European Journal of Nutrition & Food Safety

14(11): 106-121, 2022; Article no.EJNFS.92285
ISSN: 2347-5641

Functional Properties of Noodles Analogue from Water Yam, Yellow Maize, and African Yam Bean Mixtures – A Response Surface Methodology

C. E. Kalu [a*], I. C. Alaka [b], K. C. Asadu [a], K. C. OKpara [a] and C. C. Daniel [a]

[a] Department of Food Technology, Akanu Ibiam Federal Polytechnic, Unwana, Ebonyi State, Nigeria.
[b] Department of Food Science and Technology, Ebonyi State University, Abakaliki, Ebonyi State, Nigeria.

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/EJNFS/2022/v14i111269

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/92285

Original Research Article

Received 25 July 2022
Accepted 30 September 2022
Published 16 November 2022

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/cm water solubility index ranged from 4.41 to 6.36%; water absorption capacity ranged from 2.05 to 5.66% and expansion ratio ranged from 1.62 to 3.81respectively. 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.

**Corresponding author: Email: chibuikekalu@gmail.com;*

Keywords: Extrusion; noodles analogue; functional properties.

1. 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 [1]. 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. cayenesis, 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 [2]. Yam is an excellent source of starch. "Water yam (*D. aalata*) is the most economically important yam species which serve as a staple food for millions of people in tropical and subtropical countries" [3], (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).

"In the same way yellow maize has been severally used for the processing of different extruded product maize is the cereal of major importance in the developing world and has the maximum genetic production potential of all the cereal crops" [4]. More attention has been given recently to the increase of the production of maize for human food in Nigeria.

According to Omeire [5], "food legumes serve 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.

"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" [1]. "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" [6]. "It can be deduced from the report that the qualities of product depended on the proportional composition of the composites and flour product functionality" [7]. 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.

2. 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.

2.1 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^{o}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 0.50 mm 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 0.50 mm 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.

2.2 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.

2.3 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 -α - 1,+0, +1 and +α 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.

2.4 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 (Yi) was shown in equations 1 and 2:

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

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

Where Y_1 is the predicted response for proximate composition, β_o (intercept) is the value of the fitted response at the enter point of the design, βi, 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 [8,9]. 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.

2.5 Noodles Analogue Formulation

According to Kalu et al. [1] 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 [10] and thoroughly mixed using Hobeart mixer (Model: A:200; English). Thereafter, the mixture was subjected to extrusion cooking.

2.6 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.

2.7 Functional Properties Determination

2.7.1 Bulk density (BD) of noodles analogues

The bulk density (BD) of sample was determined using the method described by Iwe and Ngoddy [11]. A 10 ml 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 10 ml mark. The final volume of the sample was recorded. Bulk density (BD) was calculated as mass of sample per unit volume of sample (g/cm^3):

$$\text{Bulk Density} = \frac{\text{Weight of Sample (g)}}{\text{Volume of Sample (cm}^3\text{)}}$$

2.7.2 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 [11-14]. The milled samples (2.5 g) were mixed with 30 ml of water at 30±1°C, stirred and allowed to sand for 30 min. The mixture was then centrifuged at 1500 rpm for 15 min. 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 1 g/ml:

WAC = (weight of tube + residue after centrifuge) – Weight of empty tube x 100 / Weight of sample

2.7.3 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" [14]. Triplicate determinations was made and reported as mean value:

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

W_1 = Weight of sample
W_2 = Weight of empty dish
W_3 = Weight of dish + residue after centrifuge

2.7.4 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" [15,16]. Mean values were reported.

3. RESULTS AND DISCUSSION

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 *Yi* are presented in Table 2. The non-significant teams from the model were omitted in the equation below based on students T- ratio [17]. The contour plots for the functional properties are shown in Figs. 1 to 4.

3.1 Bulk Density (BD) of Noodles Analogue

The values of bulk density of the noodles analogue varied from 0.41 g/cm^3 (at barrel temperature of 145℃, 200°C, and feed moisture content of 24%, 30%and screw speed of 99.55rpm and 120 rpm) 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. [18]. The values of bulk density in this study were comparable to the values reported by Jiddere and Filli [19]. "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" [20]. The lower the bulk of extrudate, the higher the expansion ratio of the extrudates as they have been reported to be negatively correlated [11,21]. This actually played in this work. Filli et al. [22] 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 work may be due to high concentration of African yam bean. Shadan et al. [23] 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 3:

Bulk density = 3.96657 – 0.012000BT – 0.099691FMC – 0.016551SS – 1.55303E – 4BT* FMC. (3)

3.2 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 [24,25] on starch based extrudate. Many researchers [12], (Chakraborty et al. 2011), [26-28] 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" [29,30]. 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 term 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 WAC was shown in equation 4:

Water absorption capacity = 2.79395 – 5.22961E3BT – 1.06379FMC + 0.15649SS – 2.37121E4BT*SS + 8.45371E4SS^2 + 0.019132 FMC*FMC – 4.27927E4SS*SS (4)

3.3 Water Solubility Index of Noodles Analogue

The water solubility index ranged in values from 4.41g/ml (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 were close to the values reported by [22,24]. However higher values had also been reported earlier [24] on starch based extrudates. Earlier resarchers [25,19] reported that increase in barrel temperature and feed moisture content increased the water solubility index. Similar findings were observed in this study. Sobukola et al. [26]

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” [31-33]. “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” [34,27]. “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” [35]. Dibyakanta et al. [25] 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” [36]. This is in line with the report of Shadan et al. [23] 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” [37]. The water solubility index ranged in values from 4.41g/g (at barrel temperature of 90^{o}C, feed moisture content of 18%, and screw speed of 180rpm) to 6.36g/g (at barrel temperature of 145^{o}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.

