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Mass Flow Rate, Nutrient Composition and some Functional Properties of Single Screw Extruded African breadfruit (*Treculia africana*) Blends

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Abstract: Blends of African breadfruit (*Treculia africana*), defatted soybean and corn were extrusion cooked in a Brabender laboratory single screw extruder (DCE 330, NJ). Effects of extrusion and process variables on extrudate nutrient composition, mass flow rate, expansion ratio and bulk density, were investigated. Extrusion cooking resulted in significant ($p \leq 0.05$) changes in moisture, fat, crude fibre and energy values but not in crude protein and carbohydrate. Mass flow rate ranged from 2.99 kg h^{-1} to 6.72 kg h^{-1} as feed composition shifted from African breadfruit towards soybean. Similar o bservation was made for bulk density from 0.62 g mL^{-1} at the centre point to 0.65 g mL^{-1} at the lower corner point and 0.59g mL^{-1} at the lower star point. A reverse effect of feed composition was observed in product expansion ratio. It ranged from 1.85 at the centre to 1.64 and 2.36 at lower corner and star point formulations, respectively. Regression analysis indicated that screw speed and feed composition were the only process variables showing significant ($p \leq 0.1$) quadratic influence on mass flow rate and expansion ratio respectively. They also showed significant ($p \leq 0.05$) linear and cross product effects on bulk density. All the process variables had significant ($p \leq 0.05$) quadratic effect on bulk density.

Key words: African breadfruit, *Treculia africana,* extrusion, composition, mass flow rate, expansion ratio, bulk density, response surface analysis

INTRODUCTION

A single-screw extruder is an extruder with one screw in the barrel. Originally it was developed for use in the plastics industry, but has been adopted for wide-spread use in the production of diverse food products. A single screw extruder may be regarded as a friction pump. It relies entirely on friction between the material being processed and the barrel wall to convey material[1]. As feed material is introduced into the extruder feed section, the deep flights of the screw with greater than normal pitch convey it down the channel and begin to work it into a dough[2]. As it moves through the transition section, it is partially cooked and elevated in temperature and pressure. When the material extrudes through the final die, the sudden release in pressure causes a large fraction of the super heated vapour to flash off, puffing the dough to expand, come out as product which looks like a continuous cylindrical rod or ribbon that becomes rigid and decreased in size as it cools[3,4].

Extrusion technology is one of the most versatile and energy efficient processes currently contributing solutions to world hunger and nutritional problems[5]. However, the application of the technology to processing of African breadfruit or its blends with soybean and corn has not been reported anywhere in literature despite its world wide acceptability and adaptability to a variety of crops. African breadfruit (*Treculia africana*) constitutes a strategic reserve of essential food nutrients that are available in certain critical periods of the year particularly during planting seasons when the major staples are under cultivation. It is consumed when cooked with ingredients and eaten in form of porridge or as blends with shelled milk-corn during the early seasons of corn production. Ariahu *et al*.[6] had reported a formulation of an acceptable weaning diet from African breadfruit and soybean blends.

Generally, methods of processing African breadfruit are not only labour and cost intensive, they are inefficient. A more efficient processing technology that will rapidly and efficiently transform the breadfruit formulations such as the extrusion cooking is necessary . The non-exploitation of the technology in this regard for the processing of African breadfruit or its blends with other locally sourced ingredients is a serious omission from the stand point of product development effort in Nigeria.

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One of the most important and interesting aspects of product development is the implementation of techniques which minimize cost by reducing the number of experimental formulations required to study a particular product characteristic[7]. The method of response surfaces deals with the problem of seeking the condition of an experiment which are optimal. This can be achieved by using a small number of level combinations. The objective of this research is to adapt the single screw extruder in processing African breadfruit and its blends with corn and soybean, and to evaluate extrudate nutrient composition, mass flow rate, expansion ratio and bulk density using the response surface methodology.

MATERIALS AND METHODS

Raw material source: African breadfruit (*Treculia africana*) was purchased from Mbano, Imo State while yellow corn and soybean were purchased from Yola main market, Adamawa State, Nigeria.

Raw materials preparation: All sample materials were manually cleaned and sorted to remove extraneous materials. African breadfruit seeds were hot water blanched at 100° for 15 min and coarsely cracked in a commercial attrition mill. Cracked seeds were manually dehulled and dried in a Chirana type air convection oven (HS 201 A, Germany) at 60° for 17h. The seeds were later milled in a Brabender roller mill (made in Germany) to pass through a 75µm sieve openings integral to the mill.

