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Note

Specific Mechanical Energy Requirement of a Locally Developed Extruder for Selected Starchy Crops

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In this study, the specific mechanical energy (SME) response of a dry type single screw extruder (Length to Diameter ratio (L/D) 12:1, Compression Ratio (CR) 4.5:1) developed locally was investigated for maize, cassava and wheat flour processing. The study was necessitated by the need to provide management data for the preliminary studies of the extruder A factorial experiment in completely randomized design was employed to study the effect of extrusion variables: feed moisture (25 − 50%), extruder temperature built up by varying the duration of sampling (2 − 30 min) and screw speed (100, 150, 200 rpm) on SME. The study revealed that SME varied directly with duration of operation for cassava products and inversely with duration of operation for all maize and wheat products. SME increased with increasing speed from 100 to 150 rpm but decreased at 200 rpm. SME increased with increase in moisture content from 25 to 40%.

Keywords: extrusion variables, cassava, maize, wheat flour, specific mechanical energy

Introduction

The amount of energy used for processing raw products into consumable goods has been only narrowly explored for specific commodities. The amount of energy used in agricultural production, processing and distribution is significantly high in order to feed the expanding population and to meet other social and economic goals of society (Ziesemer, 2007). Sufficient availability of the right energy and its effective and efficient use are prerequisites for improved agricultural production. In the world at large, energy issues are now receiving considerable attention as its cost of production is increasing by the day. Also, Extrusion cooking is a versatile process that helps in the expansion of the processing technology of crops.

Starchy crops like maize and cassava are widely abundant in the diet of the low income people of Sub Saharan Africa. Extrusion processing of these crops at optimum conditions will go a long way to improve these starch diet by fortification with essential components of a balanced diet and also expand their processing technology. SME is defined as a total input of mechanical energy per unit dry weight of extrudate. It is a common measure of extrusion energy consumption. It is an indicator of the relative ease with which

List of Abbreviations

L/D ; Length to diameter ratio, CR ; Compression ratio, Cf ; Cassava flour, Cs ; Cassava Starch, Ms ; Maize Starch, Mf ; Maize flour, Wf ; Wheat flour, Dt ; Duration of extrusion (min), Mc ; % Moisture content (wet basis), Ss ; Screw speed (rpm), Dm ; interaction of Dt and M, Dsm ; interaction of Dt, Ss and M, Sm ; interaction of screw speed and moisture, Pc ; Protein Content, Sc ; Starch Content, SME ; Specific mechanical Energy (KJ/kg), N ; number of revolutions per minute (rpm), P ; Power transmitted (Watts), F_r ; feed rate (kg/h), T_c ; Corrected torque (N m), T ; Torque (Nm), SFL ; Specific Feeding Load, LSD ; Least significant Difference, GRP ; groups based on their values for each of the moisture contents and the differences between the means of the moisture contents

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a material can be extruded and the relative cost of the extrusion operation. It is often used to quantify the amount of shear that is put on material during extrusion.

SME is one of system parameters which are indicators of extrusion processes. They are the controlled variables in an extruder (Chessari and Sellahewa, 2001). SME results from independent process variables such as barrel temperature, screw speed and die geometry and it is related to the mass transformation leading to variation in expansion, density, and geometric characteristics. SME, product temperature, and residence time have been used to predict the properties of puffed products such as expansion index and sensory characteristics. The aim of this study is to characterize the SME requirement a locally developed single screw extruder for cassava and cereal crops processing so as to be able to provide management data for its use, maintenance and control.

Materials and Methods

Extrusion The extruder used in this study is the dry type (Fig. 1). It is made up of three (3) main units namely the feeding unit, the compression and melting unit and the die unit all fabricated at the Federal University of Technology, Akure (FUTA) 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 variation was 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.

As showed in Fig. 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 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. The barrel and the screw/die configuration are typical of alimentary food production equipment. The extrudates were extruded as ribbons and later cut manually into sizes.

Sample preparation 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 300 um sieve separately and the proximate analysis and moisture contents 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. The proximate composition of the samples is presented in Table 1.

