Original Research Article

Engineering parameters responses during extrusion processing of Noodles Analogue from water yam, yellow maize, and African yam bean flour mixture

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Abstract

This study investigated the effect of extrusion process on engineering properties of noodles analogue from water yam, yellow maize, and African yam bean. Flour blend from water yam, yellow maize, and African yam bean were produced using the standard method of dry milling and was used to extrude noodles analogue using a brabender single screw laboratory extruder (Duisburg DCE 330 model) fitted with 3.0mm 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 for the study and data was generated at ($p<0.05$). Results of result of the engineering properties of noodles analogue showed that toque ranged from 22.4 to 60.50Nm/s, mass flow rate ranged from 33.90 to 109g/min^{-1}, specific mechanical energy ranged from 100.19 to 385.97kj/kg, and the residence time ranged from 22 to 55s in this study. 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. It was generally observed that the changing of feed moisture content, barrel temperature, and screw speed influenced an acceptable torque, mass flow rate, and residence time during the extruder operation. The noodles analogue produced at this cheap machine operating conditions could be projected for commercial production.

KEY WORDS: Extrusion, Noodles analogue, Engineering properties

Introduction

Yam is one of the staple foods in Nigeria and other tropical African countries. The yams are members of the genus *Dioscorea*. Yams generally have high moisture content; the dry matter is composed mainly of starch, vitamins, sugars and minerals. Water yam (*Dioscoreaalata*) 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 sugar content necessary for diabetic patients (Udensi*et al.*, 2010).

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Maize (Zea mays) is an important cereal grain in the world and is widely utilized in various forms such as human food, animal fed formulation and industrial raw materials (Coutois*et al.*, 1991). Maize flour is a staple food for many people in Africa, where it is greatly utilized in the

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production of some Nigerian convenience foods such as ogi, Agidi, moi-moi, asusuo, nworii among others, is also used in the production some industrial food and livestock feed. Maize flour have great nutritional value as the contain72% starch, 10 % protein, 4.8 % oil, 8.5 % fiber, 3.0 % sugar, and 1.7 % ash (Chaudhary, 1983), and has been used extensively and successfully in the production of various baked foods product.

African yam bean (*Sphenostylisstenocarpa*), a lesser- known legume grows along with other tropical crops.The seeds and tubers are the two organs of economic importance providing food for human and livestock. However, there is cultural and regional preference for each in the meals of the Africans: West African prefers the seeds to the tubers while the tubers are important as food in East and Central Africa, especially among the Bandudus, the Shabas and the tribe at Kinshasha in Zaire (Potter, 1992; Nwokolo, 1996)The seed is highly nutritious and are used for various dietary preparations and supplementation of the protein requirements for many families throughout the year. However, the legume's potential is largely unexploited, due to its characteristic problem of hard to cook phenomenon, poor digestibility and flatulence

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Noodles are strips or strand cut from a sheet of dough from wheat flour, water, and either common salt or a mixture of alkaline salts. It is widely consumed by children and adults in Nigeria (Kim and De Ruther, 1996). Other flour types are on a trial for noodle product. Noodles can be classified based on shape, preparation process, sales form, and raw material; when a noodle is produced from non-wheat flour it is described as noodles analogue.

Extrusion has become a popular processing technique in the feed, cereal and snack food industries (Delgado-Niebes etal., 2012). Extrusion is one of the most versatile unit operations that has subunit operations within its mechanism. Extrusion systems consist of barrel housing with one or two rotating screws, a preconditioner and, an accompanying machine control system (Sorensen, 2012). The goals of the extrusion process includes, cooking sterilization, expansion, texturization,and product shaping (Liu and Rosentrater, 2011). Extruders operate continuously and have high massflow rate up to 315kgb- for snack foods and 9000kg-for dry expanded petfoods (Mans, 1982).

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During the extrusion process, changes of the extrusion conditions, especially barrel temperature, screw speed, and feed moisture content can have significant effects on the resulting chemical, physical, and engineering properties of the extrudate (Ratankein etal, 2012). Engineering properties are important because they impact on the product characteristics and extruder performance and ultimately the production economics.Many product parameters have been reported on water yam based noodles analogue; however, there is no report on the engineering aspects, even though it might have its own challenges. Therefore, the objective of this study is to determine the engineering parameters responses during extrusion processing of noodles analogue from water yam, yellow maize, and Africa yam bean flour mixture.

