ISSN 0511-5728
The West Indian Journal of Engineering
Vol.35, No.2, January 2013, pp.58-64

Expansion Characteristics of Selected Starchy Crops during Extrusion

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(Received 01 January 2012; Revised 19 September 2012; Accepted 06 December 2012)

Abstract: *In this study, the effect of extrusion process parameters of a locally developed extruder on the expansion of extrudates of the flour and starch of maize and cassava which are grown in Nigeria in large quantity was characterised. These were compared with those of wheat flour which is commonly used for the production of alimentary paste. The parameters considered include feed moisture (30, 40, 50 % d.b.), extruder temperature (40, 70, 100^{o}C) varied by continuous running of the machine, thereby building up the temperature and screw speed (100, 150, 200 rpm). Response Surface Methodology, stepwise regression, correlation and Analysis of Variance were employed to a factorial experiment in completely randomised design. An increase in temperature and screw speed increased transverse expansion. The extrudates' moisture loss is directly proportional with expansion. Increasing feed moisture content caused a decrease in transverse expansion and increase in extrudate moisture content. These starchy crops at low extrusion time are smooth and can be suitable for pasta products. The equations relating extrudates expansion and the independent variables were established to predict the performance of the machine. Generally, the response surface study revealed the range of the extrusion variables for optimum performance. Quadratic coefficients fit the extrusion data very well, better than linear models.*

Keywords: *Extrusion, cassava, maize, wheat, expansion characteristics*

1. Introduction

Food extrusion is a process in which food ingredients are forced to flow, under one or several conditions of mixing, heating and shear, through a die that forms and/or puff-dries the ingredients (Fellows, 2003). Extrusion Technology has gained popularity in the developed nations like United States and Europe by producing a range of products with different shapes, textures, colours, flavours from basic ingredients, thereby increasing the variety of food in the diet (Fellows, 2003). Wheat flour has been widely used in the extrusion industry and the effects of process variables on wheat extrudate properties have been reported (Frame, 1994). Also, Cassava (Manihot esculenta, Crantz) and maize (Zea mays) are important starch-rich crops grown in many parts of the world that contributes to economic development and food security, most especially in low income food deficient countries like Nigeria (Asiedu, 1992). Meanwhile, it is obvious that cassava as a crop is not popular for the production of extruded foods. Maize is one of the most common types of starch used for extrusion on which a lot of research work has been done but not in the developing nations where it is grown in large quantity.

The extrusion process operates in a dynamic steady equilibrium where the input variables are balanced with the output (Guy, 2001). For certain applications in the food and packaging industries, starch is extruded to achieve a desired product quality. Extrusion expansion is a complex phenomenon which occurs during high-temperature, low-moisture cooking and is a consequence of several events including starch structural transformations and phase transitions, nucleation, extrudate swell, bubble growth, and bubble collapse, with bubble dynamics dominantly contributing to the expansion phenomenon.

Expansion promotes dehydration and the development of a desirable crispy texture on the final extrudate (Patil et al., 2007). Therefore, expansion related parameters are important to determine the quality of the extruded product. An insight into the expansion characteristics of different starch crops is therefore required for new products development/formulation in developing countries like Nigeria. Such insight would help optimise extrusion processes through better equipment design and applications, and develop new products with desired characteristics that would benefit both the consumers and the industry.

2. Materials and Methods

2.1 Sample preparation

Samples of flour and starch of the two crops under study were sourced and prepared from the same varieties grown under the same cultivation practices to give room for basis of comparison of results. Cassava tubers (*Manihot esculenta Crantz*) TMS 30572, were sourced from experimental plots at the Federal College of Agriculture, Akure and processed into flour and starch respectively according to International Starch Institute Standards (2005). The materials were passed through a 300um sieve separately and the proximate analysis and moisture contents (dry basis) of samples were determined as described by AOAC (1995) approved method. White maize, EV8363-SR QPM (breeder seed) was sourced from the International Institute of Tropical Agriculture (IITA), Ibadan and processed into flour and starch respectively as described by Akanbi et al (2003). Hard durum wheat flour (*Triticum aestirum*) was purchased from Akure main market.