The corn was further dry-cleaned in a Vegvari Ferenc aspirator (OB 125 Budapest, Hungary). The seeds were then milled in a Brook Crompton laboratory hammer mill (DN 158 QW, England) before finishing up in the roller mill. The soybeans were soaked in potable water for 18hr at room temperature (30±1°O), dehulled and dried in the oven at 60° for 10h. Dried seeds were milled in the hammer mill and later in the roller mill.

Each flour sample was divided into five portions and thoroughly mixed in a Hobert mixer (A 200. England) in the ratio of 40, 55, 70, 85 and 100 for African breadfruit and 55, 40, 25, 10 and 0 for defatted soybean. The yellow corn flour was included at 5% level in all the level combinations and 0% in the 100% breadfruit flour ratio.

Extrusion cooking: Extrusion runs were carried out in a Brabender single screw laboratory extruder (DCE 330, New Jersey, USA) with a grooved barrel length to diameter ratio (L/D) of 20 :1, compression ratio screw of 4:1, variable speed of 0-200 rpm and die nozzle diameter and length of 2.2 and 40 mm, respectively. Extrusion temperature was set for the feeding, compression, metering and die zones at 120, 150, 170 and 150°C, respectively. Extruder screw speed was adjusted to the desired values of 100, 120, 140, 160 and 180 rpm as the runs progresses to conform with experimental demand. The feed was introduced gradually but continuously into the feed hopper and received at the die end as extrudates.

Preparation of extrudates for analysis: Extrudates obtained were spread on the laboratory table at room temperature for 4 h and later dried in the oven at 60°C for 10 h. Dry extrudates were mechanically milled into flour using the Brabender roller mill. Recovered flour materials were packaged per run in polyethylene bags and stored at room temperature until needed for analysis.

Proximate and energy composition of raw and extruded samples: Proximate composition and energy values of the lower corner and star–points for raw and extruded samples were determined in triplicates for moisture, crude protein (Kjeldal method), fat (Soxhlet method), crude fibre, and ash according to AOAC[8] methods. Total carbohydrate was determined by difference[9]. Energy was calculated using the Atwater factors of 4x protein,
4 x carbohydrate, and 9 x fat [10].

Determination of mineral composition for raw and extruded samples: Macro and micro elements of lower corner–and lower star points for raw and extruded samples were determined in triplicates for sample weights 1µg–1g after wet digesting with concentrated nitric acid and perchloric acid. The macro elements Ca, Fe, Mg, Mn and Zn (microelement) were determined with an atomic absorption spectrophotometer (Perkin Elmer 2380, USA)[11]. Microelements such as K and Na were determined by flame photometric method [12].

A flame photometer (Jenway flame photometer. PFP7) was used to read off absorbance readings at 569 nm and 767 nm for Na and k, respectively. The microelement P was calorimetrically determined using vanadomolybdate (yellow) method and reading off the absorbance values in a Fisher Electrophotometer II at 400 nm.

Determination of mass flow rate (Y_1): Mass flow rate was determined when steady state operation conditions were reached as indicated by constant torque and extrusion temperature[13]. At that time, a timer (stop watch) was started immediately and samples of extrudates flowing out of the extruder die orifice were collected as soon as the timer was started at 30s interval[14]. Mean weight of five such collections was calculated for each run as the mass flow rate for that run in kilogram per hour.

Table 1: Combination matrix of the central composite design using coded independent variable levels

	Coded independent variable levels		
Experimental runs	X_1	X_2	X_3
1	-1	-1	-1
2	-1	-1	-1
3	-1	1	-1
4	-1	1	1
5	1	-1	-1
6	1	-1	1
7	1	1	-1
8	1	1	1
9	1.682	0	0
10	-1.682	0	0
11	0	1.682	0
12	0	1.682	0
13	0	0	1.682
14	0	0	-1.682
15	0	0	0

X_1, = feed composition (%African breadfruit in the blend); X_2 = feed moisture (%); X_3 = screw speed (rpm); -1.682 = lower corner point, -1 = higher corner point, 0 =center point, +1 = lower star point, + 1.682 = higher star point. Both corner and star points are to be performed once while center point is to be replicated 10 times to give a total of 25 runs. Each row states the adjustment levels of the variables at one run.

