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Optimization of extrusion process parameters for the antinutritional compositions of aerial Yam (*Dioscorea bulbifera*)-soybean (*Glycine max*) flour blends using response surface methodology

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Abstract

A study on the optimization of extrusion process conditions for antinutritional factors of aerial yam-soybean flour blends was carried out, using a laboratory scale single-screw extruder with the flour blending ratio of 25% aerial yam: 75% soybean. Response surface methodology based on Box-Behken 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. Adequate and significant ($p < 0.05$) regression models with high regression coefficient, $R^2 \geq 0.9$ were obtained, showing that the models can be used to navigate the design space. Results obtained showed that the anti-nutritional factors of the extrudates ranged between 0.79±0.002 and 5.11±0.008/100g hydrogencyanide (HCN), 12.48±0.025and 32.86±0.032mg/100g phytates; 0.93±0.026 and 5.46±0.009/100g tannins; 45.81±0.024 and 102.71±1.244/100g oxalates. Analysis of variance showed that barrel temperature, screw speed and feed moisture significantly ($p < 0.05$) affected the HCN, phytates, tannins and oxalates content of the extrudates. Optimization results based on desirability concept indicated that a barrel temperature of 112.83℃, screw speed of 127.87rpm and feed moisture of 32.59% would produce extrudates of preferable anti-nutritional factors.

Keywords: optimization, extrusion, antinutritional, aerial yam, soybean, response surface

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 parameters in order to produce extrudates with the desired quality.

The 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*. 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.

Discorea bulbifera is a vigorous climber plant native of West Africa (Hamon *et al*., 1995) [4], 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).

About 50-60 species of yam (*Dioscorea* spp.) are found in Nigeria but only 5 or 6 species are important as food (Ogbuagu, 2008) [7]. Unfortunately, some of these food crops have been under-exploited for their food values, for example, *Dioscorea bulbifera* (Ogbuagu, 2008) [7].

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) [5]. 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) [5].

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).

However, 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.

Aerial yam is yet to gain recognition and popularity globally, as a food crop. 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.

Despite the increased use of extrusion process, it is still a complex process that has to be optimized for specific applications based on the nature of raw materials and desired final product. Even within a given extrusion process, small variations in processing conditions affect process variables as well as product quality (Desrumaux *et al*., 1999) [2].

This study is therefore, aimed at optimizing the extrusion process parameters for the antinutritional factors of aerial yam-soybean flour blends, using Response Surface Methodology.

Materials and Methods

Soybean seeds and Aerial yam bulbs 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 Olurin *et al*. (2006) [2]. The Aerial yam bulbs were cleaned and sorted to remove unwanted materials, before peeling with knife, washed with cleaned 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 (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) [5]. 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.

Preparation of Sample Blends

The Aerial yam–Soybean flour blend was prepared in the ratio of 25:75, expressed in percentage as 25% aerial yam flour and 75% soybean flour.

Experimental Design/ Statistical Analysis

Design Expert (version 11.0.1), a Statistical Computer Application Software Package was used in the experimental design. 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 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, 2, where -2 represents the lowest, 0 represents the medium (mid-point), and 2 represents highest levels respectively (Tables 1).

Table 1: Coded and actual values of different experimental variables

Factors	Units	Codes	Levels					Interval of Variation
			-2	-1	0	1	2	
Barrel temp.	℃	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

Extrusion Cooking

Extrusion cooking was carried out using a single-screw laboratory scale extruder in the Department of Food Science and Technology Laboratory, Federal University of Agriculture, Abeokuta, Ogun State, Nigeria. Two hundred grams (200g) of the flour blend (25% aerial yam flour, 75% soybean flour) was accurately measured and preconditioned according to the desired moisture levels, allowed to stay for about two minutes (2min) in order to ensure uniform hydration of the raw material. This was to ensure that any dry core was eliminated (Strahm, 2000) [14]. The extruder was switched-on, and the barrel temperatures (in degree Celsius-^{0}C) and the screw speeds (in revolution per minute-rpm) of the extruder were set according to the experimental design. 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.

Determination of Anti-Nutritional factors

The Hydrocyanide (HCN) was determined by the methods of Egan and Bradbury, (1998) [3]. The Oxalate was determined according to the method described by Oke, (1969). The phytate was determined by the method of Mecance and Widdowson, (1955) [6]. The Tannin content was determined according to the Folin-Dennis Spectrophotometric method described by Pearson (1976).

