

Emulsion Capacity and Foaming Capacity of Blended Aerial Yam and Soybean Flour as Affected by Extrusion Process Conditions

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Abstract

This study was conducted to determine the effect of extrusion process conditions on the emulsion capacity and foaming capacity of extruded aerial yam-soybean flour blends. Design expert (variant 11.0.1), a statistical computer application software package was used in the preliminary arrangement, with a three variable preliminary set up at five levels each, with barrel temperature, screw speed, and feed moisture levels as the free factors. Response surface methodology (RSM) was used to examine the effects of the independent components or variables on the response. The blended flour sample was extruded using a laboratory scale single-screw extruder. Twenty (20) runs were carried out during the extrusion process. Results of the laboratory analyses showed that the extrudates had emulsion capacity of between 28.51 and 34.85%, and foaming capacity of between 3.37 and 4.86%. Response surface plots for the effects of the extrusion process conditions indicated that increase in barrel temperature, screw speed, and feed moisture resulted in decreased emulsion capacity of the extrudates. Increase in barrel temperature and feed moisture resulted in increased foaming capacity, while increased in screw speed decreased the foaming capacity of the extrudates. Barrel temperature had significant effect ($p < 0.005$) on emulsion capacity; while screw speed and feed moisture showed non-significant effect ($p > 0.005$) on the emulsion capacity of the extrudates. Screw speed significantly ($p < 0.005$) affected the foaming capacity, while the barrel temperature and feed moisture showed non-significant effect ($p > 0.005$) on the foaming capacity of the extruded aerial yam and soybean flour blend.

Keywords: Extrusion Process Conditions, Foaming Capacity, Emulsion Capacity, Response Surface, Extrudates, Aerial Yam-Soybean Flour.

Introduction

Emulsifying properties of proteins are important parameters to determine their functional properties under different environmental conditions and the possible interaction with other macromolecules present in the media. Emulsion capacity is the parameter most commonly estimated in the various studies on oil in-water emulsions. Emulsion capacity of a water-soluble emulsifier is defined as the maximum amount of oil that can be dispersed in an aqueous solution containing a specific amount of the emulsifier, without the emulsion breakdown or inverting into a water-in-oil emulsion (Mena-Casonova and Totosa, 2011).

Emulsion properties are strictly related to physicochemical factors such as pH and ionic strength, controlling emulsion properties such as emulsion capacity and stability.

According to Nawaz *et al.*, (2015), foaming properties are desirable in food products such as cakes, breads, meringues, crackers, ice creams and several other bakery items to maintain their texture and structure throughout the processing and during storage. Foaming capacity depends on the surface tension at the water air interface.

Functional properties of food materials play a significant role in manufacturing, transportation, storage, stability, texture, taste and flavor of food products (Nawaz *et al.*, 2015). These properties directly or indirectly depend on type, variety, particle size and chemical composition of flour and type of processing method.

The functional properties of cereal and other flours have been reported to be influenced by various processing techniques such as freeze-thaw, extrusion, cooking, roasting and blending (Nawaz *et al.*, 2021; Feng *et al.*, 2020; Hussain *et al.*, 2018; Kaur *et al.*, 2014; Tanwar *et al.*, 2019). Formation of blends of different flours in an appropriate ratio may improve the functional properties, nutritional and product quality of food materials.

Aerial yam (*Dioscorea bulbifera*), is a perennial, semi wild food crop that grows on vines, climbing unto poles and trees, which belongs to the yam family, *Dioscoreaceae* (Umoh, 2020). The bulb is eaten after cooking, on peeling off the hard back. Its common names are: Air yam, Air potato, Bitter yam, Aerial yam, Potato yam, among others. *Dioscorea bulbifera* is a vigorous climber plant native of West, cultivated for their bulbils which are consumed once cooked like potatoes in water with oil or roasted with local sauce (a combination of palm oil and other local spices).

The aerial yam flour can be used as composite flour in the production of cookies. Princewill Ogbonna and Ezembaukwu (2015) and Umoh *et al.* (2024), reported that aerial yam 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.