Determination of extrudate expansion ratio (Y_2): Expansion ratio of partially cool dry extrudates was determined on mean of 10 measurements per sample run with a pair of calipers (Mitutoyo, Japan) accurate to 0.05mm. Expansion ratio was expressed as the ratio of the diameter of the extrudate to that of the die orifice[14]

Determination of bulk density (Y_3) for raw and extruded samples: The bulk density for raw and extruded samples was determined using the method described by Okezie and Bello[15]. A 10 mL graduated cylinder, previously tarred was gently filled with 10 g of each ground sample. The bottom of the cylinder was gently tapped on a laboratory slab 10 times[16]. The process was repeated until there was no further diminution of the sample level after filling to the 10ml mark. Bulk density was calculated as weight of sample per unit volume of sample (g mL^{-1}). Measurements were reported as means of triplicate determinations.

Experimental design and Statistical analysis: A second order central composite design on three independent variables and five level combinations was adopted[17]. The independent process variables included feed composition (X_1) : 40, 55, 70, 85, 100% African breadfruit, feed moisture (X_2) : 15, 18, 21, 24, 27%, and screw speed (X_3) : 100, 120, 140, 160, 180rpm.

The centre point (X_1 = 70%, X_2 = 21%, X_3 = 140 rpm) was replicated ten times while the corner and star points were not bringing the experimental runs to 25 (Table 1). Effects of the process variables were modeled by a second order polynomial. The response surface was fitted into a quadratic polynomial equation for each of the responses represented by using a small number of level combinations (Eq. 1).

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_{11} X_1^2 + \beta_{22} X_2^2 + \beta_{33} X_3^2 + \beta_{12} X_1 X_2 + \beta_{13} X_1 X_3 + \beta_{23} X_2 X_3 + \varepsilon \quad (1)$$

ε=error component, assumed to have a normal distribution with constant variance, and Y = the response function under study. β_s= coefficients which indicate the relative importance of their associated X value.

For each of the level combinations one observes or determines a response. Data on the fitted response surface were statistically analyzed by means of a stepwise multiple regression procedures to give estimates of β_s. Both statistical analysis and the three-dimensional graphs were done with the program statgraphic (Statistic) to visualize the effects of process variables on extrudate responses. Model developed for each index was examined for lack of fit.

RESULTS AND DISCUSSION

Nutrient composition of raw and extruded blends at lower corner-and lower star-points: The nutrient composition of raw and extruded samples as proximate and mineral content is shown in Table 2.

Effect of feed composition on Nutrient composition of Raw of samples: There were marked differences in proximate composition between the blends at the different level combinations. The difference in moisture, fat, ash and crude fibre were not significant ($p > 0.05$) while those in crude protein, carbohydrate and energy were significant ($p \leq 0.05$). It is obvious from literature that differences in level of defatted soy flour inclusion in the blends were responsible for the differences observed in raw samples. Addition of defatted or whole soybean flour to low protein sources have been reported to decrease moisture[17] but increased crude protein[18,19]. Increase in soy flour concentration or decrease in breadfruit concentration in the blend amounted to increase in protein or decrease in carbohydrate which consequently influenced the differences in energy values. The blends at both level combinations generally exhibited good values of macro-and micro-elements. Although soybean is not a major source of minerals[20], its increased addition at the lower corner point showed significantly ($p \leq 0.05$) higher values for potassium and calcium. Lasekan and Akintola[21] reported similar

Table 2: Proximate and mineral composition at Lower corner-and star-points for raw and extruded samples

	Lower corner point blend						Lower star point blend					
	Raw			Extrudate			Raw			Extrudate		
	AB	CN	SB	X_1	X_2	X_3	AB	CN	SB	X_1	X_2	X_3
Proximate composition %	40 %	5 %	55 %	40 %	15 %	100 rpm	85 %	5 %	10 %	85 %	24 %	160 rpm
MC		5.20^{a}			4.60^{b}			6.00^{a}			4.00^{b}	
CP		35.02^{a}			33.28^{a}			19.26^{b}			22.76^{b}	
Fat		13.80^{a}			13.25^{b}			11.45^{ac}			8.55^{d}	
Ash		2.50^{a}			2.50^{a}			2.00^{a}			1.00^{b}	
CF		2.60^{a}			2.80^{b}			3.10^{a}			2.80^{c}	
Carb.		40. 88^{a}			43.07^{a}			58 .19^{b}			59.89^{b}	
EN (Kg g^{-1})		800 .90^{a}			1783.53^{b}			1733.97^{b}			1711.71^{c}	
Macroelements (mg/100g)												
K		1160.0^{a}			846.0^{b}			756.0^{b}			774.0^{b}	
Na		7.0^{a}			9.0^{a}			8.0^{a}			9.5^{a}	
P		120.0^{a}			85.0^{b}			150.0^{c}			85.0^{a}	
Ca		187.50^{a}			87.50^{b}			95.83^{b}			187.50^{a}	
Mg		307.86^{a}			299.49^{b}			309.91^{a}			310.26^{c}	
Microelements (mg $100g^{-1}$)												
Zn		0.484^{a}			0.323^{a}			0.484^{a}			0.484^{a}	
Mn		ND			0.91^{a}			0.45^{b}			ND	
Fe		291.90^{a}			187.65^{b}			312.75^{c}			208.50d	
Y_3		0.60^{a}			0.62^{b}			0.56^{a}			0.61^{b}	