Results

Table 2: Anti-nutritional factors of extruded aerial yam-soybean flour blends

S/N	BT (ºC)	SS (rpm)	FM (%)	HCN (mg/100g)	Phytate (mg/100g)	Tannin (mg/100g)	Oxalate (mg/100g)
1	105	115	31	1.42±0.003	17.48±0.018	2.63±0.025	59.56±1.245
2	105	115	35	2.63±0.004	12.73±0.025	3.70±0.017	99.16±1.852
3	105	115	35	2.66±0.004	12.81±0.025	3.72±0.017	99.11±1.852
4	105	85	35	5.11±0.008	27.62±0.019	2.48±0.008	57.40±1.889
5	100	130	33	3.81±0.024	16.37±0.013	4.00±0.001	64.00±0.011
6	110	100	37	4.82±0.007	26.78±0.015	5.46±0.009	70.36±0.622
7	100	100	37	0.79±0.002	24.49±0.020	0.93±0.026	102.71±1.244
8	110	130	33	2.22±0.005	25.39±0.025	1.81±0.016	73.80±1.869
9	105	115	35	2.64±0.004	12.48±0.025	3.71±0.017	99.16±1.852
10	115	115	35	3.77±0.004	32.86±0.032	4.75±0.021	59.52±0.622
11	95	115	35	1.51±0.005	20.34±0.021	2.54±0.009	72.56±0.642
12	105	115	39	0.81±0.004	23.97±0.046	1.19±0.014	73.64±0.623
13	105	115	35	2.61±0.004	12.60±0.025	3.72±0.017	99.15±1.852
14	100	100	33	2.36±0.005	19.21±0.031	2.83±0.017	80.32±0.622
15	110	130	37	2.22±0.007	24.95±0.017	3.71±0.030	77.06±1.245
16	110	100	33	2.48±0.011	25.55±0.026	3.50±0.008	67.60±0.613

17	105	145	35	3.96±0.008	30.34±0.011	2.01±0.112	45.81±0.024
18	100	130	37	1.36±0.006	25.74±0.008	1.21±0.341	66.28±1.321
19	105	115	35	2.64±0.004	12.87±0.025	3.74±0.017	99.13±1.852
20	105	115	35	2.63±0.004	12.71±0.025	3.71±0.017	99.10±1.852

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

Table 3: Coefficient of Regression/ANOVA of Quadratic model for Antinutritional factors

	HCN		**Phytate**		**Tannin**		**Oxalate**	
	Coeff.	**p-values**	**Coeff.**	**p-values**	**Coeff.**	**p-values**	**Coeff.**	**p-values**
X_o	73.50		1803.82		110.54		-6246.40	
Linear								
X_1	-1.915	< 0.0001	-23.53	< 0.0001	-2.568	< 0.0001	61.07	0.0095
X_2	0.695	0.0136	-4.56	0.7569	1.353	0.0086	2.84	0.0026
X_3	-0.791	0.0216	-19.27	0.0007	-3.061	0.0020	171.02	0.0040
Interaction								
$X_1 X_2$	-0.0074	< 0.0001	-0.00067	0.9248	-0.0082	< 0.0001	0.109	0.0002
$X_1 X_3$	0.085	< 0.0001	-0.173	0.0073	0.107	< 0.0001	-0.233	0.1263
$X_2 X_3$	-0.012	0.0014	0.010083	0.5713	-0.0039	0.1658	-0.0817	0.1100
Quadratic								
X_1^2	-0.0005	0.7629	0.144	< 0.0001	-0.00053	0.7746	-0.315	< 0.0001
X_2^2	0.002	< 0.0001	0.0186	< 0.0001	-0.016	< 0.0001	-0.051	< 0.0001
X_3^2	-0.0988	< 0.0001	0.531	< 0.0001	-0.112	< 0.0001	-1.933	< 0.0001
Test for model adequacy								
R^2	0.9812		0.9750		0.9818		0.9740	
Pred. R^2	0.8516		0.8029		0.8521		0.8021	
Model F-value	57.87		43.34		59.80		41.56	
Lack of fit	371.56		211.82		539.75		46662.87	

