Modeling and Optimization of Extrusion Process Variables for the Functional Properties of Extrudates from Aerial Yam and Soybean Flour Blends using Response Surface Methodology

***Enobong O. Umoh[1], Madu O. Iwe[2], Phillipa C. Ojimelukwe[3] and Emmanuel O. Sam[4]**
[1,4]Department of Agricultural Engineering, Akwa Ibom State University, Ikot Akpaden, P.M.B.,1167, Uyo, Nigeria.
[2,3]Department of Food Science and Technology, Michael Okpara University of Agriculture, Umudike, Abia State, Nigeria.
*Corresponding Author E-mail Address: enobongumoh@aksu.edu.ng
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Abstract
This study x-rays the modeling and optimization of extrusionprocess variables forthe functional properties of extrudates from the blend of aerial yam and soybean flours. Laboratory scale single-screw extruder was used in extruding blend of aerial yam and soybean flours in the ratio of 25% aerial yam: 75% soybean. Response surface methodology based on Box-Behnken design at three factors, five levels of barrel temperature (95, 100, 105, 110, and115 ℃), screw speed (85, 100, 115, 130, and145rpm) and feed moisture (31, 33, 35, 37, and 39%) were used in 20 runs. Significant ($p<0.05$) regression models, describing the effects of process parameters on the functional properties of the extrudates were employed. Results obtained showed that functional properties varied between 0.4779 and 0.7211g/cm^3 bulk density; 2.52 and 3.89g/g water absorption capacity; 1.12 and 2.88g/g oil absorption capacity; 28.51 and 34.85% emulsion capacity; 3.37 and 4.86% foaming capacity. Barrel temperature, screw speed and feed moisture significantly ($p < 0.05$) affected the bulk density, water and oil absorption capacities, emulsion and foaming capacities of the extrudates. High Regression coefficient, $R^2 \geq 0.9$ were obtained, showing that the models can be used to navigate the design space. Numerical optimization results based on desirability concept indicated that 112.85 ℃ barrel temperature, 144.99rpm screw speed and 35.12% feed moisture would produce extrudates of preferable functional properties.

Keywords: *Functional properties, Extrusion variables, Response surface, Aerial yam flour, Extrudates.*

1.0 INTRODUCTION

Optimization process is essential in the area of formulation/development of acceptable food products from neglected food crops, and in controlling the process conditions or variables in order to produce extrudates with the desired quality (Umoh *et al*., 2021). Extrusion is predominantly a thermo-mechanical processing operation that combines several unit operations, including mixing, kneading, shearing, conveying, heating, cooling, forming, partial drying or puffing, depending on the material and equipment used. During extrusion processing, food materials are generally subjected to a combination of high temperature, high pressure and high shear (Dobraszczyk *et al*., 2006). This can lead to a variety of reactions with corresponding changes in the functional properties of the extruded material.Response surface methodology, or RSM, is a collection of mathematical and statisticaltechniques, useful for the modeling and analysis of problems in which a response of

interest is influenced by several variables, and the objective is to optimize this response (Montgomery, 2013).
Aerial yam (*Dioscorea bulbifera*) is recorded to be an unpopular yam among the edible yam species which unlike the traditional yam produces aerial bulbils that look like potatoes hence the name aerial/air potatoes (Ojinnaka *et al*., 2017). This species of yam is consumed by a small number of communities and is generally underutilized both at subsistence and commercial levels for a number of reasons, which include, having a relatively bitter after-taste compared to other yam species, unknown to most people, and much work has not been done on it to suggest uses to which it can be applied (Igyor *et al*., 2004).. However, there are lots of potentials for aerial yam in terms of its nutritional and functional properties that could be taken advantage of to produce diverse industrial products, as well as its socio-economic importance (Sanful and Engmann, 2016).
The Aerial yam flour can be used as composite flour in the production of cookies. Princewill-Ogbonna and Ezembaukwu (2015), reported that Aerial yam (*Dioscorea bulbifera)* has an array of good starch contents, functional and rheological properties which indicate a wider potential for utility of Aerial yam flour in the food industry as thickeners, drug/tablet binders in the pharmaceutical industries.Aerial Yam (*Dioscorea bulbifera*), being a lesser known food crop, has not been processed to any significant extent commercially. It is only a small portion of the crop that is processed into instant yam flour which is particularly popular in Yoruba speaking areas of West Africa (Orkwor *et al*., 1998).
Soybean (*Glycine max*), an important oil seed belonging to the family, *Leguminosae*, is usually grown as a food crop. Three species of soybean exist. They include: *Glycine ussuriensis*-wild, *Glycine max*-cultivated and *Glycine gracillis*-intermediate. *Glycine max* is commonly grown throughout the world as a material of commerce. Soybean production and utilization as food arose in ancient China not later than the 11th Century B.C. It then became grown in other parts of the world just in the 20th Century. The major producing countries are the United States, Brazil, China, and Argentina (Iwe, 2003). Soybean is mainly cultivated for its seeds, used commercially as human food and livestock feed, and for the extraction of oil.
Soy foods have a high protein content and high protein utilization, leading to the highest amount of protein gained (Iwe, 2003).Industrially, soy protein products had been used as late as the 1960s as nutritional and functional food ingredients in some food categories available to the consumer. The earliest known of such products in Nigeria is the soy-ogi, developed at the Federal Institute of Industrial Research (FIIRO) Oshodi (Iwe, 2003).Substituting wheat flour with soybean up to 25% will go a long way to increase noodles variety, make them affordable to many and boost their nutritional content (Omeire *et al*., 2014).
This study is aimed at modeling and optimizing the extrusion process variables for the functional properties of extrudates from aerial yam and soybean flours blend using Response surface methodology.

2.0 MATERIALS AND METHODS

2.1 Collection of Soybean Seeds and Aerial Yam Bulbs

Soybean seeds and Aerial yam bulbs used in this studywere purchased from Uyo Urban market in Uyo Local Government Area, Akwa Ibom State, Nigeria.

2.2 Sample Preparation

The flour samples used in this research were prepared in the Crop Processing and Storage Laboratory, Department of Agricultural Engineering, Akwa Ibom State University, Ikot Akpaden, Nigeria.