Water solubility index = 1.05225 + 0.028456BT + 0.14955FMC – 1.07197E–3BT*FMC + 4.79167E–4FMC*SS (5)

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

Run	BT (^{o}C)	FMC (%)	SS (rpm)	BD (g/Cm^3)	WAC (g/ml)	WSI (g/ml)	ER
1	90	18	120	0.87	3.31	4.78	2.41
2	200	18	120	0.54	3.28	5.88	2.42
3	90	30	120	0.54	3.60	5.82	2.81
4	200	30	120	0.41	4.29	5.78	3.53
5	90	18	180	0.90	4.64	4.41	2.96
6	200	18	180	0.69	3.04	6.05	2.94
7	90	30	180	0.62	5.66	6.07	3.12
8	200	30	180	0.62	4.79	6.02	3.81
9	52.5	24	150	0.75	4.21	4.92	2.42
10	237.5	24	150	0.43	4.10	6.28	3.01
11	145	13.91	150	0.75	4.17	4.90	2.28
12	145	34.09	150	0.42	5.64	6.36	3.35
13	145	24	99.55	0.41	2.05	5.35	2.95
14	145	24	200.45	0.79	2.04	5.87	3.65
15	145	24	150	0.55	3.21	5.69	1.99
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 resenting the relation between the response and the process variable

Response coefficients	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	-099691*	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}	-155303E4*	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	-5.899711E6	0.8104	1.08732E4*	0.0001
β^{22}	9.92157E4	0.1441	0.019132*	0.0001	-1.43959E5	0.9944	0.010168*	0.0001
β^{33}	4.93088E5	0.773	-4.27927E4*	0.0026	-1.34058E5	0.8710	5.97233E4*	0.0001
R^2	0.9887		0.9531		0.9273		0.9035	
Adj.R^2	0.9455		0.9109		0.8619			

**Significant at 5% levelβ_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} = BT^2; β_{22} = FMC^2; β_{33}= SS^2. 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			
	Df	BD	WSI	WAC	Expansion ratio
Regression					
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**
Residual					
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
Grand total	**19**	**0.420215**	**5.031233**	**14.11**	**10.45**

[a] Significant at $p< 0.005$
*[b] Not significant at **p**> 0.05. WAC = Water absorption capacity, WSI = Water solubility index, ER = Expansion ratio*

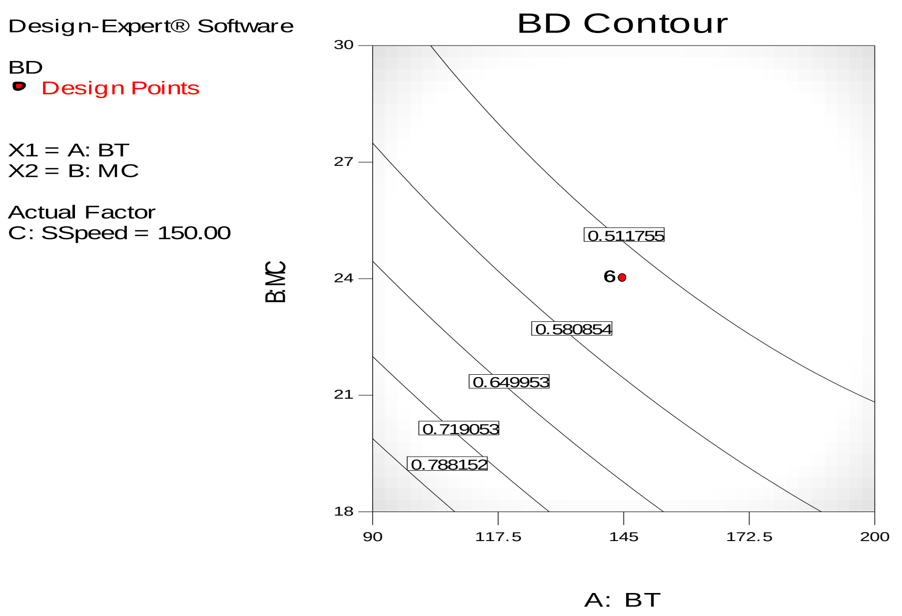
3.4 Expansion Ratio of Noodles Analogue

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 [38,19,22]. Many researchers [19,39], (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 were made in this study. Thymi et al. [40] 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".