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

Table 4: Output for numerical optimization of extrusion process parameters for antinutritional factors

Extrusion criteria	Unit	Lower limit	Upper limit	Optimization Goal	Relative Importance	Output
Barrel temperature	°C	95.00	115.00	Maximize	3	112.83
Screw Speed	rpm	85.00	145.00	Maximize	3	127.87
Feed Moisture	%	31.00	39.00	Range	3	32.59
HCN	mg/100g	0.79	5.11	Minimize	3	1.20
Phytate	mg/100g	12.48	32.86	Range	3	32.86
Tannin	mg/100g	0.93	5.46	Range	3	1.16
Oxalate	mg/100g	45.81	102.71	Range	3	86.17
Desirability						0.832

The results of the antinutritional factors of extruded aerial yam-soybean flour blends are presented in Table 3.1.

Hydrogencyanide (HCN)

The results of the hydrogencyanide (HCN) contents of the extruded aerial yam-soybean flour blends are presented in Table 3.1. The HCN contents of the extrudates ranged from 0.79± 0.002 to 5.11± 0.008mg/100g of sample. This range of values is higher than 0.11± 0.02 to 0.13± 0.01mg/100g for extruded maize-soybean protein concentrate, earlier reported by Omosebi *et al.* (2018). However, the HCN content recorded was lower than the recommended safe level of 10mg HCN/kg, db (FAO/WHO, 1991; Bandna, 2012). This suggests that extrudates produced from aerial yam-soybean flour blend could be safe from the toxicity effect of hydrogencyanide. Consumption of foods containing cyanogens could results in acute or chronic toxicity. So, it is important to ensure that minimal levels are present in food for human consumption.

Phytates

The results of the phytates contents of the extruded aerial yam-soybean flour blends are presented in Table 3.1. The phytates contents ranged between 12.48± 0.025 and 32.86± 0.032mg/100g of sample. Furthermore, the observed range of values for phytates in the extruded aerial yam-soybean flour blend is lower than 177.53 to 311.83mg/100g for extruded sorghum-soya blends (Arun kumar *et al.*, 2018); and 247.32± 3.46 to 485.69± 7.38mg/100g for sorghum-based extruded product supplemented with defatted soy meal flour (Tadesse *et al.*, 2019).

Phytates occur in several vegetable products. Seeds, grains, nuts and legumes store phosphorus as phytic acid in husks in the form of phytin or phytate salt. Their presence may affect bioavailability of minerals, solubility, functionality and digestibility of proteins and carbohydrates (Popova and Mihaylova, 2019).

Tannin

The results of the tannin contents of the extruded aerial yam-soybean flour blends are presented in Table 3.1. The tannin contents of the extrudates varied between 0.93± 0.026 and 5.46± 0.009mg/100g. This observed range of values is higher than 0.03 and 0.04% for extruded meals of quality protein maize, soybean concentrate and cassava starch (Omosebi *et al.*, 2018); 0.1942 to 0.4643 % tannic acid for extruded sorghum-soya blends (Arun kumar *et al.*, 2018); 0.28 to 0.81mg GA/g – dry matter, for soybean hull (Tabibloghmany *et al.*, 2020), but much more lower compared to 35.50± 0.02 and 130.17± 0.20mg/100g for sorghum-based extruded product supplemented with defatted soy meal flour (Tadesse *et al.*, 2019). Tannins exhibit anti-nutritional properties by impairing the digestion of various nutrients and preventing them from being absorbed by the body. Tannin can also bind and shrink proteins. Tannin-protein complex may result in digestive enzymes inactivation and protein digestibility reduction caused by protein substrate and ionizable iron interaction (Popova and Mihaylova, 2019; Ogunkoya *et al.*, 2006).

Oxalates

The results of the oxalate content of the extruded aerial yam-soybean flour blend are presented in Table 3.1. The oxalate contents ranged from 45.81± 0.024 to 102.71± 1.244mg/100g of sample. Oxalic acid can form soluble (potassium and sodium) or insoluble (calcium, magnesium and iron) salts or esters called oxalates, that are commonly found in plants or synthesized in the body. In sensitive people, even small amount of oxalate can result in burning in the eyes, ears, mouth and throat; large amount may cause abdominal pain, muscle weakness, nausea and diarrhoea (Popova and Mihaylova, 2019). The results of Regression analysis/ANOVA of the models for the responses: Antinutritional factors of extruded aerial yam-soybean flour blend are presented in Table 3.2.

