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Effect of Process Parameters on the Proximate Composition, Functional and Sensory Properties

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Abstract**—**Flour from Mucuna beans (Mucuna pruriens) were used in producing texturized meat analogue using a single screw extruder to monitor modifications on the proximate composition and the functional properties at high moisture level. Response surface methodology based on Box Behnken design at three levels of barrel temperature (110, 120, 130ºC), screw speed (100,120,140rpm) and feed moisture (44, 47, 50%) were used in 17 runs. Regression models describing the effect of variables on the product responses were obtained. Descriptive profile analyses and consumer acceptability test were carried out on optimized flavoured extruded meat analogue. Responses were mostly affected by barrel temperature and moisture level and to a lesser extent by screw speed. Optimization results based on desirability concept indicated that a barrel temperature of 120.15°C, feed moisture of 47% and screw speed of 119.19 rpm would produce meat analogue of preferable proximate composition, functional and sensory properties which reveals consumers` likeness for the product.

Keywords**—**Functional properties, mucuna bean flour, optimization, proximate composition, texturized meat analogue.

I. Introduction

LEGUMES are one of the most important sources of proteins, carbohydrates and dietary fiber for human nutrition. Generally, legumes have protein contents between 20% and 40% and a few ranges between 40% and 60% [1], [2]. One of such crops is Mucuna beans (Mucuna spp). The Mucuna bean, commonly called velvet bean, is an annual leguminous climber, with pods that are covered with velvety hairs that irritate the skin when the fruit is mature and dry. The major use for Mucuna, at present, is as a green manure/cover crop for small holder farmers in tropical regions of the world. It has nutritional potential as a rich source of protein (23-35%) [3], [4] and metabolisable energy of about 1 kcal/g for raw seeds and 3.2 kcal/g for processed seeds [5].

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However, the lack of knowledge of the nutritional qualities of lesser-known legumes, such as Mucuna, grown in developing countries is responsible for the poor utilization of these traditional crops in different food formulations. There has been increasing need for less expensive protein and the growing demand for alternatives to meat in recent years due to its scarcity and/or high price.

Meat analogues are blends of various protein sources such as isolates, glutens, and albumin and are also called meat substitute, mock meat, faux meat, imitation meat, or soy meat. These approximate the aesthetic qualities (primarily texture, flavor, and appearance) and/or chemical characteristics of certain types of meat [6].

One way of producing meat-like products is extrusion cooking of plant material to texturised fibrous meat substitutes.

Extrusion cooking is an important and popular food processing technique classified as a high temperature/short time (HTST) process to produce fiber-rich product [7]. It is a process in which moistened, expansive, starchy and/or proteinacious food materials are plasticized and cooked in a tube by a combination of moisture, pressure, temperature and mechanical shear, resulting in molecular transformation and chemical reactions [8]. In addition, the extrusion process denatures undesirable enzymes; inactivates some anti nutritional factors (trypsin inhibitors, haemagglutinins, tannins and phytates); sterilises the finished product; and retains natural colours and flavours of foods [9], [10]. The process has found numerous applications, including increasing numbers of ready-to-eat cereals; salty and sweet snacks; co-extruded snacks; indirect expanded products; croutons for soups and salads; an expanding array of dry pet foods and fish foods; textured meat-like materials from defatted high-protein flours; nutritious precooked food mixtures for infant feeding; and confectionery products [11], [12].

Despite the increased use of extrusion processing, 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 [13]. Prevention or reduction of nutrient destruction, together with improvements in starch or protein digestibility, is clearly of importance in most extrusion applications. Nutritional concern about extrusion cooking is reached at its highest level when extrusion is used specifically to produce nutritionally balanced or enriched foods, like weaning foods, dietetic foods, and meat replacers [14], [15].

Lack of sufficient protein in nutrition of large percentage of people of developing countries is becoming a major setback for human development. This is complicated by the continuous rise in population coupled with increasing demand for plant protein as a substitute for scarce and expensive animal protein. Against this background, there have been intensive research efforts aimed at finding alternative sources of protein from underutilized legume seeds in order to meet the protein demands in developing-countries [16]. Despite the vast literature on texturization of vegetable proteins in general and soya in particular, very scarce information is available on optimization of the proximate composition and functional properties during extrusion of Mucuna bean flour (MBF) into meat analogues. Therefore, the objectives of this study were to study the effect of extrusion process variables on the proximate composition and functional properties of extruded meat analogue from mucuna bean flour (MBF), to determine the optimized extrusion parameters and also to evaluate the consumer acceptability of the meat analogue.

II. Material and Methods

A. Sample Preparation Protocol

Seeds of Mucuna pruriens were obtained from the International Institute of Tropical Agriculture/International Livestock Research Institute IITA/ILRI, Ibadan, Nigeria. The seeds were cleaned, dehulled manually using pestle and mortal, ground in Christy Laboratory Mill (Cheff Food Processor, Japan) and thereafter sieved through a screen of 20 mesh sizes. Proximate composition of MBF was carried out while flours for processing were then kept in air-tight plastic containers at 30±2^{o}C prior to use. Mucuna paste was prepared ensuring three different levels of water, 44, 47 and 50% (w.b.) based on the process design. The amount of water added depended on the initial water content of the dry Mucuna flour and was adjusted to ensure that all the paste contained the specified amount. To do this, the exact water content of the flour was determined experimentally by drying in a forced air oven at 105oC for 24hrs (to constant mass). To form the paste, distilled water was added to the specific dry flour until it reached 44, 47 or 50% water content (w.b.). Half of the water was added at 28^{o}C while mixing for 2 min using a mixer. After mixing for 3 min, the rest of the water was added. This fraction of water was heated at 100^{o}C, and was poured while mixing for 2 min. The paste was them allowed to stay for about 1 hour before being fed into the extruder.