2.2.1 Preparation of Aerial Yam Flour
Aerial yam flour was prepared according to the method described by Umoh*et al*. (2021).The Aerial yam bulbswere cleaned and sorted to remove unwanted materials, beforepeeling with knife, washed with clean water and sliced to 10mm thickness using knife. The slices (chips) were then dried, using an oven at a temperature of 60℃ for 12h. The dried slices were then milled using MF120 Hammer mill made in Italy,and sieved with laboratory sieve of 600μm aperture size. The flour obtained waspackaged in a polyethene bag for subsequent use.

3.2.2Preparation of Soybean Flour
Soybean flour was prepared according to the method described by Iwe (2003).Seeds were screened to remove foreign materials, splits, and damaged beans. This was followed by washing and roll boiling at 100 ℃ for 30 minutes. It was then oven -dried at a temperature of 70 ℃ for 12h, and milled in a disc attrition mill. The milled full-fat soybean was sieved using a 100-mesh standard sieve. The flour obtained was then stored in air- tight polyethene bag at room temperature (about 22 ℃) for further use.

2.2.3 Preparation of Sample Blends
The Aerial yam and Soybean flours blend was prepared in the ratio of 25:75, expressed in percentageas 25% aerial yam flour and 75% soybean flour.

2.3 Extrusion processing
Extrusion process was carried out according to the method described by Umoh *et al.* (2021), using a single-screw laboratory scale extruder. Two hundred grams (200g) of the flours blend (25% aerial yam flour, 75% soybean flour)was accurately measured andpreconditioned according to the desired moisture levels, as shown in the experimental design layout (Table 2.2).The extruder was switched-on, and the barrel temperatures and the screw speeds of the extruder were set according to the experimental design (Table 2.2). The raw material was fed through the hopper, into the extruder. The extrudates were collected as they exit through the die, oven-dried, and packaged in air tight zip lock polyethylene bags for further laboratory analysis. Twenty runs were carried out in all, during the extrusion process, according to the experimental design.

2.4 Determination of Functional Properties
The following functional properties of the extruded aerial yam and soybean flour blendswere determined:

2.4.1 Bulk Density
Thiswas determined according to the method described by Umoh and Iwe (2023).
Theflour sample was filled in a 10 ml dried measuring cylinder and the bottom of the cylinder tapped several times on the laboratory table until there was no further diminution of the sample level after filling to 10 ml mark.

Calculation: $$\text{The bulk density(g/cm}^3\text{)} = \frac{\text{weight of sample (g)}}{\text{volume of sample (cm}^3\text{)}}$$

2.4.2 Water Absorption capacity
This was determined according to the methods described by Onwuka (2018).Ten millilitres (10ml) of distilled water was mixed with one gram (1 g) of sample in a mixer and homogenized for 30 seconds and allowed to stand at room temperature for 30 minutes and centrifuged at 5000 rpm for 30 minutes. The volume of the supernatant (free water) in a graduated cylinder was noted. The amount of water absorbed (total minus free) was multiplied by its density for conversion to grams. Density of water was assumed to be 1 g/ml.

$$\text{Water absorption capacity } (g/g) = \frac{V_1 - V_2}{W} \times \text{density of water}$$

Where:
v_1 = initial volume of water (10 ml)
v_2 = final volume after centrifugation
w = weight of sample (1 g)

2.4.3 Oil Absorption capacity

This was determined according to the methods described by Umoh and Iwe (2023).Exactly one gram (1g) of flour blend sample was mixed with 10 ml of vegetable oil. The oil and the sample were mixed and homogenized for 30 seconds and allowed to stand for 30 minutes at room temperature and then centrifuged at 5000 rpm for 30 minutes. The volume of free oil (supernatant) was noted directly from the graduated centrifuge tube. The amount of oil absorbed (total minus free) was then multiplied by its density for conversion to grams.
Density of oil was taken to be 0.88 g/ ml for bleached palm oil.

$$\text{Oil absorption capacity } (g/g) \quad = \frac{V_1 - V_2}{W} \times \text{density of oil}$$

Where:
V_1 = Initial volume of oil
V_2 = Final volume after centrifugation
w = Weight of sample.

2.4.4 Emulsion Capacity

This was determined according to the method described by Onwuka (2018).Two grams (2g) of the sample and 23ml of distilled water were blended for 30 seconds, using a blender at high speed (12,000rpm). After a complete dispersion, ground nut oil was added at a rate of 0.4ml/s from a burette and blended until phase separation emulsion break point occurred.The amount of oil added up to this point was then interpreted as emulsion capacity of the sample, and expressed in grams of oil emulsion by 1gram of sample.

$$\text{Emulsion capacity } (\%) = \frac{X}{Y} \times \frac{100}{1}$$

Where X = height of emulsified layer
Y= height of whole solution in the centrifuge tube

2.4.5 Foaming capacity

Two grams (2g) of the sample and 100ml of distilled water were blended, using a blender, at high speed for 5 minutes, and the dispersion poured into a 250ml measuring cylinder. The volume of the foam at 30 seconds after whipping was expressed as the foaming capacity (in %) of the sample (Onwuka, 2018)).

$$\text{Foaming capacity } (\%) = \frac{\text{Volume after whipping} - \text{Voume before whipping}}{\text{Volume before whipping}} \times 100$$

2.5 Experimental Design/ Statistical Analysis

Design Expert (version 11.0.1) was used in the experimental design/layout. Central Composite Randomized Design (CCRD) was used with a three factor experimental set up at five levels each, with barrel temperature (X_1), screw speed (X_2) and feed moisture levels (X_3) as the independent factors (Table 2.1). Response Surface Methodology (RSM) was used to analyze the effects of the independent factors or variables on the dependent variables (the responses).Coded values for the independent variables used were -2, -1, 0, 1, and 2.

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

The independent variables, the coded variables, un-coded variables and their coded and un-coded levels are shown in Table 2.2.

Table 2.2: Experimental layout for 3 variables and 5 levels Response Surface Experimental design for the Extrusion of Aerial yam and Soybean flour

Runs Order	Coded Factors			Actual Factors		
	X_1	X_2	X_3BT (^{O}C)	SS (rpm)	FM (%)	
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 moiture

3.0 RESULTS AND DISCUSSIONS

3.1Functional Properties of Extruded Aerial Yam and Soybean Flour Blends

The results of the functional properties of extruded aerial yam and soybean flour blends are presented in Table 3.1.