Model selection/equations for optimization

Quadratic model was selected for the optimization of extrusion process parameters for antinutritional factors (HCN, phytate, tannin and oxalate). The final regression model for HCN, in terms of actual values, is given in Equation 1 as:

$$HCN=73.50-1.915BT+0.695SS-0.791FM-0.0074BTSS+0.085BTFM-0.012SSFM-0.0005BT^{2}+0.002SS^{2}-0.0988FM^{2} \quad (1)$$

Where: *HCN*= Hydrogencyanide (mg/100g); *BT* =Barrel temperature (^{0}C); *SS* =Screw speed (rpm);

FM =Feed moisture (%).

The results of Regression analysis/ANOVA of the models for Antinutritional factors in Table 3.2 indicate a model F-value of 57.87 and *p*-value of < 0.0001, implying that the model is significant. The independent variables, their interactions and the quadratic terms are significant ($p < 0.05$) model terms (Table 3.2). This model can therefore be used to navigate the design space. The model is significant with a very low probability value < 0.0001, and a satisfactory coefficient of determination, R^2 of 0.9812 (Table 3.2), indicating that the response (HCN) model is adequate, and can explain 98% of the total variability in the response.

Model Equation for Optimization of Extrusion Process Parameters for phytate

The final regression model for phytate, in terms of actual values, is given in Equation 2 as:

$$P_t = 1803.82-23.53BT-4.56SS-19.27FM-0.00067BTSS-0.173BTFM+0.010083SSFM+0.144BT^2+0.0186SS^2+0.531FM^2 \quad (2)$$

Where

P_t = Phytate (mg/100g); *BT* =Barrel temperature (^{0}C); *SS* =Screw speed (rpm); *FM* =Feed moisture (%).

From Table 3.2, the model F-value of 43.34 implies that the model is significant. The model was significant with a satisfactory coefficient of determination, R^2 of 0.9750 (Table 3.2). This model can therefore be used to navigate the design space.

Model Equation for Optimization of Extrusion Process Parameters for Tannin

The final regression model for tannin, in terms of actual values, is given as:

$$T_n=110.54-2.568BT+1.353SS-3.061FM-0.0082BTSS+0.107BTFM-0.0039SSFM-0.00053BT^{2}-0.016SS^2-0.112FM^2 \quad (3)$$

Where

T_n= Tannin (mg/100g); *BT* =Barrel temperature (^{0}C); *SS* =Screw speed (rpm); *FM* =Feed moisture (%).

The model F-value of 59.80 and *p*-value of < 0.0001 (Table 3.2) simply means that the model is significant.

This model can therefore be used to navigate the design space. The model was significant with a satisfactory coefficient of determination, R^2 of 0.9818 (Table 3.2). This is an indication that the response (tannin) model is adequate, and can explain 98% of the total variability in the response.

Model Equation for Optimization of Extrusion Process parameters for Oxalate

The regression model equation for oxalate, in terms of actual values, is given in Equation 4 as:

$$O_{x}=-6246.40+61.07BT+2.84SS+171.02FM+0.109BTSS-0.233BTFM-0.0817SSFM-0.315BT^{2}-0.051SS^{2}-1.933FM^2 \quad (4)$$

Where

O_x = Oxalate (mg/100g); *BT* =Barrel temperature (^{0}C); *SS* =Screw speed (rpm); *FM* =Feed moisture (%).

From the results of Regression analysis/ANOVA in Table 3.2, the model F-value of 41.56, and *p*-value of <0.0001 imply that the model is significant. The “Lack of fit F-value” of 46662.87 for oxalate implies that the “Lack of fit” is not significant relative to the pure error. Significant “Lack of fit” is bad, as the aim is for the model to fit. This model can therefore be used to navigate the design space.

Numerical Optimization of Extrusion Process Parameters for Anti-nutritional factors

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

The optimization results for the goal of maximizing the optimum value for barrel temperature and screw speed for the extrusion process of aerial yam-soybean flour blends showed that the optimum barrel temperature was 112.83°C, while that of screw speed was 127.87rpm. The predicted value for feed moisture was in the range of 31 to 39% at optimal value of 32.59%.