2.2 Extrusion

The extruder used in this study is the dry type. It is made up of three (3) main units namely the feeding unit, the compression and melting unit and the die unit all fabricated using locally available materials. The feeding unit and the compression/melting unit are operated by one electric motor through a gear reducer and belt and pulley transmission system. As a test rig, allowance was given for varying the screw configuration, feed rate, screw speed, die configuration and nozzle. Speed regulation is done by varying the pulley ratios. All parts through which the feed material will pass were made of stainless steel to prevent food contamination and to withstand frictional wear. Figure 1 shows the isometric drawing of the extruder.

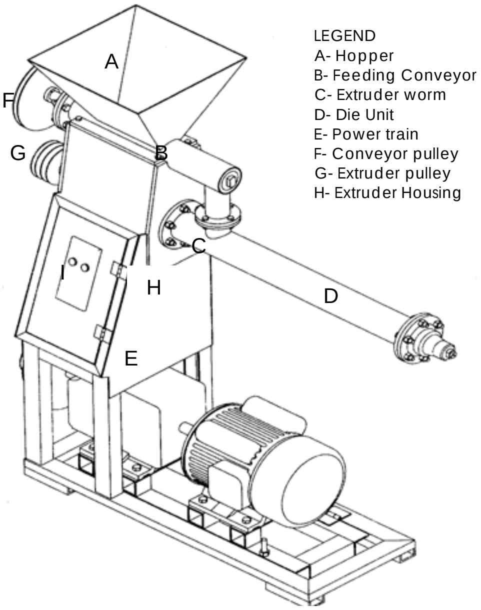

Figure 1. Isometric views of the extruder

As showed in Figure 2, the screw is of single flight, increasing diameter and tapering/decreasing pitch with a compression ratio of 4.5:1 L/D Ratio of 12:1. The diameter of the final portion of the screw is reduced to a cone. This aids in pressure built up, easy conveyance of materials through the die and in reducing wear rate. The length to diameter ratio is 12:1. An electric motor drives the screw through a gear reducer, and the backward thrust of the screw is absorbed by a thrust bearing. The barrel and the screw/die configuration are typical of alimentary food production equipment. The extrudates were extruded as ribbons to be cut with rotary cutter.

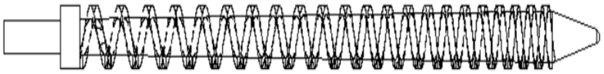

Figure 2. The screw's configuration

2.3 Experimental procedure

Samples were fed into the extruder at a feed rate 10Kg/h. The feeding section of the extruder was maintained at room temperature. The extruder was operated for 30 minutes for each set of condition. Steady state extrusion conditions is assumed to have been reached where there is no visible drifts in products temperature and torques required to turn the screw and by a steady extrusion rate. Temperature, both of the barrel and product were varied by continuous running of the machine, thereby building up the temperature. A major reason why heat was generated through viscous dissipation and not by addition through the barrel walls is that heat generated by drive unit (through viscous dissipation) is more dominant and cost efficient (Liang et al., 2002). Since barrel temperature varies with duration of operation, duration of operation was observed as the independent variable. Temperature was controlled by removing and dipping the barrel and screw in a bath of cold water at each run of sample. The amount of water needed to bring the samples to the required moisture content was calculated and added slowly while being stirred in a mixer.

2.4 Statistical Analysis

This experiment was conducted using a factorial design comprising of five levels of product classification, three levels of initial moisture content, three levels of screw speed and five levels of duration of operation of machine. The four independent variable levels were pre-selected based on the results of preliminary tests. Each treatment was replicated thrice. One way ANOVA, least significant follow up tests, and stepwise multiple regression analysis were carried out using Statistical Package for Social Scientists (SPSS 13.0) software while response surface regression and correlation analysis were carried out using the data analyst and response surface regression procedures of Statistical Analysis System (SAS) software v.9.R_1 (2003). Also, variables were analysed with and without their interaction to see if there will be any improvement in the model fit. Microsoft Excel © 2007 was used for plotting graphs.

