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Effect of Extrusion Variables on the Extrudate Properties of Wheat-plantain Noodle

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Abstract

Matured green plantain (*Musa paradisiaca*) was processed into plantain flour and composted with wheat flour prior to extrusion. In this study, the effect of extrusion cooking variables [Barrel Temperature (BT, Feed Moisture Content (FMC) and Screw Speed (SS)] on the extrudate properties of whate-plantain noodles were investigated, while predictive models were also developed. Results obtained showed that changing the cooking variables significantly ($p \le 0.05$) affected all the extrudate properties studied. An increase in the screw speed (6.3-8.4 m/s) and feed moisture content (40-50%) resulted in a substantial increase in the expansion ratio (48%), residence time (62%) and specific mechanical energy (83.6%) Likewise, an increase in barrel temperature increased the mass flow rate (64.5%) of the extrudates significantly ($p \le 0.05$). Regression analysis also revealed that the screw speed and the feed moisture content were the major extrusion cooking variables, as they showed significant ($p \le 0.05$) linear quadratic and interaction effects on mass flow rate, residence time, specific mechanical energy and expansion ratio. The study showed that optimization of the combined effects of a 50% feed moisture content, 6.3 m/s screw speed of 6.3 m/s and a 100°C barrel temperature gave the optimum processing conditions for expanded wheat-plantain noodles. These variables are important considerations for commercial and mass production of wheat-plantain noodles.

Keywords: Noodle; Extruder; Feed moisture content; Screw speed; Barrel temperature

Introduction

Plantain is an important food crop in Nigeria as well as in all humid tropical zones of Africa. Over 80% of the harvested plantain is obtained during the period of September to February of the year, and there is much wastage of this crop during this peak period as a result of glut resulting in seasonal availability and limitations of use. Wheat flour is the main raw material for noodles production. Its cultivation thrives best in temperate regions worldwide [1]. It is one of the major raw material for wide range of food products ranging from baked foods to extruded products, such as pasta and noodles.

Due to health benefits, nutritional improvement and improved utilization of local crops, attention is shifting towards substituting wheat in noodles production with a locally cultivated crop such as plantain. This fruit is an excellent source of nutrient when eaten. Furthermore, it possesses a high carbohydrate content, low fat content, they are good source of vitamins and minerals particularly iron, potassium, calcium. The sodium content is low in dietary terms hence the recommendation is made for low sodium diets. It is recommended to produce plantain flour from green fruits since it has high starch content of about 35% on wet basis [2].

Extrusion cooking process is a high temperature short time (HTST) process in which moist food material is fed into the extruder where the desired temperature and pressure are obtained over the required period of residence time [3]. For cooking of the product generally, external heat is not applied but it is achieved through shear and friction in the extruder. Extrusion cooking is used worldwide for the production of expanded snacks, starch, modified ready to eat cereals baby foods, pasta and pet foods [4,5]. This technology has many distinct advantages including versatility, low cost, better product quality and no process effluents [6]. Recently, research into the field of manufacturing and processing of pasta eliminates the needs for cooking for as long as it results in the production of noodles [7]. This therefore necessitates the need to examine the influence of extrusion cooking variables on plantain-wheat noodles and its extrudates. The objectives of this work are to evaluate the influence of some extrusion cooking variables (feed moisture content, screw speed and barrel temperature) on wheat-plantain noodles and to predict the optimum cooking temperature-time for the production of wheat-plantain noodles using response surface methodology (RSM).

Materials and Methodology

Fresh matured green plantain (*Musa paradisiaca*) and wheat flour were respectively obtained from Siun and Kuto markets in Abeokuta (7.15°N, 3.35°E), Ogun state, Nigeria.

