

Original Research Article

Functional properties of Noodles Analogue from Water Yam, Yellow Maize, and African Yam Bean Mixtures – A Response surface methodology

ABSTRACT

Response surface methodology was used to investigate the effect of extrusion process on proximate composition of noodles analogue from water yam, yellow maize, and African yam bean flour mixture. Flour blend from water yam, yellow maize, and African yam bean were produced and was used to extrude noodles analogue using a Brabender single screw laboratory extruder (Duisburg DCE 330 model) fitted with 3.0 mm die nozzle diameter. A central composite rotatable design (CCRD) with three variables, namely barrel temperature, feed moisture content and screw speed and five level coded [-a, -1, 0, +1, +a] was used and data analyzed by regression analysis. Results showed that bulk density ranged from 0.41 to 0.09 g/g; water solubility index ranged from 4.41 to 6.36 g/g; water absorption capacity ranged from 2.05 to 5.66% and expansion ratio ranged from 1.62 to 3.81% respectively. The coefficients of determinations (R^2) were high and ranged from 0.9039 to 0.9887 at 5% level. The response surface plots suggested that the models developed had a good fit and the CCRD was effective in explaining the effect of the process conditions on noodles analogue as influenced by barrel temperature, feed moisture content, and screw speed of the extruder. The data obtained from the study could be used for control of product characteristics. The study indicated that improved noodles analogue from available and cheap roots, cereal and legumes such as water yam, yellow maize, and African yam bean can be produced for possible projection for the commercial production of noodles analogue.

KEY WORDS: Extrusion, Noodles analogue, Functional Properties

Introduction

Extrusion technology as a multi-step, multi-functional, and high temperature process has numerous advantages over traditional methods of food processing. Extrusion process has been extensively used to produce variety of foods like ready to eat breakfast cereals, snacks, and noodles from myriad of crop plants. Several crops can be blended to develop a novel product that can be attractive, nutritious, safe, and easily prepared.

Yam is one of the staple foods in Nigeria and other tropical African countries. The yams are members of the genus *Dioscorea*. Yam is grown and cultivated for its energy-rich tuber. Only a few species of yams are cultivated as food crops. The most important species of *Dioscorea* include *D. rotundata*, *D. alata*, *D. cayenensis*, *D. dumetorum*, *D. esculenta*, and *D. bulbifera*, *Dioscorea alata*, called “water yam”, “winged yam” and “purple yam”, is the species most widely spread throughout the world and in Africa is second only to white yam in popularity (Mignouna et al., 2004). Yam is an excellent source of starch. Water yam (*Dioscorea alata*).

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D. alata) is the most economically important yam species which serve as a staple food for millions of people in tropical and subtropical countries (Coursey, 1967; Hahn, 1995). *D. alata* is a crop with potential for increased consumer demand due to its low sugar content necessary for diabetic patients (Udensi et al., 2010).

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In the same way yellow maize has been severally used for the processing of different extruded product (Muhammad et al., 2012). Maize is the cereal of major importance in the developing world and has the maximum genetic production potential of all the cereal crops (Muhammad et al., 2012). More attention has been given recently to the increase of the production of maize for human food in Nigeria.

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Omeire (2012) food legumes serves as an important economic source of supplementary protein. African yam bean (AYB) is one of the lesser known legumes produced in Nigeria. AYB equally contributes some desired functionality when combined in food formulation.

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Functional characteristics are required to evaluate and possibly help predicts how proteins, fat, fibre and carbohydrates may have on specific system as well as demonstrate whether or not such unconventional protein can be used to stimulate or replace conventional protein (Kalu et al., 2019). Functional properties of food products have correlation with the sensory attributes, cooking quality, handling, packaging, and storage life. Some studies were reported on the use of cereal-tuber-legume combinations for the production of various products (Kadam et al., 2012). It can be deduced from the report that the qualities of product depended on the proportional composition of the composites and flour product functionality (Oladumoye et al., 2010). The objective of this work was to determine the effect of extrusion process on the functional properties of noodles analogue from water yam, yellow maize, and African yam bean.

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Materials and Methods

The water yam TDA 297 was bought at National Root Crop Research Institute (NRCI), Umudike, Abia State, Nigeria. The yellow maize and the cream coloured African yam bean were identified and bought at National Institute of Horticulture (NIHOT) Mbato sub zone, Okigwe, Imo state. Xanthan gum (G 1253, sigma – Aldrich USA) was procured from pharmaceutical shop in Onitsha, Dangote iodized table salt was purchased from a super market in Afikpo, Ebonyi state, Nigeria.

Flour production:

Healthy water yam tubers were washed, peeled manually with a stainless steel knife under potable water containing 0.20% solution of sodium metabisulphate. The peeled yam was transferred into another container of the same concentration of solution of sodium

metabisulphate and allowed to stand for 5 min and then were sliced manually in (2 mm x 3 mm) sizes. They sliced water yam were removed and allowed to drain for 1h under air current and dried at 60°C for 6h in a Chirana type air convention oven (HS201A). Dried chips were cooled for 2h at room temperature under air current and milled using Brabender roller mill (Model 3511A). The flour sample was sieved through 0.50mm mesh size, packaged and sealed in polyethylene bag for further use.

