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Characterizing the Product Moisture Loss of Selected Starchy Crops during Extrusion

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ABSTRACT

In this study, the effect of extrusion process parameters of a locally developed extruder on the moisture loss of extrudates of the flour and starch of maize and cassava which are grown in Nigeria in large quantity were characterized. 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 %), extruder temperature (40, 70, 100^{o}C) built up by varying the duration of sampling 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 randomized design. Product moisture varies inversely with duration of operation. An increase in extrusion time decreased moisture content up to a critical value of above which it started to increase again. As feed moisture increased, higher extrudate moisture was obtained. Also, product moisture decreased from 100 to 150 rpm and then increased at 200 rpm. The minimum product moisture of 10.6% indicating maximum moisture loss was attained at 150 rpm and 25% moisture content by maize starch. The equations relating product moisture and the independent variables were established. Generally, the response surface study revealed the range of the extrusion variables for optimum performance. Directions on further experimentation for optimization are suggested. A quadratic coefficient fits the extrusion data very well, better than linear models.

Keywords: *Extrusion, Cassava, Maize, Wheat, Moisture Content*

1. INTRODUCTION

Removing water from food and agricultural products constitutes a significant portion of the processing activity for persons working in the food and agricultural processing industries. A food's storability is directly related to moisture content, along with temperature and oxygen availability. High amounts of available moisture lead to mold growth and microbial activity. High energy consumption during food processing including drying makes case for operations that combines several operations in order to reduce energy costs. 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.

Extrusion technologies have an important role in the food industry as efficient manufacturing processes. It has been proven to be a very efficient food processing technology that is capable of performing several unit operations. Extrusion technology provides several advantages over traditional methods of food and feed processing feed processing including improved product quality over other processes because processing is done in a very short time and less destruction of heat sensitive ingredients occur. There occurs loss in moisture of extrudate due to rapid fall in temperature at the exit from the die during the extrusion process (Fellows, 2003; Guy, 2001). Within parameter, a 50% loss in moisture can be achieved through the process. This allows for dehydrating many products, which have too high a moisture level for storage.

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. Wheat flour has been widely used in the extrusion industry and the effects of process variables on wheat extrudate properties have been reported. This study is aimed at chacterizing the moisture loss of cassava, maize and wheat as a function of extrusion operating conditions (temperature, moisture content, and screw speed)

2. MATERIALS AND METHODS

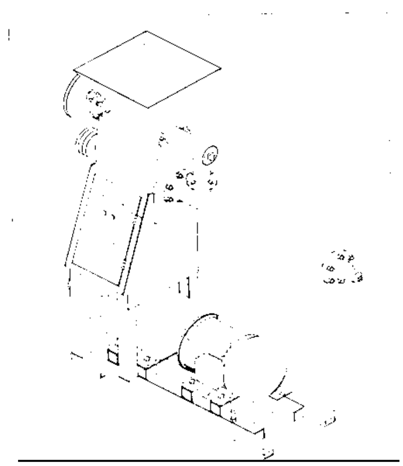
2.1 Sample Preparation

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. 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. 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.

The screw is of single flight, increasing diameter and tapering/decreasing pitch with a compression ratio of 4.5:1l/d Ratio of 12:1. The diameter of the final portion of the screw is reduced to a cone. This aid 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 is typical of alimentary food production equipment. The extrudates were extruded as ribbons to be cut with a rotary cutter.



LEGEND

A- Hopper
B- Feeding Conveyor
C- Extruder worm
D- Die Unit
E- Power train
F- Conveyor pulley
G- Extruder pulley
H- Extruder Housing
I- Control switch

Figure 1: Isometric views of the extruder

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 is better generated through viscous dissipation than that added or removed 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 an independent variable. Temperature was controlled by removing and dipping the barrel and screw in a bath of cold water each time the extruder is to be fed with samples.

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 analyzed 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. The moisture content of each extrudate was determined immediately after extrusion according to AOAC method 950.46. Approximately 2g each sample was placed in an air oven at 100 $\pm$ 2^{o}C for 16 to 18 hours. The weighing balance used was Mettler Toledo Type: PR203, Switzerland. The loss in weight represented the moisture loss. The moisture content of each sample was an average of triplicate analysis. After removal from the oven, the samples were cooled in a desiccator over calcium sulfate (0% RH) and reweighed.