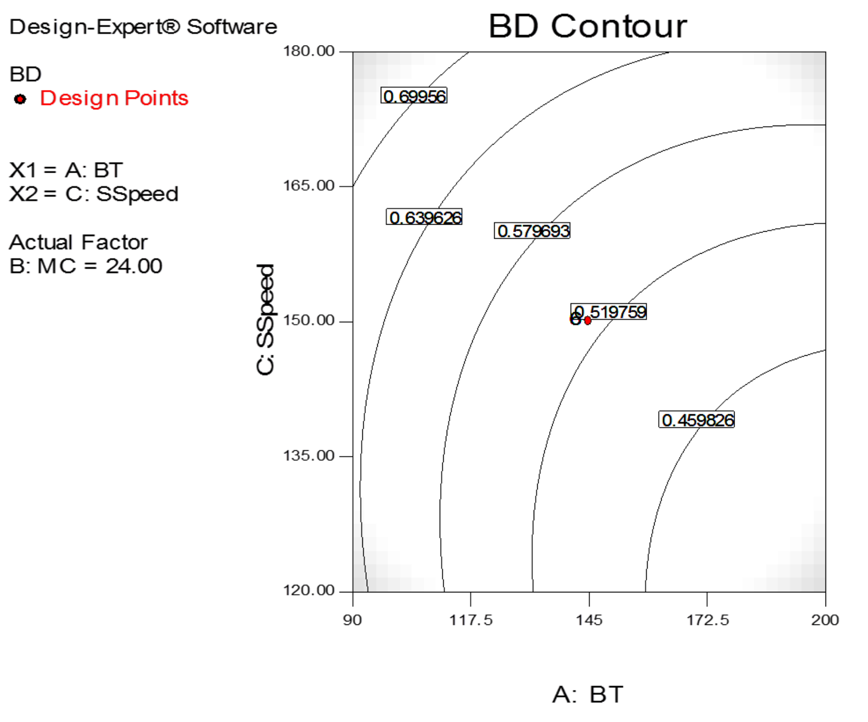
"Food with lower moisture content tends to be more viscous than those of higher moisture content and therefore the pressure differential is similar for higher moisture foods leading to a less expanded product. The expansion process can be described as nucleation in the die, extrudate swelling immediately beyond the die, followed by bubble growth collapse" [41]. 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 6:

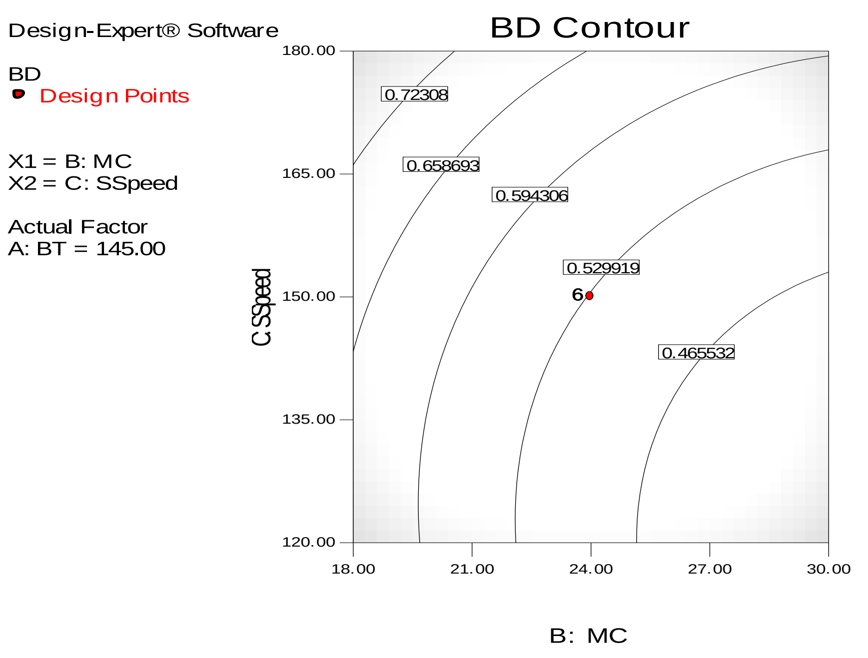
$$\text{Expansion ratio} = 21.098 - 0.04372BT - 0.4615FMC - 0.16328SS + 5.34091E{-}4BT*FMC + 1.08732E{-}4BT^2 + 0.010168\,FMC^2 + 5.97233E{-}4SS^2 \quad (6)$$



1a.

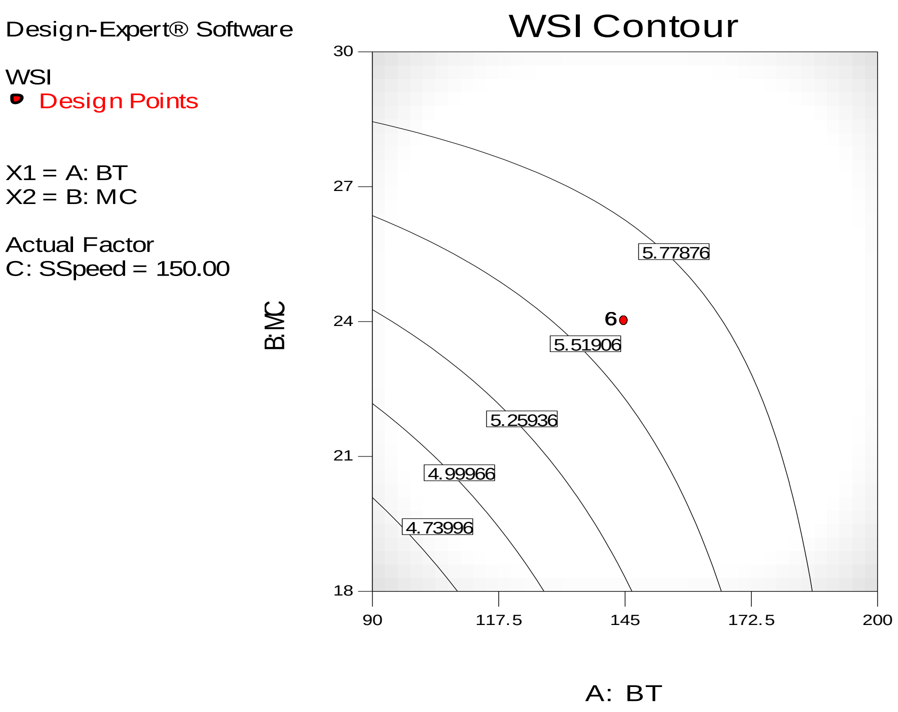


1b.

