Effect of extrusion variables on extrudates properties of water yam flours - a response surface analysis

Oke M.O.[1], Awonorin S.O.[2], Sanni L.O.[2] Asiedu R.[3] and Aiyedun P.O.[4]

[1]Department of Food Science and Engineering, LAUTECH, Nigeria.

[2] Department of Food Science and Technology, UNAAB, Nigeria.

[3] International Institute of Tropical Agriculture (IITA), Oyo Road, PMB 5320 Ibadan, Nigeria.

[4] Department of Mechanical Engineering, UNAAB, Nigeria.

*Corresponding Author

E-mail: ola4ade@yahoo.com (OKE, M.O.)

Telephone No: 2348030758356; 2347057711464

Abstract

Water yam (*D. alata*) flour of two varieties was processed using standard wet milling procedure prior to the extrusion process which led to the determination of extrudate properties of the flours. A single screw extruder (DCE 330, NJ) was used in evaluating the extrudate properties, which included torque, mass flow rate, residence time, specific mechanical energy and expansion ratio of the flours from the water yam samples. The effect of extrusion and process variables: Feed Moisture Content (FMC), Screw Speed (SS) and Barrel Temperature (BT) on the extruder torque, residence time, mass flow rate, specific mechanical energy and expansion ratio for the entire varieties were determined and predictive models were also developed using response surface methodology. It was generally observed that changing the feed moisture content, barrel temperature and screw speed significantly ($p<0.05$) affected expansion ratio, torque, mass flow rate, residence time and specific mechanical energy of all the extrudates. Increasing the feed moisture content (18-28% db) and screw speed (80-180rpm) resulted in a substantial decrease in expansion ratio (46.6%), residence time (27.5%), and specific mechanical energy (83.6%); whereas, increasing the screw speed significantly increased the mass flow rate (64.5%) of extrudates. Regression analysis indicated that screw speed and feed moisture content were the major process variables showing significant ($p<0.05$) linear, quadratic and interaction influences on mass flow rate, expansion ratio and specific mechanical energy.

Keywords: Water Yam, Flour, Extrusion Variables, Extrudate, Extrudates Properties

Introduction

Yam (*Dioscorea spp*) is a traditional food crop of great antiquity that originated in Africa, Asia, and America, and now widely distributed throughout the tropics, with a few members occurring in temperate zones (Coursey, 1983). It was reported by Coursey (1983) that yam is a preferred staple food crop in West Africa with a prominent socio-cultural role. The genus contains over 600 species with more than 10 species cultivated for food and six for pharmaceutical use (Coursey, 1976). Only six species are important staples, which are white yam (*D. rotundata*), water yam (*D. alata*), yellow yam (*D. cayenensis*), trifoliate yam (*D. esculenta*) (Tetteh and Saakwa, 1994). Besides the cultivated yam species, there are a number of wild types which are also harvested for food. The commonest of these is *D. prachensilis* which is common in the forest belt (Tetteh and Saakwa, 1994).

Water yams (*Dioscorea alata L.*) are grown widely in tropical and subtropical regions of the world. They are plants yielding tubers and contain starch between 70 and 80% of dry matter (Kim *et al.*, 1995; Zhang and Oates, 1999). Yams, the edible tubers of various species of the genus Dioscorea, are important staple foods and a potential source of ingredients for fabricated foods in many tropical countries because of their high starch content.

Virtually all production of yam is used for man food. The tubers are processed into various types of food including yam slices, yam balls, mashed yams, yam chips, yam flakes and yam starches. Dried chips are also used for flour, food colourant, and couscous production (Osagie, 1992). Noodles are pasta of narrow strips, which can be eaten with or without cooking and they are extruded products made from wheat flour, stabilizers, binders and other ingredients (Lee *et al.*, 1999). Nevertheless, attempt has been made to apply modern technology to the processing and utilization of yam as wheat flour substitute (Akinwande *et al.*, 2004).