Regression analyses were employed to fit the experimental data to second- order polynomials.

2.5 Data collection and analysis

Official methods of the Association of Official Analytical Chemists (1995) were used for moisture, ash, protein, fat and crude fibre. The carbohydrate content was determined by difference. Moisture contents of native starch samples and their extrudates were determined on a dry basis by an oven method using the AOAC (1995) method 925-09. Expansion ratio of extrudates was calculated according to Choudhury and Gautam (1998). Extrudates diameters were measured using a caliper. Radial expansion ratios of the extrudates were calculated as:

$$\frac{D^2}{d^2} \qquad \text{……………………..… Eqn.1}$$

where ***D*** is the extrudate's diameter while ***d*** is the diameter of the die. Each value of extrudate diameter was an average of three readings. Also, the photographs of the expanded extrudates were taken for purposes of comparison.

3. Results and Discussion

The Proximate composition of all the materials under study is presented in Table 1. This result shows that the protein content of TMS 30572 variety of cassava is high when compared with other varieties used in previous studies (Badrie and Mellowes, 1991). Efforts to improve cassava have being focused on increasing yield, dry matter content, nutritional and protein content as a means to contribute to a sustainable and cost effective solution to malnutrition (Dixon et al., 2007).

Table 1. Proximate compositions of samples

	MC	Protein	Fat	Ash	Fibre	Carbohydrate
CS	1.47	0.31	1.50	0.20	0.12	96.40
CF	1.90	7.36	1.40	1.62	0.24	87.48
MS	2.45	0.86	2.32	0.40	0.15	93.82
MF	1.30	3.95	2.43	0.80	0.36	91.16
WF	9.65	13.2	1.50	0.45	2.10	73.10

Keys: CS – Cassava starch, CF- Cassava flour, MS- Maize starch,
MF- Maize flour, WF- Wheat flour

Figures 3, 4 and 5 show the effect of extrusion variables (initial moisture content, duration of operation and screw speed) on expansion ratio. Expansion ratio varies directly with duration of operation (Extrusion time). At 65-70^{o}C, most materials under study had started to expand. Extrudates were stable and producing regular and puffed products. By the time a barrel temperature range of 87-94^{o}C was attained virtually all the materials had reached their maximum expansion with the onset of either collapse or reduction beyond 95^{0}C. Also, expansion ratio increased from 100 to 150 rpm and then decreased at 200 rpm. A maximum expansion ratio of 11.57% was attained through viscous dissipation in 30 minutes at 150 rpm and 30% moisture content by cassava starch.

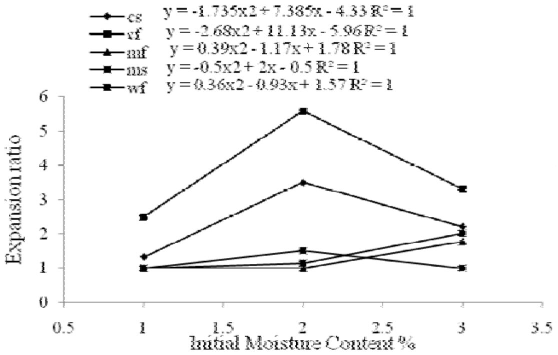

Figure 3. Variation of expansion ratio with initial moisture content at 30 minutes extrusion time and 100 rpm screw speed

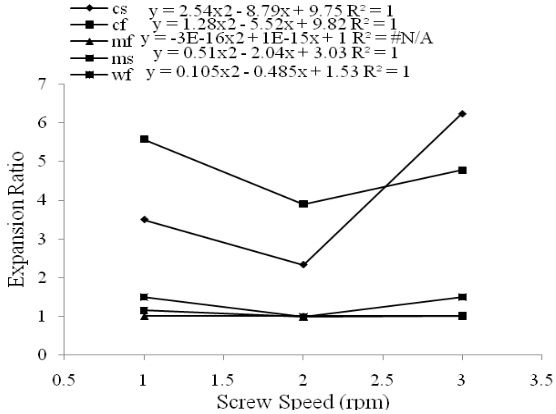

Figure 4. Variation of expansion ratio with screw speed at 30 minutes extrusion time and 30% initial moisture content