Table 3.1: Functional properties of extruded Aerial yam and Soybean flour blends

S/N	BT (℃)	SS (rpm)	FM (%)	BD (g/cm^3)	WAC (g/g)	OAC (g/g)	EC (%)	FC (%)
1	105	115	31	0.6969±0.004	2.60±0.003	1.72±0.028	31.73±0.153	3.37±0.057
2	105	115	35	0.4885±0.003	3.89±0.007	1.94±0.007	32.62±0.158	3.68±0.057
3	105	115	35	0.4790±0.003	3.81±0.007	1.98±0.007	32.58±0.158	3.70±0.057
4	105	85	35	0.6708±0.002	2.91±0.014	1.69±0.021	32.30±0.100	4.86±0.150
5	100	130	33	0.6712±0.002	3.06±0.004	1.63±0.002	29.26±0.031	3.46±0.001
6	110	100	37	0.6249±0.002	2.94±0.014	1.95±0.014	32.83±0.153	4.80±0.100
7	100	100	37	0.6175±0.003	2.88±0.021	1.76±0.007	29.87±0.252	5.00±0.100
8	110	130	33	0.7211±0.003	2.69±0.014	2.64±0.021	32.05±0.153	4.22±0.006
9	105	115	35	0.4787±0.003	3.83±0.007	1.91±0.007	32.64±0.158	3.66±0.057
10	115	115	35	0.6933±0.003	2.69±0.003	2.80±0.021	34.59±0.208	4.46±0.057
11	95	115	35	0.7167±0.003	2.58±0.141	1.12±0.028	28.51±0.030	3.57±0.173
12	105	115	39	0.6755±0.001	2.57±0.007	2.62±0.014	32.10±0.173	3.79±0.057
13	105	115	35	0.4779±0.003	3.82±0.007	1.90±0.007	32.60±0.158	3.71±0.057
14	100	100	33	0.6598±0.002	2.71±0.014	1.34±0.014	34.47±0.115	4.17±0.153
15	110	130	37	0.6043±0.002	2.80±0.007	2.88±0.007	34.85±0.115	3.95±0.057
16	110	100	33	0.6985±0.004	2.95±0.071	1.92±0.014	32.78±0.100	3.97±0.057
17	105	145	35	0.6982±0.005	2.52±0.032	1.62±0.004	30.25±0.011	3.87±0.441
18	100	130	37	0.7011±0.002	2.68±0.022	2.31±0.001	30.67±0.032	3.48±0.100
19	105	115	35	0.4788±0.003	3.81±0.007	1.98±0.007	32.59±0.158	3.74±0.057
20	105	115	35	0.4784±0.003	3.80±0.007	1.92±0.007	32.71±0.158	3.69±0.057

Note: Values are mean ± standard deviation of triplicate determination.
BT= Barrel temperature, SS= Screw speed, FM= Feed moisture, BD= Bulk density, WAC= Water absorption capacity, OAC= Oil absorption capacity, EC= Emulsion capacity, FC= Foaming capacity.

3.1.1 Bulk density

Bulk density of the extrudates variedbetween 0.4779and 0.7211g/cm^3(Table 3.1). This observed range of values for bulk density is higher than 0.24 to 0.36g/cm^3 for sorghum-based extruded product supplemented with soy meal flour (Tadesse *et al.*, 2019b); 0.0202 to 0.3503g/cm^3 for extruded rice flour-pineapple waste pulp powder-red gram powder (Kothakota *et al.*, 2013); 0.19 to 0.31g/cm^3 for fish-maize based extruded snacks (Nkubana *et al.*, 2020); and 0.114to 0.2176g/cm^3 for ready-to-eat pulse-based snacks (Alemayehu *et al.*,2019), but lower than 0.832 to 0.988g/cm^3 for meat analogue from mucuna bean seed flour (Omohimi *et al.*, 2014).

Bulk density is an index of extent of puffing, and is directly related to the texture of the final product of expanded starch-based extrudate. It is also determined by the combination of growth and subsequent shrinkage or collapse of water vapour bubbles in the extrudates, and by the effect of die swelling due to the elastic property of the melted matrix (Tadesse *et al.*, 2019b). Light density means soft structure which is desirable in such type of product.

3.1.2 Water absorption capacity

The recorded values for the water absorption capacity ranged from 2.52 to 3.89g/g (Table 3.1). This range of values is slightly higher than 2.5 to 3.56g/g for cassava/soybean extrudates (Olusegun *et al*., 2016); 1.667 to 2.320g/g for meat analogue from mucuna bean seed flour (Omohimi *et al*., 2014), but lower than 3.918 to 5.997g/g for pineapple waste pulp-rice flour-red gram powder based extrudates (Kothakota *et al*., 2013); 4.92 to 6.07g/g for fish-maize based extruded snacks (Nkubana *et al*., 2020), and 3.922 to 6.017g/g for ready-to-eat pulse-based snacks (Alemayehu *et al*., 2019).

Water absorption capacity gives an insight into the extent of gelatinization of starch in the feed ingredients generally by measuring the amount of water absorbed by starch granules after swelling in excess of water originally present in the product (Olusegun *et al*., 2016).

3.1.3 Oil absorption capacity

Oil absorption capacity of the extrudates ranged from 1.12 to 2.88g/g (Table 3.1). This recorded range of values is within the range of 1.761 to 2.389g/g for meat analogue from mucuna bean seed flour (Omohimi *et al*., 2014), but lower than 2.94 to 3.68 g/g for aerial yam-soybean flour earlier reported by Umoh (2020). Oil absorption capacity can be used as an index of the hydrophobicity of an extruded product (Tabibloghmany *et al*., 2020).

3.1.4 Emulsion/foaming capacity

The results of the functional properties of the extruded aerial yam and soybean flour blends in show that the emulsion capacity of the extrudates varied between 28.51 and 34.85% (Table 3.1). This range of value is lower than 59.49 to 62.82% for aerial yam-soybean flour, earlier reported by Umoh (2020). The foaming capacity of the extrudates ranged from 3.37 to 4.86% (Table 3.1), which is comparable with 3.07 to 5.43%, earlier reported for aerial yam-soybean flour (Umoh, 2020). Emulsion capacity is the ability of a protein solution or suspension to emulsify oil, while foaming capacity of a protein is a measure of the amount of interfacial area that can be created by whipping the protein.