AB =African breadfruit, CN = Corn, SB = soybean, X_1 = feed composition (% African breadfruit in the blend), X_2 =feed moisture, X_3 = screw speed (rpm), Carb= carbohydrate (by difference), EN =energy by Atwater factor, Y_3 = bulk density. Means in the same rows with different superscripts are significantly (p= 0.05) different.

observation in snacks made from soy –maize formulations. Samples from blend at the corner point showed higher bulk density than the corresponding raw blend made from the star point combination. This shows that soy flour addition to the blend influenced the sample density. This agrees with the report of previous researchers using blends involving soy flour[17,18].

Effect of extrusion on nutrient composition: Extrusion of the raw samples showed significant and non significant changes in nutrient composition of extrudates occasioned by the conditions of pressure and temperature in the extruder. Significant ($p \leq 0.05$) changes were observed in both level combinations for moisture, fat, crude fibre and energy content on extrusion of the raw samples. Similar observation on effect of extrusion on proximate composition of blends had been reported[9,19,21,22].

On the other hand changes in crude protein and carbohydrate were non significant ($p > 0.05$). Sotillo and Hettiarachchy[23] analyzed extruded corn meal-sun flower meal blends and reported that crude protein, starch, lipid and ash in raw material and blends were similar to those for extrudates. It was concluded that extrusion had no effect on sample chemical composition. Gujska and Khan[24] made similar observation and reported that total content of nitrogen before and after extrusion did not change.

Extrusion cooking as a heat treatment affects and alters the nature of food constituents such as starches and proteins by changing their physical, chemical and nutritional properties[22].

One remarkable effect of extrusion in this work was on fat due to physical loss as droplets during extrusion which could not be recovered. Similar observation was reported in literature for extrusion of maize and soy mixture[25], soy flour/oil and wheat bran and cassava flour[26]. Several reasons advanced for this observe included formation of complexes[26],effect of shears[27], reduction in die diameter[28] and thermal degradation of lipids[26].

There was no definite direction of change in mineral composition. Some of these changes were significant ($p \leq 0.05$) such as in phosphorous, and iron. Extrusion cooking increased bulk density which is not of much importance in infant feeding in terms of calorie and nutrient intake.

Effect of process variables on extrudate mass flow rate

Feed composition and mass flow rate: Table 3 shows that mass flow rate of the extrudates ranged between 2.99- 6.72 kg h^{-1}. Increase in defatted soybean flour from 0-55% or decrease in African breadfruit from 100-40% increased mean mass flow rate by 63.37%. Mass flow rate increased as the blend shifted from centre point to corner point by 28.31% and decreased by 21.46% as it moved towards the star point.

The effect of soybean on mass flow rate is related to its naturally occurring components particularly fat and protein which could have increased lubrication or reduced

Table 3: Mass flow rate (Y_1), Expansion ratio (Y_2), and Bulk density (Y_3) dependent variable responses

	Coded dependent variable responses		
Experimental Runs[c]	Y_1[a]	Y_2[b]	Y_3
1	4.56	1.61	0.62
2	4.75	1.58	0.67
3	5.08	1.61	0.67
4	4.73	1.86	0.67
5	5.46	1.55	0.63
6	4.84	1.63	0.59
7	5.19	1.61	0.58
8	6.72	1.50	0.65
9	5.64	1.48	0.63
10	5.71	1.44	0.61
11	4.05	1.55	0.61
12	3.93	1.60	0.64
13	4.37	2.18	0.66
14	4.65	2.00	0.60
15	4.89	2.94	0.61
16	3.48	1.62	0.58
17	4.07	1.73	0.55
18	4.70	2.66	0.62
19	4.77	1.74	0.61
20	4.35	2.12	0.61
21	3.08	1.63	0.60
22	2.99	1.56	0.61
23	3.55	1.65	0.59
24	3.90	2.12	0.57
25	3.69	2.05	0.57

Y_1 = mass flow rate (Kg h^{-1}); Y_2 = expansion ratio ; Y_3 = bulk density (g mL^{-1}). [a]Mean of 5 determinations; [b]mean of 10 determinations; [c]mean of triplicate determinations.