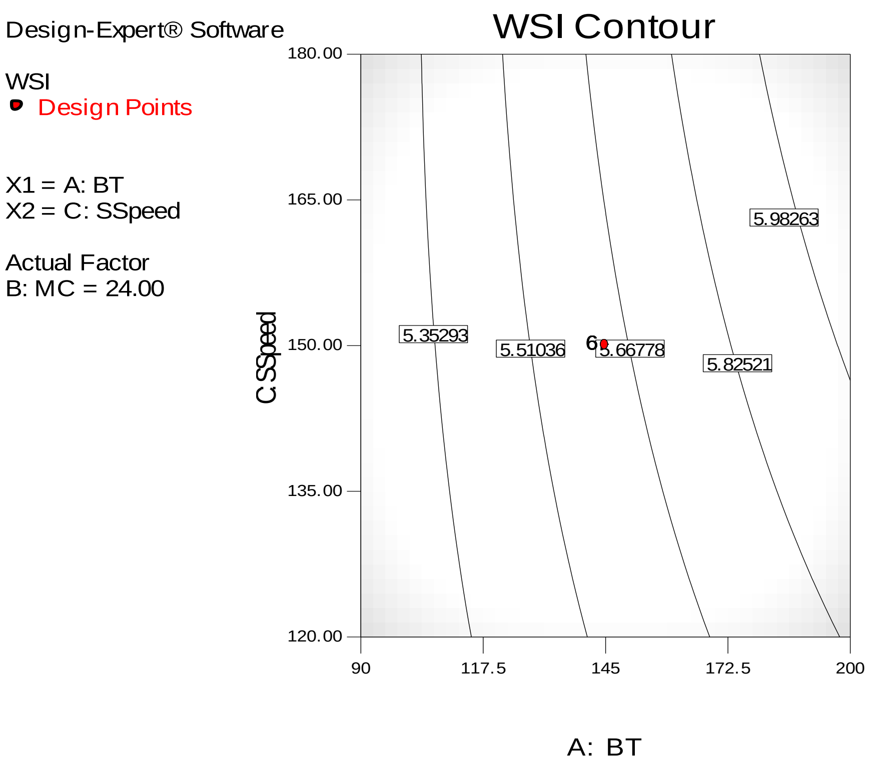


1c.

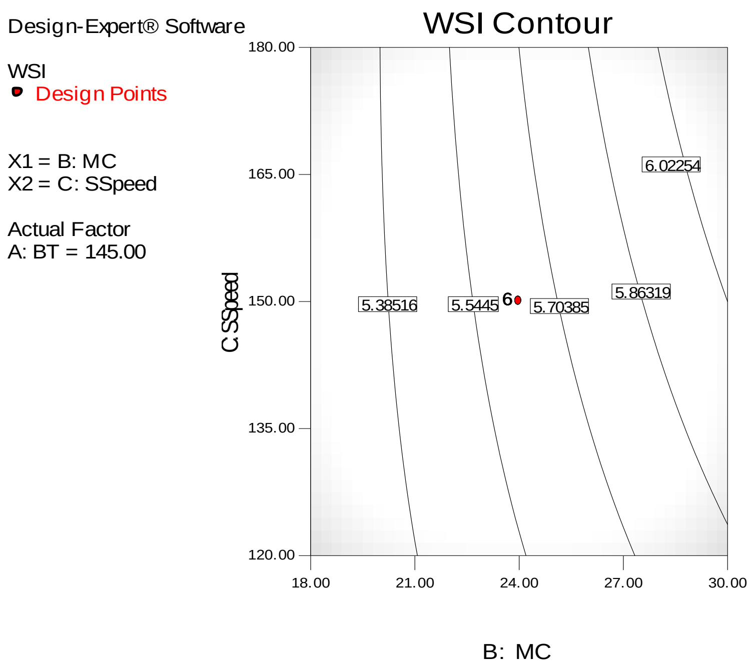
Fig. 1a-c. Contour plot showing the effect of barrel temperature, feed moisture content and screw speed on bulk density


Design-Expert® Software
WSI
Design Points
X1 = A: BT
X2 = B: MC
Actual Factor
C: SSpeed = 150.00
WSI Contour
B: MC
30
27
24
21
18
5.77876
6
5.51906
5.25936
4.99966
4.73996
90
117.5
145
172.5
200
A: BT

2a.