1. Extrusion Cooking

A laboratory scale single screw extruder with screw length per diameter (L/D), screw diameter and length of 16.43:1, 18.5 mm and 304 mm as earlier described by [17] was used for this work. The extruder has a power of 0.25hp and composed of two sections, transmission and die zone. The barrel section was heated with band heater. It was operated at full speed in all runs under the following conditions: barrel and die temperature (110, 120 and 130^{o}C), screw speed (100, 120 and 140 rev/min) and feed moisture content (44, 47 and 50%). During extrusion, the barrel temperature and screw speed were recorded when stable. A rod die (12-mm diameter) and 5-mm nozzle was used to extrude the Mucuna paste samples fed manually through a standard bin feed hopper. Mucuna bean flour paste was prepared by adding known amount of distilled water and fed into the single screw extruder. Extruded samples were cut immediately as they exit the die, allowed to cool and then packaged in polyethylene bags prior to analysis.

B. Sample Analysis

1. Proximate Composition

Proximate compositions namely crude protein, available carbohydrate, fat, moisture content, crude fiber and ash content of the Mucuna bean flour and its meat analogue samples were determined using standard methods described by [18]. The pH determination was done using Kent pH meter (Model 7020, Kent Ind. Measurement Ltd, Surreyl) with a glass electrode as described by [19].

2. Functional Properties

Lateral Expansion (LE) Determination

Sectional expansion, the ratio of diameter of extrudate and the diameter of die was used to express the expansion of extrudate [20]. Six replicates of extrudate were selected at random and the average taken.

$$LE = \text{Diameter of extrudate}/\text{Diameter of hole} \qquad (1)$$

Bulk Density

Each of the samples was weighed using a laboratory balance. The length and diameter of the sample was measured using a digital vernier caliper. The bulk density of the extrudate was calculated as shown below [21].

$$\text{Bulk density} = 4m/\pi d2L \qquad (2)$$

where m is mass (g), d is diameter (cm) and L= length (cm) of the extrudate.

Water Absorption Index (WAI)

This was determined using the method of Anderson [22]. A suspension of 2.5 g of ground extrudate sample (100 mesh) was prepared in 30 mL distilled water at room temperature for 30 min by gently stirring during this period, and then centrifuged at 3,000 rpm for 15 min. The supernatant was decanted carefully into an evaporating dish of known weight. The evaporating dish containing the supernatant was placed on the plate until all the water has evaporated. WAI was calculated as gel weight of the original dried solids.

Oil Absorption Index (OAI)

Same method of [22] was used with the replacement of distilled water with groundnut oil.

Swelling Power

One gram of sample was weighed into a 50 ml plastic centrifuge tube. Then 50 ml of distilled water was added meat analogue granule and mixed gently. The slurry was heated in a water bath at 60,70,80,90 and 100°C respectively for 10 min. The solution was shaken gently during heating to prevent clumping of the starch and the solution was centrifuged at 3,000 rpm for 10 min using SPECTRA, UK (Merlin 503) centrifuge. The supernatant was decanted and dried to determine the amount of soluble solid, and was used to calculate solubility index. The weight of the sediment was recorded and moisture content of the sediment gel was determined [23].

3. Descriptive Profile and Consumer Acceptability Test

Descriptive Analysis (DA) was performed to determine the attributes that best describe the meat analogue from mucuna bean flour. A panel of ten judges was trained by exposure to different threshold of taste in terms of saltiness, bitterness and sweetness, on a concentration of 0.75% sodium chloride solution, 4% sucrose solution and 0.02% caffeine solution, respectively. They were also trained for textural properties of meat analogue using soy meat analogue for two days before the actual experiment. Thereafter, consumer acceptability test was carried out on the samples which were presented to 50 panelists consisting mainly of students and staff of the University to evaluate their degree of likeness or dislike for the meat analogue samples in terms of colour, texture and flavor, using a 9-point Hedonic scale (1 = dislike extremely, 5 = neither like nor dislike and 9 = like extremely) [24].

4. Experimental Design and Statistical Analysis

A three factor experimental set up was used with barrel temperature (X_1), screw speed (X_2) and moisture levels (X_3) as the independent factors at three levels each. The data obtained was analyzed by response surface methodology (RSM) based on Box Behnken design (Table 1) to optimize process variables. Seventeen combinations including five replicates of the centre point was performed in random order according to the design. A second order polynomial model for the dependent variables as shown in Eq. (4) was established to fit the experimental data.

TABLE I
CODED AND UNCODED LEVELS FOR THE RESPONSE SURFACE DESIGN

Variables	Levels -1	0	+1
Screw speed (rpm, X_1)	100	120	140
Temperature (°C, X_2)	110	120	130
Moisture level (%, X_3)	44	47	50

An ANOVA test was carried out using design expert version 8.0.4 to determine level of significance at 5% level.