For the responses, the optimization results for the goal of minimizing the optimum value for HCN indicated 1.20mg/100g for HCN. More so, the optimization of the range for phytate, tannin, and oxalate gave a range of 12.48 to 32.86mg/100g, 0.93 to 5.46mg/100g, 45.81 to 102.71mg/100g and 0.79 to 2.19% at optimal values of 32.86mg/100g, 1.16mg/100g, 86.17mg/100g and 1.42% respectively. These values were obtained with a desirability of 0.832

Response surface plots for the anti-nutritional factors of aerial yam-soybean flour blends

The effect of barrel temperature and screw speed; barrel temperature and feed moisture; screw speed and feed moisture on the hydrogencyanide (HCN) contents of the extruded aerial yam-soybean flour blends are shown by the Response surface plot in Fig 5, Fig 6 and Fig 7 respectively.

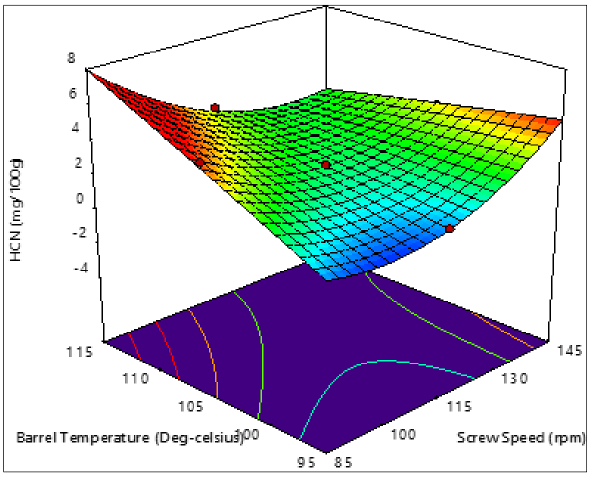

Fig 1: Response surface plots showing the effect of barrel temperature and screw speed on HCN

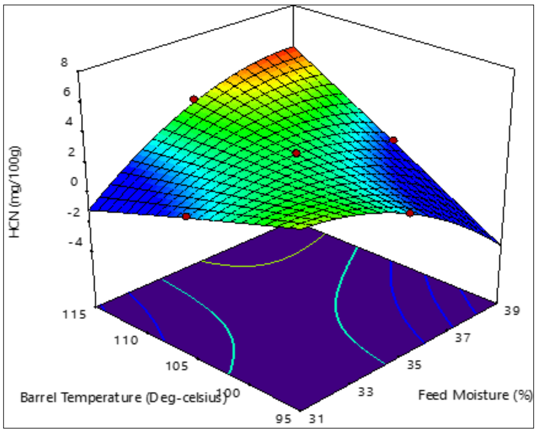

Fig 2: Response surface plots showing the effect of barrel temperature and feed moisture on HCN.

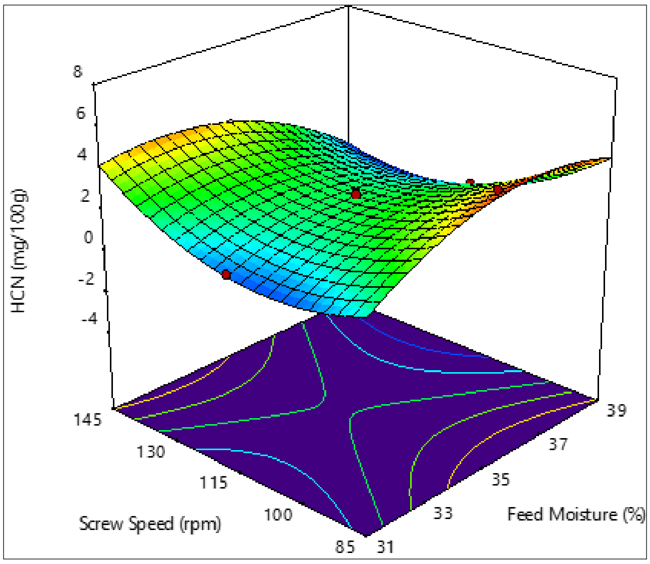

Fig 3: Response surface plot showing the effect of screw speed and feed moisture on HCN

As the barrel temperature increased, the HCN increased sharply. The HCN also increased as the screw speed increased, up to about 115.00rpm, followed by a sharp increase up to 145rpm (Fig 1).