Processing of fresh matured green plantain to flour

The plantain fruits were washed with distilled water, peeled and sliced to about 5 mm diameter using a stainless steel knife. The slices were subsequently steamed for 5 minutes to inactivate enzymes. Subsequently, the pulp was drained and dried in an oven drier (Gellamp, England) at 60°C for 24 hours, after which the dried plantain slices were milled into flour using attrition mill (Figure 1). The flour were then screened through a 0.25 mm sieve and packed in high density polythene (HDPE) bags, using the methods of Ojure and Quadri [8].

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Extrusion process of wheat-plantain noodles

Extrusion process of wheat-plantain noodles (Figure 2) was done as described by Oke, et al. [9], using a locally fabricated laboratory scale single screw extruder. The flours were mixed at a ratio of 70% wheat and 30% plantain flour. Based on the most stable product expansion and stability of the extruding product, the following extrusion conditions were used; feed moisture content varied at 30, 40 and 50%; barrel temperature of the extruder was set at 80, 100 and 120°C; screw speeds 6.3, 7.3 and 8.4 m/s, while a 2.5 mm restriction die was used. Constant feeding rate was kept throughout the experiments.

Determination of moisture content

The moisture content of the plantain was determined according to AOAC [10] method. 5 g of the samples were accurately weighed into an evaporating dish and dried in an oven until constant weight.

Measurement of extrudate properties

Torque (T): This was determined by reading directly from the extruder operation panel during extrusion runs according to Oke, et al. [9]. A value of 2.0 A was subtracted from the total obtained being the motor driving force. Means values of torque were expressed in Nm^{-1}. Hence, torque was calculated as follows:

$T = r \times f$

$T = r \times f \times \sin\theta$

Where; r = displacement vector (a vector from the point from which torque is measured to the point where force is applied); F = force vector; × = denotes the cross product; θ = angle between the force vector and the lever arm vector.

Mass flow rate (MFR): Mass flow rate was determined using the methods of Iwe, et al. [11] and Oke, et al. [9]. A constant torque and extrusion conditions were reached (steady state operation). Subsequently, a stopwatch was used to time the entry of the samples (beginning) until they were flowing out of the extruder die orifice at 60s interval. Mean weight of triplicate collections were collected for each run, as the means flow rate for that run in kilogram per second.

Hence;

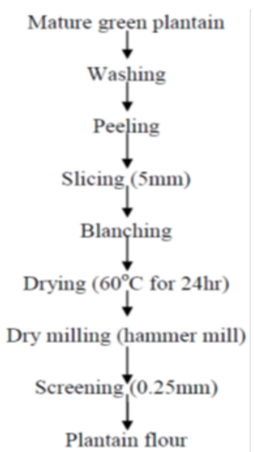

Figure 1: Flow chart for production of plantain flour (Source: Ojure and Quadri [8]).

Figure 2: Flow chart for the production of wheat-plantain noodles using extruder (Source: Oke, et al [9]).

Mass flow rate = weight/time (kg/s)

Specific mechanical energy (SME): Specific mechanical energy is defined as the total mechanical energy input to obtain 1g of extrudate (Jkg^{-1}).The SME was thus determined using the methods of Rosentrater, et al. [12] and Oke, et al. [9].

$SME = T = \omega \times 60/M_{feed}$

where; SME = specific mechanical energy consumption (Jkg^{-1}); T = Net torque exerted on the extruder drive (Nm); ω = angular velocity (rpm); M_{feed} = mass flow rate of the raw sample (kg/s)

Therefore, M_{feed} was calculated using:

$M_{feed} = M_{prod} \times 1\text{-}M_{cf}/1\text{-}M_{ci}$

where; M_{prod} = mass flow rate of the extrudate (kg/s); M_{cf} = moisture content of the collected extrudate (% w.b.); M_{ci} = moisture content of the raw sample before entering the extruder (% w.b.)

Residence time (RT): Residence time during extrusion was determined using the methods of Oke, et al. [9]. The RT (s) was expressed as the time taken for a print of red colour to show up at the die orifice.