5. Optimization Procedures

Numerical and graphical optimization procedures were applied to determine the optimum level of the three independent variables (barrel temperature, screw speed and feed moisture levels) investigated in this work using design expert version 8.0.4. Based on desirability concept whose value must be close to 1, process conditions were varied to obtain meat analogue with the maximum lateral expansion, WAI, OAI, swelling power, highest level of protein, appreciable level of carbohydrate, crude fibre and ash content as well as minimum bulk density. However, the lowest level possible of fat and moisture content is expected for increased shelf stability. A meat analogue is expected to supply almost similar level of nutrient obtainable from traditional animal meat sources.

III. RESULT AND DISCUSSION

Proximate composition result of the mucuna bean flour is as shown in Table II. This result was observed to be similar with the findings of [25] and [26]. The crude protein content, with the mean value of 31.29%, makes this variety of mucuna beans superior to cowpea (23.7%), groundnut (24.7%) and pigeon pea (26.3%) but inferior to soybeans (38.7%) [27]. MBF therefore shows potential as a protein supplement for low-protein foods and feeds such as cereal grains, a view also held by [26]. The moisture content of the flour (9.68%) is low enough to prolong its shelf-life. In dry food system, moisture content of between 6-10% has been established to prolong the shelf-life of foods, beyond which the storability of the system could be impeded by chemical and microbiological agents [28]. The low fat content observed in this legume allows it to be suitable for use in low cholesterol food formulations while the fairly low crude fiber content of the flour is an advantage in terms of digestibility.

TABLE II
PROXIMATE COMPOSITION OF MUCUNA BEAN FLOUR

Parameters	Flour
Moisture (%)	9.68±0.10
Crude Protein (%)	31.29±0.39
Carbohydrate(%)*	50.22±0.07
Ash (%)	3.25±0.00
Crude Fibre (%)	1.98±0.00
Fat	3.58±0.40
pH	6.25±0.71

Values are means of duplicate standard deviation
* Obtained by difference

A. Proximate Composition of Extrudates

Table III shows results of the proximate composition of the different meat analogue samples from different process combinations. The regression coefficients of the proximate composition of the extrudate are as shown in Table IV while Figs. 1 - 6 are the response surface plots for the proximate responses. The determination coefficient (R_2 value) of each response provided a measure of how much of the variability in the observed response values could be explained by the data and the RSM models: when R_2 approaches 1, the empirical model appropriately fits the actual data. The low value of R_2 shows that a high proportion of the observed variability is not explained by the models [29].

Every animal, including humans, must have an adequate source of protein in order to grow or maintain itself. Proteins are a group of highly complex organic compounds that are made up of a sequence of amino acids. The protein content measured for all possible runs of the extrudates ranged from 20.11-27.88%. The result of the statistical analysis of the proximate composition of the extruded meat analogue from the coefficient regression table (Table IV) revealed the effect of the independent variables on the extruded meat analogue. From the table, all the three variables were observed to have significant ($p<0.05$) effect on protein content. Response surface plot in Fig. 1 shows that there was a remarkable decrease in the protein content of the meat analogue samples as the barrel temperature increases but an increase was observed as the feed moisture and screw speed increases. The decrease in the protein content could be as a result of denaturation of the protein due to high thermal energy in which the feed was subjected to during extrusion cooking. The thermo-mechanical action during extrusion brings about gelatinization of starch, denaturation of protein and inactivation of enzymes, microbes and anti-nutritional factors [30]. As the amount of heat treatment during extrusion increases, more protein in the extrudates are denatured resulting in decrease in both the Protein dispersibility index (PDI) and Nitrogen solubility index (NSI) [31].

Also, the low residence time of the feed in the extruder due to increased screw speed resulted in an increase in the protein content. The higher the residence time (low screw speed), the more thermal energy absorbed by the feed which will cause a subsequent decrease of protein. [32] and [17] reported an increase in protein digestibility as screw speed increases during the extrusion of corn-gluten and yam starch-based pasta, respectively, because the increase in shear forces in the extruder denatures the proteins more easily, thus facilitating enzyme hydrolysis. The R_2 value is always between 0 and 1, and a value > 0.75 indicates aptness of the model [33]. For the model equation for protein content, R2 for the model equation was calculated to be 95.30% (Table IV), showing that the regression model was very suitable for describing protein under varying conditions of barrel temperature, screw speed and feed moisture within the limits of the experimental range investigated.

TABLE III
RESPONSE SURFACE ANALYSIS RESULT OF THE PROXIMATE COMPOSITION OF EXTRUDED MEAT ANALOGUE FOR THE EXPERIMENTAL RUNS

X_1	X_2	X_3	Protein	CHO	Fat	M/C	Crude fibre	Ash
100	110	47	26.15	55.573.43		11.83	1.26	4.95
100	120	44	24.41	62.663.19		6.53	1.16	3.82
100	120	50	27.93	53.6	3.18	10.15	1.19	3.93
100	130	47	20.11	60.4	5.1	9.11	1.28	3.88
120	110	44	22.4	59.495.05		8.84	1.2	4.02
120	110	50	27.45	51.023.04		13.23	1.04	4.22
120	120	47	24.02	54.444.59		11.84	1.21	3.9
120	130	50	23.46	55.655.51		10.32	1.25	3.81
120	130	44	20.54	62.984.23		7.14	1.18	3.93
120	120	47	24.38	54.513.13		11.97	1.26	4.05
120	120	47	24.39	56.934.45		9.09	1.22	3.92
120	120	47	23.5	54.644.5		11.83	0.99	4.04
120	120	47	24.38	53.065.32		11.93	1.2	4.21
140	110	47	25.53	57.154.36		7.97	1.04	3.95
140	120	44	27.88	59.041.24		6.59	1.05	4.2
140	120	50	26.99	55.45	3.43	8.83	1.2	4.1
140	130	47	22.2	60.67	4.17	7.95	0.98	4.03

