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Optimization of Carbohydrate Content and Energy value of Extruded Composite Snacks of Aerial Yam and Soybean Flours using the Response Surface Methodology (RSM)

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Abstract

The study examined the effect of extrusion process factors on carbohydrate content and energy value of extrudates from aerial yam and soybean composite flour mixes. Laboratory scale single-screw extruder was utilized in extruding blends of aerial yam and soybean flours in the ratio of 1:3. Randomized Central Composite Design (RCCD) was used with a three factor experimental set up at five levels each, with barrel temperature (X_1 : 95 °C, 100 °C, 105 °C, 110 °C, 115 °C), screw speed (X_2 : 85 rpm, 100 rpm, 115 rpm, 130 rpm, 145 rpm) and feed moisture levels (X_3 : 31%, 33%, 35%, 37%, 39%) as the independent factors. Response Surface Methodology (RSM) was utilized to analyze the effects of the independent factors on the dependent variables (the responses). Coded values for the independent factors used were -2, -1, 0, 1, 2, where -2 represents the lowest, 0 represents the medium (mid-point), and 2 represents highest levels, respectively. Significant ($p < 0.05$) regression models describing the effect of the extrusion process conditions on the carbohydrate content and energy value of the extrudates, were utilized. Results obtained from the proximate analysis revealed that carbohydrate contents differed somewhere in the range of 30.11 and 54.15%, while energy value ranged from 398.84 to 529.17 kcal. Carbohydrate contents were significantly ($p < 0.05$) impacted by barrel temperature, screw speed and feed moisture, while barrel temperature and screw speed showed significant ($p < 0.05$)

impact on energy value. High regression coefficients, $R^2 \geq 0.9$ were obtained, showing that the models can be used to navigate the design space. Optimization results based on desirability concept indicated that 112.11 °C barrel temperature, 136.49 rpm screw speed and 34.65% feed moisture would produce composite snacks of better carbohydrate content and energy value.

Keywords: Barrel temperature, Screw speed, Feed moisture, Extrudates, Response surface.

1.0 Introduction

Southeast Asia, West Africa, South and Central America are all regions where the aerial yam (*Dioscorea bulbifera*) is grown. The wild species also exist in Asia and Africa (Nwosu, 2013). According to research by Ojinnaka *et al.* (2017), *Dioscorea bulbifera* is one of the unpopular sweet potato varieties that produce bulbils that resemble potatoes rather than the traditional sweet potato. This gives the variety the nickname "flying/air potatoes." For a variety of reasons, which include, being generally more obscured, to most people and having a generally more severe delayed flavor sensation, compared to other sweet potato species, this is rarely consumed and is typically neglected both at the household and industrial levels (Igyor *et al.*, 2004). Additionally, not enough research has been done on this variety to suggest the potential uses for it.

Nevertheless, *Dioscorea bulbifera* has a large potential of application and therefore could be applied in the development of new industrial products, as well as its economic relevance (Sanful and Engmann, 2016). *Dioscorea bulbifera* can be a good potential for the treatment of kidney disorders (Ahmed *et al.*). This spice was also found to be effective in treating spleen and lung diseases as well as many types of loose stools, improving processing and digestion. This spice has been highly advocated for the treatment of diabetes in Asia. Although this feature has not yet been deductively proven, it has traditionally been employed to lower glycemic index, providing a more supported form of energy and greater insurance against weight and diabetes (Brand-Miller *et al.*, 2003).

Dioscorea bulbifera, a less common food crop, has not undergone any significant industrial processing. Only a small portion of the harvest is used to create instant aerial yam flour, which is particularly popular in the Yoruba-speaking regions of West Africa (Orkwor *et al.*, 1998). Processing aerial yam into flour will help reduce our excessive reliance on wheat flour for our baked foods and post-harvest losses (Prince-will and Ezembaukwu, 2015).

A major oil seed belonging to the *Leguminosae* family called soybean (*Glycine max*) is typically grown for food. To increase the variety of extruded food products, make them affordable to more people, and support their nutritional content, wheat flour can be substituted with soybean flour up to 25% (Omeire *et al.*, 2014).