Table 3.2: Coefficient of Regression/ANOVA for Functional properties

	BD (g/cm^3)		WAC (g/g)		OAC (g/g)		EC (%)		FC (%)	
	Coeff.	**p-value**	**Coeff.**	**p-value**	**Coeff.**	**p-value**	**Coeff.**	**p-value**	**Coeff.**	**p-value**
X_O	36.44		-250.14		-10.11		374.43		39.50	
Linear										
X_1	-0.394	0.6366	2.55	0.5611	0.0714	< 0.0001	-1.42	0.0095	-0.9872	< 0.0001
X_2	-0.04170	0.1513	0.4482	0.0448	0.0097	0.0355	-1.98	0.0026	-0.2177	< 0.0001
X_3	-0.7262	0.0307	5.39	0.7130	0.0991	0.0069	-9.42	0.0040	1.53	0.0096
Interaction										
X_1X_2	-0.00016	0.2079	-0.00092	0.1140			0.0095	0.0002	0.00272	< 0.0001
X_1X_3	0.0023	0.0276	0.00388	0.3520			0.0755	0.1263	-0.00363	0.0353
X_2X_3	0.00012	0.6835	-0.001792	0.2055			0.0365	0.1100	-0.00796	< 0.0001
Quadratic										

${X_1}^2$	0.000233	< 0.0001	-0.0123	< 0.0001			-0.0098	< 0.0001	0.00397	0.0191
${X_2}^2$	0.00024	< 0.0001	-0.00128	< 0.0001			-0.00139	< 0.0001	0.00083	< 0.0001
${X_3}^2$	-0.0134	< 0.0001	-0.0799	< 0.0001			-0.03844	< 0.0001	-0.002358	< 0.0001
Test for model adequacy										
R^2	0.9663		0.9757		0.7418		0.9492		0.9223	
Pred. R^2	0.7415		0.8240		0.5159		0.6154		0.3817	
Model F-value	31.85		44.63		15.32		20.78		13.18	
Lack of fit	70.80		164.46		77.84		239.05		90.54	

Note: X_o = intercept, X_1 = Barrel temperature, X_2 = Screw speed, X_3 = Feed moisture, BD= Bulk density, WAC= Water absorption capacity, OAC= Oil absorption capacity, EC= Emulsion capacity, FC= Foaming capacity.
Significance at $p< 0.005$.

The results of Regression analysis/ANOVA of the models for the responses: functional properties of extruded aerial yam-soybean flour blend are presented in Table 3.2.

3.2 Model Selection/Equation for Optimization of Extrusion Process variables

3.2.1 Model Selection/Equation for Optimization of Extrusion Process variables for Bulk Density

Quadratic model was selected for the optimization of extrusion process parameters for bulk density. The final regression model for bulk density is given in equation 3.1 as:

$$\mathrm{B_D} = 36.44 - 0.7262\mathrm{FM} + 0.0023\mathrm{BTFM} + 0.00233\mathrm{BT}^2 + 0.00024\mathrm{SS}^2 - 0.0134\mathrm{FM}^2 \quad (3.1)$$

Where: $\mathrm{B_D}$ = Bulk density (g/cm^3), BT= Barrel Temperature (^{o}C), SS = Screw Speed (rpm), FM = Feed moisture.

The positive terms signify direct relationship between the extrusion process variables (BT, SSand FM), and their interactions (linear and quadratic) with bulk density, while the negative terms indicate an inverse relationship between them. The results of Regression analysis/ANOVA of the models for functional properties indicate a model F-value of 31.85 for bulk density (Table 3.2), which implies that, the model is significant.

3.2.2 Model Selection/Equation for Optimization of Extrusion Process variable for Water Absorption Capacity

Quadratic model was selected for the optimization of extrusion process variables for water absorption capacity. The final regression model for water absorption capacity is given in equation 3.2 as:

$$\mathrm{W_{AC}} = -250.14 + 0.4482SS - 0.0123\mathrm{BT}^2 - 0.00128\mathrm{SS}^2 - 0.0799\mathrm{FM}^2 \quad (3.2)$$

Where:$\mathrm{W_{AC}}$ = Water absorption capacity (g/g), BT= Barrel Temperature (^{o}C), SS = Screw Speed (rpm), FM = Feed moisture.

The positive terms signify direct relationship between the extrusion process parameters and their interactions with the levels of water absorption capacity, whereas, the negative terms indicate an inverse relationship between them.
The model F-value of 44.63 (Table 3.2), implies that the model is significant.

3.2.3 Model Selection/Equation for Optimization of Extrusion Process variables for OilAbsorption Capacity

Linear model was selected for the optimization of extrusion process variables for oil absorption capacity. The final regression model for oil absorption capacity is given in Equation 3.3 as:

$$O_{AC} = -10.11 + 0.0714BT + 0.0097SS + 0.0991FM \quad (3.3)$$

Where: O_{AC} = Oil absorption capacity (g/g), BT= Barrel Temperature (^{0}C),
SS = Screw Speed (rpm), FM = Feed moisture.

The positive terms signify direct relationship between the extrusion process parameters and the level of oil absorption capacity. All the extrusion process parameters (BT, SS and FM), were observed to have direct relationship with the oil absorption capacity (O_{AC}). Results of Regression analysis/ANOVA indicatea model F-value of 15.32 (Table 3.2),implying that the selected model is significant.

3.2.4 Model Selection/Equation for Optimization of Extrusion Process Variables for Emulsion Capacity

Quadratic model was selected for the optimization of extrusion process parameters for emulsion capacity. The final regression model for emulsion capacity is given in equation 3.4 as:

$$E_C = 374.43 - 1.42BT - 1.98SS - 9.42FM + 0.0095BTSS + 0.0365SSFM - 0.0098BT^2 - 0.00139SS^2 - 0.03844FM^2 \quad (3.4)$$

Where: E_C = Emulsion capacity (%), BT= Barrel Temperature (^{o}C), SS = Screw Speed (rpm), FM =Feed moisture.

The positive terms signify direct relationship between the extrusion process parameters and their interactions with the levels of emulsion capacity, while the negative terms indicate an inverse relationship between them. A model F-value of 20.78 (Table 3.2), implies that the model is significant.

3.2.5 Model Selection/Equation for Optimization of Extrusion Process variables forFoaming Capacity

Quadratic model was selected for the optimization of extrusion process parameters for foaming capacity. The final regression model for foaming capacity is given in equation 3.5 as:

$$F_C = 39.50 - 0.9872BT - 0.2177SS + 1.53FM + 0.00272BTSS - 0.00363BTFM - 0.00796SSFM + 0.00397BT^2 + 0.00083SS^2 - 0.002358FM^2 \quad (3.5)$$

Where: F_C = Foaming capacity (%), BT= Barrel Temperature (^{o}C), SS= Screw Speed (rpm), FM = Feed moisture.