Yellow maize grain were sorted, and cleaned in an aspirator (Model: OB 125 Bindapst Hungary) located at the Food Processing Laboratory of Federal Polytechnic, Mubi. The cleaned maize grains were conditioned by manually sprinkling of clean potable water at interval of 15 min and the moisture content was maintained at 21 to 22 % for 30 min in a stainless steel container. The grains were dried at 60°C for 6h to 15 % MC in a Chirana type air convention oven (HS201A) and then cracked and milled with Brabender roller mill (Model 3511A). The seed coats were removed to obtain the maize flour to pass through a screen with 0.50mm openings. The flour was stored in an air tight plastic container at room temperature for further use.

Cream coloured African yam bean grains were sorted, cleaned in an aspirator (Model: OB 125 Bindapst Hungary) and washed at the Food Processing Laboratory of Federal Polytechnic, Mubi. Cleaned grains were soaked for 3 h at room temperature and dehulled. The dehulled grains were dried at 60°C for 10 h in a Chirana type air convention oven (HS201A) and milled with Brabender roller mill (Model 3511A) to pass through a screen aperture with 0.50 mm openings. The flour was stored in an air tight plastic container at room temperature for further use.

Flour blending ratio

Flour samples were blended in the ratio of 60% water yam, 10% yellow maize, and 30% African yam bean based on preliminary result

Experimental design

A central composite rotatable design (CCRD) for three variable was employed to examine the response pattern of the effects of barrel temperature, BT (°C), feed moisture content, FMC (%) and screw speed, SS (rpm) on proximate composition of the noodles analogue. Each variable was evaluated as shown in Table 1. Each variable were at five levels, namely $-\alpha - 1, +0, +1$ and $+\alpha$ gave 15 variable combinations in which the 15th combination was replicated 5 time at the center point (0, 0, 0) of the design to generate a total of 20 experimental runs used.

Statistical analysis

The data obtained from triplicate run using Central Composite Rotatable Design was analyzed statistically using Response Surface Methodology, so as to fit the quadratic polynomial equations generated using Design Expert software version 8.0.7.1 (Stat-ease Inc., USA).

A second order polynomial equation was used to fit the experimental data given in Table 2. The model proposed for the response (Y_i) was shown in equation 1 and 2

$$Y_1 = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_{11} X_1^2 + \beta_{22} X_2^2 + \beta_{33} X_3^2 + \beta_{12} X_1 X_2 + \beta_{13} X_1 X_3 + \beta_{23} X_2 X_3 + \beta_{123} X_1 X_2 X_3 \dots (1)$$

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$$Y_1 = \beta_0 + \beta_1 BT + \beta_2 FMC + \beta_3 SS + \beta_{11} BT^2 + \beta_{22} FMC^2 + \beta_{33} SS^2 + \beta_{12} BTFMC + \beta_{13} BTSS + \beta_{23} FMCSS + \beta_{123} BTFMCSS \dots (2)$$

Comment [Ayman9]: BTSS +

Where Y_1 is the predicted response for proximate composition, β_0 (intercept) is the value of the fitted response at the enter point of the design, β_i , β_{ii} , β_{ij} (regression coefficient term) being the linear, quadratic and cross product terms respectively and e is the random error term. In order to deduce workable optimum conditions, a graphical technique was used (Floros and Chinnan, 1988; Giovanni, 1983). To visualize the relationship between the responses and experimental levels for each of the factors the fitted polynomial equation was expressed as surface contour plots.

Noodles analogue formulation

According to Kalu *et al.*, (2019) each one hundred grams (100g) of flour was mixed in the desired water level according to the experiment design (Table 2), 1g Iodized salt and xanthan gum 0.5 g each respectively was added for thickening and stability (Gambus *et al.*, 2007) and thoroughly mixed using Hobart mixer (Model: A:200; English). Thereafter, the mixture was subjected to extrusion cooking.

Extrusion cooking

A single screw Brabender laboratory extruder (Model DCE 330, New Jersey, USA,) located at the Food Processing Laboratory of Federal Polytechnic, Mubi, Nigeria, was used for the cooking. The extruder feed hopper equipped with auxiliary auger-screw rotating at variable speed on vertical axis was set at 60 rpm for all the sample runs. The extruder was allowed to run to stabilization over a period of 30 min at screw speed of 40 to 45rpm during which time the no-load torque and temperature and pressure regimes were displayed on the control panel before the experimental runs commenced for each set of conditions. The moisture content of flours, barrel temperature and screw speed were adjusted according to the experimental design (Table 1). The

feed was introduced gradually but continuously into the feed hopper and were received at the die end with of 3.00mm diameter as dried strands or pellets. The samples were allowed to cool and packaged in a polythene bag for analysis.