About 50-60 species of yam (*Dioscorea* spp.) are found in Nigeria but only 5 or 6 species are important as food. Unfortunately, some of these food crops have been under-exploited for their food values, for example, *Dioscorea bulbifera* (Umoh *et al.*, 2021). Processing aerial sweet potato to flour can help reduce our reliance on wheat flour for warmed foods and post harvest adversities (Umoh and Iwe, 2023)

Soybean (*Glycine max*), an important oil seed belonging to the family, *Leguminosae*, is usually grown as a food crop (Umoh and Iwe, 2023). Soybean has a unique chemical composition on an average-dry-matter basis; it contains about 40% protein and 20% oil. With this composition, it ranks highest in terms of protein content among all the legumes (Iwe, 2003; Umoh *et al.*, 2021).

Soybean is predominantly developed for its seeds, utilized as human food and animals feed, and for the extraction of oil. Soy food varieties are turning into the absolute quickest developing classes in the food business, with items going from customary soy food varieties

to protein fixings, and from dairy and meat options in contrast to different sorts of Western and conventional food sources enhanced with soybean flour as well as its parts (Iwe, 2003; Umoh and Iwe, 2022).

Soy foods have a high protein content and high protein utilization, leading to the highest amount of protein gained. 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 (Umoh and Abasiokong, 2024; Umoh *et al.*, 2024).

As indicated by Iwe (2003), food extrusion has been in practice for over sixty years. Extrusion cooking is a significant and famous food handling strategy named a high temperature/short time frame (HTST) interaction to create fiber-rich items (Gaossong and Vasanthan, 2000). It is an interaction where dampened, sweeping, bland and additionally proteinacious food materials are plasticized and cooked in a cylinder by a mix of dampness, tension, temperature and mechanical shear, bringing about atomic change and substance responses (Castells *et al.*, 2005; Umoh and Iwe, 2022).

Problem Statement

Aerial yam (*Dioscorea bulbifera*) is one of the underutilized crops, and is yet to gain recognition and popularity globally, as a food crop. Blending of aerial yam and soybean, and or extrusion cooking of the blend, has not been adequately studied for its potential application in food products formulation. Processing it into stable flour/blend, and subsequent extrusion processing to produce pasta, will increase the visibility of the crop in food trade, thereby bringing to limelight its potential food uses/values to the food industry (Princewill-Ogbonna and Ezembaukwu, 2015; Umoh *et al.*, 2021). This would ultimately promote value addition in food processing and ensure food security.

Functional properties of food materials play a significant role in manufacturing, transportation, storage, stability, texture, taste and flavor of food products (Nawaz *et al.*, 2015).

This study is aimed at evaluating the effect of extrusion process conditions, namely; barrel temperature, screw speed and feed moisture on the emulsion capacity and foaming capacity of extruded aerial yam-soybean flour blend using Response Surface Methodology (RSM).

Materials and Methods

Collection of Soybean Seeds and Aerial Yam Bulbs

Soybean seeds and aerial yam bulbs (Plate 1), used in this study were purchased from Uyo Urban market in Uyo Local Government Area, Akwa Ibom State, Nigeria.

Preparation of Aerial Yam Flour

Aerial yam flour was prepared according to the method described by Umoh *et al.* (2021). The Aerial yam bulbs were cleaned and sorted to remove unwanted materials, before peeling with knife, washed with cleaned water and sliced to 10 mm thickness using knife.

The slices (chips) were then dried, using an oven at a temperature of 60 °C for 12 h. The dried slices (chips) were then milled using a hammer mill and sieved with laboratory sieve of 600µm aperture size. The flour obtained was packaged in a polyethene bag for subsequent use.

Preparation 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 °C for 30 minutes. It was then oven -dried at a temperature of 70 °C 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 for further use.

Preparation of the Sample Blend

The aerial yam and soybean flour blend was prepared in the ratio of 25:75, expressed in percentage as 25% aerial yam flour and 75% soybean flour (Umoh *et al.*, 2021).

Experimental Design/Statistical Analysis

Design expert (variant 11.0.1), a Statistical Computer Application Software Package was used in the preliminary arrangement, with a three variable preliminary set up at five levels each, with barrel temperature, screw speed, and feed moisture levels as the free factors. Response surface methodology (RSM) was used to examine the effects of the independent components or variables on the response (Umoh *et al.*, 2023).