The positive terms signify direct relationship between the extrusion process parameters and their interactions with the levels of foaming capacity, while the negative terms indicate an inverse relationship between them. A model F-value of 13.18 (Table 3.2), implies that the model is significant.

3.3 Optimization of Extrusion Process variables for Functional Properties of Aerial Yam and Soybean Flour Blends

3.3.1 Numerical Optimization of Extrusion Process variables for Functional Properties

The main criteria for constraints optimization of the extrusion process variables were maximum possible barrel temperature and screw speed, and then the range for feed moisture. The optimization goal for the responses was the range.
The desired optimization goals and output for each extrusion process variables and response is presented in Table 3.3.

Table 3.3: Output for numerical Optimization of extrusion process variables for Functional properties

Extrusion Criteria	Unit	Lower limit	Upper limit	Optimization Goal	Relative Importance	Output
Barrel temperature	℃	95.00	115.00	Maximize	3	112.85
Screw Speed	rpm	85.00	145.00	Maximize	3	144.99
Feed Moisture	%	31.00	39.00	Range	3	35.12
Bulk Density	g/cm^3	0.4779	0.7211	Range	3	0.8165
WAC	g/g	2.52	3.89	Range	3	1.58
OAC	g/g	1.12	2.88	Range	3	2.85
Emulsion Capacity	%	28.51	34.85	Range	3	34.85
Foaming Capacity	%	3.37	5.00	Range	3	5.00
Desirability						0.972

Note: WAC = Water absorption capacity, OAC = Oil absorption capacity.

The optimal extrusion process parameters obtained were 112.85°C for barrel temperature, 149.99 rpm for screw speed and 35.12% for feed moisture. Also, the optimum functional properties obtained were 0.8165g/cm^3 for bulk density, 1.58g/g for water absorption capacity, 2.85g/g for oil absorption capacity, 34.35% for emulsion capacity and 5.00% for foaming capacity, with a desirability of 0.972% (Fig 3.1).

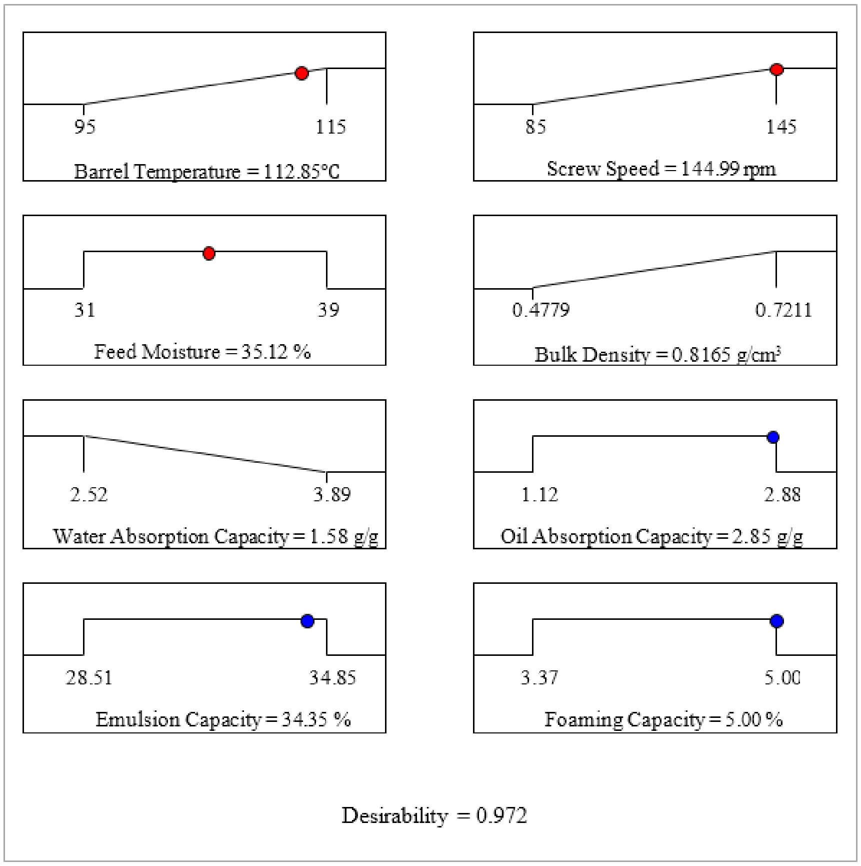

Fig. 3.1: Ramp for optimization of extrusion process variables for Functional properties of Aerial yam and Soybean flour blends

3.4 Response Surface Plots for Functional Properties

3.4.1 Effect of Extrusion Process variables on Bulk Density

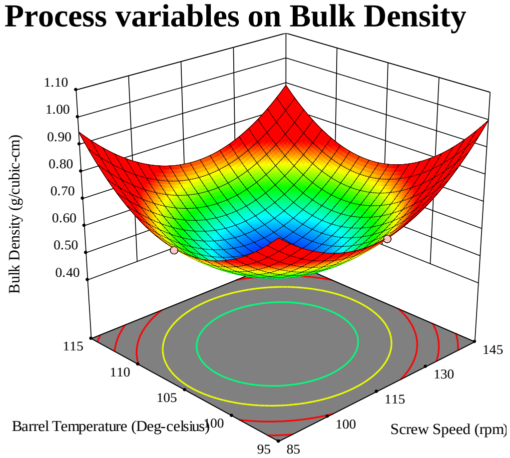

Fig. 3.2: Response surface plot showing the effect of Barrel and Screw speed on

Bulk density

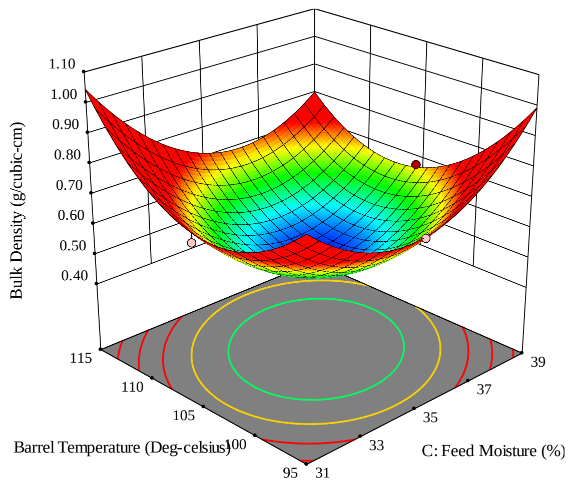

Fig. 3.3: Response surface plot showing the effect of Barrel temperature and Feed moisture on Bulk density