X_1- Screw speed, X_2- Barrel temperature, X_3- Feed moisture content, CHO-Carbohydrate, M/C- Moisture Content
Values reported are means of duplicate

Carbohydrates range from simple sugars to more complex molecules, like starch and non starchy materials. The carbohydrate level of the meat analogue samples ranged between 50.49-66.93% which indicates an increase compared to that of the flour which could be attributed to modifications. From the regression table, screw speed was observed to have a significant ($p<0.05$) effect on carbohydrate. The response surface plot (Fig 2) shows that carbohydrate content increases as both barrel temperature and screw speed increase but decreases as moisture increases. These increase in carbohydrate content when screw speed increases can be attributed to the effect of intense mechanical shearing during the extrusion processes.

TABLE IV
THE COEFFICIENT OF REGRESSION OF EQUATION (1) WITH RESPECT TO PROCESS VARIABLES FOR THE PROXIMATE COMPOSITION OF THE MEAT ANALOGUE

Coefficients	Protein	CHO	Fat	M/C	Crude fiber	Ash
Xo	24.15	4	1.17	11.33	4.62	54.72
X_1	0.94*	0.14*	-0.09	-0.79	-0.21	0.01
X_2	-1.56*	0.005	0.031	-0.92	0.39	3.18*
X_3	1.67*	0.011	0.011	1.68*	0.18	-2.4*
X_1X_2	0.24	-0.075	-0.05	0.68	-0.47	-0.33
X_2X_3	-1.55*	-0.05	0.03	-0.34	0.55	1.37
X_1X_3	-0.78	-0.08	0.058	-0.3	0.82*	-1.96
X_{12}	1.03*	-0.07	-0.01	-1.99*	-1.02*	3.19*
X_{22}	-2.12*	-0.091	-0.01	-0.13	0.67	0.53
X_{32}	1.18*	0.082	0.01	-1.32*	-0.84*	-0.23
R_2	0.953	0.663	0.537	0.876	0.846	0.894
F-value	15.3	1.53	0.9	5.48	4.28	6.53
P-value	0.001	0.294	0.567	0.018	0.034	0.011

*Significant value at 5% level
X_1- Screw speed, X_2- Barrel temperature, X_3- Feed moisture
CHO-Carbohydrate, M/C- Moisture Content

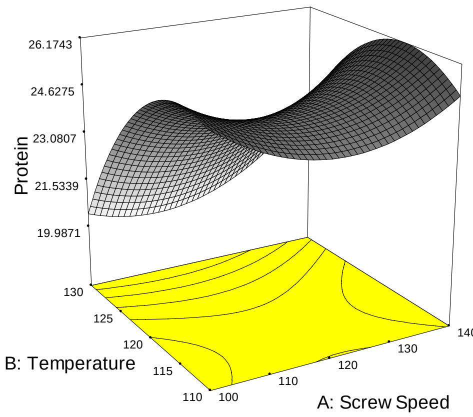

Fig. 1 Response surface plot of protein content (%) of the extruded meat analogue from mucuna bean flour as a function of screw speed and temperature at constant moisture content (47%)

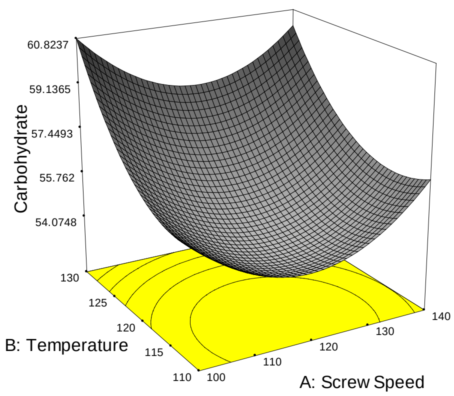

Fig. 2 Response surface plot of carbohydrate content (%) of the extruded meat analogue from mucuna bean flour as a function of screw speed and temperature at constant moisture content (47%)

Mechanical shearing can bring about mechanical breakage of bonds holding down some carbohydrate materials within the matrix. As this shearing intensifies coupled with a higher temperature, some hitherto unavailable carbohydrate materials are released into the matrix. The model equation developed in predicting product carbohydrate could explain about 66.30% of the variations and a non-significant lack of fit of 1.53 (Table IV).

