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Extrusion cooking on pasting properties and relative viscosity of selected starch crops

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Rheological properties of food are very important indicators of the quality and texture of food products. In this study, the relative viscosity and pasting characteristics (cold and hot paste viscosity) of extrudates from a locally developed extruder (L/D 12:1, CR 4.4:1, 4 KW) were determined. The extrudates were processed from the flour and starch of cassava and maize and wheat flour. Stepwise regression and other follow up tests were employed to a factorial experiment in completely randomized design. Relative viscosity increased positively with duration of operation for cassava products and negatively for cereal products. For Hot Paste Viscosities (HPV) and Cold Paste Viscosities (CPV) however, both products decreased negatively with extrusion. The most stable of the products is Cassava Starch at 40% moisture content. Also, retrogradation decreased with increasing extrusion time and moisture content. The equations relating the various dependent and independent variables were established to predict the quality of the products. Quadratic coefficients fitted the extrusion data very well than linear models.

Key words: Extrusion, hot and cold paste viscosities, relative viscosity, food stability, cassava, maize, wheat.

INTRODUCTION

In Nigeria and West Africa, starches from cereals, roots and tubers are used as a staple food in the diet of the people. Nigeria production of cassava (*Manihot esculenta*, Crantz), a starch-rich root tuber crops is the largest in the world, producing more than 70 million tonnes of cassava annually (Yisa, 2008; UNCTAD, 2004). However, a high percentage of the crops are lost because of inadequate processing. There is need for alternative processing options for cassava to add to its value and for its sustainability. One of the means to arrest post-harvest losses is by expansion of the processing technology. Food extrusion, 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, is a versatile process that helps in the expansion of the processing technology of crops. Efficient and increased processing will be enhanced by developing an indigenous extruder (Ademosun, 1997). Cassava as a starchy crop has high potential for production of extruded foods. Meanwhile it is obvious that cassava is not popular for production of extruded foods. Maize and wheat are however popular

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Table 1. Proximate compositions of samples.

Variable	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	3.10

cs, Cassava starch; cf, cassava flour; mf, maize flour; ms, maize starch; wf, wheat flour.

for production of extruded foods.

Viscosity is one of the factors that determine acceptability of fabricated foods and to know or monitor the effect of any treatment on the starch. Also, 'the knowledge of the rheological properties of melted dough is very important in food extrusion systems because they affect extrudate expansion, texture, appearance and hydration properties as well as the thermal and mechanical energy input etc' (Lo et al., 1998). Functional and pasting properties of flour and starch products are important for their use in the food industry. For example, the characteristics of products formulated with starch, such as food thickeners and other flour or starch based products, are greatly influenced by functional and pasting properties (Niba et al., 2001). According to Osundahunsi (2005), pasting characteristics is necessary to determine the nature of food if it to be in paste form. The ability of a starch-containing food to form a paste or a gel is one of the principal factors that determine the texture and the quality of that food product. Functional properties of starch such as pasting viscosities influence the textural and gross structure of the food products and they provide information that could be used to determine specific end use applications (Henshaw and Adebowale, 2004).

Cold viscosity, the viscosity of the paste when cooled to the required temperature, is an important property if the extruded starch will be used as an ingredient in the foods that require cold thickening capacity, like instant soups, creams or sauces while hot paste viscosity is the viscosity of the paste at the start of cooling after heating. The aim of this study is to characterize the relative viscosity and hot and cold paste viscosities of the flour and starch of cassava and maize and wheat flour from a locally developed extruder.

MATERIALS AND METHODS

Sample preparation

Samples of flour and starch of cassava 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 (*M. 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 (dry basis) of samples were determined as described by AOAC (1995) approved method (Table 1). 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. Table 1 shows the proximate compositions of samples.

Extrusion

The extruder used in this study is the dry type. It is made up of three 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 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. Figure 1 shows the isometric drawing 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 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 are typical of alimentary food production equipment. The extrudates were extruded as ribbons and later cut manually.