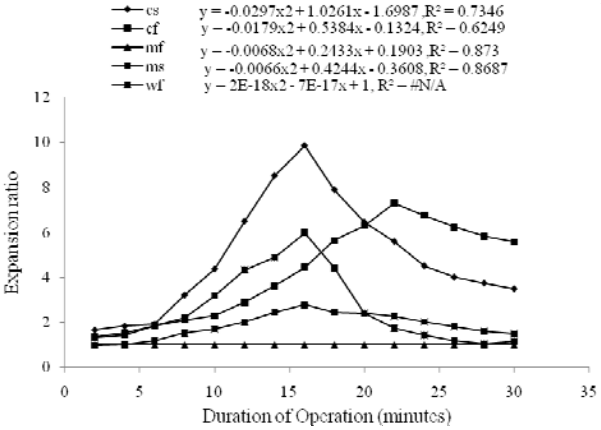

Figure 5. Variation of product expansion ratio with duration of operation at screw speed 100 rpm and initial moisture content 30%

A range of feed moisture from 25-40% w.b. was selected for cassava flour, starch and wheat flour while 30 - 50% was selected for maize. This was because samples with lower moisture contents to these ranges blocked the rotation of the screw as there was no transition from the original floury nature to a melted state typical of most extrusion processing. This may be because the moisture content was not sufficient to solvate the starch polymers and allow them to move freely in the mass. Hence there was resistance to deformation and no expansion was effected. This problem of getting stocked at lower moisture levels can be overcome by improving the torque.

The physical appearance of the extrudates arranged in order of duration of sampling (2-24) and degree of expansion are shown in Plates 1-10.

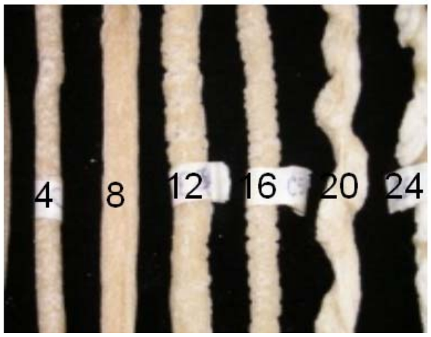

PLATE 1: Cassava Flour @ Moisture Content 25% & Screw speed 100 rpm arranged in order of duration of operation 2-24 minutes.

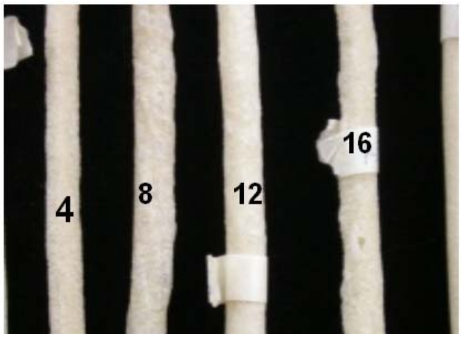

PLATE 2: Maize Flour @ Moisture Content 40% & Screw Speed 100rpm arranged in order of duration of operation 2-24 minutes.

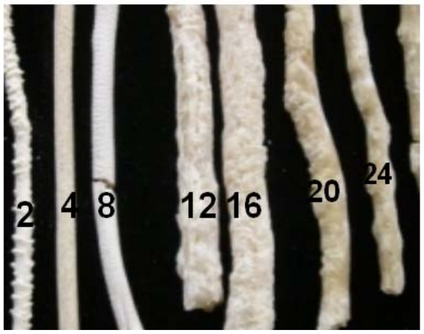

PLATE 3: Wheat Flour @ Moisture Content 30% & Screw speed 100 rpm arranged in order of duration of operation 2-24 minutes.