Extrusion Process

This was done using a single-screw research center scale extruder, according to the method described by Umoh *et al.* (2023). 200 g of the flour blend was definitively assessed and preconditioned by the ideal clamminess levels, allowed to stay for two 2 min to ensure uniform hydration of the raw substance. The extruder was turned on, and the barrel temperatures and the screw speeds of the extruder were set by the preliminary arrangement. The normal substance was dealt with through the compartment into the extruder. The extrudates (plate 2), were collected as they exit through the die; grill dried, and packaged in impervious zip lock polyethylene sacks for additional laboratory examination. Twenty runs were done by and large, during the expulsion cycle, according to the preliminary arrangement.



Plate 1: Aerial yam bulbs



Plate 2: Sample of the extrudates

Determination of Emulsion Capacity

This was determined according to the method described by Beuchat *et al.* (1975). Two grams (2g) of the sample and 23 ml of distilled water were blended for 30 seconds, using a blender at high speed (12,000 rpm). 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, using equation 1

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

Where X = height of emulsified layer

Y = height of whole solution in the centrifuge tube

Determination of Foaming Capacity

Two grams (2g) of the sample and 100 ml of distilled water were blended, using a blender, at high speed for 5 minutes, and the dispersion poured into a 250 ml measuring cylinder. The volume of the foam at 30 seconds after whipping was expressed as the foaming capacity (in %) of the sample, using equation 2 (Lawhon *et al.*, 1972).

$$\text{Foaming capacity (\%)} = \frac{\text{Volume after whipping} - \text{Volume before whipping}}{\text{Volume before whipping}} \times 100 \dots\dots\dots [2]$$

Results and Discussions

The results of the emulsion capacity and foaming capacity of extruded aerial yam-soybean flour blend are presented in Table 1.

Table 1: Emulsion capacity and foaming capacity of extruded aerial yam and soybean flour blend

S/N	Barrel Temp (°C)	Screw Speed (rpm)	Feed Moisture (%)	Emulsion Capacity (%)	Foaming Capacity (%)
1	105	115	31	31.73±0.153	3.37±0.057
2	105	115	35	32.62±0.158	3.68±0.057
3	105	115	35	32.58±0.158	3.70±0.057
4	105	85	35	32.30±0.100	4.86±0.150
5	100	130	33	29.26±0.031	3.46±0.001
6	110	100	37	32.83±0.153	4.80±0.100
7	100	100	37	29.87±0.252	5.00±0.100
8	110	130	33	32.05±0.153	4.22±0.006
9	105	115	35	32.64±0.158	3.66±0.057
10	115	115	35	34.59±0.208	4.46±0.057
11	95	115	35	28.51±0.030	3.57±0.173
12	105	115	39	32.10±0.173	3.79±0.057
13	105	115	35	32.60±0.158	3.71±0.057
14	100	100	33	34.47±0.115	4.17±0.153
15	110	130	37	34.85±0.115	3.95±0.057
16	110	100	33	32.78±0.100	3.97±0.057
17	105	145	35	30.25±0.011	3.87±0.441
18	100	130	37	30.67±0.032	3.48±0.100
19	105	115	35	32.59±0.158	3.74±0.057
20	105	115	35	32.71±0.158	3.69±0.057

Note: Values are mean ± standard deviation of triplicate determination

Emulsion Capacity

The result shows that the emulsion capacity of the extrudates ranged between 28.51 and 34.85% (Table 1). This range of values is lower than 54.49 to 62.82%, for blended aerial yam and soybean flour, earlier reported by Umoh (2020). Emulsion capacity is the ability of a protein solution or suspension to emulsify oil.

Foaming Capacity

Foaming capacity of the extrudates ranged from 3.37 to 4.86% (Table 1). This range of values is slightly lower than 3.07 to 5.43% for aerial yam and soybean flour blend, earlier reported by Umoh (2020). Foaming capacity of a protein is a measure of the amount of interfacial area that can be created by whipping the protein.