Experimental procedure

Samples were fed into the extruder at a feed rate 10 Kg/h at room temperature. The extruder was operated for 30 min 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 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 dipping the barrel and screw in a bath of cold water at

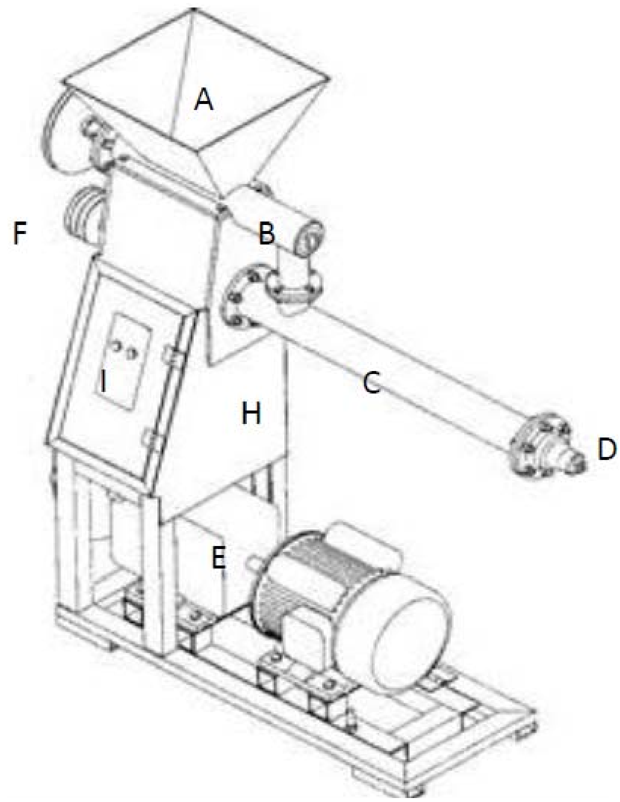

Figure 1. Isometric view of the extruder.**A**- Hopper, **B**- Feeding Conveyor, **C**- Extruder worm, **D**- Die Unit, **E**- Power train, **F**- Conveyor pulley, **G**- Extruder pulley, **H**- Extruder Housing, **I**- Control.

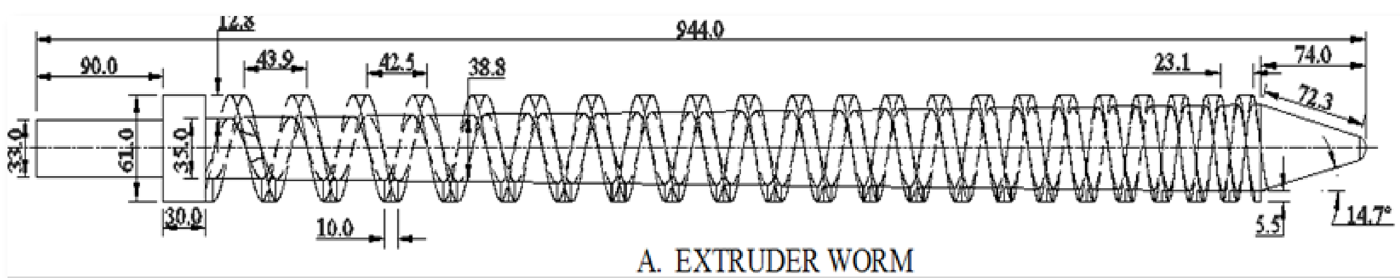

Figure 2. The screw's configuration.

each run of sample.

Statistical analysis

This experiment was conducted using a factorial design comprising of five levels of product classification, three employed to fit the experimental data to second-order 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 preselected 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. 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. Also, response surface methodology was applied to the extrusion data using a second order polynomial as fitted to the data to obtain regression equations showing the importance of each independent variable and their interactions on the response variables considered using (SAS) software v.9.R1 (2003). The generalized regression model fitted to the experimental data is given as follows:

$$Y=Bo + b1PC + b2SC + b3MC + b4DT + b11PC^2 + b21SC.PC + b32\ MC.SC + b31MC.PC + b33MC^2 + b4\ 1(DT*PC) + b42DT.SC + b43DT.MC + b44\ (DT^2) + \varepsilon$$