However, the effect of barrel temperature and feed moisture on HCN was observed to be quite different from that of the barrel temperature and screw speed. Although there was an increase in HCN as the barrel temperature increased, it was not significant, while there was decrease in HCN as the feed moisture increases, (Fig 2).

More so, screw speed and feed moisture, as extrusion process parameters had a significant effect on HCN contents of the extrudates. As shown in Fig 3, the HCN content of the extrudates was observed to increase as the screw speed increased, and decreased as the feed moisture increased.

Analysis of Variance for HCN (mg/100g) at 5% significance level, showed that the barrel temperature, screw speed, and feed moisture have statistical significant effect on the HCN contents of the extrudates ($p < 0.05$).

Effect of Extrusion Process Parameters on Phytate

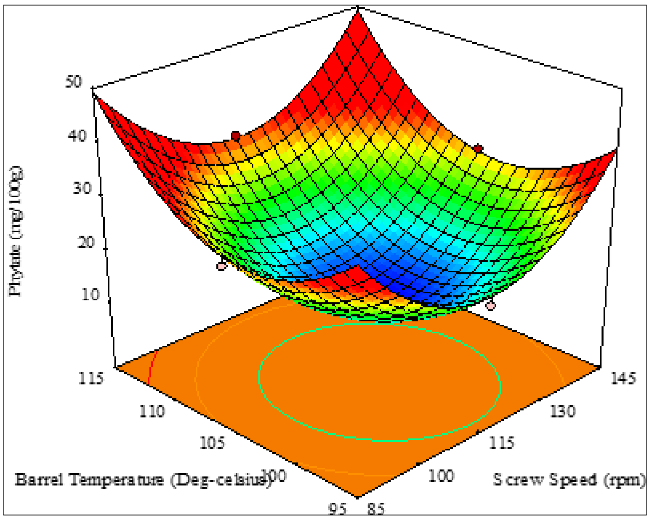

Fig 4: Response surface plots showing the effect of barrel temperature and screw screw speed on Phytate.

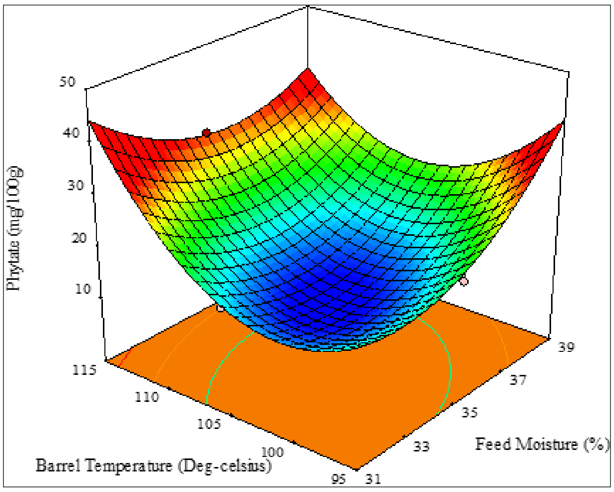

Fig 5: Response surface plot showing the effect of barrel temperature and feed moisture on Phytate

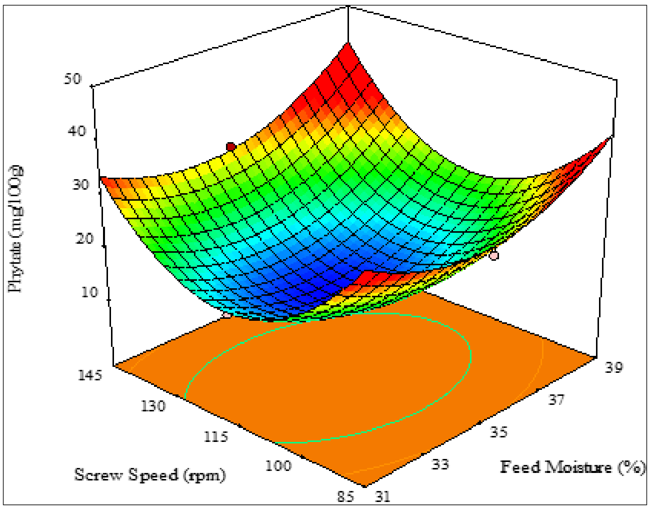

Fig 6: Response surface plot showing the effect of screw speed and feed moisture on Phytate

In Fig. 4, it was observed that increase in both the barrel temperature and screw speed of the extruder resulted in quadratic increase in phytate levels in the extrudates. This observation is in agreement with that of Arun kumar *et al.* (2018).