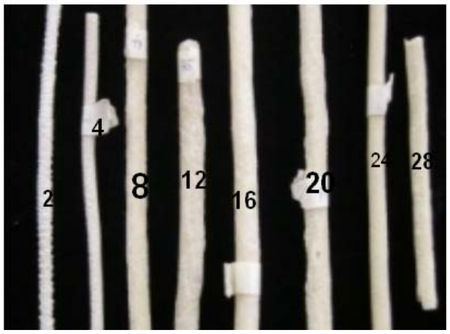

PLATE 4: Wheat Flour @ Moisture Content 40% & Screw Speed 100rpm arranged in order of duration of operation 2-24 minutes.

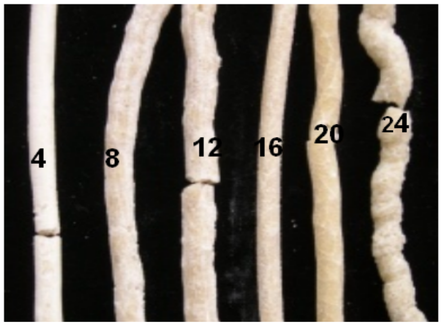

PLATE 5: Maize Flour @ Moisture Content 40% & Screw speed 100 rpm arranged in order of duration of operation 2-24 minutes.

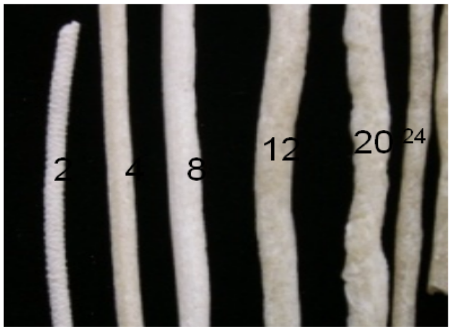

PLATE 6: Maize Starch @ Moisture Content 40% & Screw speed 100 rpm arranged in order of duration of operation 2-24 minutes.

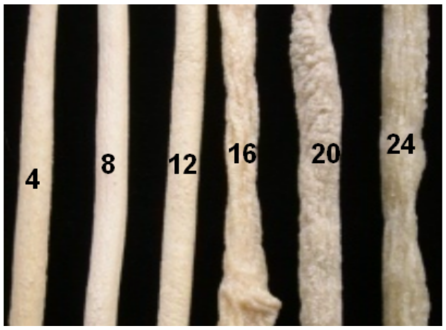

PLATE 7: Cassava Flour @ Moisture Content 30% & Screw speed 100 rpm arranged in order of duration of operation 2-24 minutes.

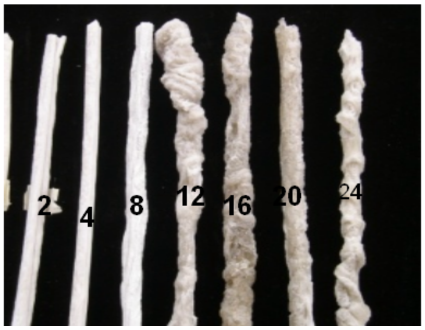

PLATE 8: Cassava Starch @ Moisture Content 30% & Screw speed 100 rpm arranged in order of duration of operation 2-24 minutes.

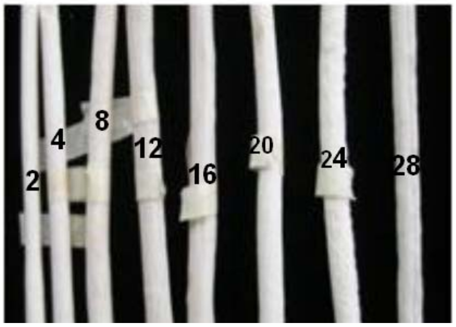

PLATE 9: Cassava Starch @ Moisture Content 40% & Screw speed 100 rpm arranged in order of duration of operation 2-24 minutes.