The application of extrusion technology is one of the most economic processes; being used increasingly in the food industries for the development of new products such as snacks, baby foods, breakfast cereals and modified starch from cereals and tubers. So, extruded yam products would be of economic assistance to the producing countries. The extrusion cooking of starch materials has been widely investigated for the last ten years. Conversion of starch in the extruder depends on a large number of variables in the machine and raw material control parameters. Knowledge of the properties and nature of raw material flow under the complete range of conditions within the extruder mainly in the transition zone of the screw (high pressure and metering zone) and also in the die zone is very important to control the extruder behaviour for producing good quality, extruded end products (Changi *et al.*, 1998).

Some research has demonstrated the feasibility of using root crops and tubers as main extrusion feed ingredients (Grossmann, *et al.*, 1988). Others have proposed physical and chemical properties changes in the starch granule during extrusion (Linko *et al.*, 1980; Linko *et al.*, 1984). Other methods such as die pressure may, however, be used as an index of the viscosity of the melt (Tadmor and Gogos, 1979). During extrusion, the introduction of specific thermal and mechanical energy causes various changes in starch structure. The principal effect of this thermomechanical treatment is to rupture the granular structure of starch. Kalentunc and Bresslauer (1993) proposed the use of glass transition temperature measurements on extrudates as a criterion for adjusting operating extruder conditions. Wen *et al.* (1990) indicated the amount of fragmentation is highly affected by the chemical nature of the extrudate, design and configuration of the extruder and extruder operating conditions.

In addition to the extruder characteristics, the specific power consumption, throughput and extrudate properties were expressed, as functions of parameters such as die diameter, screw speed, barrel temperature and feed moisture. In the field of extruded starchy products, some important progress has recently been made to explain product starch granule. However, little or nothing has been done on the effects of extrusion variables on the extrusion cooking of water yam flours in order to evaluate their extrudates' properties. Thus there is a need to establish the influence of some extrusion cooking variables on extrudates' properties.

Materials and Methods

Sources of *D. alata* and Sample Preparation

The *D. alata* of two (2) varieties (TDa 00/00104 and TDa 00/00194) used in this study were planted on the research farm of the International Institute of Tropical Agriculture, Ibadan and harvested at full maturity. The yam samples for flour were peeled, diced into cubes and placed in paper bags. All samples were dried in the oven at 60 ^{o}C for four days. The dried chips were subsequently milled into flour with a micro mill to pass through a mesh of 150 m screen size. The flour samples were put in zip-lock bags and kept in covered plastic containers until used for analyses.

Measurement of extrudate properties

Torque, T. This was determined by reading directly from the extruder operation panel during extrusion runs according to Iwe *et al.* (2001). A value of 2.0A was subtracted from the total obtained, being the motor driving force as reported by Iwe (2000). Three readings were taken for each run except where the torque was difficult to monitor from the panel. Mean values of torque were expressed in Nm s^{-1}.

Mass Flow Rate, MFR. Mass flow rate was determined when steady state operation conditions were reached as indicated by constant torque and extrusion temperature. At that time, a timer (stop watch) was started immediately and samples of extrudates flowing out of the extruder die orifice were collected as soon as the timer was started at 60s interval. Mean weight of three such collections was calculated for each run as the mass flow rate for that run in gram per minute.

Residence Time, RT. Residence time was determined during extrusion as reported by Iwe *et al.* (2001). A print of red food colour was introduced at the feeding port and the time taken for the colour to first show-up at the die opening was recorded as the residence time. Three determinations were taken for each run.

Specific Mechanical Energy, SME. Specific mechanical energy, defined as the total mechanical energy input to obtain 1 g of extrudate (J g^{-1}), was determined using Eqn. 1 (Rosentrater *et al.,* 2009).

$$SME = \frac{T \times \ \times 60}{M_{feed}} \qquad (1)$$

Where,

SME = Specific mechanical energy consumption (J g^{-1})

T = Net torque exerted on the extruder drive (N m)

ω= Screw speed (rpm)

M_{feed} = Mass flow rate of the raw sample (g min^{-1})

M_{feed} was calculated using eq. 2:

$$M_{feed} = M_{prod} \times \frac{1 - Mc_f}{1 - MC_i} \qquad (2)$$

where,

M_{feed} = Mass flow rate of the raw sample (g min^{-1})

M_{prod} = Mass flow rate of the extrudate (g min^{-1})

MC_f = Moisture content of the collected extrudate (% wb)

MC_i = Moisture content of the raw sample before entering the extruder (% wb)

Expansion Ratio, ER. Expansion ratio was determined as described by Conway and Anderson (1973) and Rosentrater *et al.* (2009). The diameter of the extrudates for each variety was measured with vernier caliper and then divided by the diameter of the die nozzle (5.0 mm).