Umoh and Iwe (2022) asserted that the extrusion process parameters of barrel temperature, screw speed, and feed moisture, as well as their interactions, have an impact on the extruded aerial yam-soybean flour mixes in both favorable and unfavorable ways.

Response surface methodology (RSM) is a multivariate equation solving technique, which uses experimental data to fit mathematically in a theoretical design through a response function (Santelli *et al.*, 2006). The parameters that affect the process are called independent variables,

while the responses are called dependent variables. This technique is applied to describe the individual and interactive effects of the independent variables on the response. The RSM helps in optimizing a set of operational variables of the process (Myers and Montgomery, 2002). The RSM approach has widely been applied in extruded food product development (Yagci and Gogus, 2009; Seth and Rajamanickam, 2012).

As a crop for human consumption, *Dioscorea bulbifera* still needs to gain recognition and acceptance globally. Processing it into a stable blend and subsequent extrusion processing to produce different products will increase the visibility of the crop in the food trade, thereby bringing to limelight its potential food uses to the food industry. This study is pointed toward determining the impacts of extrusion process variables on the carbohydrate content and the energy value of extrudates made from a mixture of aerial yam and soybean flour.

2.0 Materials and Methods

The aerial yam bulbs and soybean seeds were bought from Uyo Urban Market in the Nigerian Akwa Ibom State local government of Uyo, for use in this study.

2.1 Aerial Yam Flour Preparation

According to Olurin *et al.* (2006), the bulbils were sorted, peeled before washing and sliced into chips, utilizing the blade. This was followed by drying at 60 °C for 12 hours (using model KX350A Oven, Kenxin International Co. Ltd., Guangdong, China), milled into powder using a Food Grade model SK-30-SS disc attrition mill (manufactured by Munson Machinery Co. Inc., New York), sieved with a laboratory sieve of 600 µm aperture size. The flour obtained was then stored properly for subsequent use.

2.2 Soybean Flour Preparation

This was carried out according to the method described by Iwe (2003). The soybean seed was sorted, washed, roll boiled at 100 °C for 30 minutes, and subjected to drying at 70 °C for 12 hours, before milling using a Food Grade model SK-30-SS disc attrition mill (Munson Machinery Co. Inc., New York). This was followed by sieving, utilizing a 100-mesh standard laboratory sieve. The flour was properly preserved, for further utilization.

2.3 Extrusion Cooking

This was carried out utilizing a single- screw laboratory scale extruder; 200 g of the flour mix was accurately measured and preconditioned for 2 minutes (Strahm, 2000). The raw material was thereafter fed into the extruder, setting the speed of the screw and temperature accordingly. The pasta were gathered, as they exited through the die, they were then dried and packaged in polyethylene bags for laboratory analyses.

2.4 Carbohydrate Content Determination

Determination of carbohydrate content of the sample was carried out by subtracting the total estimations (in %) made of nitrogen (protein), fat, ash and crude fibre contents from 100%. The resultant value gave the percentage carbohydrate content by difference, using equation 2.1.

$$\text{Carbohydrate (\%)} = 100 - (a + b + c + d) \dots \dots \dots \text{Equation 2.1}$$

Where:

a = percentage protein content

b = percentage lipid content

c = percentage ash content

d = percentage fibre content

2.5 Energy (caloric) Value Determination

This was obtained using the Atwater factor method. Constant values of 4, 9, and 4 were multiplied by the values of the carbohydrate, fat and crude protein contents, respectively. The result obtained represented the energy value (in kcal) of the extrudate, as shown in equation 2.2.

$$\text{Energy value (kcal)} = (x \times 4) + (y \times 9) + (z \times 4) \dots \dots \dots \text{Equation 2.2}$$

Where:

x = carbohydrate content

y = fat content

z = crude protein content

2.6 Design of Experiment/Analysis of Statistics

The experimental design and layout (Table 2.2) were done using a licensed Design Expert, version 11.0.1, form Stat-Ease Inc., Minneapolis, MN55418, United States of America. Central Composite Randomized Design (CCRD) was used with a three factor experimental setup at five levels each, with barrel temperature (X_1), screw speed (X_2) and feed moisture levels (X_3) as the independent factors. Coded values for the independent factors used were -2, -1, 0, 1, 2, where -2 represents the lowest, 0 represents the medium (mid-point), and 2 represents highest levels, respectively (Table 2.1). The impacts of the independent factors on the dependent variables were assessed using Response Surface Methodology.