Functional properties determination:

Bulk density (BD) of noodles analogues

The bulk density (BD) of sample was determined using the method described by Iwe and Ngoddy (1998). A 10ml graduated cylinder, previously tarred was gently filled with 10g of each flour sample. The initial volume of the sample was recorded. The bottom of the cylinder was gently tapped on laboratory bench until there was no further diminution of the sample level after filling to the 10ml mark. The final volume of the sample was recorded. Bulk density (BD) was calculated as mass of sample per unit volume of sample (g/ml)

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$$\text{Bulk Density} = \frac{\text{Weight of Sample (g)}}{\text{Volume of Sample (ml)}}$$

Water absorption capacity (WAC) of noodles analogues

The water absorption capacity (WAC) of raw flour blends (RFB) and noodles analogue were determined in triplicates using the procedure described in literature (Andersson, 1982; Sefa – Dedeh and Saalia, 1997; Iwe, 1998; Rampersad *et al.*, 2003). The milled samples (2.5 g) were mixed with 30ml of water at 30±1°C, stirred and allowed to sand for 30min. The mixture was then centrifuged at 1500 rpm for 15min. Water absorption capacity (WAC) was calculated as the increase in weight of the solid formed after decanting the supernatant. Water density was assumed to be 1g/ml

$$\text{WAC} = \frac{(\text{weight of tube} + \text{residue after centrifuge}) - \text{Weight of empty tube} \times 100}{\text{Weight of sample}}$$

Water solubility index (WSI)

The supernatant from the water absorption capacity determination was decanted into pre-weighed moisture dish and evaporated to constant weight in a precision oven (III.60647, USA) at 103°C. The water solubility index (WSI) was calculated as the percent weight of the original sample weight recovered (Rampersad *et al.*, 2003). Triplicate determinations was made and reported as mean value.

$$\text{WSI} = \frac{W_3 - W_2}{W_1} \times 100$$

W_1 = Weight of sample

W_2 = Weight of empty tube

W_3 = Weight of tube + residue after centrifuge

Comment [Ayman11]: Tube or dish

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Expansion ratio (ER) of noodles analogues

Expansion ratio (ER) of cool, dry extrudates was determined on mean of ten determinations per sample run with a pair of calipers (Mitutoyo, Japan) accurate to 0.05mm. Expansion ratio (ER) was expressed as the ratio of the diameter of the extrudates to that of the die orifice (Halek *et al.*, 1989; Artz *et al.*, 1990). Mean values were reported.

RESULT AND DISCUSSION

Table 1: Effect of barrel temperature, feed moisture content and screw speed on the Functional composition of Noodles analogue.

Run	BT(°C)	FMC (%)	SS(rpm)	BD(ml)	WAC(g/g)	WSI(g/g)	ER
1	90	18	120	0.87	3.31	4.78	2.4
2	200	18	120	0.54	3.28	5.88	2.4
3	90	30	120	0.54	3.60	5.82	2.8
4	200	30	120	0.41	4.29	5.78	3.5
5	90	18	180	0.90	4.64	4.41	2.9
6	200	18	180	0.69	3.04	6.05	2.9
7	90	30	180	0.62	5.66	6.07	3.1
8	200	30	180	0.62	4.79	6.02	3.8
9	52.5	24	150	0.75	4.21	4.92	2.4
10	237.5	24	150	0.43	4.10	6.28	3.0
11	145	13.91	150	0.75	4.17	4.90	3.0
12	145	34.09	150	0.42	5.64	6.36	3.3
13	145	24	99.55	0.41	2.05	5.35	2.9
14	145	24	200.45	0.79	2.04	5.87	3.6
15	145	24	150	0.55	3.21	5.69	1.9

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16	145	24	150	0.58	3.54	5.68	1.68
17	145	24	150	0.49	3.72	5.71	1.70
18	145	24	150	0.59	3.66	5.66	1.99
19	145	24	150	0.47	3.37	5.61	1.62
20	145	24	150	0.50	3.61	5.44	1.66

BT = Barrel temperature, FMC = Feed moisture content, SS = Screw speed, BD = Bulk density, WAC = Water absorption capacity, WSI = Water solubility index, ER = Expansion ratio.

Table 2: Estimated regression coefficients of the fitted second order polynomial resending the relation between the response and the process variable.

Response coefficient	BD (g/ml)		WAC_(g/g)		WSI_(%)		Expansion ratio	
	Coefficient	P-value	Coefficient	P-value	Coefficient	P-value	Coefficient	P-value
Linear								
β^0	3.96657		2.79395		1.05225		21.098	
β^1	-0.012000*	0.0003	-5.22961E3*	0.0472	0.028456*	0.0001	-0.040372*	0.0003
β^2	-0.99691*	0.0001	-1.06374*	0.0001	0.14955*	0.0001	-0.46157*	0.0001
β^3	-0.016551*	0.0007	0.15649*	0.0001	-0.01047	0.1631	-0.16328*	0.0001
Interaction								
β^{12}	-1.55303E4*	0.0351	5.49242E4	0.0723	-1.07197E3*	0.0004	+5.34019E4*	0.0020
β^{13}	1.89394E5	0.1682	-2.37121E4	0.0015	4.01515E5	0.3501	-5.30303E6	0.8412

β^{23}	7.63889E5	0.5281	1.02083E5	0.0690	4.79167E4*	0.2308	-3.40278E4	0.1807
Quadratic								
β^{11}	1.27618E5	0.1175	8.45371E5	0.0245	-	0.8104	1.08732E4*	0.0001
			*		5.899711E6			
β^{22}	9.92157E4	0.1441	0.019132*	0.0001	-1.43959E5	0.9944	0.010168*	0.0001
β^{33}	4.93088E5	0.773	-	0.0026	-	0.8710	5.97233E4*	0.0001
			4.27927E4		1.34058E			
			*		5			
R^2	0.9887		0.9531		0.9273		0.9035	
Adj. R^2	0.9455		0.9109		0.8619			

Significant at 5% level β_1 =Barrel temperature (BT); β_2 =Feed moisture content (FMC); β_3 = Screw speed (SS); β_{12} = BT FMC; β_{13} = BT* SS; β_{23} = FMC* SS; β_{11} = BT²; β_{22} = FMC²; β_{33} = SS². WAC = Water absorption capacity, WSI = Water solubility index, ER = Expansion ratio.