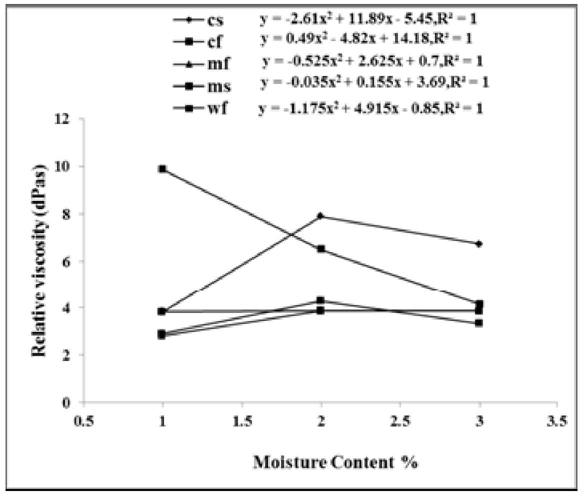

Figure 3. Variation of relative viscosity with duration of operation at screw speed 100 rpm and initial moisture content 30%.

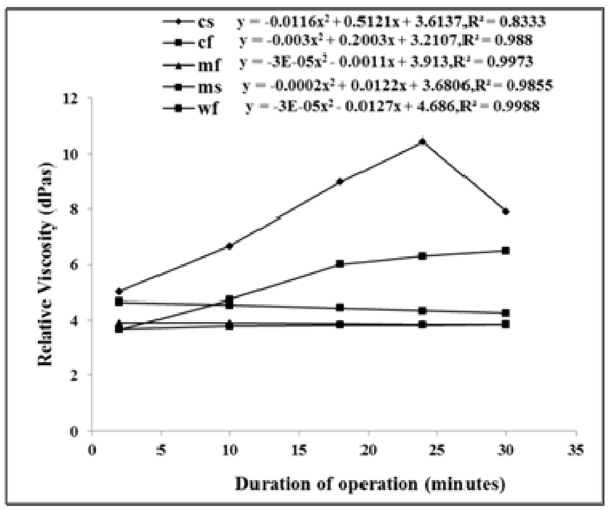

Figure 4. Variation of relative viscosity with initial moisture content at 30 min extrusion time and 100 rpm screw speed.

Data collection

The extruded samples were dried according to Iwe et al. (1999), coarsely ground in a high speed laboratory blender (Waring Commercial Heavy Duty Blender, New Hartford, Conn. U.S.A.), milled in a domestic blender (Martex, Dawan) and passed through a 300 um sieve. The viscosity of the melts was determined with Capillary Viscometer Method, AOAC (1995) using Equation 1.

$$\frac{\text{Flow rate of sample solution at 20 oC} \times \text{specific gravity of sample solution} \times 1.002\ (\text{specific gravity of water})}{\text{flow rate of water}} \quad (1)$$

Pasting properties (hot and cold paste viscosity) were determined as described by Wang et al. (2011) but with a few modification e.g. the instrument used to measure the pasting viscosity of the extrudates is the Rion viscotester (VT – O4E – Japan) (Mouquet, 1998; Owolarafe et al., 2008). Also, the samples were heated to 90°C and the HPV determined. This was because all the materials under study had a gelatinization temperature much less than 90°C. The test fluid was then cooled at a constant rate to 30°C. This value represents the CPV at which temperature the product is normally eaten or the room temperature.

RESULTS AND DISCUSSION

The effect of extrusion conditions on relative viscosity

The effect of duration of operation and moisture contents on relative viscosity at different extrusion conditions are shown in Figures 3 and 4. Relative viscosity increased positively as the duration increased for cassava starch and flour whereas it decrease with increase in duration of

Table 2. The stepwise regression data analysis of relative viscosity.