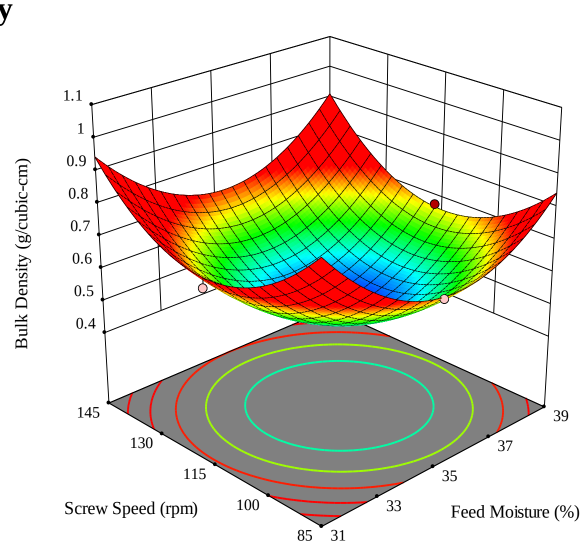

Fig. 3.4: Response surface plot showing the effect of Screw speed and Feed moisture on Bulk density

Fig. 3.2 shows the Response surface plot for effect of barrel temperature and screw speed of the extruder on bulk density of the extrudates. Increase in barrel temperature and screw speed resulted in quadratic increase in bulk density of the extrudates. This observation is at variance with that of Omohimi *et al*. (2014); Alemayehu *et al*. (2019), and in agreement with that of Kothakota *et al*. (2013).

Similarly, the Response surface plot showing the effects of barrel temperature and feed moisture on bulk density (Fig. 3.3), showed that increase in both barrel temperature and feed moisture resulted in quadratic increase in bulk density of the extrudates. The observation that increase in feed moisture increased the bulk density is in agreement with that of Peluola-Adyemi and Idowu

(2014); Ajita and Jha (2017), and contrary to an earlier report by Guldiken *et al*. (2019) for desi chickpea-barley extrudates. Increase in bulk density with increase in feed moisture may be attributed to reduction in elasticity of dough and lower expansion (Kothakota *et al*., 2013; Ajita and Jha, 2017).

The Response surface plot showing the effects of screw speed and feed moisture on bulk density (Fig 3.4) indicated that increasing the screw speed and feed moisture resulted in quadratic increase in bulk density of the extrudates. This observation is in agreement with that of Omohimi *et al*. (2014), but contrary to that of Ajita and Jha (2017). The increase in bulk density as screw speed increases might be due to intensified effect of temperature on extrudate melt under increased shear environment, which may increase the extent of gelatinization process and so gave extrudates with higher bulk density (Omohimi *et al*., 2014).

Analysis of variance indicates that the three extrusion process variables (Barrel temperature, Screw speed and Feed moisture) showed statistical significant effect ($p < 0.05$) on bulk density of the extrudates.

3.4.2 Effect of Extrusion Process variables on Water Absorption Capacity

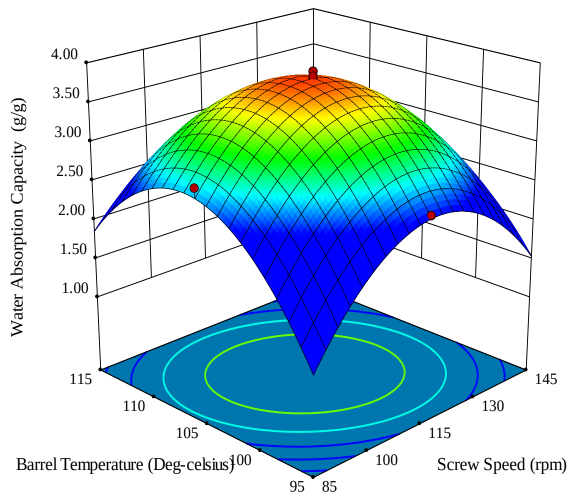

Fig. 3.5: Response surface plot showing the effect of Barrel temperature and Screwspeed on Water absorption capacity

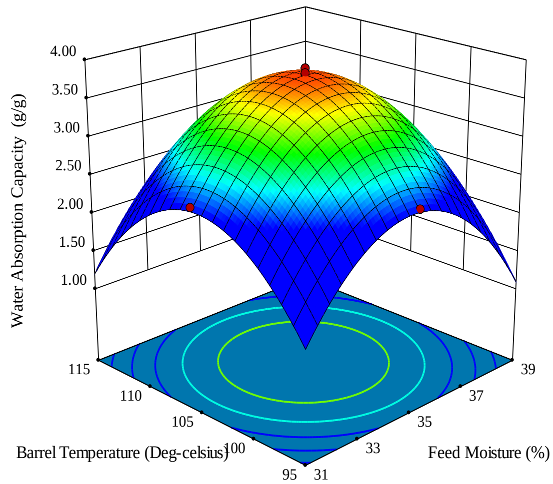

Fig. 3.6: Response surface plot showing the effect of Barrel temperature and Feed moisture on Water absorption capacity

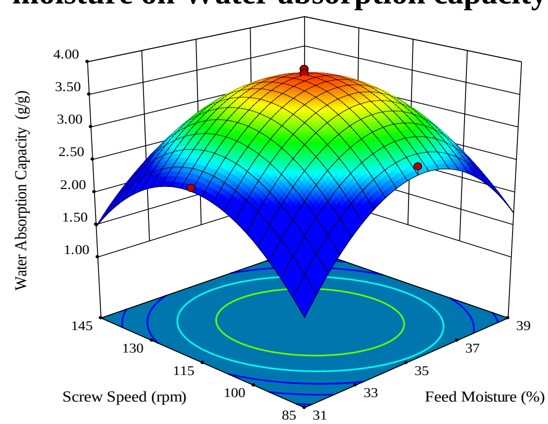

Fig. 3.7: Response surface plot showing the effect of Screw speed and Feed moisture on Water absorption capacity

Response surface plot for the effect of barrel temperature and screw speed on water absorption capacity indicates that increase in barrel temperature and screw speed resulted in quadratic decrease in water absorption capacity of the extrudates (Fig 3.5). This assertion is similar to that of Omohimi *et al*. (2014), but contrary to that of Kothakota *et al*. (2013).
Similarly, increasing the barrel temperature of the extruder and feed moisture led to a quadratic decrease in water absorption capacity of the extrudates (Fig 3.6). This statement is however, contrary to that of Lin *et al*. (2000); and Lazou and Krokida (2010).
Initial increase in screw speed of the extruder, up to 115rpm, and feed moisture up to 35% resulted in initial increase in water absorption capacity (Fig 3.7). These observations corroborate the earlier findings by Peluola-Adeyemi and Idowu (2014); Tabibloghmany *et al*. (2020). Further increase in the screw speed beyond 115rpm and feed moisture beyond 35%, resulted in a slight decrease in water absorption capacity of the extrudates.