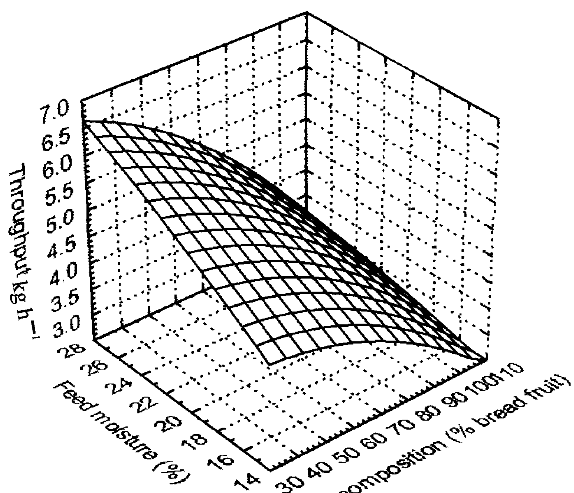

Fig. 1: Response surface plot of effect of feed component (% bread fruit) and feed moisture (%) on extrudate mass flow rate (throughput)(kg h^{-1})

friction and pressure at the die end of the extruder barrel, thus causing higher flow rate at the corner point than at either centre or star point formulations.

This greater volume of extrudate flow at these points translated to higher mass for a given bulk density. Similar observation of effect of naturally occurring components indigenous to raw food materials has been demonstrated with raw corn and pure corn starches[29].

Screw speed and mass flow rate: Mass flow rate increased with increase in screw speed from 100-180 rpm by 12.33% from centre towards corner point. The estimated regression coefficients and analysis of variance in Table 4 indicate that no process variable had significant ($p > 0.05$) linear or cross product effect on mass flow rate. The linear effect of feed moisture (Fig.1) though non significant was sharp. On removing the non significant terms the polynomial becomes:

$$Y_1 = -8.31530 + 0.000419X_3^2 \qquad (2)$$

Only the extruder screw speed had a significant ($p \leq 0.05$) quadratic effect on the responses (Eq.(2). The response surface plot (Fig.2) shows clearly this effect. The effect is expected as mass flow rate depends on the rate at which the extrudate leaves the die nozzle at specific time intervals during the steady state operation. The rate of exit from die orifice on the other hand depends on screw performance. The model contributed 89.76% of the total variation in the response.

Effect of process variables on extrudate expansion ratio

Feed composition and expansion ratio: Table 3 data show the effect of extrusion variables on expansion ratio of

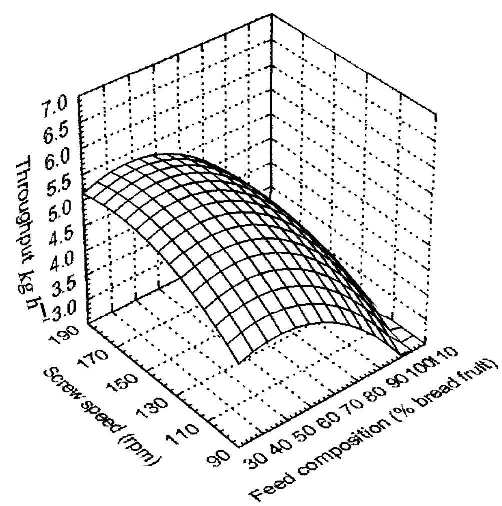

Fig. 2: Response surface plot of effect of feed composition (% bread fruit) and screw speed (%) on extrudate mass flow rate (throughput)(kg h^{-1})

Table 4. Coefficient estimates for the response Y_1 and sources X_1, X_2, and X_3

(a) Regression coefficients

Source	Coefficient	Standard error	df	*p*-values
Regression on constant	-8.31530	9.00687		
X_1	0.09649	0.12108	1	0.4389
X_2	0.77670	0.53781	1	0.1707
X_3	0.05669	0.06518	1	0.3991
X_1X_1	-0.00045	0.00027	1	0.1248
X_1X_2	-0.00435	0.00508	1	0.4067
X_1X_3	-0.00023	0.00084	1	0.7855
X_2X_2	-0.02192	0.01595	1	0.1908
X_2X_3	0.00262	0.00300	1	0.3977
X_3X_3	0.00042	0.00020	1	0.0538 [a]
R^2	0.89759			