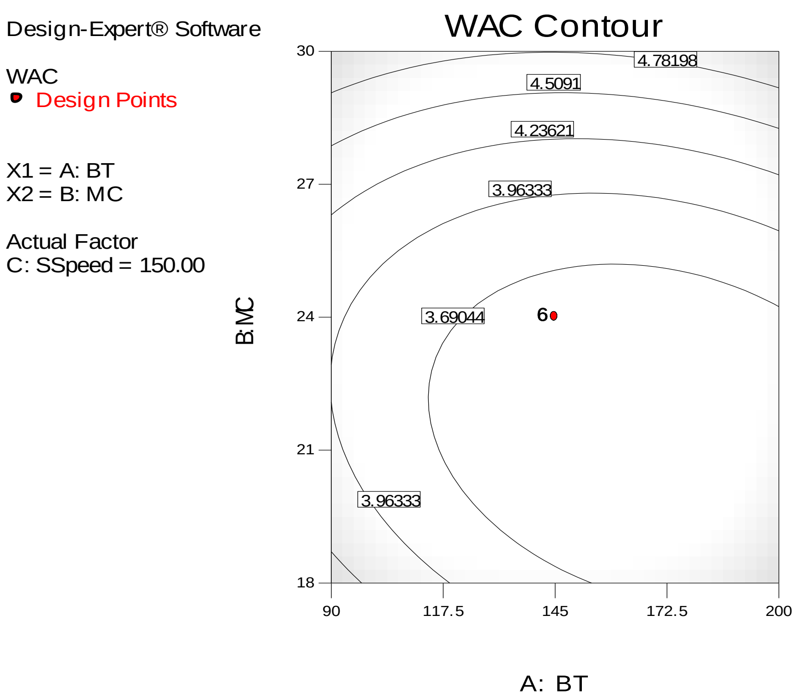

Design-Expert® Software
WSI
Design Points
X1 = A: BT
X2 = C: SSpeed
Actual Factor
B: MC = 24.00
WSI Contour
C: SSpeed
180.00
165.00
150.00
135.00
120.00
5.98263
5.35293
5.51036
6
5.66778
5.82521
90
117.5
145
172.5
200
A: BT

2b.

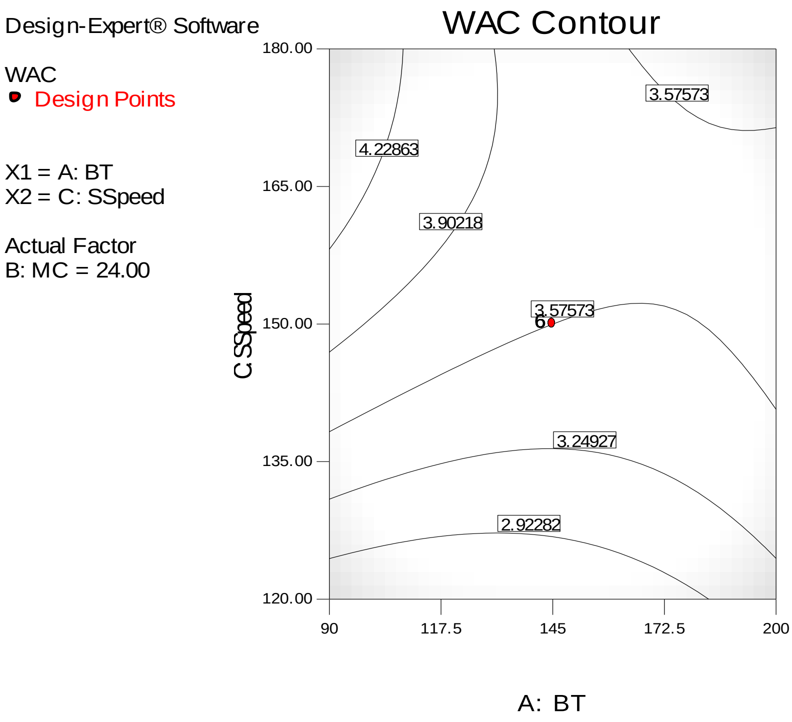


2c.

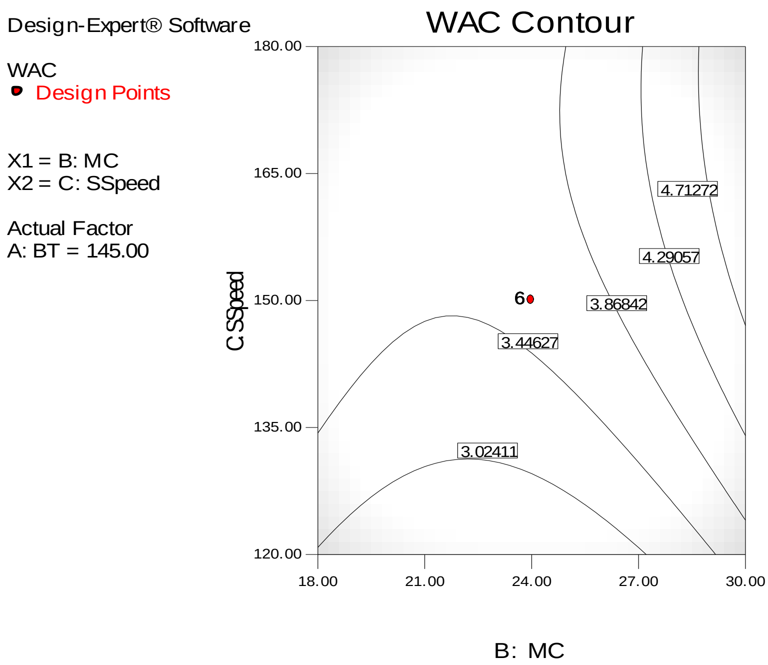
Fig. 2a-c. Contour plot showing the effect of barrel temperature, feed moisture content and screw speed on water solubility index



3a.