The observed decrease in water absorption capacity of the extrudates may be attributed to the decomposition or degradation of starch.

Analysis of variance indicated that the three extrusion process parameters (barrel temperature, screw speed and feed moisturehad statistical significant effect ($p < 0.05$) on water absorption capacity of the extrudates.

3.4.3 Effect of Extrusion Process Parameters on Oil Absorption Capacity

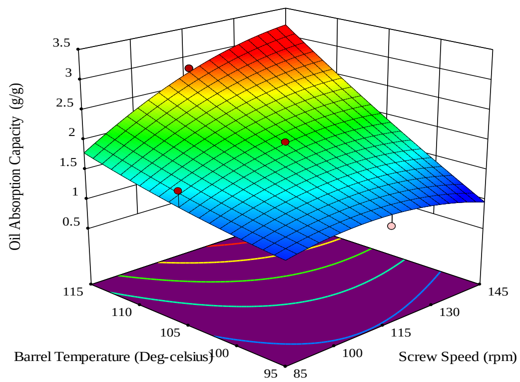

Fig.3.8: Response surface plot showing the effect of Barrel temperature and Screw speed on Oil absorption capacity

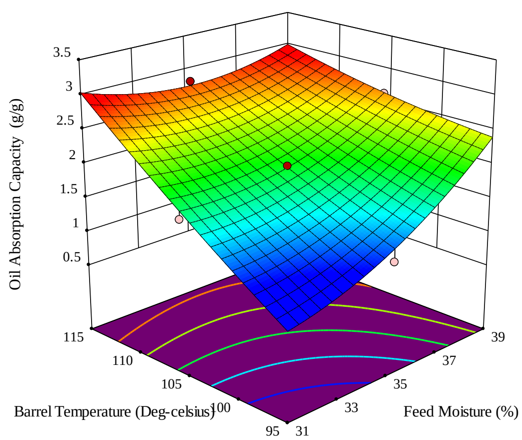

Fig. 3.9: Response surface plot showing the effect of Barrel temperature and Feed moisture onOil absorption capacity

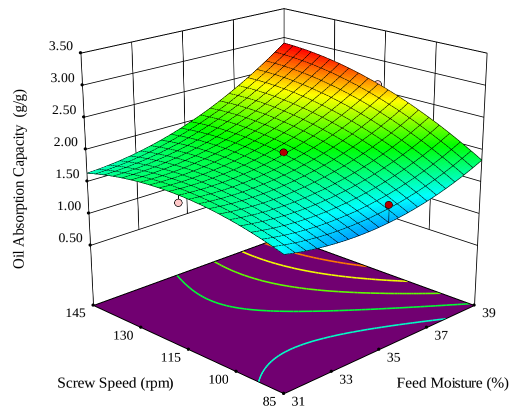

Fig. 3.10: Response surface plot showing the effect of Screw speed and Feed moisture on Oil Absorption Capacity

The Response surface plot indicates that increase in barrel temperature led to a linear increase in oil absorption capacity, while increase in screw speed resulted in a decrease in oil absorption capacity of the extrudates (Fig 3.8). This observation correlates with the earlier findings by Omohimi *et al*. (2014). The increase in oil absorption capacity may be attributed to high level of starch degradation in the extrudates as a result of high input of thermal energy (Omohimi *et al*., 2014).

Increase in both barrel temperature and feed moisture resulted in a sharp increase in oil absorption capacity of the extrudates (Fig 3.9).

Increase in screw speed resulted in initial increase in oil absorption capacity. Further increase in screw speed resulted in decrease in oil absorption, while increase in feed moisture led to increase in oil absorption capacity of the extrudates (Fig 3.10). These observations are in agreement with the earlier findings of Tabibloghmany*et al*. (2020).

Analysis of variance showed that all the three extrusion process variables: barrel temperature; screw speed; feed moisture significantly ($p < 0.05$) affected the oil absorption capacity of the extrudates.

3.4.4 Effect of Extrusion Process Parameters on Emulsion Capacity

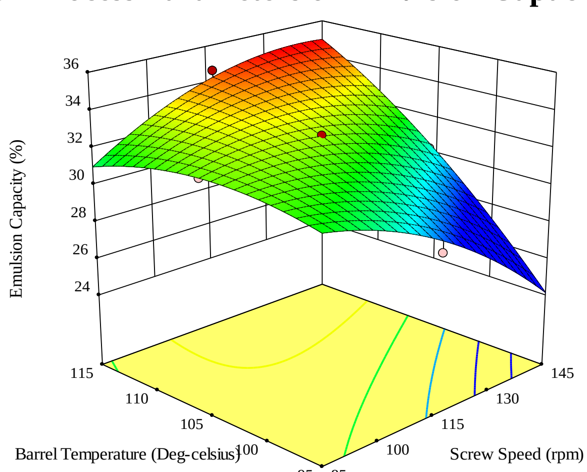

Fig. 3.11: Response surface plot showing the effect of Barrel temperature and Screw speed on Emulsion capacity

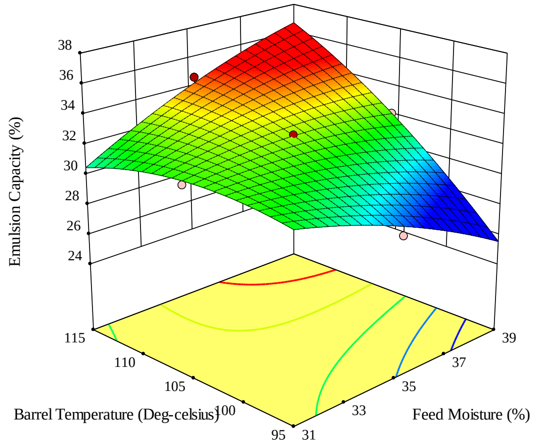

Fig. 3.12: Response surface plot showing the effect of Barrel temperature and Feed moisture on Emulsion capacity