Table 3: Analysis of variance for the fitted second order polynomial model as per CCRD

		Sum of squares			
	D	BD	WSI	WAC	Expansion ratio
	f				
<i>Regression</i>					
First order terms	3	0.322 ^a	3.563 ^b	6.91 ^a	2.38 ^a
Second order terms	6	0.063215 ^b	1.098233 ^b	6.55 ^b	7.9306 ^b
Total	9	0.385215	4.661233	13.46	10.310
<i>Residual</i>					
Lack of fit	5	0.023 ^b	0.32 ^b	0.46 ^b	0.0005715
Pure error	5	0.013	0.050	0.19	0.14
Total error	10	0.035	0.37	0.65	0.14
<i>Grand total</i>	19	0.420215	5.031233	14.11	10.45

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^a Significant at $p < 0.005$

^b Not significant at $p > 0.05$. WAC = Water absorption capacity, WSI = Water solubility index, ER = Expansion ratio.

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Four responses, namely bulk density content (Y_1) water solubility index (Y_2), water absorption capacity (Y_3) and expansion ratio (Y_4) which described the functional properties of the noodles analogue were evaluated. The coefficients for the actual functional relation for predicting Y_i are presented in Table 2. The non-significant terms from the model were omitted in the equation below based on students T- ratio (Khuri and Cornell, 1987). The contour plots for the functional properties are shown in appendix 1 to 4.

Bulk Density (BD) of noodles analogue

The values of bulk density of the noodles analogue varied from 0.41 g/g (at barrel temperature of 145°C, 200°C, and feed moisture content of 24%, 30% and screw speed of 99.55rpm and 120rpm) to 0.90g/g (at barrel temperature of 90°C, feed moisture content of 18%, and screw speed of 180rpm) indicating increase in bulk density of the noodles analogue with decrease in barrel temperature, feed moisture content with increase in screw speed. Similar observation was reported by Oluwole *et al* 2010). The values of bulk density in this study was comparable to the values reported by Jiddere and Filli (2016). The bulk density (BD) is important in relation to their ability to float or sink when poured into water and their packaging requirement and had been reported to be one of the most important indices of quality in extruded food products (Saini, 2015). The lower the bulk of extrudate, the higher the expansion ratio of the extrudates as they have been reported to be negatively correlated (Iwe, 1998; Nwabueze, 2008). This actually played in this work. Filli *et al.* (2013) reported that the bulk density is a measure of how much expansion has occurred as a result of extrusion. The relative high bulk density in this current

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work may be due to high concentration of African yam bean. Shadan *et al.* (2014) reported that increase in soy and green pea in their mixture, which is a direct influence of increased protein content, increased the bulk density of the extrudates. High bulk density product is an indication of more uniform and continuous protein matrix and therefore, the extrudate is dense with parallel layers, no air pockets and is not spongy upon hydration. The linear effect of barrel temperature feed moisture content and screw speed negatively and significantly affected the bulk density in the noodles analogue at 5% level. The interaction of barrel temperature and feed moisture content positively and significantly affected the bulk density in the noodles analogue at 5% level. The interaction of barrel temperature and screw speed, feed moisture and screw speed and quadratic effects of the three variables were not significant at 5-% level (Table 2). The first order term was significant, but the second order term and lack of fit were not significant at 5% level (Table 3). The coefficient of determination (R^2) for the fit was 0.9887, indicating that the model provided an excellent fit and explained 98.87% of the variability of bulk density in the noodles analogue. The model equation developed for predicting protein was shown in equation 1.

$$\text{Bulk_density} = 3.96657 - 0.012000\text{BT} - 0.099691\text{FMC} - 0.016551\text{SS} - 1.55303\text{E-4BT*FMC.}$$

(1)

Water absorption capacity of noodles analogue

The water absorption capacity ranged from 2.04% (at barrel temperature of 145°C, feed moisture content of 24%, and screw speed of 200.45rpm) to 5.66% (at barrel temperature of 90°C, feed moisture content of 30%, and screw speed of 180rpm). The result revealed that the water absorption capacity of the noodles analogue increased with a decrease in barrel temperature and