Table 2.1: 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

Table 2.2: Experimental layout for 3 variables and 5 level response surface and experimental design for the extrusion of aerial yam and soybean flour blends

Runs	Coded Factors			Actual Factors		
	Order	X_1	X_2	X_3	$BT (^{\circ}C)$	$SS (rpm)$
1	0.000	0.000	-2.000	105.00	115.00	31.00
2	0.000	0.000	0.000	105.00	115.00	35.00
3	0.000	0.000	0.000	105.00	115.00	35.00
4	0.000	-2.000	0.000	105.00	85.00	35.00
5	-1.000	1.000	-1.000	100.00	130.00	33.00
6	1.000	-1.000	1.000	110.00	100.00	37.00
7	-1.000	-1.000	1.000	100.00	100.00	37.00
8	1.000	1.000	-1.000	110.00	130.00	33.00
9	0.000	0.000	0.000	105.00	115.00	35.00
10	2.000	0.000	0.000	115.00	115.00	35.00
11	-2.000	0.000	0.000	95.00	115.00	35.00
12	0.000	0.000	2.000	105.00	115.00	39.00
13	0.000	0.000	0.000	105.00	115.00	35.00
14	-1.000	-1.000	-1.000	100.00	100.00	33.00
15	1.000	1.000	1.000	110.00	130.00	37.00
16	1.000	-1.000	-1.000	110.00	100.00	33.00
17	0.000	2.000	0.000	105.00	145.00	35.00
18	-1.000	1.000	1.000	100.00	130.00	37.00
19	0.000	0.000	0.000	105.00	115.00	35.00
20	0.000	0.000	0.000	105.00	115.00	35.00

Note: BT = Barrel temperature, SS = Screw speed, FM = Feed moisture.

The empirical expression for the responses is represented in Equation 2.3 as:

$$Y = \beta_0 + \sum_{i=1}^2 \beta_i X_i + \sum_{i=1}^2 \beta_{ii} X_i^2 + \sum_{i=1}^2 \sum_{j=i+1}^2 \beta_{ij} X_i X_j \quad \dots \quad \text{Equation 2.3}$$

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.

3.0 Results and Discussions

Results of the carbohydrate content and energy value of extrudates from aerial yam and soybean flours blends are shown in Table 3.1.

3.1 Carbohydrate Content

The results of the carbohydrate content of blends of aerial yam and soybean are presented in Table 3.1. The carbohydrate content was in the range of 30.11 and 54.12%. These range of values is fairly low, compared to 54.47 and 82.96% for top notch cassava-Tiger nut extruded snacks (Kareem *et al.*, 2015); 62.60 to 74.20% for sorghum-based extrudates enhanced with defatted soy flour (Tadesse *et al.*, 2019); and 69.55 to 76.58% for selected aerial yam cultivar and African breadfruit extruded snacks (Olatoye and Arueya, 2021). The values of carbs in the samples could be attributed to the fact that soybean, which represented 75% of the flour mixes, is not so rich in carbohydrates. Likewise, a considerable level of carbohydrates has been destroyed because of extrusion cooking.

