C), SS= Screw speed, FM= Feed moisture

The extrusion process parameters and their interactions with the response (texture) are directly related, as indicated by the positive terms in Equation 1, whilst the negative terms show an inverse relationship. It was observed that two out of the three extrusion process parameters: BT and SS, including their interactions (BTSS and BTFM) have direct relationship with the response (texture). This indicates that when barrel temperature (BT), screw speed (SS), BTSS, and BTFM rise, so does the texture. The response (texture) and quadratic terms (SS^2 and FM^2) are inversely related. The model F-value for texture in the regression analysis/ANOVA results is 25.65, suggesting that the model is significant. Significant model terms are indicated by values of "prob > F" less than 0.0500. All of the model factors in this instance are significant, with the exception of FM^2, which has a p-value of 0.2943, which is higher than the significance criterion of 0.0500 (Table 4). The texture "Lack of fit" F-value of 31.98 indicates that the "Lack of fit" is not significant in comparison to the pure error. A "Lack of fit F-value this large could occur due to noise" has a mere 0.08% probability. Since the goal is for the model to fit, a significant "lack of fit" is undesirable. A signal-to-noise ratio of more than four is considered "adequate precision" (Montgomery, 2001; Aydar, 2018). Consequently, the texture ratio of 16.4086 shows a sufficient signal, therefore, the design space can be navigated using this approach. With a satisfactory coefficient of determination (R^2) of 0.9585, the model was significant (Table 4). Excellent association between the independent variables (barrel temperature, screw speed, and feed moisture) and the response was demonstrated by the high coefficient of determination. This shows that the response (texture) model is sufficient and can account for 95% of the response's overall variability.

Model selection/equation for optimization of extrusion process parameters for aroma

The quadratic model was picked for the optimization of extrusion process parameters for aroma, taking into account the model with the lowest standard deviation (0.1479) and the highest coefficient of determination, R^2 (0.9831), Adjusted R^2 (0.9679), and projected R^2 (0.8634). Equation 2 provides the final regression model for aroma as follows:

$$\boldsymbol{A_M = -482.80 + 5.71BT + 1.37SS - 0.00482BTSS - 0.0161BTFM - 0.0149SSFM - 0.0217BT^2 - 0.00154SS^2 - 0.0406FM^2} \quad (2)$$

where: A_M = Aroma, BT = Barrel temperature (^{0}C), SS= Screw speed, FM= Feed moisture

The extrusion process parameters and their interactions with the response are directly related, as indicated by the positive terms in Equation 2, whilst the negative terms show an inverse relationship. All three of the extrusion process parameters were found to be: While their interactions—BTSS, BTFM, and SSFM, including the quadratic terms (SS^2 and FM^2)—have an inverse relationship with the response (A_M), BT and SS have a direct relationship with the response. Aroma's model F-value of 64.68 in Table 4 indicates that the model is significant. Significant model terms are indicated by values of "prob > F" less than 0.0500. All of the model terms in this instance are significant, with the exception of FM, which has a p-value of 0.0541.

The model's "Lack of Fit" F-value of 24.77 indicates that the "Lack of Fit" is not substantial in relation to the pure error. Since the goal is for the model to fit, non-significant "lack of fit" is beneficial. As a result, the design space can be navigated using this approach. With a satisfactory coefficient of determination (R^2) of 0.9831, the model was significant (Table 4). Excellent association between the independent variables (barrel temperature, screw speed, and feed moisture) and the response was demonstrated by the high coefficient of determination. This shows that the response quadratic model is sufficient, accounting for 98% of the response's overall variability.

Numerical optimization of extrusion process parameters for texture and aroma

The maximum barrel temperature and screw speed, followed by the feed moisture range, were the primary factors used to optimize the extrusion process parameters for texture and aroma characteristics. Table 5 shows the intended optimization objectives and results for every extrusion process parameter and response.

Table 5: Output for numerical optimization of extrusion process parameters for texture and aroma characteristics

Extrusion Criteria	Unit	Lower limit	Upper Limit	Optimization Goal	Relative Importance	Output
Barrel Temperature	°C	95.00	115.00	Maximize	3	114.12
Screw Speed	Rpm	85.00	145.00	Maximize	3	100.56
Feed Moisture	%	31.00	39.00	Range	3	38.02
Texture		4.38	6.02	Range	3	6.02
Aroma		4.45	7.00	Range	3	5.80
Desirability						0.943

The ideal extrusion process parameters were found to be 38.02% feed moisture, 100.56 rpm screw speed, and 114.12 ºC barrel temperature. Additionally, the best scores for texture and fragrance qualities were 5.34 and 5.80, respectively, with a desirability of 0.943% (Table 5). In the meantime, the optimization findings for the objective of optimizing the range for the answers were 4.45 to 7.00 for scent and 4.38 to 6.02 for texture.

Conclusions

According to the study's findings, optimization results based on the desirability concept show that extrudates with desired texture and aroma characteristics would be produced at a barrel temperature of 114.12 °C, a screw speed of 100.56 rpm, and a feed moisture content of 38.02%. Additionally, the ideal scores of 5.34 for texture and 5.80 for scent, with a desirability of 0.943%, are desirable.

Conflict of Interest

The author declares that there are no conflicts interest.

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