Fat provides lubrication effect in the compressed polymer mix as well as modifies the eating quality of extrudates [34]. The fat content of the extruded meat analogues ranges between 1.24-5.10%. None of the process variables was observed to have any significant ($p<0.05$) effect on the fat content from the regression analysis table (Table IV). However, an increase in fat content of some of the extruded meat analogue was observed as the barrel temperature increases as shown on the response surface plot (Fig. 3). This increase could be as a result of the gelatinization of the starch granules of the feed in the course of extrusion cooking which exposed the internal matrix to thermal energy thus melting the fat. The melting of the fat consequently increases its level in the final product. Fat content of the meat analogue reduces as screw speed increases. This could be as a result of short residence time of the feed in the extruder which consequently reduced the rate of exposure of the dough to thermal energy responsible for the melting of fat. The R_2 value for fat (53.70%) was low, showing that a high proportion of variability was not explained by the model. Asp and Bjorck (1989) stated that high temperature (>200^{o}C) and screw speed (>300 rpm) during extrusion can cause lipids degradation. Also fatty acids in the material can form complexes with amylose making it more difficult to extract crude fat for quantification. However, the temperature (110-130^{o}C) and screw speed (100-140 rpm) used in this work were far below these levels and probably may be responsible for the no significant effect on the fat content.

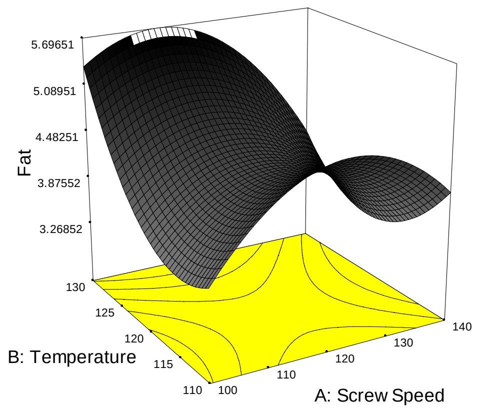

Fig. 3 Response surface plot of fat content (%) of the extruded meat analogue from mucuna bean flour as a function of screw speed and temperature at constant moisture content (47%)

Moisture content of samples is presumed as one of the most important determination of shelf stability. Values between 6.53-11.93% were observed for the extruded meat analogue samples. This is within a range that could prevent microbial activity that enhances spoilage and also ensure shelf stability of the extrudates. High moisture products usually have shorter shelf life stability compared to lower moisture products [35]. From Fig. 4, the feed moisture content decreases as barrel temperature and screw speed increase but increases expectedly as feed moisture increases. Extrusion cooking aided by high temperature and screw speed induces structural changes in food proteins in the form of shrinkage that causes a pressure-driven flow of water out of the extrudates which resulted in a reduction in water holding capacity. Feed moisture content was observed to significantly ($p<0.05$) affect the final moisture content of the extrudates. This is similar to the findings of [36], despite the fortification with legumes; and also to the findings of [17]. The model developed in predicting product moisture could explain 87.6% of the variation and a lack of fit value of 5.48 (Table IV).

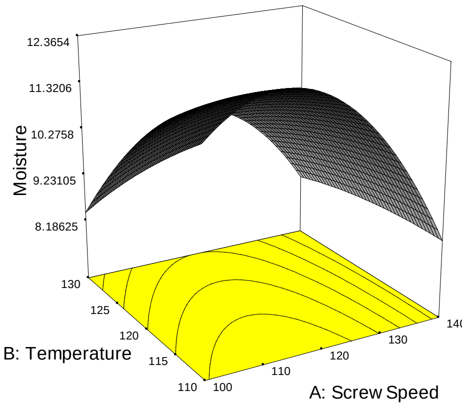

Fig. 4 Response surface plot of moisture content (%) of the extruded meat analogue from mucuna bean flour as a function of screw speed and temperature at constant moisture content (47%)

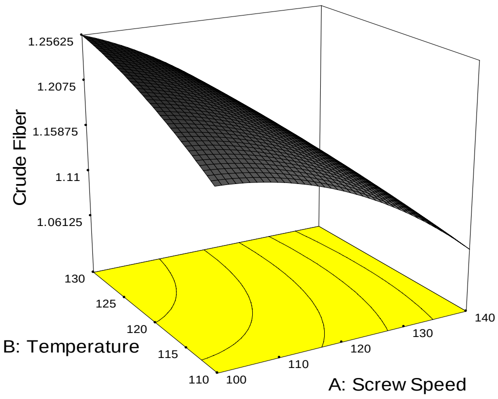

Fig. 5 Response surface plot of crude fibre content (%) of the extruded meat analogue from mucuna bean flour as a function of screw speed and temperature at constant moisture content (47%)

Crude fiber content of the extrudates was equally observed to increase as temperature increases but decreases as screw speed increases. A change in fiber content of extruded products has been reported to be insignificant when carried out at mild extrusion conditions but at severe conditions, major changes can be observed [37]. However, the changes observed in this work can be attributed to alterations in fibers structures where there might be a shift in form from insoluble dietary fibers to soluble dietary fibers, and the formations of resistant starch and enzyme-resistant indigestible glucans formed by transglycosidation. [38] also mentioned that insoluble and soluble fibers are redistributed after extrusion, producing thermomechanical transformation that will not appear in a proximal determination of crude fiber due to the techniques low sensitivity. The crude fiber content of the meat analogues was significantly affected by screw speed and moisture content of the feed. The regression models developed to predict the crude fiber content explained 84.6% of the variations and a lack of fit of 4.28.