Table 3.1: Carbohydrate content and energy value of extrudates from aerial yam and Soybean flours blends

S/N	BT (°C)	SS(rpm)	FM (%)	Carbohydrate (%)	Energy value(kcal)
1	105	115	31	30.11±0.062	478.88±0.891
2	105	115	35	53.99±0.009	415.38±0.844
3	105	115	35	53.96±0.009	415.43±0.844
4	105	85	35	30.90±0.027	529.17±0.960
5	100	130	33	31.63±0.020	468.72±1.249
6	110	100	37	38.87±0.025	489.43±1.109
7	100	100	37	54.12±0.022	398.84±1.025
8	110	130	33	36.87±0.023	448.05±1.003
9	105	115	35	53.95±0.009	415.35±0.844
10	115	115	35	30.16±0.040	517.91±0.998
11	95	115	35	23.97±0.012	507.23±0.711
12	105	115	39	38.79±0.016	448.11±0.714
13	105	115	35	53.92±0.009	415.31±0.842
14	100	100	33	31.24±0.017	486.15±0.022
15	110	130	37	37.44±0.031	470.54±0.614
16	110	100	33	34.45±0.018	500.89±1.010
17	105	145	35	24.21±0.032	479.76±0.111
18	100	130	37	35.10±0.001	446.70±0.222
19	105	115	35	53.94±0.009	415.47±0.844
20	105	115	35	53.98±0.009	415.40±0.844

Note: Values are mean \pm standard deviation of triplicate determination.

BT = Barrel Temperature, SS = Screw Speed, FM = Feed Moisture.

3.2 Energy Value

The results of the energy value of the extruded aerial yam and soybean flour mixes are presented in Table 3.1. The energy value was in the range of 398.84 and 529.17 kcal. The high range of values for caloric (energy) value of the samples signifies that extrudates produced from aerial yam and soybean flour mixes might be exceptionally helpful in providing, or enhancing the daily energy requirement of the human body

3.3 Impact of Extrusion Process on Carbohydrate

In Figure 3.1, it was seen that expansion in barrel temperature and screw speed prompted quadratic decrease in carbohydrate content of the extrudates. The carbohydrate content, at first expanded with an underlying expansion in barrel temperature up to 105 °C. Further increase in barrel temperature above 105 °C, resulted in a reduction in carbohydrate content of the extrudates. Additionally, increasing the screw speed, at first up to 115 rpm led to an increase in the carbohydrate content. Further increase in screw speed above 115 rpm resulted in decreased carbohydrate content of the extrudates. The macromolecular modifications that happened during extrusion might be ascribed to this perception.

A similar pattern was seen in Figure 3.2, which shows the response surface plot for the impact of barrel temperature and feed moisture on the carbohydrate content of the extrudates. Expansion in barrel temperature and feed moisture prompted quadratic decrease in carb content of the extrudates. The carbohydrate content, at first expanded with an underlying expansion in barrel temperature up to 105 °C. Further increase in barrel temperature, above 105 °C, brought about a decrease in carbohydrate content of the extrudates.

Likewise, an initial increase in feed moisture up to 35% brought about an initial increase in carbohydrate content. Further increase in feed moisture above 35% resulted in decreased carbohydrate content of the extrudates. Similarly, increase in screw speed and feed moisture resulted in quadratic decrease in carbohydrate content of the extrudates, but the decrease was more pronounced with increase in screw speed than with feed moisture. Also, increasing the screw speed initially up to 115 rpm increased the carbohydrate content. Increase in screw speed above 115 rpm decreased the carbohydrate content of the extrudates. Initial increase in feed moisture up to 35% led to increased carbohydrate content. Further increase in the feed moisture above 35% resulted in decrease in the carbohydrate content of the extrudates (Figure 3.3).

Analysis of variance (ANOVA) for the impact of barrel temperature, screw speed and feed moisture on carb showed that the p-values for barrel temperature, screw speed and feed dampness were 0.001, 0.001 and 0.002, respectively. This implies that the three extrusion process boundaries (barrel temperature, screw speed and feed moisture) had a significant effect ($p < 0.05$) on the carb content of the extrudates.