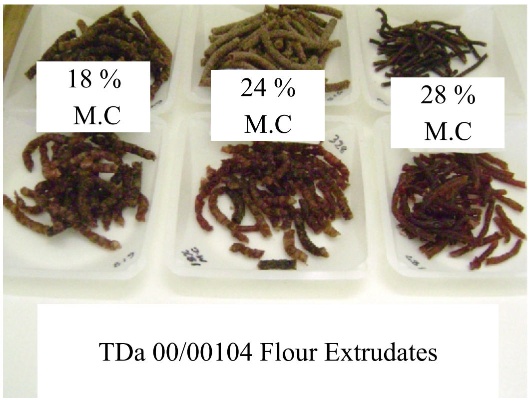
Statistical analysis

Response Surface Methodology (RSM) was used to build up a mathematical models that will make it possible to qualitatively interpret and describe the relationships between the extrusion dependent variables selected (torque, mass flow rate, residence time, specific mechanical energy, and expansion ratio) and the extrusion independent parameters/variables (feed moisture content, screw speed rate and barrel temperature). That is, extrusion was carried out following a five variable response surface analysis using a central composite rotatable design that was nearly orthogonal.

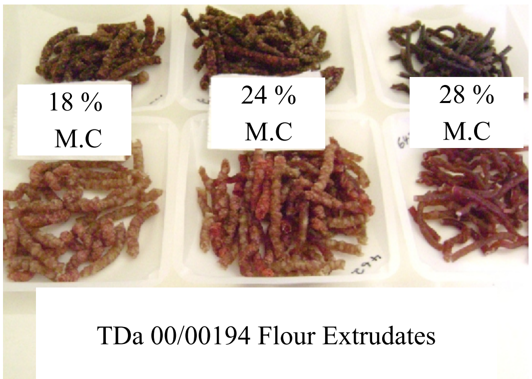
The generalized regression model fitted was $Y = B_o + b_1FMC + b_2SS + b_3BT + b_{11}FMC^2 + b_{22}SS^2 + b_3BT^2 + b_{12}FMC*SS + b_{13}FMC*BT + b_{23}SS*BT + \varepsilon$. where Y = Objective response, FMC = feed moisture content, SS = Screw speed, BT = barrel temperature and ε = random error in which the linear, quadratic and interaction effects were involved. A computer programme SAS (9.1), SAS Inc. was used with the resulting models tested for significance using analysis (ANOVA) and coefficient of determination (R^2). Significant terms were accepted at $p<0.05$. The R^2 of 0.6 was accepted for predictive purposes (Anuonye, 2007). The terms that were not significant were deleted from the model equations.

Results

The flour extrudates of the two (2) varieties of *D. alata* studied were presented in Plate 1 while their properties which include torque, residence time, mass flow rate, specific mechanical energy and expansion ratio are shown in Tables 1-2. The estimated regression coefficients and ANOVA results of the effect of Feed Moisture Content (FMC), Screw Speed (SS) and Barrel Temperature (BT) on the extruder torque, residence time, mass flow rate, specific mechanical energy, and expansion ratio for the two (2) varieties were used for the mathematical modeling for the flour extrudates.