Expansion ratio (ER): Expansion ratio was determined as described by Conway and Anderson [13] and Rosentrater, et al. [12]. The ratio of diameter of extrudate and diameter of die was used to express the expansion of the extrudate. The diameter of extrudate was determined as the mean of 10 random measurements made with a vernier caliper. The expansion ratio was calculated as

Expansion ratio = diameter of extrudate (mm)/die diameter (mm)

Response surface methodology (RSM)

All results obtained were subjected to RSM. This was used to build up mathematical models that will facilitate the qualitative interpretation and description of the relationships existing between the selected dependent extrusion variables selected (torque, MFR, RT, SME, ER) and the independent extrusion variables (FMC, SS and BT). The extrusion cooking was carried out adopting a five variable response surface analysis using a central composite design (CCD) which was nearly orthogonal.

The generalized regression model fitted was $Y = Bo + b_1FMC + b_2SS + b_3BT + b_{11}FMC^2 + b_{22}SS_2 + b_3BT^2 + b_{12}FMC*SS + b_{13}FMC*BT$

+ b_{23}SS*BT + ϵ. Where Y = objective response, FMC = feed moisture content, SS = Screw speed, BT = barrel temperature and ϵ = random error in which the linear, quadratic and interaction effects were involved.

The resulting models were tested for significance using Analysis of variance (ANOVA) and coefficient of determination (R^2). This was determined by SAS 9.1 (SAS Inc. USA). Significant terms were accepted at $p > 0.05$. The R^2 of 0.6 was accepted for predictive purposes [9].

Results and Discussion

The wheat-plantain flour extrudates properties which include torque, residence time, mass flow rate, specific mechanical energy and expansion ratio are shown in Table 1. The effect of FMC, SS and BT on the extruder torque, MFR, RT, ER and SME are shown in Figures 3-7, respectively. The extruder torque (T) ranged between 68.75 and 91.66 Nm, the mass flow rate (MFR) ranged between 2.07 and 3.04 kg/s, the residence time (RT) ranged between 49.0 and 62.0 s, the expansion ratio (ER) ranged from 2.4 to 6.0 and the specific mechanical energy (SME) ranged between 10459.23 and15505.61 kJ/s. According to Oke, et al. [9], the estimated torque of an extruder is related to the power consumed and approximately 98% of this power input is utilized for shearing and less than 5% is consumed for pumping. The results were similar with the observed extrudate that increase in feed moisture content leads to increase in torque values [9,11,13]. Increase in screw speed at constant feed moisture content and barrel temperature leads to decrease in torque value, residence time and specific mechanical energy, while mass flow rate and expansion ratio of the extrudate increases [5,14].

The regression equations presented in Table 2 were used to generate surface plots shown in Figures 3-7. The response surfaces of all the responses measured were vertically displaced to significantly value ($p < 0.05$). The low R^2 value observed for the responses, ER (0.2725) and SME (0.2067) indicated that they were not influenced by the FMC and SS as suggested by RSM. The coefficient of determination was quite high for b-values. Specific mechanical energy input (SME) has been described as a good quantitative descriptor of extrusion processes, as it allows for the direct comparison of different combinations of extrusion conditions such as rates, MFR and torque [15]. The quantity and amount of mechanical energy delivered to the extruded material directly relates to the extent of macromolecular transformations which takes place. This includes starch conversion and changes in the rheological properties of the dough [15]. As stated by Mitchell and Areas [16], increased SME results in a lower viscosity which thus promotes mobility may lead to an increase in rate bubble growth rate. Residence time and temperature relation is important in maillard reactions. An increase in temperature for longer time leads to an increase of the reactivity between the sugar and the amino group. The combined effects of the feed moisture content of 50%, screw speed of 6.3 m/s and extrusion temperature of 100°C could be subsequently used for the production of expanded wheat-plantain noodles [17,18]. These composite blends (wheat-plantain flour) could be of significance in the formulation of diets for diabetic patients and also for use as binders or disintegrants in tablet formulations.