Models	Coefficients		T-test	Prob	Adjusted R^2	F value	Prob	VIF
1	B_0	-577	-0.287	-0.775	0.068	6.396	0.014	1.000
	Sc	0.057	2.529	0.014				
2	B_0	-13.493	-2.578	0.012	0.139	6.986	0.002	6.224
	Sc	0.188	3.487	0.001				6.224
	Pc	0.246	2.655	0.010				
3	B_0	-14.095	-2.751	0.008	0.178	6.341	0.001	6.224
	Sc	0.188	3.568	0.001				6.224
	Pc	0.246	2.716	0.008				
	Dt	0.036	2.096	0.040				1.000
4	B_0	-14.645	-2.939	0.004				6.239
	Sc	0.194	3.783	0.000				
	Pc	0.251	2.857	0.006	0.224	6.355	0.000	6.228
	Dt	0.123	2.966	0.004				6.201
	dm	-0.003	-2.292	0.025				6.206

B0, constant term; Sc, starch content; Pc, protein content; Dt, duration of operation; dm, interaction of Dt and Moisture content.

operation for cereal products. The maximum relative viscosity of 10.45 (0.001 Pas) was attained at 30% moisture content by cassava starch. The relative viscosity at 30% moisture content was higher than 25 and 40% for the entire products expect cassava flour.

This shows a difference between the behaviour of the viscosity of cassava flour and its starch. This may be because at 25% mc, there was no transition of the starch from the original floury nature to a melted state typical of most extrusion because of blockage of the screw. This problem of getting stocked at lower moisture levels can be overcome by improving the torque. Also, the maximum value for the viscosity occurs where the cellulose is least, that is, 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).

Viscosity decreases with duration of operation, product temperature and moisture content for cereal products. This can be due to the fact that within normal operating ranges starches and protein rich material are shear thinning (Lin et al., 2009; Moscicki and van Zuilichem, 2011). This justifies the use of a power low constitutive equation for the shear dependency of viscosity. However, the result of relative viscosity for cassava products generally showed a deviation from above concept. Only at extreme temperature does the equation applied to cassava product and by this time, from observation, the cassava is already becoming dextrinized. Also, it has been reported (Lo et al., 1998) that as the temperature of the dough rises above the gelatinization range the starch granules undergo swelling. The force may have been great enough to break these fragile granules into smaller fragments thereby causing a reduction in viscosity. For cassava products, the rise in viscosity with temperature before a decline may be due to the fact that it requires greater force to break the strong bonds that exists between the starch molecules than those of cereals because of their higher amyl pectin contents (Huang et al., 2008; Moorthy, 2004).

Also, the gelatinization temperature for cassava is lower than that of maize and wheat. (Ihekoronye and Ngoddy, 1985; Van Zuilichem and Stolp, 1987). The stepwise regression data analysis of relative viscosity is shown in Table 2. The low R^2 for relative viscosity is an indication that the relationship is not best described by a linear model. The polynomial models as shown on the graph have better representation of the relationships. The interaction terms did not improve the model R^2. As food, the extrudates with low relative viscosity can easily be eaten by infants while those with high viscosity can only be eaten easily by adults because they tend to be hard and cohesive in texture than samples with low viscosities.

Effect of extrusion variables on pasting properties

Hot paste viscosity

The effect of extrusion variables (initial moisture content, duration of operation and screw speed) on hot paste viscosity are shown in Figures 5 and 6. Hot paste