Effect of Extrusion Process Parameters on Emulsion Capacity

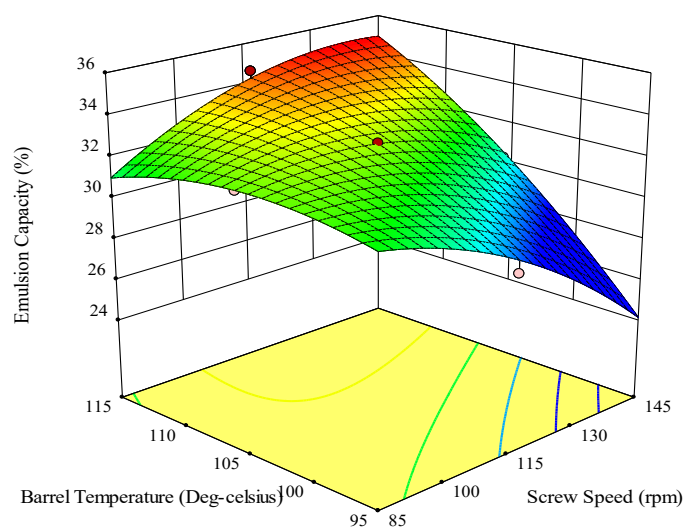


Fig. 1: Response surface plot showing the effect of barrel temperature and screw speed on emulsion capacity

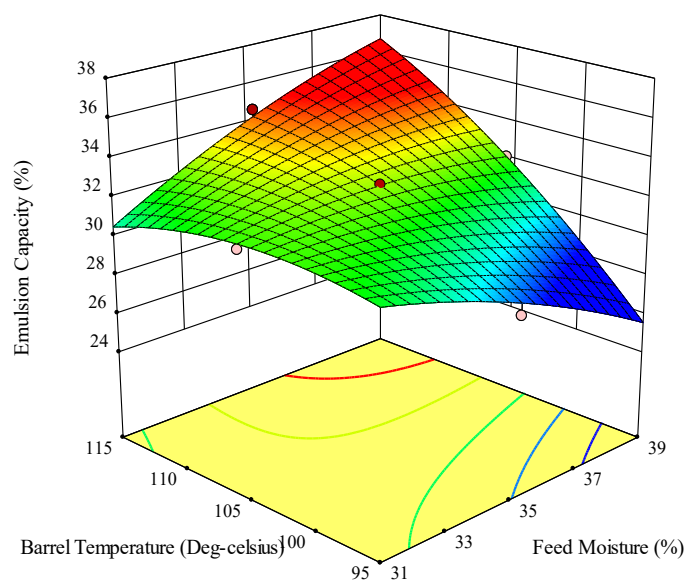


Fig. 2: Response surface plot showing the effect of Barrel temperature and Feed moisture on Emulsion capacity

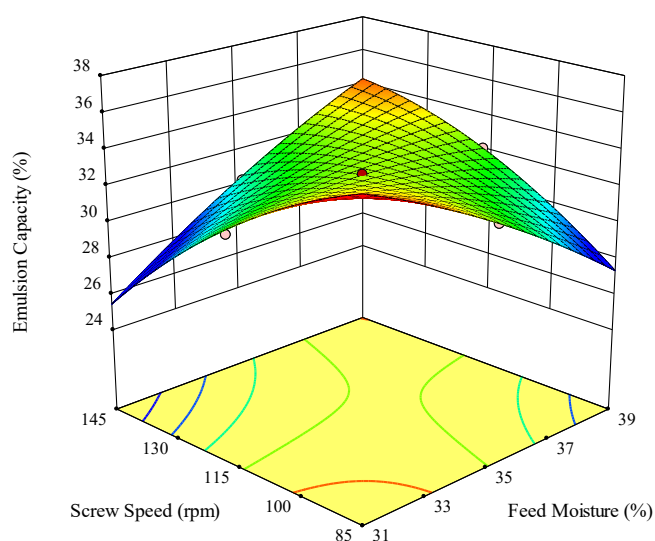


Fig. 3: Response surface plot showing the effect of Screw speed and feed moisture on emulsion capacity

The Response surface plots showing the effect of barrel temperature and screw speed on emulsion capacity; effect of barrel temperature and feed moisture on emulsion capacity; effect of screw speed and feed moisture on emulsion capacity are presented in Fig.1, Fig. 2 and Fig. 3, respectively.