Experimental procedure Samples were fed into the extruder at a feed rate 10 Kg/h at room temperature. The extruder was operated for 30 minutes for each set of condition. Temperature, both of the barrel and product were varied by continuous running of the machine, thereby building up the temperature. Duration of operation was measured with a stop watch as the extruder was running by varying the time of sample collection. Since barrel temperature varies with duration of operation, duration of operation was observed as the independent variable. Temperature was controlled by dipping the barrel and screw in a bath of cold water at each run of sample. The SME was calculated using the "Eq. 1" as described by Chi- Chuang and Yeh, (2004) as follows:

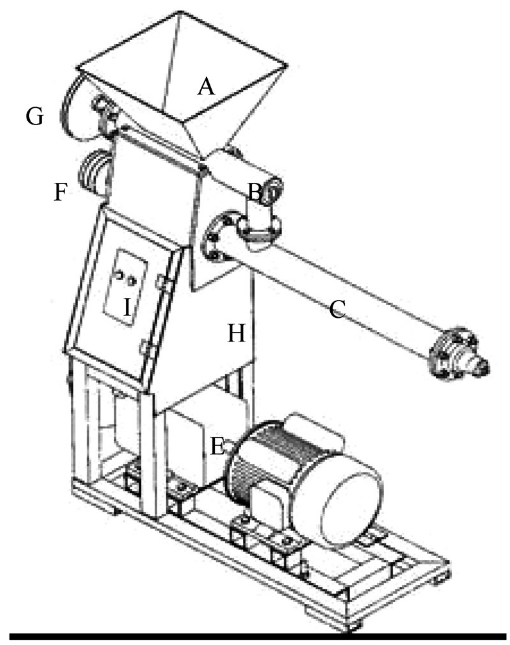

Fig. 1. Isometric view of the extruder
LEGEND A- Hopper, B- Feeding Conveyor, C- Extruder worm, D- Die Unit, E- Power train, F- Conveyor pulley, G- Extruder pulley, H- Extruder Housing, I- Control switch

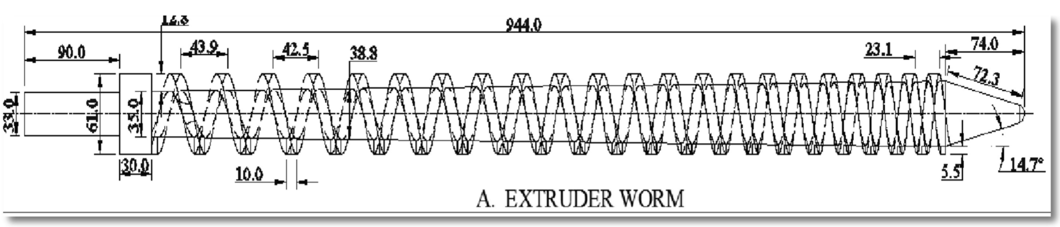

Fig. 2. The extruder screw's configuration

Table 1. Proximate compositions of samples (dry basis).

	Mc%	Protein%	Fat%	Ash%	Fibre%	Carbohydrate%
cs	1.47	0.31	1.50	0.20	0.12	96.40
cf	1.90	7.36	1.4	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	13.20	1.50	0.45	2.17	83.10

cs-cassava starch, cf-cassava flour, mf-maize flour, ms-maize starch, wf-wheat flour, Mc- moisture

$$SME = \frac{2\pi \times \mathrm{Tc} \times S_s / 60}{Fr} \times 3.6\ [kj / kg] \qquad \text{……Eq. 1}$$

$\mathbf{T_c}$ is the corrected torque (N m), $\boldsymbol{S_s}$ the screw speed (rpm), $\boldsymbol{F_r}$ the feed rate (kg/h) and equivalent to the product output at stable conditions. The torque T required to drive the screw was calculated using the "Eq. 2" according to Khurmi (2006).

$$\mathrm{T} = 60P / 2\pi N \qquad \text{……Eq. 2}$$

Where N = number of revolutions per minute (rpm), P = Power transmitted (Watts).

The torque (T%) during extrusion is the ratio of the actual torque during operation and the permissible torque. No-load torque was measured while operating with flood feeding of water. The no-load torque was subtracted from the operational torque to obtain the corrected torque.

Statistical Analysis A factorial experiment in completely randomized design was employed to study the effect of extrusion variables: feed moisture (25 − 40%), extruder temperature built up by varying the duration of sampling (2 − 30 min) and screw speed (100, 150, 200 rpm) on SME. In order to understand the effects of the starch and protein contents on the extrusion process, their percentage composition were used to characterize the samples and subjected to response surface regression, One Way Analysis of Variance, and stepwise regression analysis. The one way analysis of variance was to assess the effect of moisture content at 30 min duration of operation upon the response variables at three different screw speeds.

Variables were analyzed with and without their interaction to improve the model fit. The response surface regressions was carried out using the response surface regression procedures of Statistical Analysis System (SAS) software v.9.R1 (2003) and it generated the coefficients of the second order polynomials for SME. The order of importance of the variables was determined with stepwise regression analysis using Statistical Package for Social Scientists (SPSS 13.0) software.