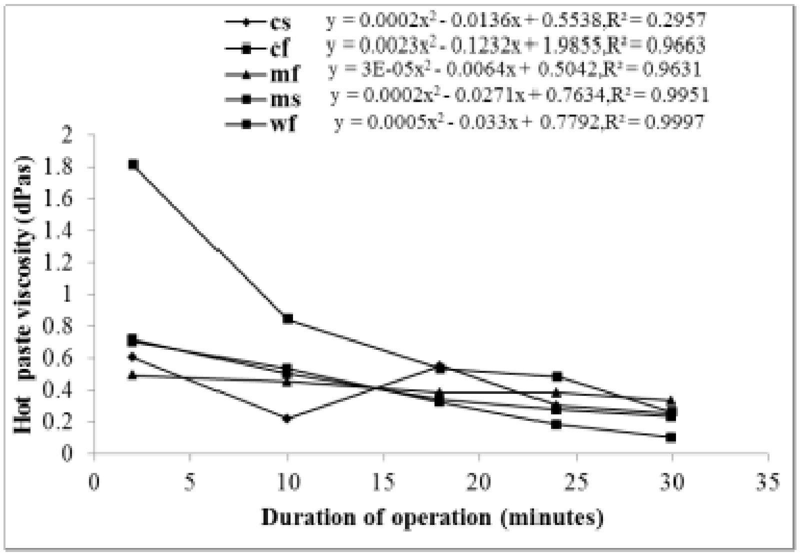

Figure 5. Variation of hot paste viscosity with initial moisture content at 30 in extrusion time and 100 rpm screw speed.

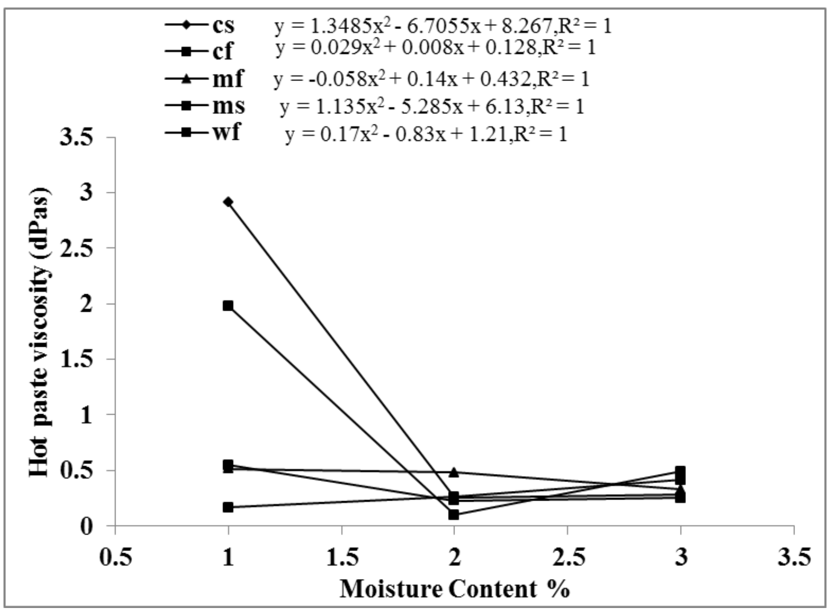

Figure 6. Variation of hot paste viscosity with duration of operation at screw speed 100 rpm and initial moisture content 30%.

viscosity (HPV) varies inversely with duration of operation that is, HPV decreases with increase in duration of operation and decreased with increase in moisture content from 25 to 30% and increased at 40%. Maximum (HPV) of 9.1 dPas was attained at 25% (not shown on graph). The stepwise regression data analysis of HPV is shown in Table 3. The R^2 showed that the relationship is not best described by a linear model. However, the polynomial equation generated by the response surface regression (Appendix Table 1) gave a better fit.

Cold paste viscosity

The effect of extrusion variables (initial moisture content, duration of operation and screw speed) on cold paste viscosity is shown in Figures 7 and 8. Cold paste viscosity (CPV) varied inversely with duration of operation and decrease with increase in moisture content from 25 to 30% and an increase at 40%. Maximum CPV of 12.98 dPas was attained at 25% moisture content. A CPV of 16.47 dPas was attained at 0 duration of operation (that

Table 3. Stepwise regression analysis for hot paste viscosity

Models	Coefficients		T-test	Prob.	Adjusted R^2	F value	Prob.	VIF
1	B_0	0.664	8.777	0.000	0.605	16.347	0.003	1.000
	Dt	-0.016	-4.043	0.003				
2	B_0	1.216	6.099	0.000	0.782	18.962	0.001	
	Dt	-0.014	-4.614	0.002				1.058
	Mc	-0.017	-2.882	0.020				1.058
3	B_0	1.800	15.154	0.000	0.966	94.511	0.000	
	Dt	0.061	-8.513	0.000				35.319
	Mc	-0.035	-9.733	0.000				2.491
	dm	0.001	6.604	0.000				39.982

B_0, constant term; Dt, duration of operation; Mc, moisture content; dm, interaction of Dt and Mc.