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Materials and Methods

Procurement of Raw materials: 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: According to (Kalu*et al*., 2019) water yam tubers were washed, peeled manually with a stainless steel knife under water containing 0.20% solution of sodium metabisulphate. The peeled yam were transferred into another container containing a potable water of the same concentration 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.

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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 grain were sorted to eliminate contaminants, cleaned in an aspirator (Model: OB 125 Bindapst Hungary) and washed located at the Food Processing Laboratory of Federal Polytechnic, Mubi. Cleaned grains were soaked for 3h at room temperature and dehulled. The dehulled grains were dried at 60^{o}C for 10h 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

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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 (^{o} C), feed moisture content, FMC (%) and screw speed, SS (rpm) on proximate composition of the noodles analogue. Each variable was evaluated 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.

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 equation 1 and 2

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

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

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, $\beta_{ii,}$ 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

Every 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*etal.,* 2007) and thoroughly mixed using Hobeart mixer (Model: A:200; English). Thereafter, the mixture was subjected to extrusion cooking.

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Extrusion cooking

A single screw Brabender laboratory extruder (Model DCE 330, New Jersey, USA, Plate iv) 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

Engineering properties of Noodles analogue(extrudates)

Torque (T)

Torque (t) was read directly from the torque indicator on the control panel as each sample was collected and reported in Ampere (Maga and Kim, 1989 and Arora et al., 1993). Mean of triplicate readings were recorded for each run

Mass flow rate

The Mass flow rate was obtained by determining the weight of the extrudate flowing out of the die at 30s interval during steady state operation (Iwe et al., 2001). Mean of five determinations for every run was calculated.

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Specific mechanical energy (SME)

SME was determined based on the ratio of power consumption (watts) to throughput (kg/h) in triplicates. Power consumption was calculated from the product of torque and voltage determined for each extruder speed (Iwe et al., 2001).

Residence time (RT)

The methods reported by earlier researchers (Likimani et al., 1990 andFichtali et al., 1995) for determination of residence time (RT). When steady state-operation conditions were reached as indicated by constant torgue (T) and extrusion temperature (ET) (Fichtali et al., 1995) the extruder was assumed to operate -at a choke-fed-condition (Likimani et al., 1990). At that point, 0.05g of congo red tracer (Hong et al., 1991) was manually introduced into the middle of the feed hopper. A timer (stop watch) was started immediately and samples of extrudates were collected as soon as the timer was started at 5s interval at the die end until the red dye was no longer visible (Likimani et al., 1990). The minimum residence time (tn) the feed particles spent in the extruder from introduction of the congo red indicator at the extruder feed port until it first appeared at the die was noted.

RESULT AND DISCUSSION

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

EXP Run	BT (^{o}C)	FMC (%)	SS (rpm)	Torque (Nm/s)	Mass flow ratio (MFR) (gmin^{-1})	SMEkj/ kg	RT(S)
1	90	18	120	22.4	100	100.19	50
2	200	18	120	44.8	109	200.24	48
3	90	30	120	47.4	99.11	288.24	48
4	200	30	120	33.22	89.00	250.85	38
5	90	18	180	33.78	67.99	360.82	35
6	200	18	180	42.10	74.10	232.10	36
7	90	30	180	29.99	70.00	276.33	29
8	200	30	180	34.22	57.90	111.60	31
9	52.53	24	150	31.11	33.90	120.00	30
10	237.5	24	150	33.20	65.20	124.15	40
11	145	13.91	150	39.90	74.50	180.00	29
12	145	34.09	150	38.40	75.21	163.25	45
13	145	24	99.55	40.15	78.00	183.56	55
14	145	24	200.45	41.20	75.80	121.70	22
15	145	24	150	60.50	88.90	385.97	34
16	145	24	150	32.66	87.88	168.37	33
17	145	24	150	34.11	88.99	157.03	35
18	145	24	150	34.33	89.90	160.71	33
19	145	24	150	32.22	90.10	155.71	43

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20	145	24	150	33.12	88.20	181.82	33

EXPT = experimental; BT = Barrel temperature; FMC = Feed moisture content; SS = Screw speed; SME= Specific mechanical energy; RT= Residence time.