Results and Discussion

The effect of extrusion variables (initial moisture content, duration of operation and screw speed) on SME is shown in Tables 2 − 6. The table shows that SME varies directly with duration of operation for cassava products under study and inversely for maize and wheat products. Also SME increased with increasing speed from 100 to 150 rpm but decreased at 200 rpm and decreased with increase in moisture content from 25 to 40%. Maximum SME of 241.71 kJ/kg was attained in 30 minutes through viscous dissipation at 150 rpm and 30% moisture content by cassava starch while a minimum of 24.79 kJ/kg occurred at 200 rpm and 40% moisture content by wheat flour.

Generally for all the products, a moisture content >20% was required for the extrusion process; else the extruder screws will not rotate. This problem of getting stocked at lower moisture levels can be overcome by improving the torque and torque is closely related to SME.

Low-moisture materials require more mechanical energy to cause flow. The improvement of the torque would be achieved by arranging the bigger pulley to be on the extruder screw shaft. A good explanation for this arrangement is derived from Eq. 2 i.e. speed is inversely proportional to torque, since N is directly proportional to the diameter of pulley. Smaller diameter produces more N than bigger pulleys when running at the same speed. Therefore, the pulley on the extruder shaft must be bigger than that of the driver pulley to increase its torque. It is therefore advisable to select a high speed prime mover and attempt to step down its speed on the extruder by using a bigger pulley.

These low SME values at 200 rpm for all the products may result from increasing screw speed at a constant feed rate which reduced the number of flights of the extruder that were filled. The common practice to avoid such occurrence is to maintain a constant percentage filled flight of the extruder by determining the appropriate feed rate at each screw speed. The ratio of the feed rate to screw speed required to maintain a constant percentage filled flight is called Specific Feeding Load (SFL).

At fixed feed rate, an increase in screw speed decreased the amount of feed conveyed per flight by the screw and therefore decreased the filling ratio in the screw elements (Choudhury and Gautam, 1998).

The increase in SME with extrusion time for cassava products might be due to the rise in viscosity with temperature. The viscosity of cassava increased with increase in extrusion time. Therefore, higher SME is required for it flow through the extruder. Also, it requires greater force to break the strong bonds that exists between cassava starch molecules than those of cereals because of their

Table 2. SME requirement for cassava starch extrudates at different extrusion conditions

Duration of operation (Min)	100 rpm			150 rpm			200 rpm		
	Moisture Content			Moisture Content			Moisture Content		
	25%	30%	40%	25%	30%	40%	25%	30%	40%
2	53.5	50.67	28.65	128.03	55.83	32.45	30.87	42.64	24.79
10	70.3	100.4	50.00	144.85	112.97	61.02	53.22	88.22	50.65
18	92.5	142.5	75.27	165.97	155.48	82.18	74.74	121.29	63.34
30	121.0	221.69	149.11	183.11	241.71	162.02	142.24	191.4	126.62

Table 3. SME requirement for cassava flour extrudates at different extrusion conditions

Duration of operation (min)	100 rpm			150 rpm			200 rpm		
	Moisture Content			Moisture Content			Moisture Content		
	25%	30%	40%	25%	30%	40%	25%	30%	40%
2	37.51	18.70	28.2	40.35	34.05	20.46	30.87	20.3	15.36
10	69.10	46.60	56.6	70.92	64.94	43.32	63.73	43.16	42.54
18	88.60	64.97	78.0	96.75	86.03	65.65	74.74	64.1	54.61
30	195.91	136.84	155	212.26	187.91	148.84	167.24	125	116.01

Table 4. SME requirement for maize starch extrudates at different extrusion conditions

Duration of operation (Min)	100 rpm			150 rpm			200 rpm		
	Moisture Content			Moisture Content			Moisture Content		
	25%	30%	40%	25%	30%	40%	25%	30%	40%
2	83.60	40.39	32.00	103.95	44.24	25.42	80.42	33.89	40.20
10	79.01	36.5	27.05	70.04	40.57	19.94	55.23	30.89	31.97
18	75.74	33.2	23.2	93.11	36.38	15.83	37.39	27.83	24.50
30	66.05	11.3	4.7	78.46	12.34	6.27	15.60	9.72	6.70

Table 5. SME requirement for maize flour extrudates at different extrusion conditions

Duration of operation (Min)	100 rpm			150 rpm			200 rpm		
	Moisture Content			Moisture Content			Moisture Content		
	25%	30%	40%	25%	30%	40%	25%	30%	40%
2	130.61	50.67	43.97	142.6	55.83	48.11	110.65	42.68	37.46
10	123.32	43.23	35.02	88.43	40.54	41.4	81.18	34.45	29.51
18	119.51	33.3	28.65	66.76	36.38	32.45	51.70	28.27	21.55
30	91.01	11.3	11.3	32.45	12.34	12.34	15.64	9.72	9.72