In Fig 5, the response surface plots for the effect of barrel temperature and feed moisture on phytate, indicated that increase in barrel temperature of the extruder led to quadratic increase in phytate levels in the extrudates. Also, increase in feed moisture resulted in quadratic increase in the phytate levels in the extrudates. This observation is in agreement with the earlier finding of Arun kumar *et al.* (2018). The Response surface plot for the effect of screw speed and feed moisture on phytate is presented in Fig 6. It was observed from the plots that increase in both the screw speed of the extruder and feed moisture resulted in increase in the phytate content of the extrudates.

All the three extrusion process parameters (barrel temperature, screw speed and feed moisture) had significant effect ($p < 0.05$) on the phytates content of the extrudates (Table 3.6).

Effect of Extrusion Process Parameters on Tannin

The effects of extrusion process parameters on tannin are shown by the Response surface plots in Fig. 7 to Fig. 9.

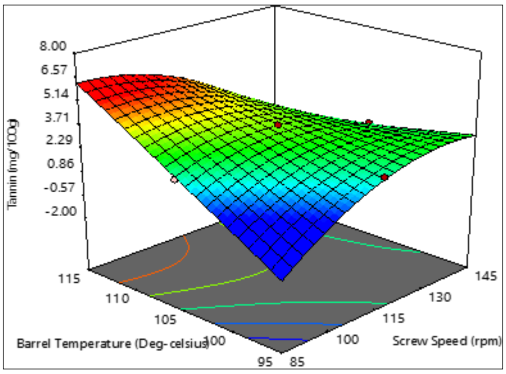

Fig 7: Response surface plot showing the effect of barrel temperature and screw speed on Tannin

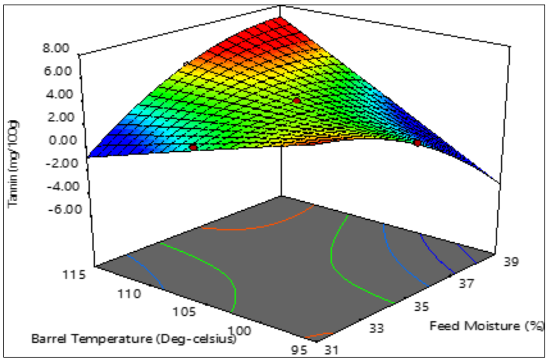

Fig 8: Response surface plot showing the effect of barrel temperature and feed moisture on Tannin

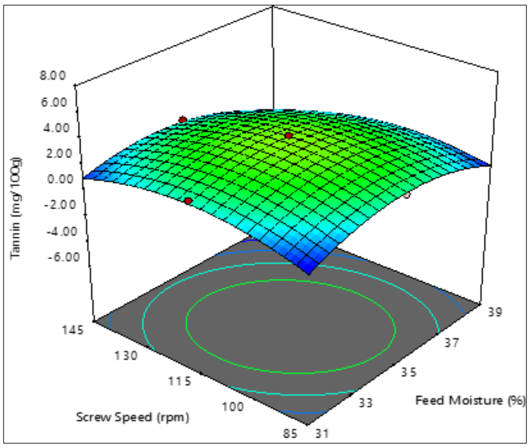

Fig 9: Response surface plots showing the effect of screw speed and feed moisture on Tannin

The generated Response surface plot for the effect of barrel temperature and screw speed on tannin showed that increase in barrel temperature resulted in increased level of tannin, while increase in screw speed up to 115rpm increased the level of tannins initially. Increasing the screw speed beyond 115rpm resulted in decreased tannin contents of the extruded aerial yam-soybean flour blend (Fig. 7).

Increasing the barrel temperature and feed moisture did not result in corresponding increase in tannin contents of the extrudates (Fig. 8). This observation is in agreement with that of Arun kumar *et al.* (2018). Rather, the tannin level was observed to decrease as the feed moisture increased. Increase in barrel temperature showed little or no effect on the tannin level in the extrudates.