screw speed but with increase in feed moisture content. The values observed in this study were comparable to the values reported by earlier researchers (Yadav *et al.*, 2015 and Dibyakanta *et al.*, 2013) on starch based extrudate. Many researchers (Anderson 1982; Chakraborty *et al.*, 2011; Sobukola *et al.*, 2012; Ding *et al.*, 2005; Singh *et al.*, 2007) demonstrated strong relationship of barrel temperature and feed moisture content on water absorption capacity. The water absorption capacity is the amount of water that absorbed by starch and can be used as an index of starch gelatinization, since native starch does not absorb water at room temperature (Filli *et al.*, 2010; Anderson *et al.* 1970). The gelatinization is the conversion of raw starch into cooked and digestible material by the application of water and heat. Hydration depends on the availability of hydrophilic groups which bind water molecules and on the gel forming capacity of macromolecules. The ability of food to absorb and retain water plays a major role in the texture performance of foods. The linear effects of barrel temperature, feed moisture content negatively and significantly affected the water absorption capacity of the noodles at 5 % level. But linear effect of screw speed positively and significantly ($P < 0.05$) affected the water absorption capacity. The interaction effect of barrel temperature and screw speed negatively and significantly affected the water absorption capacity. The quadratic effects of the three independent variables positively and significantly affected the water absorption capacity except for the screw speed which was negative at 5-% level (Table 2). The first order terms was significant at 5-% level. However, the second order term and lack of fit were not significant at 5 % level (Table 3). The test of fit was significant with R^2 of 0.9531. The regression model therefore explained about 95.31% of the total variation in water absorption capacity in noodles analogue. The model equation developed for predicting protein was shown in equation 2.

$$\text{Water absorption capacity} = 2.79395 - 5.22961E3BT - 1.06379FMC + 0.15649SS - 2.37121E4BT*SS + 8.45371E4SS^2 + 0.019132FMC*FMC - 4.27927E4SS*SS. \dots (2)$$

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Water solubility index of noodles analogue

The water solubility index ranged in values from 4.41g/100g (at barrel temperature of 90°C, feed moisture content of 18%, and screw speed of 180rpm) to 6.36g/g (at barrel temperature of 145°C, feed moisture content of 34.09 %, and screw speed of 150 rpm indicating increase in water solubility index of the noodles analogue with increase in barrel temperature, feed moisture content and decrease in screw speed. The values observed in this study ~~was~~ were close to the values reported by (Filli *et al.*, 2013; Yadav *et al.*, 2015). However higher values had also been reported earlier (Dibyakanta *et al.*, 2013) on starch based extrudates. Earlier resarchers (Dibyakanta *et al.*, 2013; Jiddere and Filli 2016) reported that increase in barrel temperature and feed moisture content increased the water solubility index. Similar findings ~~was~~ were observed in this study. Sobukola *et al.* (2012) maintained that, increased barrel temperature increases water solubility, due to increased solubility of starch molecules. Insufficient water uptake, which is directly related to swelling, usually results in noodles with hard and coarse texture, but excess water uptake has been linked to noodles that are too soft and sticky (Oluwole, 2008, Petitot *et al.*, 2010; Adedotun *et al.*, 2015). The water solubility index is related to the quantity of water soluble molecules, and is associated to dextrinization. In other words, WSI can be used as an indicator of the degradation of molecules, and is associated to measure of the starch degradation resulted from extrusion cooking (Colonna *et al.*, 1989; Ding *et al.*, 2005). Water solubility index is an indicator of degree of degradation of starch and reflects the amount of free polysaccharide or polysaccharide released from the granule after addition of excess water (Sriburi and Hill, 2000). Dibyakanta *et al.* (2013) reported that, WSI value is an indication of state of protein in

proteinaceous blends, since in this study, the proportion of protein through African yam bean inclusion (30%) was high, the increase might be due to partial protein denaturation at higher temperature (Oikonomou and Krokida, 2011). This is in line with the report of Shadan *et al.* (2014) that the water solubility index of the extruded formulas increased when cowpea and chick pea flour were as a part of combination with ratio more than 10%. The influence of high temperature, pressure and the starch chain shearing forces intensifies depolymerisation process which in turn contributes to an increase in water solubility index value of the extrudates (Balandran *et al.*, 1998). The water solubility index ranged in values from 4.41g/g (at barrel temperature of 90°C, feed moisture content of 18%, and screw speed of 180rpm) to 6.36g/g (at barrel temperature of 145°C, feed moisture content of 34.09 %, and screw speed of 150 rpm) indicating increase in water solubility index of the noodles analogue with increase in barrel temperature, feed moisture content and decrease in screw speed.

$$\text{Water solubility index} = 1.05225 + 0.028456BT + 0.14955FMC - 1.07197E-3BT*FMC + 4.79167E-4FMC*SS. \dots (3)$$

Expansion ratio of noodles analogue

The values of expansion ratio varied from 1.62 (at barrel temperature of 145°C, feed moisture content of 24%, and screw speed of 150 rpm) to 3.81% (at barrel temperature of 200°C, feed moisture content of 30%, and screw speed of 180 rpm). This indicates that increase in barrel temperature, feed moisture content and screw speed respectively, favoured increased in expansion ratio. The values in the study were comparable to the earlier reports by many researchers (Oliveira *et al.*, 2015; Jiddere and Filli 2016; Filli *et al.*, 2013). Many researchers (Jidere and Filli, 2016; Filiet *et al.*, 2012; Kothakota *et al.*, 2013; Kumar *et al.*, 2010) opined that increase in barrel temperature, feed moisture content and screw speed increased the expansion

ratio of extrude. Similar findings ~~was~~ were made in this study. Thymi *et al.* (2005) showed that apparent density, porosity and expansion ratio of extrudates from corn grits were dependent more upon the feed moisture, residence time and temperature, but screw speed had no effect. Moisture is the main plasticizer of the cereal flours which enables them to undergo a glass transition during the extrusion process and thus facilitates the deformation of the matrix and its expansion.