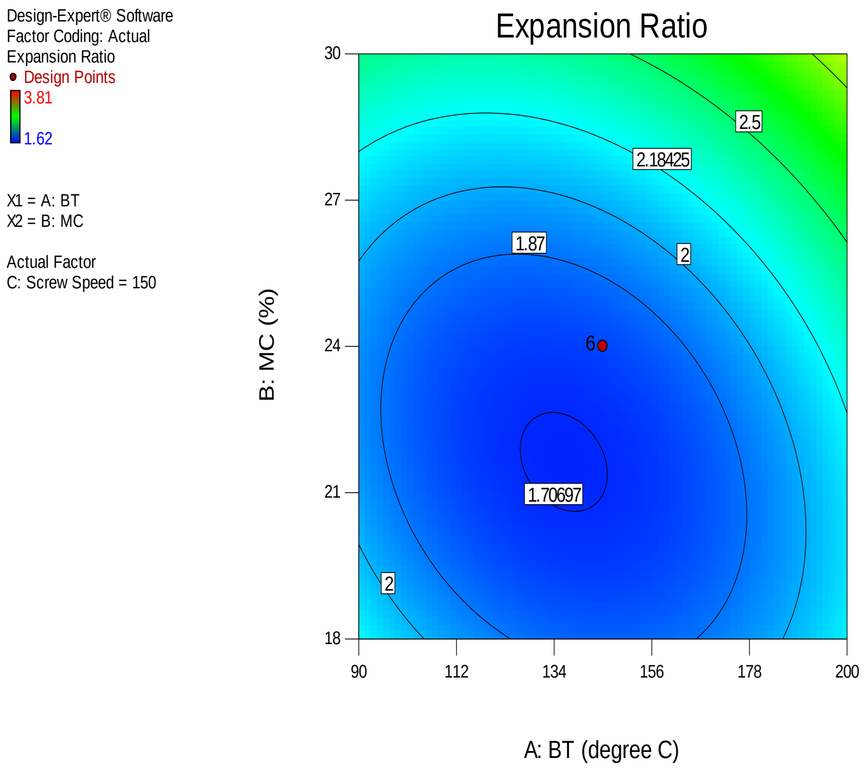


3b.

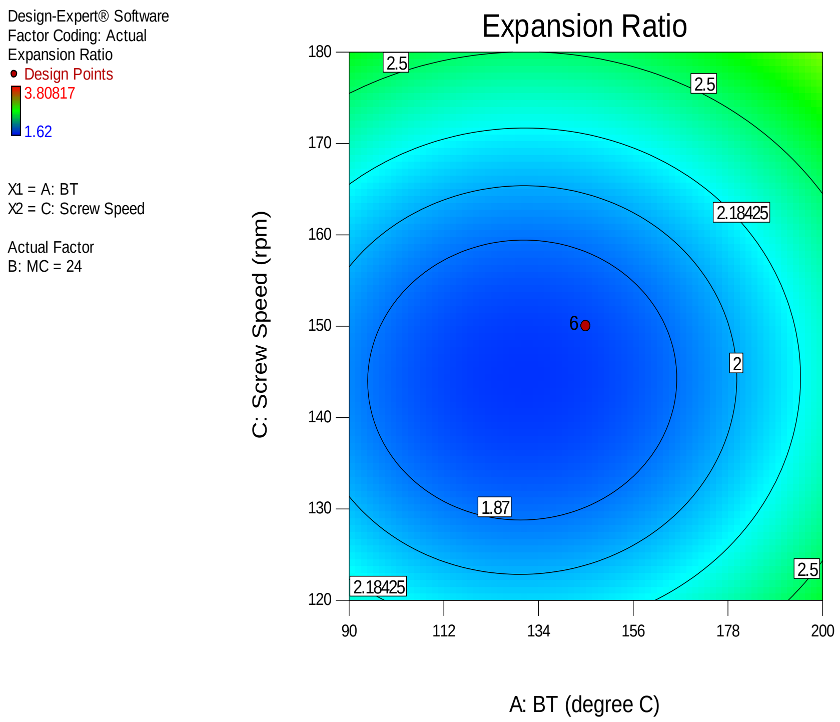


3c.

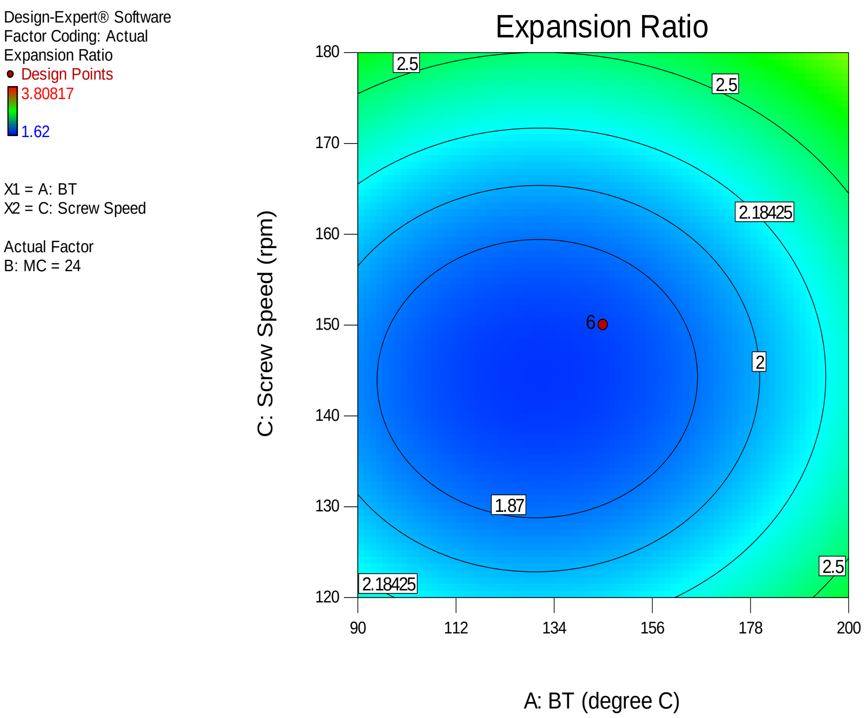
Fig. 3a-c. Contour plot showing the effect of barrel temperature, feed moisture content and screw speed on water absorption capacity