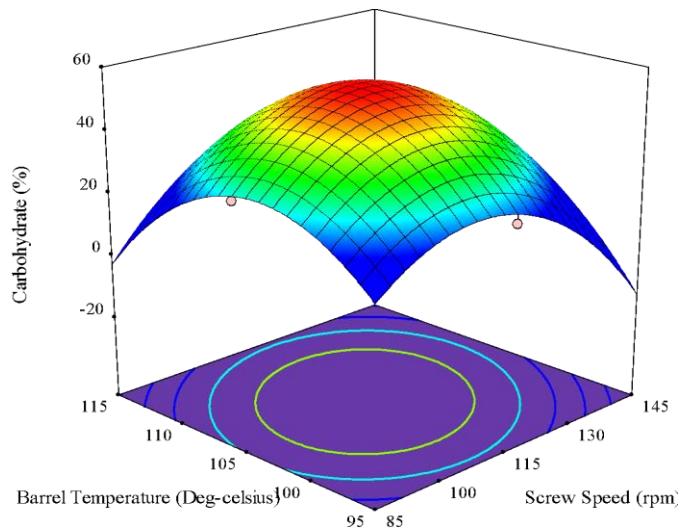


Figure 3.1: Response surface plot of carbohydrate against barrel temperature and screw speed

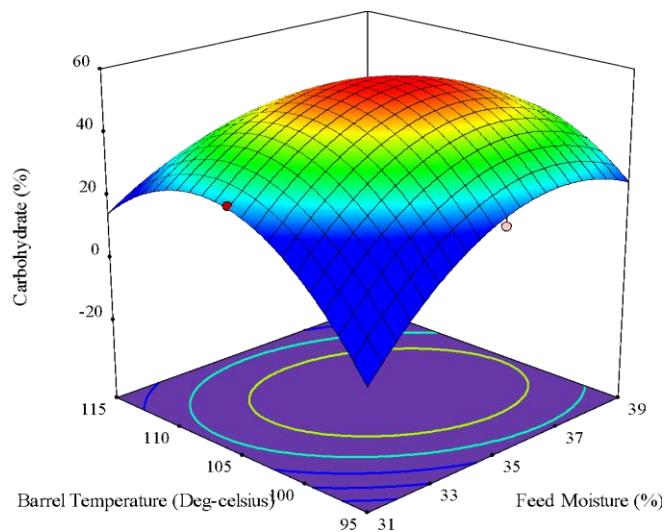


Figure 3.2: Response surface plot of carbohydrate against barrel temperature and feed moisture

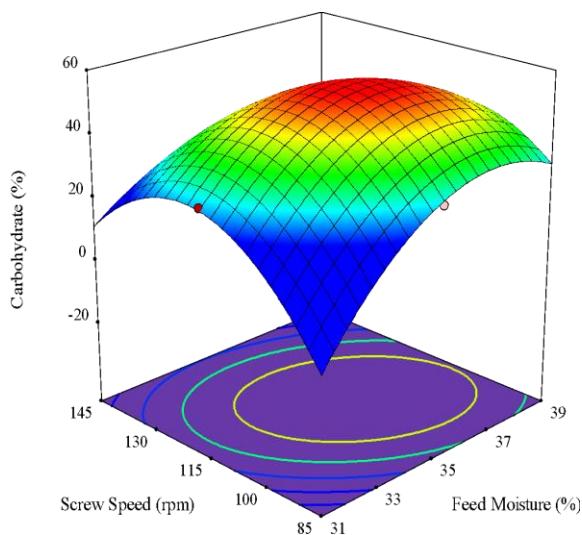


Figure 3.3: Response surface plot of carbohydrate against screw speed and feed moisture

3.4 Impact of Extrusion Process Parameters on Energy Value

The impacts of extrusion process parameters (barrel temperature, screw speed and feed moisture) on the calorific (energy) value of extruded aerial yam and soybean flour blends are shown in Figure 3.4 - 3.6.