TDa 00/00104 Flour Extrudates



TDa 00/00194 Flour Extrudates

Plate 1: The flour extrudates from TDa 00/00104 and TDa 00/00194

Table 1: Effect of Feed Moisture Content (FMC), Screw Speed (SS) and Barrel Temperature (BT) on the Extrudates Properties of TDa 00/00104 Flour

FMC (%d.b)	SS (rpm)	BT(°C)	T (Nm/s)	MFR gmin^{-1})	RT (s)	SME (J/g)	ER
18.00	80.00	100.00	70.75	80.50	41.00	31088.89	1.65
18.00	80.00	125.00	71.75	82.50	43.50	30763.59	1.64
18.00	80.00	150.00	72.25	83.50	45.50	30588.83	1.63
18.00	130.00	100.00	66.00	90.00	37.50	42158.24	1.74
18.00	130.00	125.00	68.00	92.00	38.00	42390.95	1.71
18.00	130.00	150.00	68.75	93.50	39.50	42277.98	1.69
18.00	180.00	100.00	59.50	105.00	30.50	45092.44	1.78
18.00	180.00	125.00	61.50	105.50	34.00	46361.73	1.77
18.00	180.00	150.00	62.50	106.50	35.50	46763.91	1.76
24.00	80.00	100.00	68.25	75.50	48.50	19300.37	1.53
24.00	80.00	125.00	71.50	76.50	50.50	19962.51	1.53
24.00	80.00	150.00	73.25	77.50	52.50	20193.01	1.53
24.00	130.00	100.00	50.75	86.50	44.50	20353.33	1.56
24.00	130.00	125.00	51.75	87.50	45.00	20524.77	1.53
24.00	130.00	150.00	52.75	89.50	45.50	20453.69	1.51
24.00	180.00	100.00	32.75	99.50	36.00	15816.70	1.60
24.00	180.00	125.00	33.25	101.50	36.00	15736.34	1.56
24.00	180.00	150.00	34.25	102.00	36.50	16139.52	1.52
28.00	80.00	100.00	52.50	50.50	56.50	23705.97	1.33
28.00	80.00	125.00	56.50	52.50	57.00	24540.58	1.32
28.00	80.00	150.00	60.50	54.50	58.00	25313.92	1.30
28.00	130.00	100.00	31.25	55.00	50.50	21059.95	1.44
28.00	130.00	125.00	32.25	57.50	51.50	20787.58	1.36
28.00	130.00	150.00	33.00	60.00	53.00	20388.03	1.30
28.00	180.00	100.00	19.75	76.00	45.00	13334.34	1.47
28.00	180.00	125.00	20.75	77.00	46.50	13831.67	1.41
28.00	180.00	150.00	21.25	78.50	48.50	13889.65	1.36

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

Table 2: Effect of Feed Moisture Content (FMC), Screw Speed (SS) and Barrel Temperature (BT) on the Extrudates Properties of TDa 00/00194 Flour

FMC (%d.b)	SS (rpm)	BT(^{o}C)	T (Nm/s)	MFR gmin^{-1})	RT (s)	SME (J/g)	ER
18.00	80.00	100.00	47.75	68.00	43.00	17861.96	1.67
18.00	80.00	125.00	48.75	72.50	44.00	17102.40	1.67
18.00	80.00	150.00	49.25	73.50	47.50	17042.92	1.66
18.00	130.00	100.00	41.75	79.00	35.00	21841.31	1.78
18.00	130.00	125.00	42.75	80.00	38.50	22089.74	1.72
18.00	130.00	150.00	43.75	82.00	41.50	22052.62	1.69
18.00	180.00	100.00	30.00	104.00	31.00	16507.02	1.92
18.00	180.00	125.00	32.00	105.00	33.50	17446.18	1.87
18.00	180.00	150.00	33.25	106.50	35.50	17866.92	1.81
24.00	80.00	100.00	44.25	64.00	49.50	16597.11	1.53
24.00	80.00	125.00	45.25	65.50	51.50	16596.36	1.48
24.00	80.00	150.00	46.00	67.50	52.50	16367.42	1.45
24.00	130.00	100.00	38.75	74.00	41.00	20427.33	1.55
24.00	130.00	125.00	39.75	76.00	44.00	20425.75	1.52
24.00	130.00	150.00	40.75	78.50	45.50	20253.27	1.50
24.00	180.00	100.00	28.25	94.00	35.50	16227.30	1.58
24.00	180.00	125.00	28.50	95.50	37.50	16125.18	1.55
24.00	180.00	150.00	28.75	99.00	38.50	15680.56	1.54
28.00	80.00	100.00	40.25	55.00	53.50	15954.89	1.23
28.00	80.00	125.00	41.25	58.50	55.50	15368.66	1.18
28.00	80.00	150.00	42.00	61.50	56.50	14884.00	1.14
28.00	130.00	100.00	36.00	64.50	49.50	19765.15	1.31
28.00	130.00	125.00	37.75	66.50	51.50	20100.58	1.17
28.00	130.00	150.00	39.75	67.50	52.00	20855.74	1.11
28.00	180.00	100.00	26.75	77.50	42.00	16925.21	1.34
28.00	180.00	125.00	27.75	79.50	45.50	17116.27	1.33
28.00	180.00	150.00	28.75	80.00	47.50	17624.26	1.33