Conclusion

This study showed that the wheat and plantain flour could be useful to produce noodles of good quality using extrusion cooking. It was observed that changes in the barrel temperature, feed moisture content and screw speed significantly ($p \leq 0.05$) affected the torque, residence time, specific mechanical energy, expansion ratio and mass flow rate of all the extrudates studied. Increase in the feed moisture content (40-50%) and screw speed (6.3-8.4 m/s) resulted in a substantial increase in the expansion ratio (48%), residence time (62%) and specific mechanical energy (83.6%), while increase in the barrel temperature also significantly affected the mass flow rate (64.5%) of the extrudates. The study showed that optimization of the combined effects of the feed moisture content of 50%, screw speed of 6.3 m/s and extrusion temperature of 100°C gave the optimum processing conditions for wheat-plantain noodles. These variables are important considerations for commercial and mass production of expanded wheat-plantain noodles and for health conscious individuals and also

Run	Factor 1 FMC (%)	Factor 2 S.S (m/s)	Factor 3 BT (°C)	Response 1 Torque (Nm)	Response 2 MFR (kg/s)	Response 3 RT (s)	Response 4 ER	Response 5 SME (kJ/s)
1	30	5.23	80	91.66	2.07	62	2.4	15505.61
2	50	5.23	80	91.66	2.87	52	4.8	10459.23
3	40	6.28	100	78.57	2.48	56	4	12933.67
4	40	5.23	100	91.66	2.33	60	4.4	13014.89
5	40	6.28	100	78.57	2.48	56	4	13305.69
6	40	6.28	100	78.57	2.47	57	4	12984.72
7	50	5.23	120	91.66	2.94	51	5.2	13316.16
8	40	6.28	100	78.57	2.47	56	4	13396
9	40	6.28	100	78.57	2.43	57	2.8	12984.72
10	30	6.28	100	78.57	2.19	59	2.8	10924.41
11	50	6.28	100	78.57	2.92	50	5.6	10804.8
12	30	5.23	120	91.66	2.08	61	3.2	16068.66
13	40	6.28	80	78.57	2.4	58	4	13041.92
14	40	6.28	120	78.57	2.49	56	3.6	14097.7
15	30	7.33	120	68.75	2.16	60	3.2	16986.65
16	30	7.33	80	68.75	2.08	62	2.4	16891.75
17	40	7.33	100	68.75	2.68	52	3.6	13378.87
18	50	7.33	80	68.75	2.99	50	4.8	10798.66
19	50	7.33	120	68.75	3.04	49	6	11108.18

FMC: Feed Moisture Content; SS: Screw Speed; BT: Barrel Temperature; T: Torque; SME: Specific Mechanical Energy; MFR: Mass Flow Rate; RT: Residence Time; ER: Expansion Ratio.

Table 1: Table of results for extrusion runs.

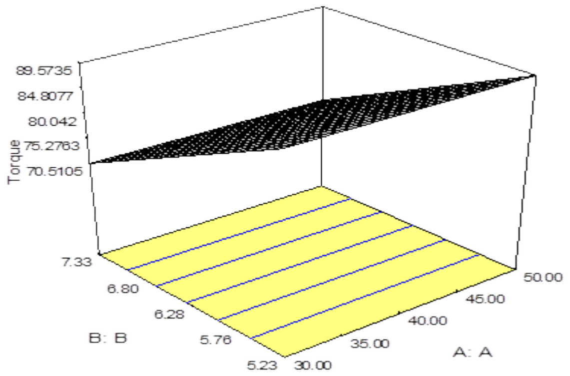

Figure 3: Response for torque.