Ash gives an indication of inorganic elements that are present in a food as minerals. The original ash content of the flour was 3.25% but after extrusion cooking, it increased to between 3.81-4.95%. The increase in ash content of the extrudates was similar to the findings of [36], although, in their study, fortification of cereals with legumes (groundnut and cowpea) caused the increased ash content of the extrudates. The value (89.4%) observed for ash content of the extrudates showed that the regression model was very suitable for describing the effect of the independent variables on the ash content of the extrudates. The ash content is significantly ($P<0.05$) affected by barrel temperature, moisture content and screw speed. Higher extrusion temperature might have favoured ash content while its increase due to increase in moisture content and screw speed may be attributed to the addition of these minerals through process water during extrusion and also from the extruder barrel [39].

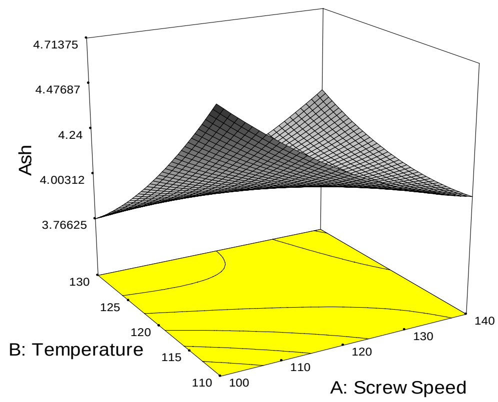

Fig. 6 Response surface plot of ash content (%) of the extruded meat analogue from mucuna bean flour as a function of screw speed and temperature at constant moisture content (47%)

B. Functional Properties of Extrudates

Table V displays the response surface result of the functional properties of the meat analogue samples from different process combination. The lateral expansion (Y_1), bulk density (Y_2), water absorption index (Y_3), oil absorption index (Y_4) and swelling power (Y_5) of the extruded meat analogue ranged between 0.084 and 0.139, 0.832 and 0.988, 1.677and 2.320, 1.761 and 2.389; and 0.740 and 3.470, respectively. The statistical results of the response data obtained using multiple linear regression equation (Equation 1) are displayed in Table VI and varied between 0.658 and 0.894, with Y_3 having the highest value and Y_2 with the lowest.

TABLE V
RESPONSE SURFACE ANALYSIS RESULT OF THE FUNCTIONAL PROPERTIES OF EXTRUDED MEAT ANALOGUE FOR THE EXPERIMENTAL RUNS

X1	X2	X3	Y1	Y2	Y3	Y4	Y5
100	110	47	0.092	0.821	2.09	2.31	2.27
100	120	44	0.13	0.931	2.15	1.98	1.28
100	120	50	0.125	0.909	2.32	2.25	0.81
100	130	47	0.127	0.832	1.99	2.09	1.47
120	110	44	0.089	0.922	2.1	1.89	1.31
120	110	50	0.084	0.982	2.15	2.35	1.68
120	120	47	0.116	0.941	2.2	1.89	0.78
120	130	50	0.105	0.914	1.94	2.1	3.47
120	130	44	0.116	0.918	1.84	2.39	1.02
120	120	47	0.127	0.961	2.06	1.99	1.01
120	120	47	0.094	0.85	1.93	2.12	1.81
120	120	47	0.094	0.902	2.10	1.8	0.96
120	120	47	0.116	0.914	2.06	1.83	0.89
140	110	47	0.099	0.87	1.74	1.76	0.94
140	120	44	0.139	0.916	1.86	1.85	0.82
140	120	50	0.094	0.988	1.78	1.96	1.01
140	130	47	0.118	0.964	1.68	1.91	1.03

X_1- Screw speed, X_2- Barrel temperature, and X_3- Feed moisture
Y_1- Lateral expansion, Y_2- Bulk density, Y_3- Water absorption capacity, Y_4- Oil absorption capacity and Y_5- Swelling power

Product expansion ratio, an index of degree of puffing, is one of the important physical characteristics of extrudate. Barrel temperature had a significant ($p<0.05$) effect on the lateral expansion of the meat analogue (Table VI).

TABLE VI
THE COEFFICIENTS OF REGRESSION OF EQUATION (1) WITH RESPECT TO PROCESS VARIABLES FOR THE FUNCTIONAL PROPERTIES OF THE MEAT ANALOGUE

Coefficients	LE	BD	W.A.I	O.A.I	SP
X_o	0.11	0.91	2.07	1.92	0.97
X_1	0.003	0.031	0.19*	-0.14*	-0.25
X_2	0.013*	0.004	-0.078*	0.022	0.099
X_3	-0.008	0.013	0.031	0.07	0.32
X_1X_2	-0.004	0.021	0.008	0.093	0.22
X_1X_3	-0.01	0.023	-0.062	-0.038	0.17
X_2X_3	-0.002	-0.016	0.011	-0.19	0.52
X_{12}	0.012	-0.02	-0.086	-0.04	-0.21
X_{22}	-0.012	-0.022	-0.11*	0.13	0.68*
X_{32}	0.001	0.042	0.047	0.12	0.23
R_2	0.766	0.658	0.894	0.846	0.7
F-value	2.54	1.5	6.57	4.29	1.81
P-value	0.116	0.304	0.011	0.034	0.222

*Significant values at 5% level
X_1- Screw speed, X_2- Barrel temperature, X_3- Feed moisture, LE- Lateral expansion, BD- Bulk density, W.A.I- Water absorption index, S.P- Swelling power, O.A.I- Oil absorption index