Food with lower moisture content tends to be more viscous than those of higher moisture content and therefore the pressure differential is similar for higher moisture foods leading to a less expanded product. The expansion process can be described as nucleation in the die, extrudate swelling immediately beyond the die, followed by bubble growth collapse (Kokini *et al.*, 1991). The linear effect of all the three independent variables negatively and significantly ($p < 0.05$) affected the expansion ratio. The interaction effect of barrel temperature and feed moisture content and screw speed negatively and significantly ($p < 0.05$) affected the expansion ratio.

The quadratic effect of all the independent variables positively and significantly ($p < 0.05$) affected the expansion ratio. The interaction effects of barrel temperature and screw speed; feed moisture content and screw speed were not significant at 5% level (Table 2). The first order term was significant at 5% level. The second order term and lack of fit were not significant at 5% level (Table 3). The coefficient of determination (R^2) for the fit was 0.9035, indicating that the model provided an excellent fit and explained 90.35 % of the variability of expansion ratio in the noodles analogue. The model equation developed for predicting expansion ratio was shown in equation 4.

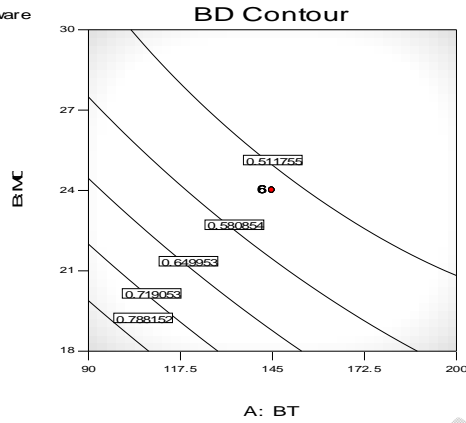
$$\text{Expansion ratio} = 21.098 - 0.04372BT - 0.4615FMC - 0.16328SS + 5.34091E-4BT*FMC + 1.08732E-4BT^2 + 0.010168 FMC^2 + 5.97233E-4SS^2 \dots (4).$$

Design-Expert® Software

BD
● Design Points

X1 = A: BT
X2 = B: MC

Actual Factor
C: SSpeed = 150.00



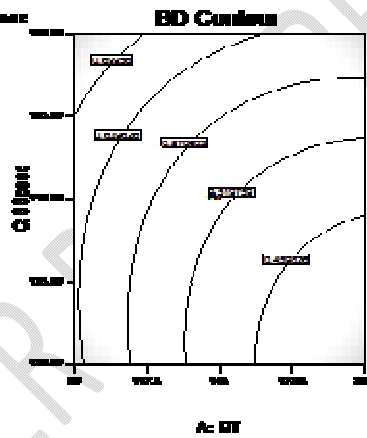
1b.

Design-Expert® Software

BD
● Design Points

X1 = A: BT
X2 = C: SSpeed

Actual Factor
B: MC = 30.00



1c.

Design-Expert® Software

BD
● Design Points

X1 = B: MC
X2 = C: SSpeed

Actual Factor
A: BT = 145.00

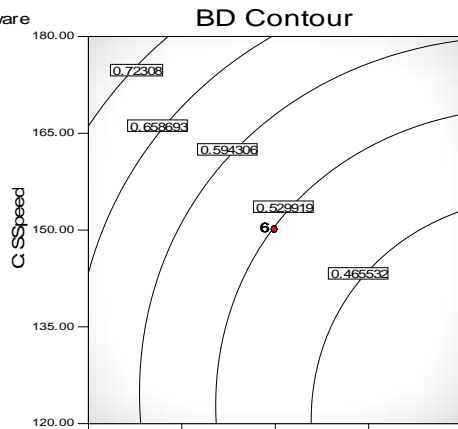
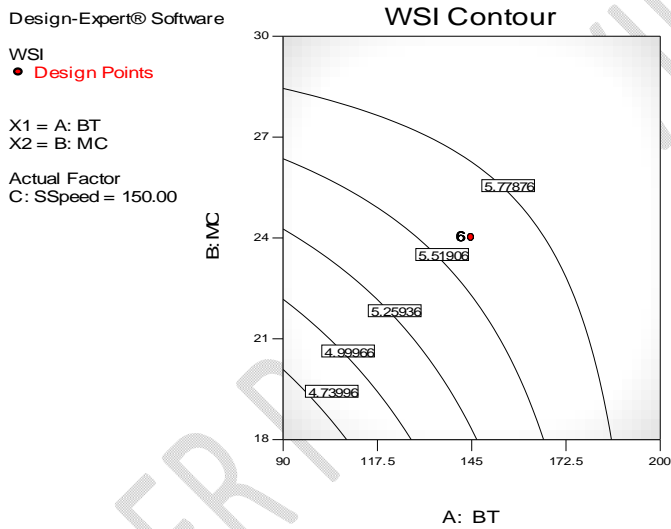
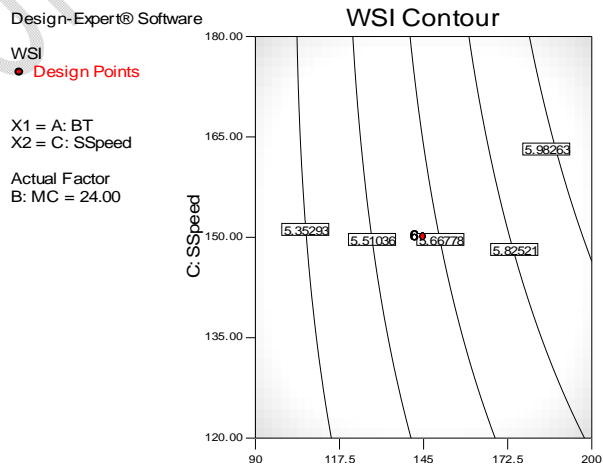