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

Discussion

Torque

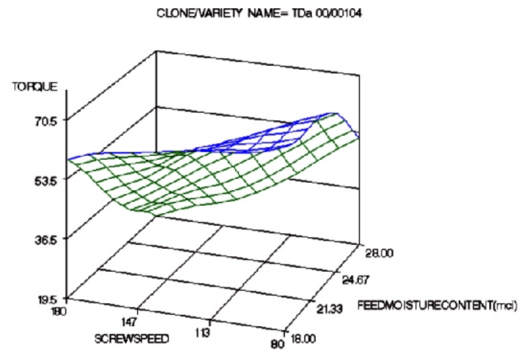
The results for torque values obtained from this study varied from 19.75 - 73.25 Nm for flour extrudates (Tables 1-2). These values were in agreement with the values reported for aquafeeds containing DDGS and tapioca starch (Rosentrater, 2009). The torque is related to the power consumed by the extruder and about 98% of the power input into the extruder is used for shearing and less than 1.5% is consumed in pumping. The results were in line with observed extruder trends that increase in feed moisture content lead to increase in torque values. Increase in screw speed at constant feed moisture content and barrel temperature lead to decrease in torque value, residence time and specific mechanical energy, while mass flow rate and expansion ratio of the extrudates increase (Bhattacharya and Prakash, 1984; Choudhury and Gautam, 1999). The regression analysis indicated that barrel temperature as an independent variable had no significant ($p>0.05$) effect on the mass flow rate.

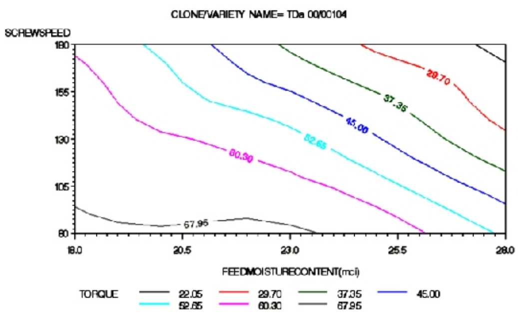
The cross product effects of FMC*SS, SS*BT and FMC*BT significantly ($p<0.05$) affected the torque exerted on extrudates in the two varieties. The quadratic effect of the FMC^2 and SS^2, however, exerted the greatest effect on torque. The analysis of variance, however, showed significant ($p<0.05$) model fitnesses. Removing the non significant terms, the resulting polynomial equations became:

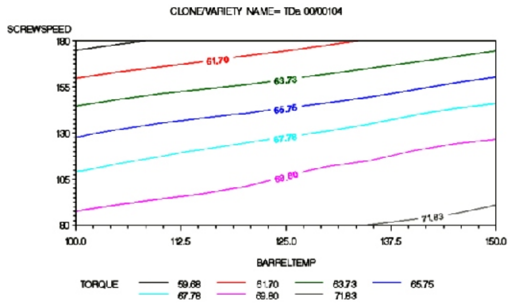
$$Y_{T\,TDa\,00/00104\,flour} = 59.305\ \ 0.146FMC^2 + 0.0008SS^2$$