Design-Expert® Software
Factor Coding: Actual
Expansion Ratio
Design Points
3.81
1.62
X1 = A: BT
X2 = B: MC
Actual Factor
C: Screw Speed = 150
Expansion Ratio
B: MC (%)
A: BT (degree C)
30
27
24
21
18
90
112
134
156
178
200
2.5
2.18425
1.87
2
6
1.70697
2

4a.


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
Expansion Ratio
C: Screw Speed (rpm)
A: BT (degree C)
180
170
160
150
140
130
120
90
112
134
156
178
200
2.5
2.5
2.18425
6
2
1.87
2.5
2.18425

4b.



4c.

Fig. 4a-c. Contour plot showing the effect of barrel temperature, feed moisture content and screw speed on expansion ratio

4. 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.

COMPETING INTERESTS

Authors have declared that no competing interests exist

REFERENCES

1. Kalu CE, Alaka IC, Ekwu FC, Ikegwu OJ. Effect of extrusion processing on the cooking characteristics of noodles analogue from water yam, yellow maize and African yam bean. NIFST proceeding of the 43rd Conference and General Annual Meeting. 2019;385-386.
2. Mignouna HDMM Abang, Asiedu R. Harnessing modern biotechnology for tropical tuber crop improvement: Yam (*Dioscorea Spp.*) molecular breed. African Journal of Biotechnology. 2004;212; 478–485.
3. Coursey DG. Dioscoreacea in: Evolution of crop plants. Simmonds NW, Ed Longmans, London and New York. 1967;70–74.
4. Muhammad, Rzwan Razzaq, Faqir, Muhammed Anjum, Muhammed, Issa Khan, Moazzan, Rafig Khan, Muhammad Nadeem, Muhammed Sammen Aved, Muhammed Wasim Sajid. Effect of temperature, screw speed and moisture variations on extrusion cooking behaviour of maize (*Zea Mays*. L). Pak. J. Food Sci. 2012;22(1):12-22.
5. Omeire GC. (2012). Amino acid profile of raw and extruded blends of African Yam bean (*Sphenostylis stenocarpa*) and cassava flour. American journal of Food and Nutrition 2013;2(3):65-68.
6. Kadam ML, Salve RV, Mehrajfatema ZM, More SG. Development and evaluation of

composite flour for missi roti/chapatti. Food processing and Technology. 2012;3:134. DOI:10.4172/2157-7110.1000134
7. Oladumoye OO, Akinoso R, Olapade AA. Evaluation of some physical chemical properties of wheat, cassava, maize and cowpea flours for bread making. Journal of Food Quality. 2010;33:693-708. DOI:10-11
8. Floros JD, Chinnan MS. Computer graphics optimization for product and process development. Food Technology. 1988;42:71–78.
9. Giovanni M. Response surface methodology and product optimization. Food Technol. 1983;47 (11):41-45,83.
10. Gambus H, Sikora M, Zioboro R. The effects of composition of Hydrocolloids on properties of gluten. Free Bread *Acta seintiarum* Polonorum Technologia Alimentria. 2007;6(3):61–74.
11. Iwe MO. Effects of extrusion cooking on functional properties of mixtures of full-fatsoy and sweet potato. Plant Foods Hum. Nutr. 1998;53:37-46.
12. Anderson RA. Water absorption and solubility and amylograph characteristics of roll cooked small grain products. Cereal Chem. 1982;59:265-269.
13. Sefa-Dedeh S, Saalia FK. Extrusion of maize-cowpea blends in a modified oil expeller. J.Sci. Food Agric. 1997;73: 160-168.
14. Rampersed R, Badrie N, Comisciong E. Physico-chemical and sensory characteristies of flavoured snaks from extruded cassava/pigeon – pea flour. Journal Food Science. 2003;68(1): 363-367.
15. Halek GW, Paik SW, Chang KLB. The effect of moisture content on mechemical properties and texture profile parameters of corn meal extrudates. Journal of Texture Studies, 1989;20: 43-55.
16. Artz WE, Warren C, Villota K. Twin – screw extrusion modification of z corn fibre and corn starch extruded blend. J. Food See. 1990;55(3):746–754.
17. Khuri AI, Cornell JA. Response surface design and analyses. New York: Marcell Dekker. Montomery DC. Design and analysis of experiments. Singapore: Wiley; 1987.
18. Oluwole OB, Awonrin SO, Henshaw FO, Elemo GN, Benkole AK, Olatunji O. (). An evaluation of an extrusion cooking process of white yam *Dioscorea rotundata* and white bambara groundnut (*Vigna subterranean*) blends proc. 11th ISTR – AB Syrup: Kinshasa, DR congo. 2010; 587–600.
19. Jiddere G, Filli KB. Physicochemical properties of sorghum malt and bambara groundnut based extrudates. J. Food Sci. Technol. Nepal. 2016;9:55–65.
20. Saini CS. Preparation of corn flour based extruded product and evaluate its physical characteristics. World Academy of Science, Engineering and Technology International Journal of Biologival, Agricultural, Food and Biotechnological Engineering. 2015;9(8):929–936.
21. Nwabueze TU. Growth performance of rats fed with raw and extruded African bread fruit based complementary diet. A response surface analysis. J. Sci. Food Agric. 2008;88(3):522-528.
22. Filli KB, Nkama I, Jideani VA, Ibok UI. Effects of process variabls on the hydration properties and acceptability of extruded millet – soy bean blends for fura manufacture: A Nigerian traditional food. Publication British Food Journal. 2013;115: 884–898.
23. Shadan MR, Waghray K, Khoushabi F. Formulation, preparation and evaluation of low-cost extrude products based on cereal and pulses-food and nutrition science. 2014;5:1333–1340.
24. Yadav KC, Pashupati M, Pramesh GD, Ranjit R, Ghanendra G, Sushiel D. Effect of incorporation of cassava flour on characteristics of corngrit-rice grit chickpea flour blend expanded extrudate. African journal of Food Science. 2015;9(8): 448-455.
25. Dibyankanta, S, Laxmikant SB, Rijayalakshmi G. (2013). Effect of feed composition, moisture content and extrusion temperature on extrudate characteristies of yam – corn – rice based snack food. Published Online; 2013. Doi 10.1007/s/3197 – 013 – 1181 – x PMCID: PMD 4348316
26. Sobukola OP, Babajide JM. Ogunsade O. Effect of brewer spent grain addition and extrusion parameters on some properties of extruded yam starch-based pasta. J. food process. preserv. 2012;(2):5:163-171.
27. Ding Q, Ainsworth P, Tucker G, Marson H. The effect of extrusions on the physicochemical properties and sensory ch Dhital S, Katawal S, Shrestha A. (2010). Formation of resistant starch during