In Fig. 1, emulsion capacity increased initially with increase in barrel temperature. Further increase in the barrel temperature brought about decrease in the emulsion capacity, whereas increase in screw speed was observed to bring about decrease in emulsion capacity of the extrudates.

In Fig. 2, the response surface plot indicates 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.

Fig. 3 shows that increase in both the screw speed and feed moisture resulted in decreased emulsion capacity of the extrudates.

Table 2: Analysis of variance for emulsion capacity (%) at 5% significance level

Source	Sum of Squares	df	Mean Square	F-value	p-value
Barrel Temp	28.698	3	9.566	4.403	0.036
Screw Speed	6.045	3	2.015	0.927	0.466
Feed Moisture	0.836	3	0.279	0.128	0.941
Error	19.553	9	2.173		
Total	20661.803	20			
Corrected Total	53.603	19			

Analysis of variance (ANOVA) at 5% significance level, for the effect of barrel temperature, screw speed and feed moisture on emulsion capacity (Table 2), shows that the p-value for the three extrusion process conditions are 0.036 for barrel temperature, 0.466 for screw speed and 0.941 for feed moisture. This implies that only barrel temperature had significant effect ($p < 0.05$) on emulsion capacity; while screw speed and feed moisture showed non-significant effect ($p > 0.05$) on the emulsion capacity of the extrudates.

The “Test of between-subjects effects” of extrusion process conditions on emulsion capacity showed that all the extrusion process conditions, including their interactions significantly ($p < 0.05$) affected the emulsion capacity of the extrudates.

Effect of Extrusion Process Condition on Foaming Capacity

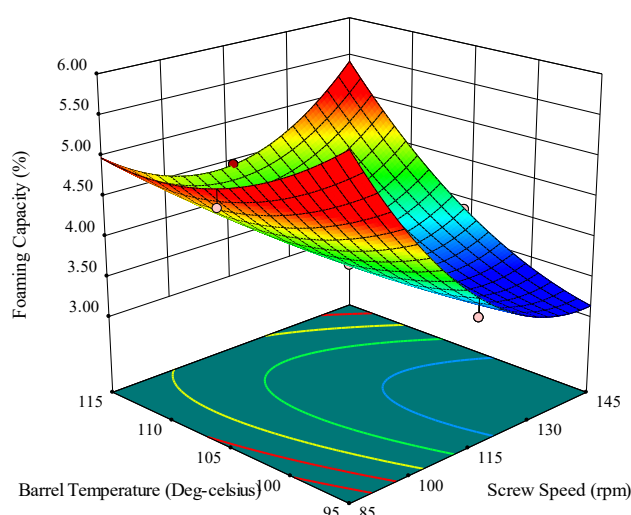


Fig. 4: Response surface plot showing the effect of barrel temperature and screw speed on foaming capacity

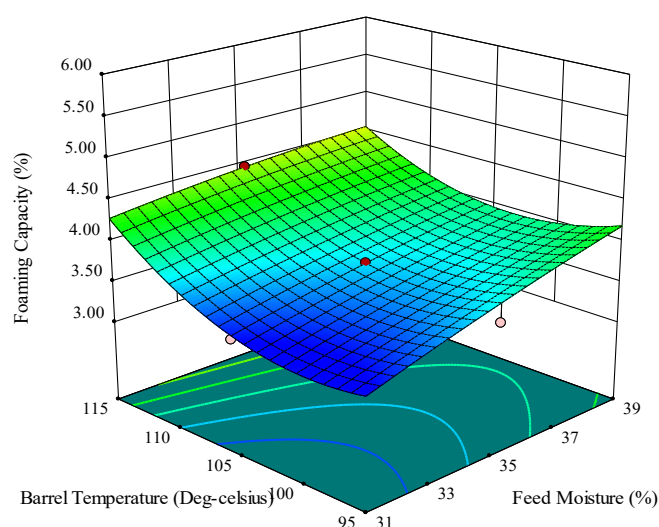


Fig. 5: Response surface plot showing the effect of barrel temperature and feed moisture on foaming capacity