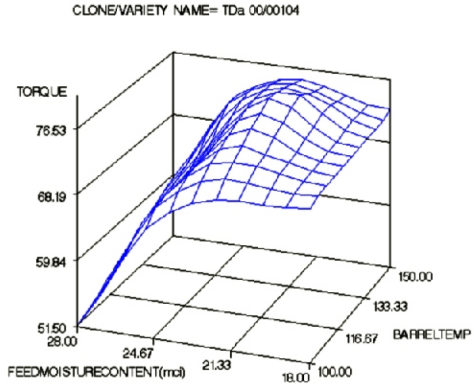
$$Y_{T\,TDa\,00/00194\,flour} = 69.631 - 1.479FMC - 0.001SS^2 + 0.0076FMC*SS$$

The response surface and contour plots generated for torque, feed moisture content and screw speed are shown in Figs. 1-2 for the flour extrudates.









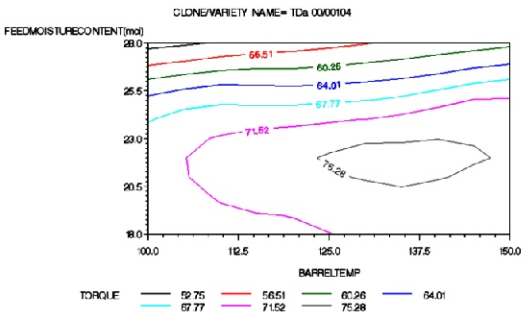
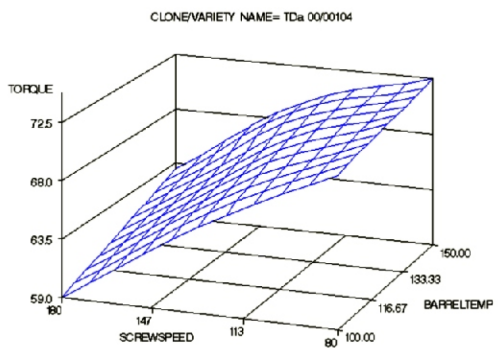
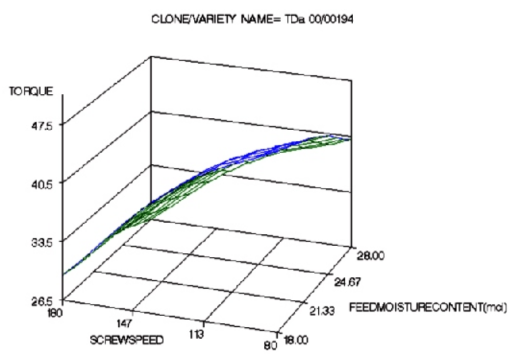
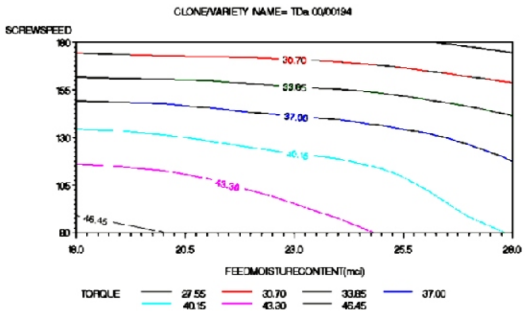
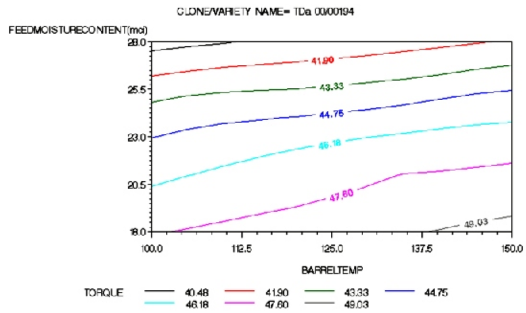