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	1.5	0.2	0.12	96.4
cf	1.9	7.36	1.4	1.62	0.24	87.48
ms	2.45	0.86	2.32	0.4	0.15	93.82
mf	1.3	3.95	2.43	0.8	0.36	91.16
wf	9.65	13.2	1.5	0.45	2.1	73.1

Figure 3 - 5 show the effect of extrusion variables (initial moisture content, duration of operation and screw speed) on product moisture content. Product moisture varies inversely with duration of operation. An increase in extrusion time decreased moisture content up to a critical value of above which it started to increase again. As feed moisture increased, higher extrudate moisture was obtained. Lo et al. (1998) reported similar result with yellow corn maize. Also, product moisture decreased from 100 to 150 rpm and then increased at 200 rpm. 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. A high process temperature produced extrudates with low moisture content. The minimum product moisture of 10.6% indicating maximum moisture loss was attained at 150 rpm and 25% moisture content by cassava flour. A maximum moisture loss of 57.6% was obtained. The mass temperature fell with increasing extrudate moisture. Thus on increasing feed moisture of cassava and other products, the drop in barrel temperature created lower vapour pressure in the dough resulting in less flashing of moisture and reduced expansion.

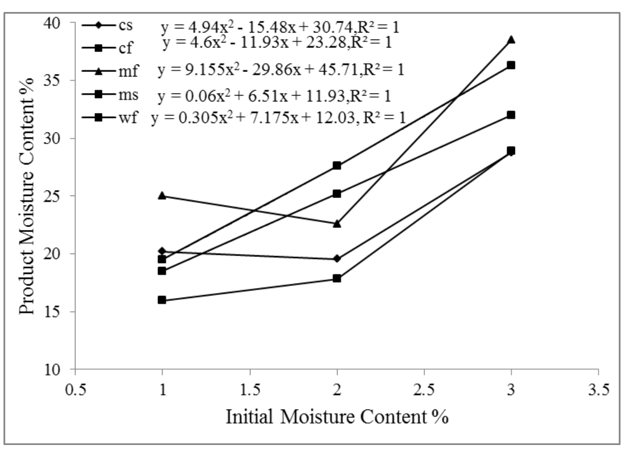


Figure 3: Variation of product moisture content with initial moisture content at 30 minutes extrusion time and 100 rpm screw speed

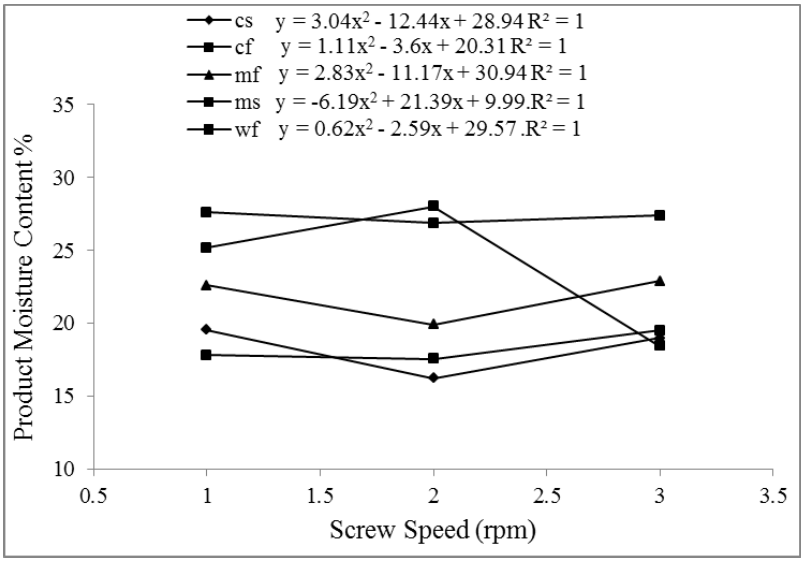


Figure 4: Variation of product moisture contents with screw speed at 30 minutes extrusion time and 30% initial moisture content