Fig 1a-c: contour plot showing the effect of barrel temperature, feed moisture content and screw speed on bulk density.

2a.



2b.



2c.

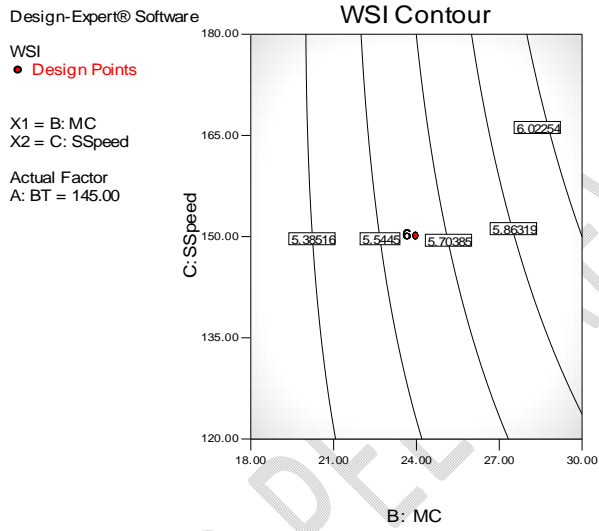
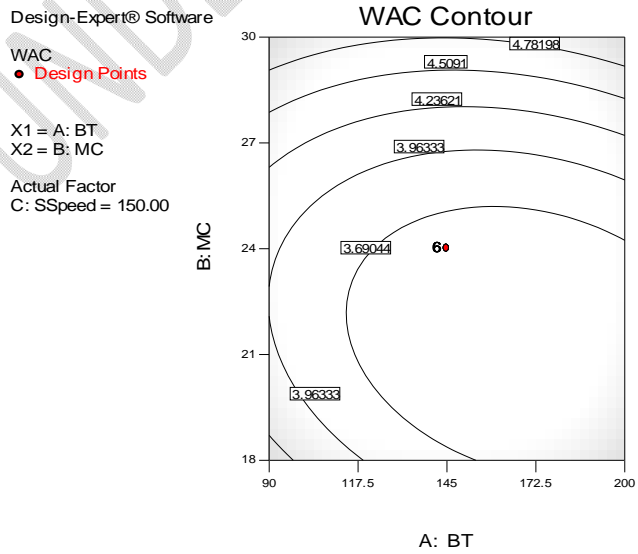
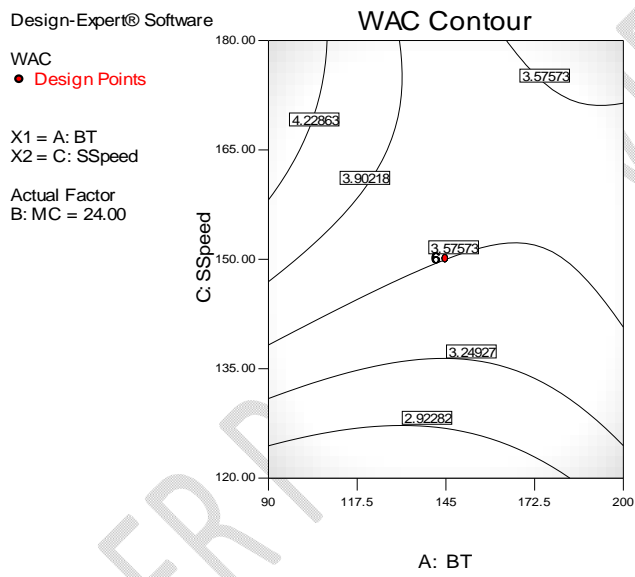


Fig 2a-c: contour plot showing the effect of barrel temperature, feed moisture content and screw speed on water solubility index.

3a.



3b.



3c.