Table 6. SME requirement for wheat flour extrudates at different extrusion conditions

Duration of operation (Min)	100 rpm			150 rpm			200 rpm		
	Moisture Content			Moisture Content			Moisture Content		
	25%	30%	40%	25%	30%	40%	25%	30%	40%
2	45.2	36.95	28.65	44.5	40.35	32.45	38.9	30.89	24.79
10	42.5	28.5	23.2	42.0	32.00	27.5	36.01	22.45	18.62
18	40.0	22.3	18.5	39.5	24.46	24.46	32.6	18.73	15.36
30	35.0	9.3	7.5	34.5	8.27	8.27	30.00	6.37	6.22

Table 7. Stepwise regression data analysis of SME

Models	Coefficients		T-test	Prob.	Adjusted R^2	F value	Prob.
1	Bo	30.411	0.302	0.764	0.159		
	Sm	−0.003	7.768	0.000		33.368	0.000
2	Bo	30.411	0.562	0.578	0.278		
	Sm,	−0.004	15.316	0.000		35.018	0.000
	Sc	0.690	−9.198	0.000			
3	Bo	−35.892	0.610	0.546	0.317	28.394	0.000
	Sm,	2.411	15.316	0.000			
	Sc,	0.000	−3.890	0.000			
	Dt,	−0.004	−2.627	0.013			
4	Bo	0.752	0.681	0.501	0.331	22.857	0.000
	Sm,	4.390	6.453	0.000			
	Sc,	0.000	1.728	0.094			
	Dt,	−0.016	−3.758	0.001			
	dsm	−0.062	−2.972	0.006			

Table 8. Least Significant Means of Products for SME

Variable	Linear Term	Quadrat-ic Term	Interaction					R^2
Intercept	−139.18		X_1	X_2	X_3	X_4	X_5	0.657
Protein Content, X_1	165.21^{**}	-1.874^{NS}	–	-1.656^{**}	–	–	–	
Starch Content, X_2	15.430^{*}	–	–	–	–	–	–	
Moisture Content , X_3	-3.377^{NS}	0.022^{NS}	-1.656^{**}	0.117^{NS}	–	–	–	
Screw speed, X_4	-3.186^{NS}	-0.006^{*}	0.019^{NS}	0.026^{NS}	0.008^{NS}	–	–	
Duration of operation, X_5	-47.097^{**}	0.022^{NS}	0.531^{**}	0.737^{**}	0.083^{*}	0.006^{NS}	–	

Significant at $^{*}p \leq 0.05$; $^{**}p \leq 0.01$, NS-Non significant at $p = 0.05$.

higher amylopectin contents (International Starch Institute, 2005). This would increase the resistance to turn the screw and hence require more mechanical power to dissipate into the material. Also, this deviation from previous studies may be because of the different variety of cassava used. Infact, it was observed that while a moisture content < 20% could solvate samples in previous studies e.g. Hashimoto and Grossmann (2003), it required a minimum of 25% moisture content in this case.

TMS 30572 cassava variety is known for its exceptional stability (Fayose *et al.,* 2009). Also, the gelatinization temperature for cassava is lower than that of maize and wheat (Bokanga and Tewe 1995, Zuilichem and Stolp, 1987). It was easier for cassava to cook/gelatinize under the heat provided by the extruder, with a higher solubility and viscosity. The stepwise regression data analysis for all the products is shown in Table 7 and the response surface regression analysis in Table 8. Table 7 shows that the interaction term sm has the highest contribution of 15.9%, to R^2 of SME. There was an improvement in the R^2 of the response surface regression i.e. 0.657 (Table 8) than the linear regression model of 0.331 (Table 7). This shows that the model is better represented by a quadratic model.

Conclusion

The specific mechanical energy response of a locally developed single screw extruder has being well characterized. The study revealed that SME varied directly with duration of operation for cassava products and inversely with duration of operation for all maize and wheat products. SME increased with increasing speed from 100 to 150 rpm but decreased at 200 rpm. SME increased with increase in moisture content from 25 to 40%. SME response of maize and wheat were less sensitive to changes in extrusion variables than cassava. The specific mechanical energy response of the extruder can be improved by improvement of the torque to improve the pumping ability of the extruder. The interaction term of screw speed and moisture content, sm has the highest overall contribution to R^2 of SME. Also, the SME model is better described by a quadratic model than a linear one. Finally, the study has provided database on extrusion of selected foodstuffs beneficial to the food industry in Sub Sahara Africa.

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