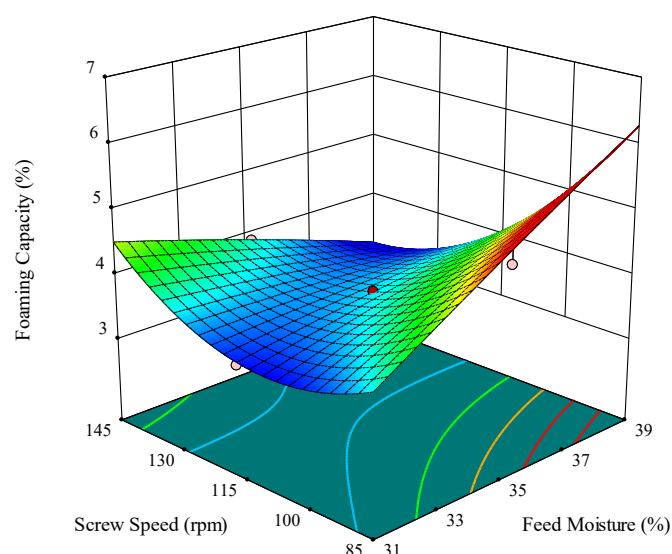


Fig. 6: Response surface plot showing the effect of screw speed and feed moisture on foaming capacity

Response surface plots showing the effect of the extrusion process conditions on foaming capacity are presented in Fig. 4 to Fig. 6.

The Response surface plot for the effect of barrel temperature and screw speed on foaming capacity (Fig. 4), 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.

In Fig. 5, the Response surface plot shows that increase in both the barrel temperature and feed moisture led to a corresponding increase in foaming capacity of the extrudates.

Similarly, increase in both the screw speed and feed moisture brought about increase in foaming capacity (Fig. 6). Foaming capacity/stability is important in products such as cake and yam balls.

Table 3: Analysis of variance for foaming capacity (%) at 5% significance level

Source	Sum of Squares	Df	Mean Square	F-value	p-value
Barrel Temp	0.634	3	0.211	2.340	0.142
Screw Speed	2.161	3	0.720	7.976	0.007
Feed Moisture	0.357	3	0.119	1.318	0.328
Error	0.813	9	0.090		
Total	317.633	20			
Corrected Total	4.396	19			

Analysis of variance (ANOVA) at 5% significance level, for the effect of extrusion process conditions on foaming capacity showed that only screw speed, with a p-value of 0.007, significantly ($p < 0.05$) affected the foaming capacity, while the barrel temperature and feed moisture with p-values of 0.142 and 0.328, respectively (Table 3), showed non-significant effect ($p > 0.05$) on the foaming capacity of the extrudates.

The results of the "Test of between-subjects effect" of extrusion process conditions on foaming capacity shows that the interactions of the extrusion conditions significantly affected ($p < 0.05$) the foaming capacity of the extrudates

Conclusions

This study has shown that extrusion process conditions, namely; barrel temperature, screw speed, and feed moisture have positive and negative impacts, as well as statistical significant and non-significant effects on the emulsion capacity and foaming capacity of the extruded aerial yam-soybean flour blend.

Increase in barrel temperature, screw speed, and feed moisture result in decreased emulsion capacity of the extrudates. Barrel temperature has significant effect on emulsion capacity; while screw speed and feed moisture show non-significant effect on the emulsion capacity of the extrudates.

As the barrel temperature and feed moisture increase, foaming capacity also increases, whereas increase in screw speed decreases the foaming capacity of the extrudates.

Screw speed significantly affects the foaming capacity, while the barrel temperature and feed moisture show non-significant effect on the foaming capacity of the extruded aerial yam-soybean flour blend.

Recommendations

Based on the findings of this study, the following actionable recommendations are made:

- Further studies should be conducted on the effect of other extrusion process conditions such as feed ratio and residence time on the extrusion processing of aerial yam and its blends.
- Extrusion study should be carried out, using a twin-screw extruder, for the feed material to undergo more shear and produce extrudates that might have different quality attributes, in terms of the functional properties.
- The range of values for the barrel temperature, screw speed and percentage feed moisture used in this study should be varied, and subsequent extrusion processing of aerial yam and soybean flour blends carried out, for a more comprehensive conclusions on the effect of extrusion conditions on some functional properties of the extrudates.

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