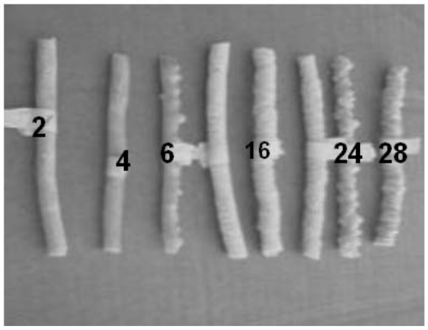

PLATE10 : Maize Starch @ Moisture Content 30% & Screw speed 100 rpm arranged in order of duration of operation 2-24 minutes.

All extrudates of maize starch at higher product temperature were characterised by their appearance, porous structure and fragility. Increase in temperature of maize starch to make it possible to obtain a texture with higher porosity and greater fragility. These changes in product characteristics are a result of modification of the starch and protein components under high temperature. Also, back pressure developed in the die resulted in high initial expansion and then collapse of extrudates, after a brief time, leading to smaller diameter extrudates. Ganjyal and Hanna (2004) observed that this phenomenon was because the pressure drop exerted tensile forces in the cell material in excess of its elastic limits.

Previous studies also reported increased radial expansion with increased barrel temperature and reduced feed moisture content for corn grits and corn starch (Mercier and Feillet, 1975), rice flour (Ding et al., 2005), wheat flour (Ding et al., 2006) and cassava (Chang and EiDash, 2003). As the barrel temperature increased the viscosity of the feed material decreased resulting in better expansion (Mercier and Feillet, 1975; Lo et al., 1998; Ding et al., 2005).

Although maize starch was observed to start puffing before maize flour but it could not expand as much as maize flour because it does not develop sufficient strength/structure and adhesiveness to form a continuous matrix. Hence there were lots of bubbles in the surfaces of the extrudates making them very, very weak to touch. However, this quality makes it very suitable as ready to eat snacks product, because since it is very weak and brittle, masticating it will be very easy. All products at low extrusion time are smooth and can be suitable for pasta products.

The stepwise regression data analysis of expansion ratio is shown in Table 2. From the stepwise linear multiple regression analysis conducted, the R^2 was very low. But a high R^2 was obtained for the plot (Graph) when fitted to a sixth order polynomial trend. The interaction term Sm has the highest contribution, 6%, to R^2 of expansion ratio. The variable, starch content accounted for only 1.3% and protein content 13.1% of the total variation in R^2. This low R^2 for expansion ratio is an indication that it the relationship is not best described by a linear model. The (VIF) value for all parameter estimates and those of (ds, Mc, dsm) were 1.0.

Therefore, it can be concluded that multicollinearity is not a problem in this case. However, for the 3rd model of the interaction terms ds and dsm, the VIF value of 26.79 and above can be an indication that at least one of the independent variables is a perfect linear function of one or more other independent variable in the equation.

The detailed statistical analysis using response surface methodology (RSM) generated the coefficients of the second order polynomials for the response functions (eqn 1). Generally, there is an improvement in the R^2 (0.86) of the response surface regression model than for the stepwise regression model.

$$Y = 2.99X_1 + 0.73X_2 + 1.65X_3 - 0.056X_4 - 1.19X_5 - 0.01X_1^2 - 0.025X_1X_2 - 0.025X_3X_2 - 0.014X_3X_1 - 0.005X_3^2 + 0.0015X_4X_2 + 0.0011X_4X_1 + 0.0003X_4X_3 - 0.0002X_4 + 0.021X_5X_2 + 0.014X_5X_1 + 0.004X_5X_3 + 0.0003X_5X_4 - 0.009X_5^2 \quad \ldots\ldots\ldots\ldots \text{Eqn.2}$$

The canonical analysis indicates that the predicted response surface is shaped like a saddle. The eigenvalue of 3.32 shows that the valley orientation of the saddle is downward curved than the hill orientation, with eigenvalue of 0.99. The coefficients of the associated eigenvectors show that the value is more aligned with Duration and the hill with SS. Because the canonical analysis resulted in a saddle point, the estimated surface does not have a unique optimum. However, the ridge analysis indicates that maximum ER will result from relatively high Pc, Sc, moderate MC, high SS and moderate Duration. Note from the analysis of variance for the model that the test for the SS is not significant.