The values of Torque ranged from 22.40 (at barrel temperature of 90^{o}C, feed moisture content of 18% and screw speed of 120rpm) to 60.50Nm/s at (barrel temperature of 145^{o}C, feed moisture content of 24%, and screw speed of 150 rpm) indicating that increase in barrel temperature, feed moisture content increased the toque value.The values in this study is in agreement with the values reported for extrudate properties of water yam (Okee*t al*., 2010) and aquafeeds containing DDGS and tapioca starch (Rosentrater, 2009). The torque is related to the power consumed by the extruder to turn the extrusion screw and about 98% of the power input into the extruder is used for shearing and less than 1.5% is consumed in pumping. The results were in line with observed extruder trends that increase in feed moisture content lead to increase in torque values. Toque input to the screw is determined at the coupling that connects the extruder device to the transducers (Haper,1989). The value of mass flow ratio ranged from 33.90 at (barrel temperature of 52.53, feed moisture content of 24%, and screw speed of 150rpm to 109g/min^{-1} (at barrel temperature of 200^{o}C, Feed moisture content of 18% screw speed 120 rpm) indicating that increase in mass flow return value was favouredby increase in barrel temperature at reduced feed moisture content and screw speed respectively. The values in this study is in agreement with the values reported for extrudate properties of water yam (Okee*t al*., 2010). Mass flow rate in a single screw extruder is dependent on the drag flow developed by the rotation of the screw and the pressure developed due to the restriction of the die (Mercier *et al*., 1989; Rosentrator*et al*., 2009)

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The value of specific mechanical energy ranged from 100.19 at (barrel temperature of 90^{o}C, feed moisture content of 18%, and screw speed of 120 rpm to 385.97KJ/kg at (barrel temperature of 145^{0}C, feed moisture content 24%, and screw speed of 150 rpm) indicating that specific mechanical energy increase was favoured by increase in barrel temperature, feed moisture content, and screw speed. The values in this study is within the values reported for extrudate properties of water yam (Oke*et al*., 2010). However, Oke*et al*. (2010) related that there were no clear effects on specific mechanical energy consumption due to the changes in processing barrel temperature, except for the results due to the changes in feed moisture content and the screw speed. Other researchers (Hanna, 1987 and Fichtali*et al*., 1995) reported that specific mechanical energy was affected by change in feed composition. Studying the specific mechanical energy (SME) is for a common way to quantify the severity of treatment of fragmentation of starch molecules in both single and twin-screw extruders (Colonna *et al*., 1989; Rosentrator*et al*., 2009) during processing. Specific mechanical energy integrates extrusion responses, such as net torque, screw speed and the product mass flow rate (Onwulata*et al.,* 1998).

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Specific mechanical energy represents consumption per unit mass of product (Liang *et al*., 2002) and ranges between 100 and 600kj/kg in single screw extruders but usually higher in twin-screw extruders.

The value of Residence time ranged from 22 at (barrel temperature of 145^{o}C, feed moisture content of 24%, and screw speed of 200.45 rpm to 55s at (barrel temperature) of 145^{o}C, feed moisture content of 24%, screw speed of 99.55 rpm) indicating that residence time increased with decrease in screw speed but at constant barrel temperature and feed moisture content respectively. The values in this study is within the values reported for extrudate properties of water yam (Oke*et al*., 2010). However, Anuonye*et al*.(2007) reported that resident time was a function of screw speed, barrel temperature, and feed moisture content. Resident time is used to measure the time particles spend in the extruder as well as used as indicator of the time at different screw speeds. Literature reports indicate residence time values of 30 to 80s (Colonna *et al*., 1989) depending on the extrusion condition (Iwe*et al*., 2001) different screws and barrel geometries (Mosso*et al*., 1982).

CONCLUSION

Noodles analogue was produced from water yam yellow maize, and African 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 engineering parameters of the noodles analogue. The torque ranged from 22.4 to 60.50Nm/s, mass flow rate ranged from 33.90 to 109g/min^{-1}, specific mechanical energy ranged from 100.19 to 385kj/kg, and the residence time ranged from 22.0 to 55.5.

The second order model was found sufficient in describing the Torque, mass flow rate, specific mechanical energy, and Residence time of the extruder. The data obtained from the study could be used for control of product characteristics with more consistent quality. The noodles analogue produced at this cheap machine operating condition could be projected for commercial production.

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