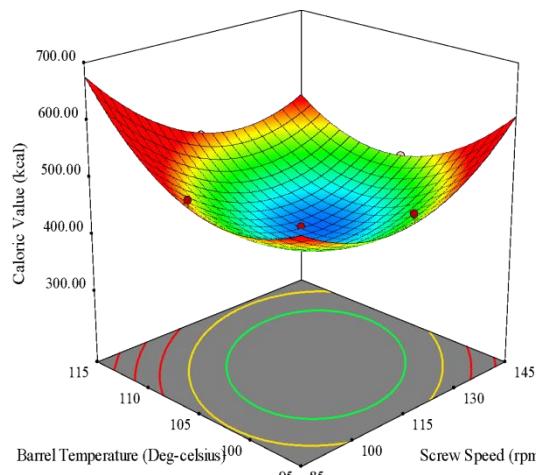


Figure 3.4: Response surface plot of energy value against barrel temperature and screw speed

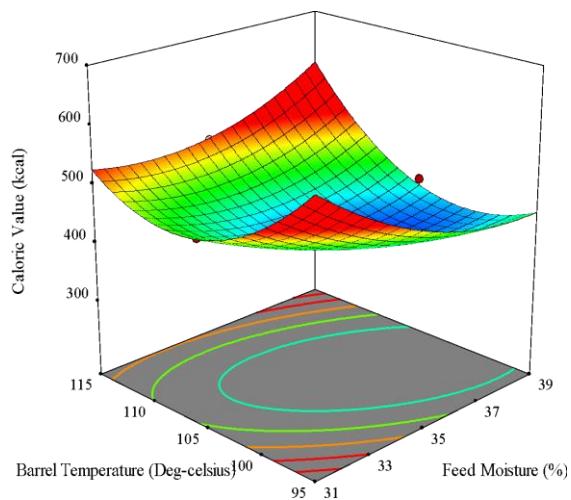


Figure 3.5: Response surface plot of energy value against barrel temperature and feed moisture

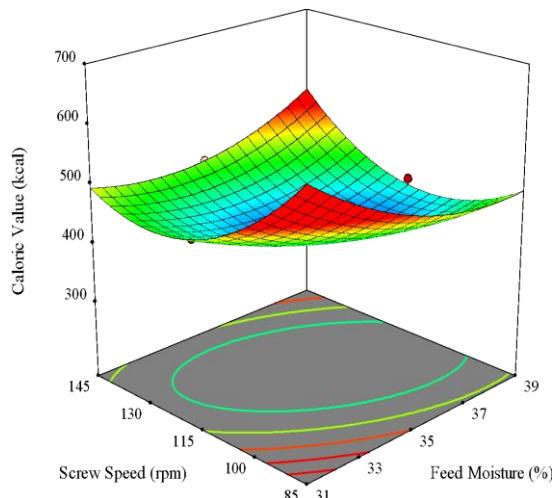


Figure 3.6: Response surface plot of energy value against screw speed and feed moisture

In Figure 3.4, it was seen that increase in both the barrel temperature and screw speed prompted a quick increase in the caloric (energy) value. Likewise, the plot for the impact of barrel temperature and feed dampness on energy (caloric) value showed that increase in the barrel temperature and feed moisture brought about increase in the caloric (energy) value (Figure 3.5). In Figure 3.6, the reaction plot demonstrated that increase in the screw speed and feed dampness prompted an increase in the caloric value.

Analysis of variance for the impact of barrel temperature, screw speed and feed moisture on the energy value showed that the extrusion parameters (barrel temperature, screw speed and feed moisture) had p-values of 0.003, 0.005 and 0.065 respectively. It is apparent that the p-values for barrel temperature and screw speed are less than 0.05 (5%) level of significance; it subsequently implies that barrel temperature and screw speed had significant impact ($p < 0.05$) on the energy value. Then again, the p-value for feed moisture is greater than 0.05 (5%) level of significance, subsequently feed moisture showed no significant effect ($p > 0.05$) on the energy value.

3.5 Model Equation for Optimization of Extrusion Process Parameters for Carbohydrate

The regression model for carbohydrates is given in Equation 3.1 as:

$$C_b = -5692.06 + 60.85BT + 6.42SS + 123.33FM + 0.0327BTSS - 0.2670BTFM \\ + 0.0969SSFM - 0.2627BT^2 - 0.0287SS^2 - 1.18FM^2$$

Where:

C_b =Carbohydrates (%)

BT = Barrel Temperature ($^{\circ}\text{C}$)

SS =Screw Speed (rpm)

FM = Feed Moisture

In Equation 3.1, the positive terms signify direct relationship between the extrusion process parameters and their interaction with percentage carbohydrate content, while the negative terms signify an inverse relation between them. All the three extrusion parameters: barrel temperature screw speed and feed moisture have direct relationship with carbohydrate content. The interaction effect of the independent variables was observed to have a direct relationship with the percentage carbohydrate content of the samples.