The result of one-way analysis of variance (see Table 3) shows that expansion is significantly different at 95% confidence interval at 100, 150 rpm and 200 rpm for maize flour but not for all other products. This was due to the fact that maize flour being the densest of all materials under this study requires minimum moisture content 40% to flow through the extruder.

Table 2. Stepwise Regression of expansion ratio for all product classification

Models	**Coefficients**		**T-test**	**Probability**	**Adjusted R^2**	**F value**	**Probability**	**VIF**
1	B_0	1.692	12.222	.000	.067	51.706	.000	1.000
	sm	1.04E-005	7.191	.000				
2	B_0	-1.132	-1.270	.204	.080	31.332	.000	1.000
	sm	1.04E-005	7.192	.000				1.000
	Sc	.032	3.208	.001				
3	B_0	-23.608	-10.602	.000	.211	63.682	.000	1.000
	Sm	1.03E-005	7.685	.000				6.241
	Sc	.260	11.345	.000				6.240
	Pc	.428	10.869	0.000				

Table 3. Least significant means of products for expansion ratio

SS	MC	GRP	Products				
			CS	CF	MS	MF	WF
150	1	2	21.860	31.003	7.900	-2.939**	1.203
		3	38.835*	18.330	10.213*	-.568	2.078
	2	1	-21.860	-31.003	-7.900	2.939**	-1.203
		3	16.975	-12.673	2.313	2.371**	.875
	3	1	-38.835*	-18.330	-10.213*	.568	-2.078
		2	-16.975	12.673	-2.313	-2.371**	-.875
100	1	2	15.488	11.820	5.278	-2.642**	.520
		3	27.335*	35.503	8.243*	-2.205**	1.17
	2	1	-15.488	-11.820	-5.278	2.642**	-.520
		3	11.848	23.683	2.965	.43667	.650
	3	1	-27.335*	-35.503	-8.243*	2.205**	-1.170
		2	-11.848	-23.683	-2.965	-.437	-.650
200	1	2	-4.597	47.180	3.165	-2.748**	.628
		3	2.550	27.015	3.206	-1.245*	1.061
	2	1	4.596	-47.180	-3.165	2.748**	-.628
		3	7.147	-20.165	0.042	1.503*	.434
	3	1	-2.550	-27.015	-3.206	1.245*	-1.061
		2	-7.145	20.165	-0.042	-1.503*	-.4338

Remarks: pc - protein content; sc - starch content, MC 1, 2, 3 - Moisture content 25%, 30% and 40%; Ss – screw speed; Dt - duration of operation; PT - Product temp (^{0}C); GRP - group, CS - Cassava starch; CF- Cassava flour; MS- Maize starch; MF- Maize flour; WF- Wheat flour (-ve means negative but significant effect). Significant at $*P \leq 0.05$; $** P \leq 0.01$.

8. Conclusion

The expansion response of the extrudates of a locally developed single screw extruder has being well characterised. Expansion of maize and wheat were less sensitive to changes in extrusion variables when compared to cassava. Database on extrusion of the crops under study, which are of benefit in food and feed processing, are established. Specific end uses to which the products at different extrusion conditions can be put are identified. Also, the canonical analysis of the response surface analysis resulted in a saddle point; the estimated surface does not have a unique optimum. However, directions on further experimentation for optimisation are suggested.

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Folasayo T. Fayose *is an Agricultural Engineer with special interest in Agro Processing Machinery and currently a Senior Lecturer and the Ag. Director of the Centre for Research and Development at the Ondo State owned Rufus Giwa Polytechnic, Owo, Nigeria. She holds B. Eng. (Hons), M. Eng, and Ph.D. in Agricultural Engineering. Dr. Fayose is a 2011 recipient of the Post Doctoral Fellowship of the African Women in Agricultural Research and Development (AWARD) and has published widely. Her current research focuses on Optimisation and Product Development of Food and Feed Extrusion using Cassava and other locally sourced Ingredients. Also, different products develop temperatures during extrusion which she aims to control in order to meet their specific temperature for good quality. She is a Registered Engineer.*

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