$Y_1 = -8.31530 + 0.09649 X_1 + 0.77670 X_2 + 0.05669 X 3 -0.00045 X_1X_1 - 0.02192 X_2X_2 + 0.00042 X_3 X_3 -0.00435 X_1 X_2 - 0.0023 X_1 X_3 + 0.00262X_2X_3$ Y_1 = Mass flow rate (kg h^{-1}); [a] significant at p = 0.1; X_1, X_2, X_3 = linear order; $X_1 X_2$, $X_1 X_3$, $X_2 X_3$ = cross product order; $X_1 X_1$, $X_2 X_2$, $X_3 X_3$=quadratic order.

(b) Analysis of variance of the second –order model for the response Y_1 and factors X_1, X_2 and X_3

Factor	df	Sum of squares	Sig of F
X_1	4	12.645	0.000
X_2	4	0.771	0.085
X_3	4	1.358	0.017

X_1 = feed composition (% African breadfruit), X_2 = feed moisture (%), X_3 =screw speed(rpm)

Table 5: Coefficient estimates for the response Y_2 and sources X_1, X_2, and X_3

(a) Regression coefficients

Source	Coefficient	Standard error	df	*p*-value
Regression on constant	-6.35946	6.14447		
X_1	0.08714	0.08260	1	0.3093
X_2	0.39268	0.36689	1	0.3026
X_3	0.05151	0.04446	1	0.2660
$X_1 X_1$	-0.00034	0.00019	1	0.0938[a]
$X_1 X_2$	-0.00160	0.00347	1	0.6512
$X_1 X_3$	-0.00054	0.00057	1	0.3592
$X_2 X_2$	-0.01124	0.01088	1	0.3190
$X_2 X_3$	-0.00045	0.00205	1	0.8286
$X_3 X_3$	-0.00014	0.00014	1	0.3379
R^2	0.57223			

$Y_2 = -6.35946 + 0.08714X_1 + 0.39268X_2 + 0.0515X_3 - 0.00034X_1X_1 - 0.01124X_2X_2 - 0.00014X_3X_3 - 0.00160X_1X_2 - 0.00054X_1X_3 - 0.00045X_2X_3$

Y_2 = expansion ratio; [a] significant at p = 0. 1; X_1, X_2, X_3 =linear order; $X_1 X_2$, X_1X_3, $X_2 X_3$, = cross product order; $X_1 X_1$, $X_2 X_2$, $X_3 X_3$ = quadratic order.

(b): Analysis of variance of the second-order model for the response Y_2 and factors X_1, X_2 and X_3

Factor	df	Sum of squares	Sig. of F
X_1	4	0.613	0.096
X_2	4	0.262	0.408
X_3	4	0.190	0.556

X_1 = feed composition (% African breadfruit), X_2 = feed moisture (%), X_3 = screw speed(rpm).

extrudates. Expansion ratio ranged from 1.44 to 2.66. It increased at higher African breadfruit levels and decreased defatted soybean or protein levels. The decrease in product expansion ratio from 1. 85 at the centre point to 1.64 at the lower corner point of soybean addition is attributable to increase in fat and protein components to as indicated in Table 2. This observation agrees with the reports in literature[17,19,29] that increase in lipid and /or protein sources generally reduced product expansion.

On the other hand, the increased extrudate expansion ratio from 1.85 at the centre point blend to 2.36 at the lower star point indicates that expansion ratio is influenced by carbohydrate sources due to starch dextrinization[19]. The estimated regression analysis of data on expansion ratio in Table 5a shows that the model contributed about 57% of the total variation in the response and exhibited a non –significant lack of fit. The polynomial equation after removing non significant terms becomes:

$$Y_2 = -6.35946 - 0.00034 X^2_1 \quad (3)$$

From Eq(3), it was obvious that there was no significant ($p>0.05$) linear or cross product effects of process variables on extrudate expansion ratio. Feed composition was the only process variable exhibiting significant ($p\leq 0.1$) quadratic influence on the response. The significant ($p= 0.1$) contribution of feed composition to the extrudate expansion ratio was confirmed from the analysis of variance on full regression (Table 5b).