From the response surface graph (Fig. 7), there was an appreciable increase in lateral expansion as barrel temperature increases while increase in screw speed did not give a remarkable increase at constant moisture content (47%). From the response surface plot, the highest and lowest values of Y1 were observed to be 0.122 and 0.092, respectively. According to [40], high input of thermal energy due to high residence time leads to the creation of enhanced level of superheated steam; hence the product will have good expansion which creates flashy and porous structures due to formation of air

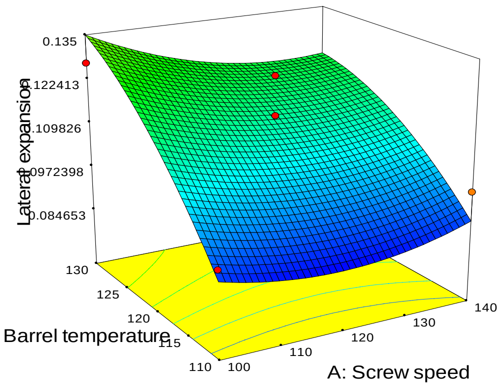

Fig. 7 Response surface plot of lateral expansion of the extruded meat analogue from mucuna bean flour as a function of screw speed and temperature at constant moisture content (47%)

cells. When extrusion cooked melt exits the die, they suddenly go from high pressure to atmospheric pressure. This pressure drop causes a flash-off of internal moisture and the water vapour pressure, which is nucleated to form bubbles in the molten extrudate, allows the expansion of the melt [41].

The goodness of fit of the mathematical model was checked by the determination coefficient (R2). In this case, the value of the R2 (76.6%) for Eq. (1) indicated that the sample variation of 76.6% for lateral expansion was attributed to the independent variables and that 23.4% of the total variation could not be explained by the model.

Bulk density considers expansion of extrudate in all direction. In this study, none of the process independent variables had any significant ($p<0.05$) effect on the bulk density. It was observed that an increase in screw speed resulted in an extrudate with higher density while an increase in barrel temperature gave an extrudate of lower density. According to [42], an increase in the barrel temperature will increase the degree of superheating of water in the extruder encouraging bubble formation and also a decrease in melt viscosity, leading to reduced density, which was observed in this work. Temperature and feed moisture have been found to be the main factors affecting extrudate density and lateral expansion [43]. The effects of temperature and screw speed were found to be dependent on each other. The increase in bulk density as screw speed increases might be due to intensified effect of temperature on extrudate melt under increased shear environment (high screw speed) which may increase the extent of gelatinization process and so gave higher extrudate which is in agreement with the report of [44].

The model showed that it had the lowest coefficient of determination (R^2= 0.658), which means that a high proportion of the variability was not explained by the model with a nonsignificant lack of fit value of 2.54.

WAI has been generally attributed to the dispersion of starch in excess water, and the dispersion is increased by the degree of starch damage due to gelatinization and extrusion induced fragmentation, it measures the degree of volume occupied by the starch granule after swelling in excess water

[45]. Gelatinization, the conversion of raw starch to a cooked and digestible material by the application of water and heat, is one of the important effects that extrusion has on the starch components of foods [46]. WAI of extrudate, which relate to product juiciness or moistness upon hydration, decreases with increase in temperature and screw speed at constant moisture content (Fig. 9). These factors exerted a significant negative effect on water absorption index (Table VI). So many studies have shown that WAI increases at a higher extrusion temperature whereas it decreases with increasing screw speed. This statement correlate with the findings of [47] and [22] on cereals, but it is however contrary to the findings of this study. It is possible however in this study that WAI decreases with increase in temperature if dextrinization or starch melting prevails over the gelatinization phenomenon [46]. A decrease in WAI with increasing temperature was probably due to decomposition or degradation of starch [48]. In this study the effect of processing variables on water absorption index, presented in Table VI, shows that the coefficient of determination for the model equation was calculated to be 89.4%, which means that the R_2 value was considered sufficiently accurate for prediction purposes.

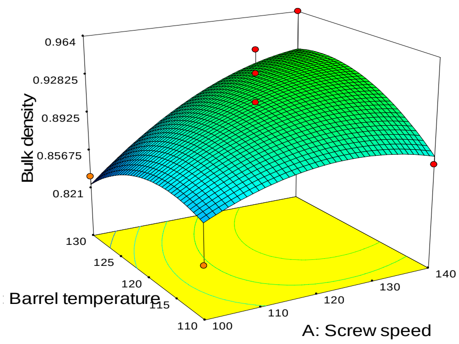

Fig. 8 Response surface plot of bulk density of the extruded meat analogue from mucuna bean flour as a function of screw speed and temperature at constant moisture content (47%)

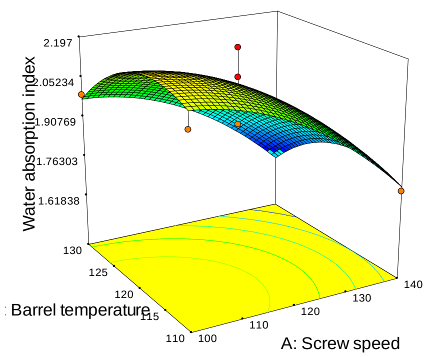

Fig. 9 Response surface plot of water absorption index of the extruded meat analogue from mucuna bean flour as a function of screw speed and temperature at constant moisture content (47%)

Oil absorption index is the ability of a product to entrap oil and this is known to improve flavor and increase mouth feel of a food material [49]. In this study, Oil absorption index of the extrudates increases with increase in barrel temperature and decreases with increase in screw speed. The increase in oil absorption might be due to high level of starch degradation in the extrudate as a result of high input of thermal energy. Increase in the oil absorption of the extrudates could be of advantage if the product is to be used in the preparation of soup or sauce. Meat analogue is expected to imitate meat from animal protein source in its functional characteristics. The quadratic model developed for Oil absorption index can explain 84.6% of the variation in the data with a non-significant lack of fit of 4.29.