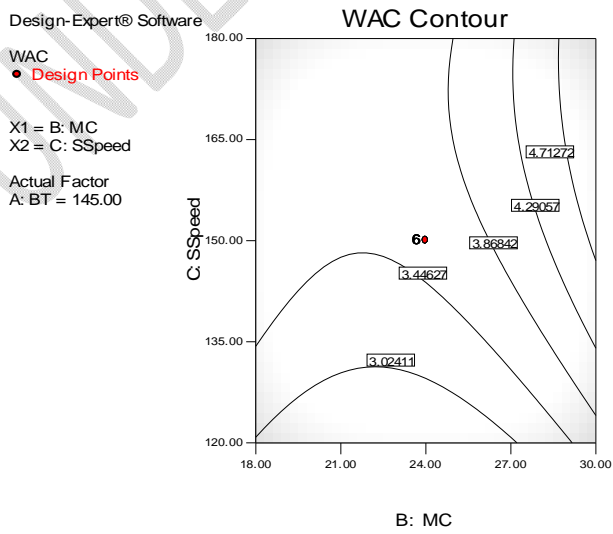
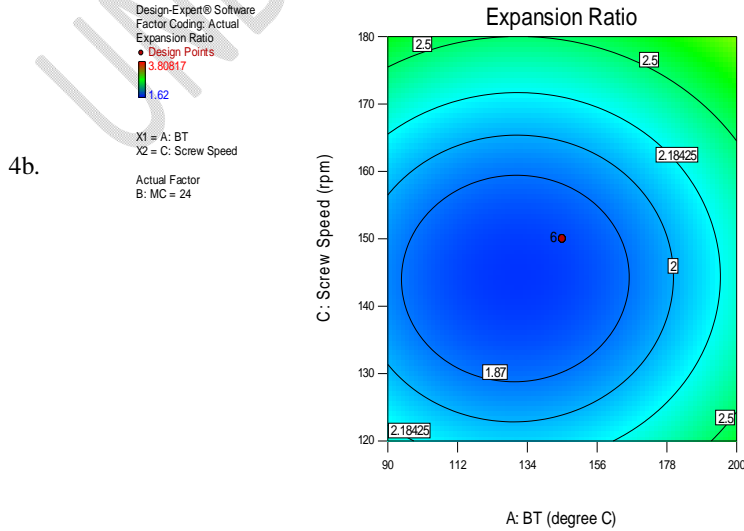
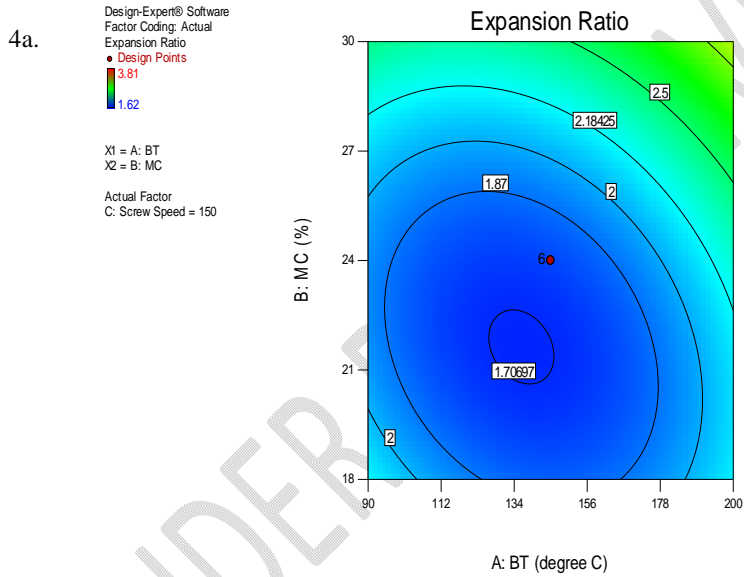


Fig 3a-c: contour plot showing the effect of barrel temperature, feed moisture content and screw speed on water absorption capacity



4c.

Design-Expert® Software
Factor Coding: Actual
Expansion Ratio
● Design Points
3.80817
1.62
X1 = A: BT
X2 = C: Screw Speed
Actual Factor
B: MC = 24

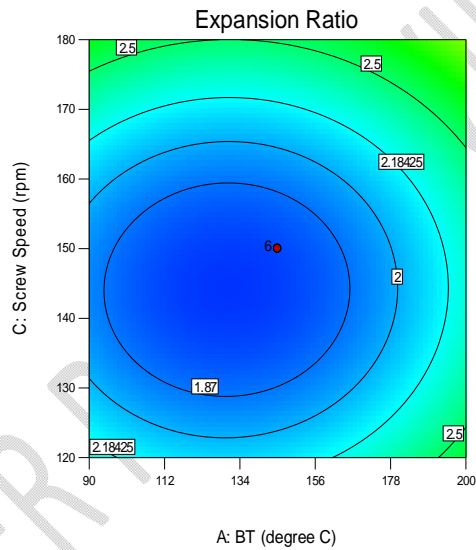


Fig 4a-c: contour plot showing the effect of barrel temperature, feed moisture content and screw speed on equilibrium moisture content.

Comment [Ayman22]: ???

Conclusion

Noodles analogue was produced from water yam, yellow maize, and African yam bean blend using a single barrel extruder. The extrusion variables such as barrel temperature, feed moisture content, and screw speed of the extruder influenced the functional properties of the noodles analogue. The second order model was found to be sufficient in describing the bulk density, water solubility index, water absorption capacity, and expansion ratio. The data obtained from the study could be used for control of product characteristics with more consistent quality.

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Comment [Ayman23]: References style should be corrected according to the journal

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