Feed moisture and expansion ratio: Low moisture feeds exhibit more drag and therefore exert more pressure at the die resulting into greater expansion at the exit of the die than high moisture feeds[30, 31]. Generally, the raw blends used in this study were of low moisture content (5.0-6.0%, Table 2) and could have contributed to expansion ratio observed in Table 3.

The combination of low moisture and high starch content of the African breadfruit had a major contribution to the increased expansion ratio particularly at lower screw speed as indicated in the response surface plot (Fig. 3). This is because low screw speed translates to increased residence time which results in longer shearing action[17] and hence leads to increased expansion.

Screw speed and expansion ratio: At higher screw speed radial expansion is expected to reduce while axial expansion increases due to reduced residence time[32], reduced degree of gelatinization of starch and hence

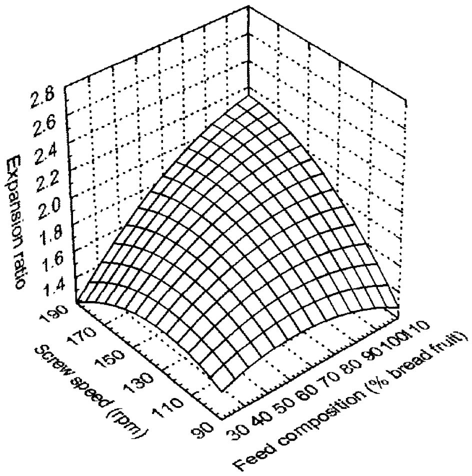

Fig. 3: Response surface plot of effect of feed composition (% bread fruit) and Screw speed (rpm) on extrudate expansion ratio

reduce expansion[33]. It will be noted that data on expansion ratio reported in this study were obtained on partially cool dry extrudates. The response may likely change when determined directly at exit point or as completely cool and dry products. This is because cooling and drying cause shrinkage and /or collapse of products with weak cell structure. Expansion ratio measurements change with time and position at which measurement is taken.

Effect of process variables on extrudates bulk density

Feed composition and bulk density: Table 3 shows data on bulk density of extrudates from African breadfruit blends. It ranged from 0.55 g mL^{-1} to 0.67 g mL^{-1}. It increased from 0.62 g mL^{-1} mean value at the centre point blend to 0.65 g mL^{-1} mean value at the lower corner point and decreased to 0.59 g mL^{-1} mean value at the lower star point blend. It means that extrudate bulk density increased as defatted soybean concentration in the blend increased and decreased as African breadfruit is reduced.

These effects of feed composition on bulk density were related to differences in nutrient composition of the blends. The higher fat and protein content of the lower corner blend (higher soy concentration) could have lubricated and hence reduced dough viscosity inside the extruder than the lower star point blend (higher African breadfruit) . The resultant effect being that dough mass spends less residence time and undergoes less shear effect. Consequently, the extrudate exits the extruder die orifice with reduced expansion ratio and product volume thus increasing extrudate bulk density. Bulk density therefore shows relatively opposite response to feed composition from that reported for expansion ratio. High concentration of African breadfruit amounts to high starch source which influences expansion ratio and hence reduces bulk density.

Effects of starch and protein sources on extrudate bulk density had been severally reported in literature. While Badrie and Mellowes[19] reported that starch addition to cassava flour reduced bulk density, addition of pigeon pea flour to cassava flour[9] increased it. Similarly, addition of soybean to rice flour irrespective of variety[18] or to sweet potato[17] positively influenced bulk density of extrudates.

Bulk density and variable interactions: The estimated regression coefficient and analysis of variance on bulk density are shown in Table 6. The polynomial equation developed from the regression model after removing the non-significant terms becomes:

$$Y_3 = -0.61909 + 0.01450\,X_1 + 0.01134X_3 - 1.0548X_1X_3 - 0.00003X^2_1 - 0.00181X^2_2 + 0.00005\,X^2_3 \quad (4)$$

Table 6: Coefficient estimates for the response Y_3 and sources X_1, X_2 and X_3
(a) Regression coefficients

Sources	Coefficient	Standard error	df	p –values
Regression on constant	-6.19090	0.37837		
X_1	0.01450	0.00509	1	0.0128[a]
X_2	0.04296	0.02259	1	0.0780 [b]
X_3	0.01134	0.00274	1	0.0010[a]
$X_1 X_1$	0.00003	0.00001	1	0.0299[a]
$X_1 X_2$	- 0.00043	0.000213	1	0.0662[b]
$X_1 X_3$	- 1.05481	0.00004	1	0.0097[a]
$X_2 X_2$	-0.00181	0.00067	1	0.0175[a]
X_2X_3	0.000150	0.00013	1	0.2537
$X_3 X_3$	-0.00005	0.00001	1	0.0001[a]
R^2	0.87531			