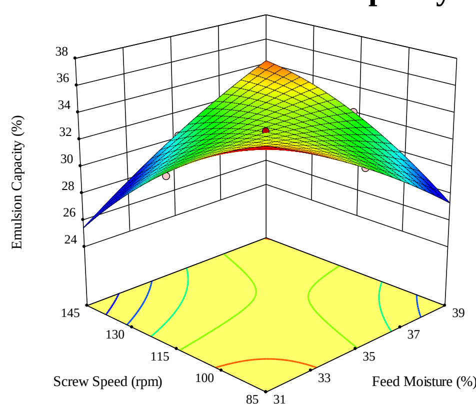

Fig. 3.13: Response surface plot showing the effect of Screw speed and Feed moisture on Emulsion capacity

Emulsion capacity increased initially with increase in barrel temperature. As the barrel temperature further increased, the emulsion capacity decreased, whereas increase in screw speed was observed to bring about decrease in emulsion capacity of the extrudates (Fig 3.11).

In Fig. 3.12, the response surface plot showed that increase in both barrel temperature and feed moisture resulted in decrease in emulsion capacity. The decrease in emulsion capacity as a result of increase in barrel temperature was preceded by an initial increase in emulsion capacity of the extrudates.

It was observed that increase in both the screw speed and feed moisture resulted in decreased emulsion capacity of the extrudates (Fig 3.13).

Analysis of variance showed that only barrel temperature had significant effect ($p < 0.05$) on emulsion capacity, while screw speed and feed moisture non-significantly ($p > 0.05$) affected the emulsion capacity of the extrudates.

3.4.5 Effect of Extrusion Process Parameters on Foaming Capacity

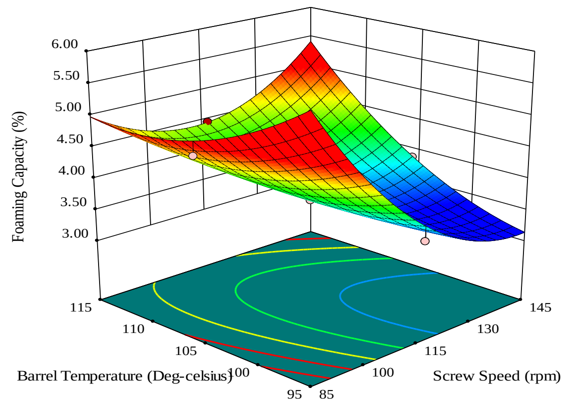

Fig. 3.14: Response surface plot showing the effect of Barrel temperature and Screw speed on Foaming capacity

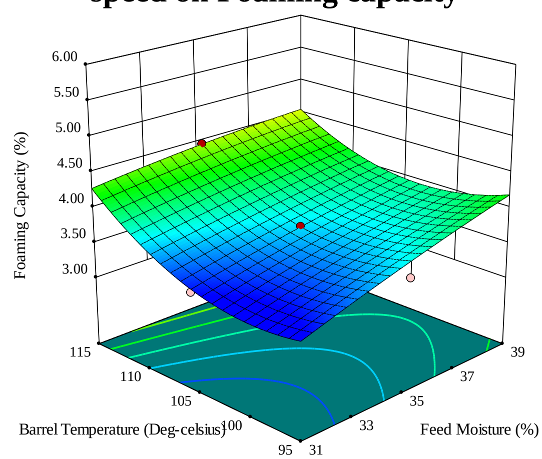

Fig. 3.15: Response surface plot showing the effect of Barrel temperature and Feed moisture onFoaming capacity

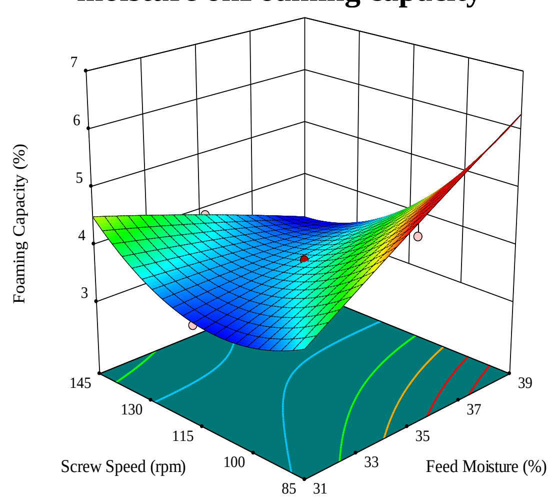

Fig. 3.16: Response surface plot showing the effect of Screw speed and Feed moisture on Foaming capacity

In Fig. 3.14, the Response surface plot for the effect of barrel temperature and screw speed on foaming capacity, indicates that increase in barrel temperature led to increase in foaming capacity, while increase in screw speed resulted in decrease in foaming capacity of the extrudates.Increase in both the barrel temperature and feed moisture led to a corresponding increase in foaming capacity of the extrudates (Fig 3.15).Similarly, increase in both the screw speed and feed moisture brought about increase in foaming capacity (Fig. 3.16). Analysis of variance showed that only screw speed significantly ($p< 0.05$) affected the foaming capacity of the extrudates, while the barrel temperature and feed moisture insignificantly ($p > 0.05$) affected the foaming capacity of the extrudates.

4.0 CONCLUSION

This study has shown that extrusion process parameters: barrel temperature; screw speed; feed moisture have both positive and negative effects on the functional properties of the extruded aerial yam and soybean flour blends. The bulk density of the extrudates was significantly affected by all the extrusion variables. The extrusion variables had significant effect on the water absorption capacity of the extrudates. Oil absorption capacity of the extrudates was significantly affected by the three extrusion variables. Emulsion capacity of the extrudates was significantly affected by only barrel temperature, while the screw speed and feed moisture showed no significant effect on emulsion capacity. Screw speed had significant effect, while barrel temperature and feed moisture had no significant effect on foaming capacity. Optimization results based on desirability concept indicated that 112.85 ℃ barrel temperature, 144.99 rpm screw speed and 35.12% feed moisture would produce extrudates of preferable functional properties.

Conflicts of Interest

The Authors of this article hereby declare that no conflicts of interest exist.

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