From the Response surface plot showing the effect of screw speed and feed moisture on tannin (Fig 9), increase in both screw speed and feed moisture up to 115rpm and 35% respectively, resulted in initial increase in tannin. Further increase in both the screw speed and feed moisture resulted in decreased tannin contents of the extrudates, which is in agreement with the earlier findings of Arun kumar *et al*. (2018); Tabibloghmany *et al*. (2020). Analysis of variance (ANOVA) at 5% significance level, for the effect of extrusion process parameters on tannin showed that all the three extrusion process parameters (barrel temperature, screw speed and feed moisture) showed significant effect ($p < 0.05$) on the tannin levels in the extrudates.

Effect of Extrusion Process Parameters on Oxalate

The effect of extrusion process parameters on oxalate levels in the extruded aerial yam-soybean flour blends are as shown by the Response surface plot in Fig. 10 to Fig. 12.

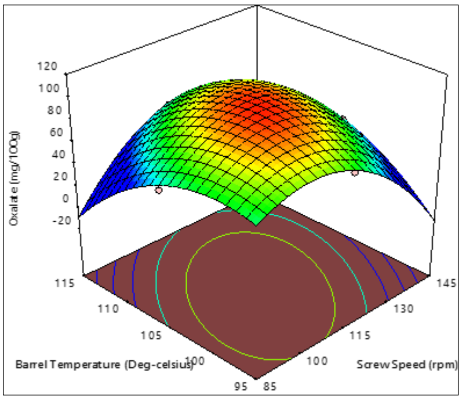

Fig 10: Response surface plot showing the effect of barrel temperature and screw speed on Oxalate

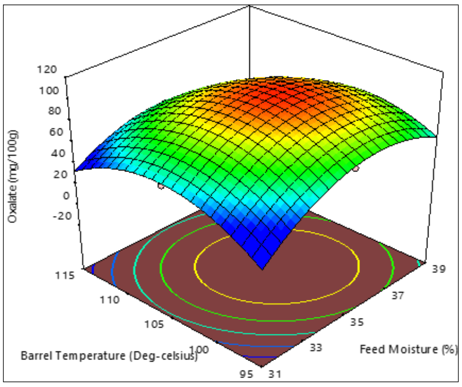

Fig 11: Response surface plot showing the effect of barrel temperature and feed moisture on Oxalate

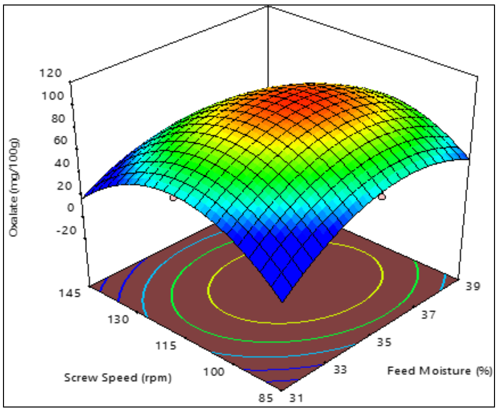

Fig 12: Response surface plot showing the effect of screw speed and feed moisture on Oxalate

Increase in both the barrel temperature and screw speed of the extruder decreased the levels of oxalates in the extrudates (Fig. 10). There was an initial increase in oxalate contents of the extrudates with increase in barrel temperature and feed moisture up to 105°C and 35% respectively. This was followed by a decrease in the levels of oxalates with further increase in both the barrel temperature of the extruder and feed moisture beyond 105°C and 35% respectively (Fig. 11).

The Response surface plot showed that the level of oxalate initially increased with increase in screw speed and feed moisture up to 115rpm and 35% respectively, and then decreased with further increase in both the screw speed of the extruder and feed moisture beyond 115rpm and 35% respectively (Fig. 12).

Analysis of variance showed that all the three extrusion process parameters (barrel temperature, screw speed and feed moisture) showed significant effect ($p < 0.05$) on the oxalate content of the extrudates.

Conclusion

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 parameters in order to produce extrudates with desired quality.

Optimization results based on desirability concept indicate that a barrel temperature of 112.83°C, screw speed of 127.87rpm and feed moisture of 32.59% would produce extrudates of preferable anti-nutritional factors

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