Regression analysis showed that the quadratic model was significant ($p < 0.05$), with regards to the p-values of the model and model terms, and a satisfactory coefficient of determination (R^2), implying that the model can be used to navigate the design space.

3.6 Model Equation for Optimization of Extrusion Process Parameters for Energy Value

The regression model for energy value is given in Equation 3.2 as:

$$E_v = 20572.65 - 227.65BT - 18.98SS - 404.57FM - 0.1703BTSS + 1.50BTFM + 0.4135SSFM + 0.9343BT^2 + 0.0948SS^2 + 2.77FM^2$$

Where:

E_v = Energy value (kcal),

BT = Barrel temperature (°C)

SS = Screw speed (rpm)

FM = Feed moisture

In Equation 3.2, the positive terms signify a direct relationship between the extrusion process parameters and their interaction with the energy value, while the negative terms signify an inverse relation between them. Barrel temperature, screw speed and feed moisture have an inverse relationship with energy value. This means that the energy value decreased with increase in barrel temperature, screw speed and feed moisture. The interaction effect of the independent variables showed a direct relationship with the energy value.

The model is significant ($p < 0.05$), considering the p-values of the model and its terms, and a high coefficient of determination (R^2), signifying that the model can be used to navigate the design space.

3.7 Optimization of Extrusion Process Parameters for Carbohydrate Content and Energy Value

The optimization of the extrusion process parameters (barrel temperature, screw speed and feed moisture) was done using the numerical method in response surface methodology (RSM), with the optimization goals of maximizing the barrel temperature and screw speed, and then possible range for the feed moisture (Table 3.2).

Table 3.2: Output for numerical optimization of extrusion process parameters for carbohydrate content and energy value

Extrusion criteria	Unit	Lower limit	Upper limit	Optimization Goal	Relative Importance	Output
Barrel Temp	°C	95.00	115.00	Maximize	3	112.11
Screw Speed	rpm	85.00	145.00	Maximize	3	136.49
Feed Moisture	%	31.00	39.00	Range	3	34.65
Carbohydrate	%	23.97	54.12	Range	3	31.40
Caloric Value	kcal	398.84	529.17	Range	3	472.74
Desirability	-	-	-	-	-	0.857

Table 3.2 shows the output for the numerical optimization of extrusion process parameters for carbohydrate contents and energy value of extrudates from aerial yam and soybean composite flours. The results indicate optimal barrel temperature of 112.11 °C, screw speed of 136.49 rpm and feed moisture of 34.65%. On the other hand, the optimum carbohydrate contents and energy value of 31.40% and 472.74 kcal, with a desirability of 0.857 were also obtained.

A test run under the obtained optimal extrusion parameters of barrel temperature (112.11°C), screw speed (136.49rpm) and feed moisture (34.65%) was carried out in order to validate the quadratic model for carbohydrate content and energy value. The experimental values obtained were 31.47% for carbohydrates and 472.68 kcal for energy value

4.0 Conclusion

The extrusion process parameters, together with their interactions, had a significant impact on the carbohydrate contents of the extrudates. Barrel temperature and screw speed showed significant effect on the energy value, whereas feed moisture showed no significant impact. The interactions of the extrusion process parameters significantly affected the energy value of the extrudates. Optimization results based on desirability concept indicated that 112.11 °C barrel temperature, 136.49 rpm screw speed and 34.65% feed moisture would produce composite snacks of better carbohydrate content and appreciable energy value. The findings from this study, is a confirmation of previous research, of the possibility of developing new food products from aerial yam and its composites by the application of extrusion processing technology.

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