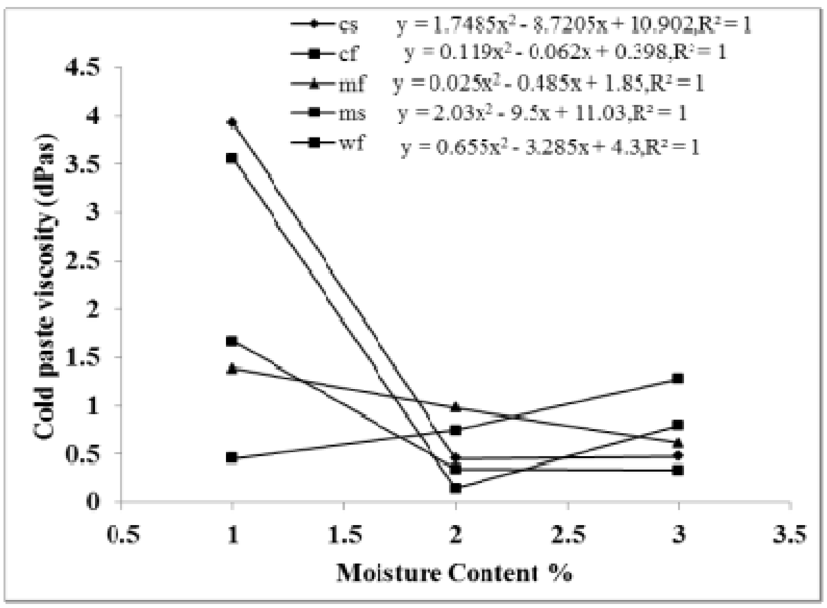

Figure 7. Variation of cold paste viscosity with initial moisture content at 30 min extrusion time and 100 rpm screw speed.

is, when the cassava starch was not run through the extruder). However, a minimum CPV of 0.477 dPas was attained at 25% and 30 min duration of operation. The stepwise regression data analysis of CPV is shown in Table 4. The Duration of sampling has the highest contribution 52.8% to R^2 of CPV. The variable, moisture content accounted for 18.8% and screw speed only 2.7% of the total variation in R^2.

Stability of the products

Table 5 shows the stability of the extrudates obtained from the differences obtained between the HPV and CPV of each sample. From the analysis, MS at 25% m.c is the least stable, having the highest difference between its CPV and HPV values. This is followed by Wf at 25% mc. Also, the most stable of the products. Also, the most stable of the products is MS at 30% mc, followed by Wf, and then CS. If the HPV and CPV are far apart indicating lower stability then its tendency for retrogadation is very high. Table 5 shows there is generally an improvement in the stability of the extruded products when compared to the raw samples. Also, the stability of cassava products were improved better than cereal products. According to Chang et al. (1998), starch with low moisture content extruded at a high temperature results in an extrudate characterized by a low degree of retrogradation, while