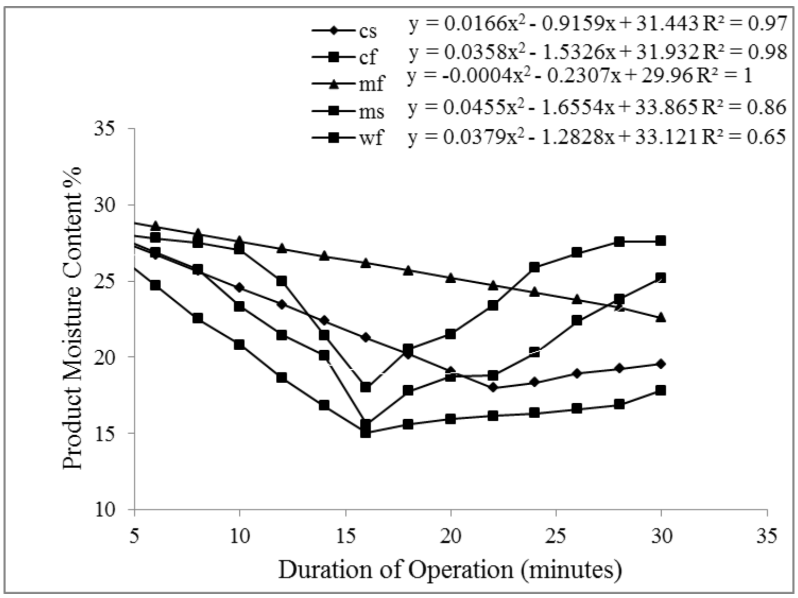


Figure 5: Variation of product moisture content with duration of operation at screw speed 100 rpm and initial moisture content 30%

The best reaction was obtained at 30% moisture content for maize starch, cassava starch and wheat flour, 25% for cassava flour and 40% for maize flour.

From every indication, cassava flour has a lower and faster moisture loss than cassava starch. This difference obtained between cassava flour and its starch may be due to difference between their viscosities at high temperature/shear environment. An increase in extrusion time decreased moisture content up to a critical value of 10.7 above which it started to increase again. The maximum value for the peak occurs where the cellulose is least i.e. starch. For higher concentration as contained in flour it decreased. This may be due to the fact that cellulose, being a major component of flour does not develop viscosity (Arambula, et al. 2002). Cassava starch therefore could not dry faster than its flour because of its higher viscosity. The stepwise regression data analysis of Product moisture is shown Table 5.8. The moisture content has the highest contribution, 71.2%, to R^2 of Product moisture. The interaction term dm accounted for 6.8%, starch content for 0.6% and protein content 2.7% of the total variation in R^2. The VIF value for all parameter estimates were 1.0. Therefore, it can be concluded that multicollinearity is not a problem in this case.

Table 2: Stepwise regression of product moisture for all product classification

Models	Coefficients		T-test	Prob	Adjusted R^2	F value	Prob	VIF
1	B_0	-3.300	-4.328	.000	0.712	1709.93	.000	1.000
	Mc	0.928	41.351	.000				
2	B_0	-3.285	-4.932	.000	0.780	1228.08	.000	1.000
	Mc	1.045	49.397	.000				1.000
	dm	.007	-14.672	.001				
3	B_0	3.939	2.297	.022	0.786	849.19	.000	1.000
	Mc	1.050	50.260	.000				1.169
	dm	-0.007	-14.882	.000				1.165
	Sc	-0.083	-4.561	0.000				
4	B_0	42.042	10.139	0.000	0.813	752.70	0.000	1.169
	Mc	1.054	53.939	0.000				1.165
	dm	-0.007	-15.906	0.000				6.241
	Sc	-0.471	-11.083	0.000				6.240
	Pc	-0.728	-0.965	0.000				

The findings of this study agrees with the findings of Camire et al. (1991) who reported the influence of moisture content of the material before extrusion depends on the moisture content of the extruded samples from mixtures of corn meal and glandless cotton seed. This could be due to insufficient vaporization occurring at high moisture (Harris et al., 1988). Extrusion at 150°C barrel temperature gave extruded products, which showed higher expansion and retained the lowest moisture after puffing for the same feed moisture content. Similar results were reported in extruding wheat flour (Andersson and Hedlund, 1991). High moisture contents were associated with less expanded extrudates and required additional energy input to remove the water (Camire, et al., 1991).

The result of one way analysis of variance (Table 3) shows that product moisture is significantly different at $P \leq 0.05$ and $P \leq 0.01$confidence interval at 100, 150 rpm and 200 rpm for all the products but not for cassava flour at 200 rpm. This was due to the range of feed moisture that was selected for the products studied i.e. from 25 - 40% w.b. 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. This problem of getting stocked at lower moisture levels can be overcome by improving the torque.