Swelling power is the ability of the starch in the meat analogue to absorb water such that the starch granules increase in size, which indicates the degree of exposure of the internal structure/matrix of the granules to action of water [50]. From the response surface plot (Fig. 11), swelling power capacity of the extrudates increases with increase in barrel temperature and decreases with increase in screw speed. From Table VI, the coefficient of determination R_2 for the model equation was calculated to be 70%, which means that the R_2 value was considered sufficiently accurate for prediction purposes.

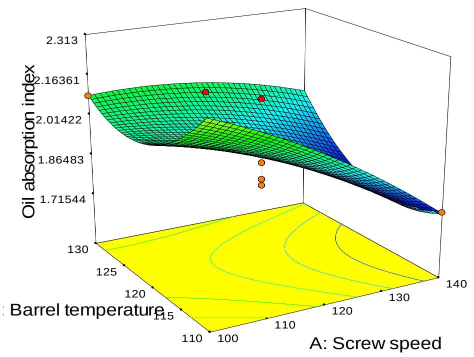

Fig. 10 Response surface plot of oil absorption index of the extruded meat analogue from mucuna bean flour as a function of screw speed and temperature at constant moisture content (47%)

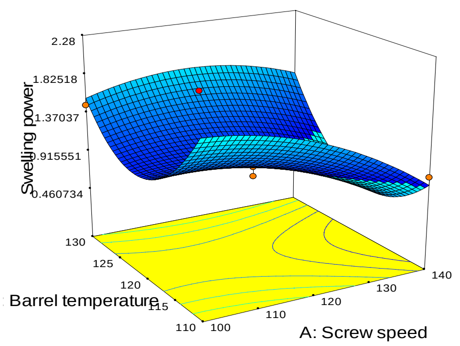

Fig. 11 Response surface plot of swelling power of the extruded meat analogue from mucuna bean flour as a function of screw speed and temperature at constant moisture content (47%)

C. Quantitative Descriptive Analysis (QDA) and Consumer Acceptability of Optimized Mucuna Meat Analogue

Quantitative descriptive analysis (QDA) provides a means to know how a product compares to other competitive product in terms of flavour, appearance and or texture characteristics [51]. Amongst all the sensory attributes investigated, hardness, texture and fibrousness were described high with mean values of 8.16, 7.69 and 7.48, respectively. The extrudates juiciness also has a fairly high value (6.85) while other attributes such as colour (4.51), firmness (4.69), meatiness (4.18), chewiness (3.56) and saltiness (3.54) were described with low intensities as shown in Fig. 12.

The mean scores for the acceptability test of the extrudates as shown in Fig. 13 revealed that the panelist preferred the saltiness (2.77), colour (2.98) and juiciness (3.13) of the product as the values fall within the like region compared to other attributes such as chewiness (3.78) and meatiness (3.81) which were moderately liked. The panelist rated hardness (6.89) and texture (6.99) high, indicating their dislike for the hard texture of the product. Previous studies on similar product reported that both moisture and barrel temperature were significant factors affecting the texture of soya protein meat analogue. These studies showed that a decrease in moisture content causes an increase in hardness of the extrudates [52], [53].

Fig.12 Descriptive profile of the extruded meat analogue from MBF

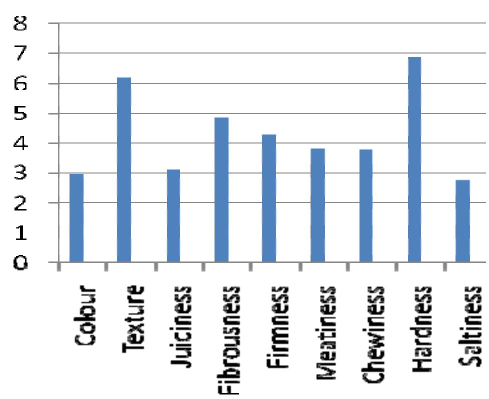

Fig. 13 Bar chart of mean hedonic scores for the sensory acceptability of the meat analogue

IV. Conclusion

Flour from Mucuna bean seeds was used to produce extruded meat analogue at different barrel temperature, screw speed and feed moisture content. Proximate composition of the mucuna bean flour (MBF) revealed that the flour is high in protein content, low in fat, crude fiber and ash content. The proximate and functional properties of the product were mostly affected by barrel temperature and moisture level and to a lesser extent by screw speed. However, the optimization results based on desirability concept indicated that a barrel temperature of 120.15 °C, feed moisture of 47% and screw speed of 119.19 rpm would produce meat analogue of preferable proximate composition and functional properties. This work has shown the potential of Mucuna pruriens in food formulation as well as in the development of acceptable product from neglected agricultural crops.

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