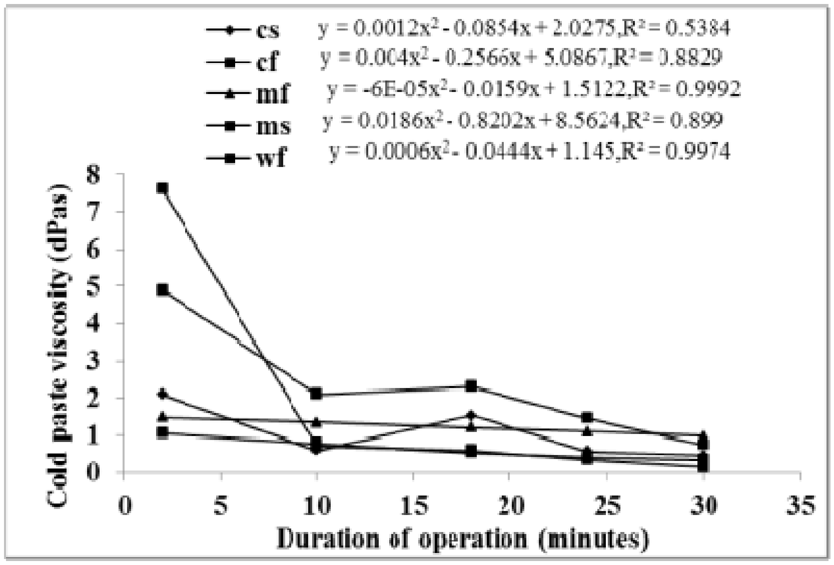

Figure 8. Variation of cold paste viscosity with duration of operation at screw speed 100 rpm and initial moisture content 30%.

Table 4. Stepwise regression analysis for cold paste viscosity

Models	Coefficients		T-test	Prob	Adjusted R^2	F value	Prob.	VIF
1	B_0	1.621	8.317	0.000	0.674	21.640	0.001	1.000
	Dt	-0.049	-4.652	0.001				

B0, constant term; Dt, duration of operation.

Table 5. Differences in pasting characteristics of extrudates at the various moisture contents.

Variables	Differences in pasting characteristics			
	25% mc	30%mc	40%mc	Raw samples
cs	1.02	0.205	0.19	7.5
cf	0.29	0.49	0.87	10.09
mf	0.88	0.5	0.29	5.66
ms	1.58	0.05	0.31	0.38
wf	1.12	0.12	0.11	1.54

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

starch with a moderate to high moisture content (190 to 260 g kg^{-1}) extruded at a moderate temperature (125-190°C) produces an extrudate with a high degree of retrogradation. However, in this work, retrogradation decreased with increasing extrusion time and moisture content.

Conclusion

The relative viscosity and pasting behaviour of extrudates from a locally developed single screw extruder at different conditions have been well studied. Relative viscosity increased with increase in duration of operation for cassava products whereas it decreases with increase in duration of operation for cereal products. HPV decreases with increase in duration of operation and decrease with increase in moisture content from 25 to 30% and an increase at 40%. Cold paste viscosity decreased when moisture decreased and temperature increased. Retrogradation decreased with increasing extrusion time and moisture content. The study provided database on extrusion of selected foodstuffs beneficial to the food industry. The equations relating the various dependent and independent variables were established to predict this quality attributes of the products. Both quadratic coefficients and linear models fitted the extrusion data very well expect for relative velocity quadratic where quadratic coefficient proved better.

Conflict of Interest

The authors have not declared any conflict of interest.

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APPENDIX

Appendix Table 1. Models generated by response surface analysis for RV, HPV, CPV.

R. Var	Coefficients													
	b0	b1	b2	b3	b4	b1*b1	b1*b2	b3*b2	b3*b1	b3**	b4*b2	b4*b1	b4*b3	b4**	R^2
RV	-91.909	3.480^{NS}	0.895*	2.264*	-0.937^{NS}	0.0032^{NS}	-0.0236^{NS}	-0.042^{NS}	-0.019*	-0.004^{NS}	0.0202^{NS}	0.0136*	-0.007*	-0.003 ^{NS}	0.634
CPV	140.008	-14.353*	-1.028^{NS}	-4.087*	-0.05 ^{NS}	0.264^{NS}	0.105^{NS}	0.075**	0.026^{NS}	0.017*	0.0014^{NS}	-0.006^{NS}	0.0075^{NS}	0.005^{NS}	0.713
HPV	42.133 ^{NS}	-6.463 ^{NS}	-0.172 ^{NS}	-1.688^{NS}	-0.024^{NS}	0.154^{NS}	0.046^{NS}	0.027^{NS}	0.007^{NS}	0.012*	0.002^{NS}	-0.003^{NS}	0.005^{NS}	0.002^{NS}	0.611

Significant at *p<0.05; **p<0.01, NS-Non significant at p=0.05. Coef, Coefficients: Bo, (constant term) b1, b2, b3, b4, b5 linear effect of protein content, starch content, moisture content, screw speed and duration of operation respectively. R.Var, Response variable.