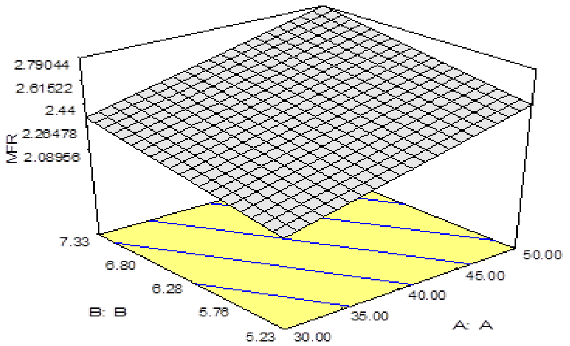

Figure 4: Response for mass flow rate (MFR).

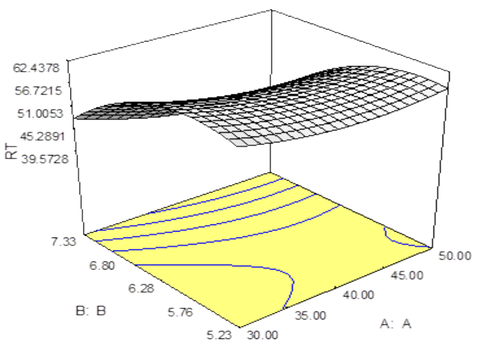

Figure 5: Response for residence time (RT).

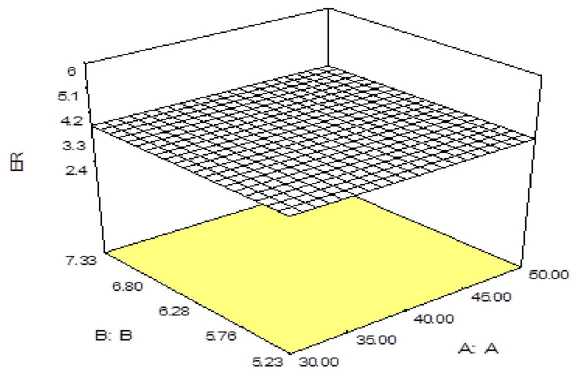

Figure 6: Response for expansion ratio (ER).

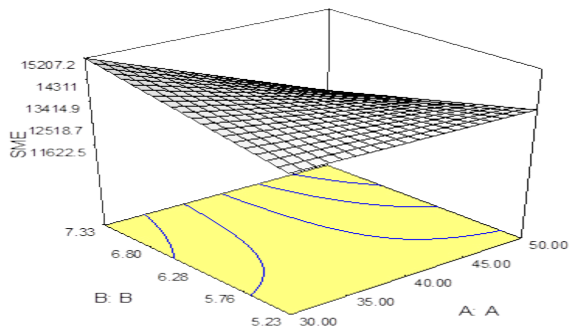

Figure 7: Response for specific mechanical energy (SME).

	TORQUE	MFR	RT	ER	SME
Intercept	80.04	2.44	55.90	3.78	13539.70
A	0.00	0.22	2.66	-	926.68
B	9.53	0.13	7.85	-	-124.83
C	0.00	0.03	0.12	-	611.60
A^2	-	-	2.41	-	-
B^2	-	-	6.57	-	-
C^2	-	-	2.06	-	-
AB	-	-	1.63	-	865.85
AC	-	-	-1.38	-	657.83
BC	-	-	1.38	-	-721.01
R^2	0.8458	0.4672	0.6381	0.2725	0.2067
Adjusted R^2	0.8169	0.3672	0.3184	0.1361	0.0579
Predicted R^2	0.7893	0.1525	-1.5949	-0.1345	0.3590
Lack of fit	0.27 NS	0.86 NS	13.29 NS	0.97 NS	2.26 NS

R^2: Coefficient of Determination; SME: Specific Mechanical Energy; MFR: Mass Flow Rate; RT: Residence Time; ER: Expansion Ratio

Table 2: Regression equation coefficient, presented as actual terms and statistical analysis for response of extrudates.

for use as binders or disintegrants in tablet and diet formulations. It is therefore, recommended that further studies on the effect of different ratios of wheat-plantain flour and other ingredients for the production of large scale snacks and others pasta should be investigated to provide a broader understanding of the feed moisture content and extruder variables.

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