Y_3 = - 6.19090 + $0.01450X_1{}^a$ + $0.04296X_2{}^b$ + 0.01134 $X_3{}^a$ - $0.00003X_1X_1{}^a$ $-0.00181X_2X_2{}^a$ - $0.00005X_3X_3{}^a$ - 0.00043 $X_1X_2{}^b$ - $1.05481X_1X_3{}^a$ + $0.000150X_2\,X_3$. Y_3 = bulk density (g mL^{-1}); [a] significant at p = 0.05; [b] significant at p = 0.1; X_1, X_2, X_3= linear order; $X_1 X_2$,X_1X_3, $X_2 X_3$ = cross product order; $X_1 X_1$, X_2X_2, X_3X_3= quadratic order.

(b): Analysis of the second-order model for the response Y_3 and factors X_1, X_2, and X_3

Factor	df	Sum of squares	Sig of F
X_1	4	0.008	0.005
X_2	4	0.005	0.017
X_3	4	0.007	0.007

X_1= feed composition (% African breadfruit); X_2 =feed moisture (%); X_3 = screw speed (rpm).

Information from Eq. (4) indicates that all the process variables had significantly ($p \le 0.05$) quadratic influence on bulk density. Feed composition and screw speed exhibited significant ($p \le 0.05$) linear and cross product effects on bulk density. Response surface plots (Fig. 4 and 5) confirmed the quadratic effects of screw speed on the response. e xhibited significant ($p \le 0.05$)

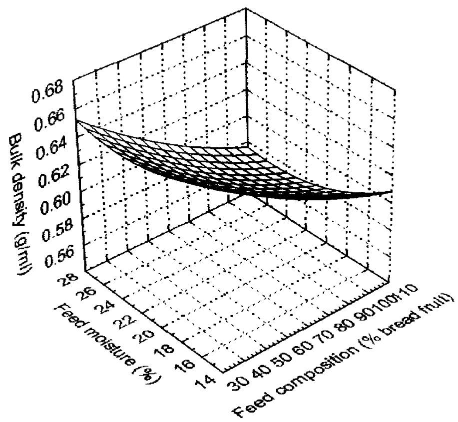

Fig. 4: Response surface plot of effect of feed composition (% bread fruit) and feed moisture (%) on extrudate bulk density (g mL^{-1})

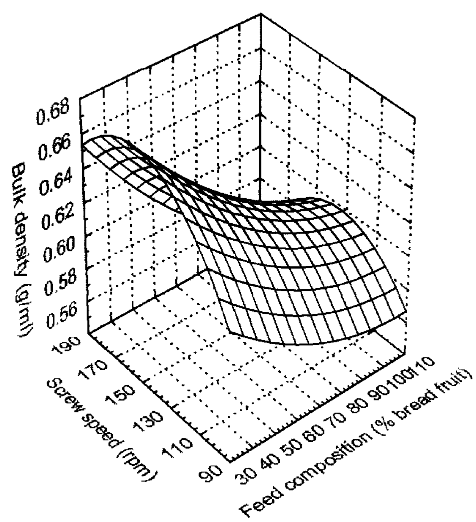

Fig. 5: Response surface plot of effect of feed composition (% bread fruit) and screw speed (rpm) on extrudate bulk density (g mL^{-1})

linear and cross product effects on bulk density. Response surface plot (Fig. 4) shows the quadratic effect of screw speed and feed moisture on the response respectively. The model contributed about 88% to the variation in bulk density and showed significant ($p \leq 0.05$) lack of fit.

CONCLUSIONS

Marked differences in nutrient composition of blends made from different level feed composition were observed. The blends at the lower corner point exhibited higher nutrient values than those produced from either centre or lower star points. Extrusion cooking produced significant and non significant changes in extrudate nutrient values.

Mass flow rate and bulk density increased with increase in soybean concentration but decreased as African breadfruit concentration was raised. Expansion ratio and bulk density of the extrudates showed an inverse relationship. All process variables showed significant ($p \leq 0.05$) quadratic influence only on bulk density. No process variable exhibited significant ($p > 0.05$) linear or cross product effect on either mass flow rate or expansion ratio.

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