processing and storage of instant noodles. Int. J. Food Properties. 2005;13:454–463.

28. Singh S, Gamiah S, Wakeling L. Nutritional aspects of food extrusion: A review. International Journal of food Science and Technology. 2007;42:916- 929.
29. Filli KB, Nkama I, Abubakar UM, Jideani VA. Influence of extrusion variables on some functional properties of extruded millet-soybean for the manufacture of fura: A Nigerian traditional food. African Journal of Food Science. 2010;4:342-351.
30. Anderson RA, Conway HF, Peplinski AJ. Gelatinization of corn grit by roll and extrusion cooking. Starch-stark. 1970;22: 130-135.
Available: http: dx
Doi.org/10.1002/star.19700220408
31. Oluwole OB. Effect of thermo extrusion cooking on physiochemical, textural and sensory qualities of yam (*Dioscorea rotundata*) and bambara groundnut (*Voandezia subterranean* L. Thou) blends. Unpublished Ph. D thesis, UNAAB, Abeokua, Nigeria. 2008;117–213.
32. Petitot M, Boyer L, Minier C, Micard V. Fortification of pasta with split pea and faba bean flours: Pasta processing and quality evaluation. Food Res. Int. 2010;43: 634-641.
33. Adedotun H, Adebowale AA, Olayiwola IO, Shittu TA, Sanni LO. Production and quality evaluation of noodles from sweet potato starch. Journal of Culinary Science and Technology. 2015;13(1):79-93. DOI:1080/15428052.2014.952479
34. Colonna P, Tayeb J, Mercier C. Extrusion cooking of starch and starchy products In: Mercier C, Linko CP, Harper JM Eds. Extrucsion cooking, American Associetion of Cereal Chemists, Inc, St Paul. 1989; 247-319.
35. Sriburi P, Hill SE. Extrustion of cassava starch with either variations in ascorbic acid concentration or P^H. International Journal of Food science and Technology. 2000;35:141–154.
36. Oikonomou NA, Krokida Mk. Literature data compilation of WAI and WSI of extrudate food products. Int. J. Food properties. 2011;14:199-240.
37. Balandran–Quintana RR, Barbosa–Canovas GV, Zazuet –Morates JJ, Anzaddria, Morates A, Quinteno-Ramos A. Functional and nutritional properties of extrude whole pinto bean meal (*Phaseolus vulgaris* L.). J. Food Sci. 1998;63:113–116.
38. Oliveira CT, Glutierrez EMR, Caliari M, Monteiro MRP, Labanca RA, Carreina RL. Development and characterization of extruded broken rice amd lupine. American Journal of Plant Science. 2015;6: 1928-1936.
39. Filli KB, Nkama I, Abubakar UM, Jideani VA. The effect of extrusion conditions on the physicochemical properties and sensory characteristics of millet – cowpea basesd fura. European Jornal of Food Research & Review. 2012;2:1–23.
40. Thymi S, Krodida MK, Pappa A, Moroulis ZB. Structural properties of extruded corn starch. J. Food Eng. 2005;68:579–526.
41. Kokini JLC, Hang CN, Lai LS. The role of rheological properties on extrudate expansion. In Kokini JK, Ho CT, Karwe MR. (Eds.). Food extrusion science and technology. Marccl Dekker, New York. 1991;345-360.

Peer-review history:
The peer review history for this paper can be accessed here:
https://www.sdiarticle5.com/review-history/92285