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 (Table 2).

$$\begin{aligned} Y = {} & 7.50X_1 - 0.38X_2 - 0.70X_3 - 0.11X_4 + 1.405X_5 - 0.20X_1^2 - 0.083X_1X_2 \\ & + 0.04X_3X_2 + 0.015X_3X_1 + 0.004X_3^2 + 0.0004X_4X_2 + 0.0002X_4X_1. \\ & - 0.0004X_4X_3 + 0.0004X_4 - 0.022X_5X_2 - 0.019X_5X_1 - 0.010X_5X_3 \\ & - 0.0003X_5X_4 + 0.0155X_5^2 \end{aligned} \tag{1}$$

The canonical analysis for product moisture content indicates that the predicted response surface is shaped like a saddle. The eigenvalue of 4.08 shows that the valley orientation of the saddle is less curved than the hill orientation, with eigenvalue of 0.93. The coefficients of the associated eigenvectors show that the value is more aligned with Duration and the hill with Pc. From the canonical analysis, all terms in the regression model are significant. Also, the estimated surfaces are shaped like a saddle with no unique minimum or maximum. However, the ridge analysis (Table 5) indicates that maximum PM will result from relatively high Pc, Sc, MC, SS and low

Duration. Note from the analysis of variance for the model that the test for the Sc, MC and SS factors are not significant. If further experimentation is undertaken, it might be best to fix these factors at a moderate to high values and to concentration on the effect of Duration. Both Linear and Quadratic models fit the data very well.

Table 3: Least significant means of products for product moisture

SS	MC	GRP	PRODUCTS				
			CS	CF	MS	MF	WF
100	1	2	-3.839**	-.375	-.844**	.000	-1.572**
		3	-.676	2.119**	.000	-2.748**	-1.702**
	2	1	3.839**	.375	.844**	.000	1.572**
		3	3.163**	2.493**	.844**	-2.748**	-.130
	3	1	.676	-2.119**	.000	2.748**	1.702**
		2	-3.163**	-2.493**	-.844**	2.748**	.1300
150	1	2	-4.585**	.666	-.404**	.000	-1.773**
		3	-4.024**	2.310*	-.267*	-2.939**	-1.358**
	2	1	4.585**	-.666	.404**	.000	1.773**
		3	.561**	1.644*	.137	-2.939**	.415
	3	1	4.024	-2.310*	.267*	2.939**	1.358**
		2	-.561**	-1.644*	-.137	2.939**	-.415**
200	1	2	-5.053	.253	-.237**	.000	-1.570**
		3	-1.653*	.441	-.033	-2.642**	-1.436
	2	1	5.053**	-.253	.237**	.000	1.570**
		3	3.399**	.188	.204**	-2.642**	.134
	3	1	1.653*	-.44133	.033	2.642**	1.43600
		2	-3.399**	-.18800	-.204**	2.642**	-.13400

Significant at *P $\leq$ 0.05;** P$\leq$0.01, PC - protein content, SC - starch content, MC - Moisture content, 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 sig effect)

Table 4: The canonical analysis for product moisture content

	Eigenvectors				
Eigenvalues	**PC**	**SC**	**MC**	**SS**	**Duration**
4.082740	-0.014315	-0.393210	-0.340825	-0.018178	0.853633
0.934366	-0.016150	-0.048667	-0.291492	0.947770	-0.118888
0.551692	-0.287021	0.793938	0.229367	0.163616	0.455962
0.436126	0.254702	-0.323131	0.846445	0.273064	0.199197
-9.483633	0.923190	0.329037	-0.172602	-0.008170	0.097959

Stationary point is a saddle point

Table 5: Estimated Ridge of Maximum Response for Product Moisture

Radius	Coded Response	Estimated Error	Standard PC	SC	Uncoded Factor Values MC	SS	Duration
0.0	32.061492	0.557486	6.655000	84.895000	37.500000	150.000000	16.000000
0.1	33.562395	0.610203	6.441924	84.349305	38.475177	149.955324	15.677201
0.2	35.007284	0.658434	6.299302	83.831600	39.510053	149.890350	15.308954
0.3	36.414593	0.703445	6.217860	83.353863	40.585792	149.806264	14.886837
0.4	37.799912	0.746251	6.185784	82.925716	41.685507	149.705752	14.401968
0.5	39.176127	0.787430	6.191398	82.554910	42.795446	149.592566	13.845400
0.6	40.553987	0.827181	6.224456	82.247931	43.904437	149.471191	13.208862
0.7	41.942737	0.865461	6.276443	82.010148	45.002904	149.346573	12.485833
0.8	43.350625	0.902157	6.340459	81.845428	46.082187	149.223811	11.672785
0.9	44.785217	0.937263	6.411026	81.755470	47.134444	149.107733	10.770223
1.0	46.253545	0.971060	6.483942	81.739242	48.153004	149.002433	9.783099

4. CONCLUSION

The moisture loss of the extrudates of a locally developed single screw extruder has being well characterized. Moisture loss of cassava and wheat were less sensitive to changes in extrusion variables when compared to maize starch. Database on extrusion of the crops under study which are of benefit in food and feed processing are established. 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 optimization are suggested.

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