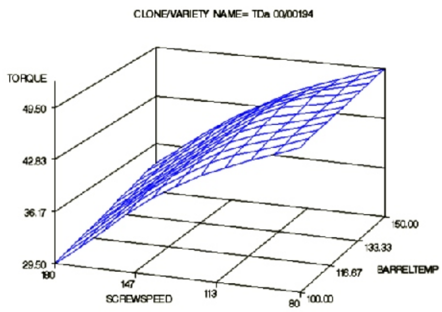
Fig. 1: Response surface and contour plots of effect of feed moisture content (%), screw speed (rpm) and barrel temperature (°C) on TDa 00/00104 flour extrudates torque

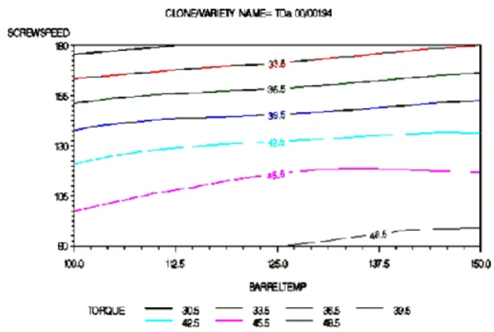












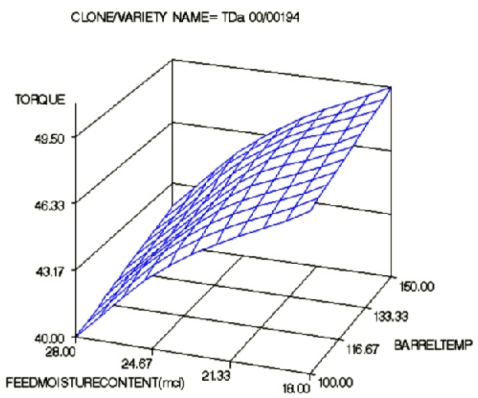


Fig. 2: Response surface and contour plots of effect of feed moisture content (%), screw speed (rpm) and barrel temperature (°C) on TDa 00/00194 flour extrudates torque

Mass flow rate

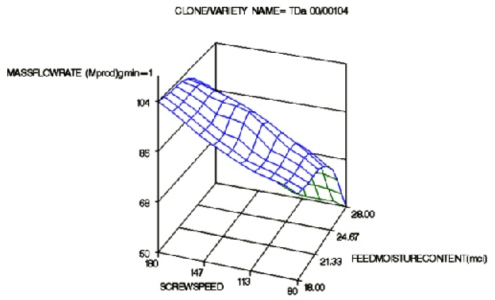
Mass flow rate in a single screw extruder is dependent on the drag flow developed by the rotation of the screw and the pressure developed due to the restriction of the die (Mercier *et al.*, 1989; Rosentrator et al., 2009). From the results of the estimated regression for mass flow rates for the two varieties studied, it was observed that processing temperatures (BT) did not affect the mass flow rate values. However, changes in the feed moisture content and screw speed did exhibit significant effects on the values (Choudhury and Gautam, 1999; Chevanan *et al.*, 2007b). Increasing the feed moisture content from 18 28% db resulted in decreased mass flow rate while increase in screw speed from 80180 rpm resulted in increase in mass flow rate. Similar results were reported by Gonzalez *et al.* (2005); Chevanan *et al.* (2007c) and Chevanan *et al.* (2008).

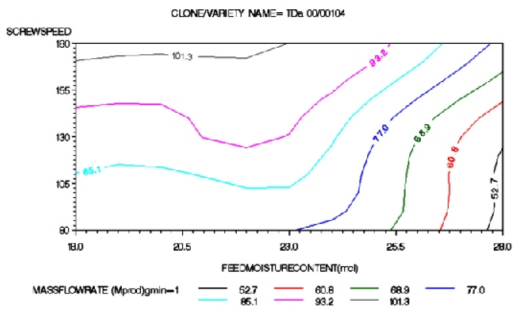
The regression analysis indicated that barrel temperature as an independent variable had no significant ($p>0.05$) effect on the mass flow rate. The analysis of variance however showed significant ($p<0.05$) model fitnesses. Removing the non significant terms, the resulting polynomial equations became:

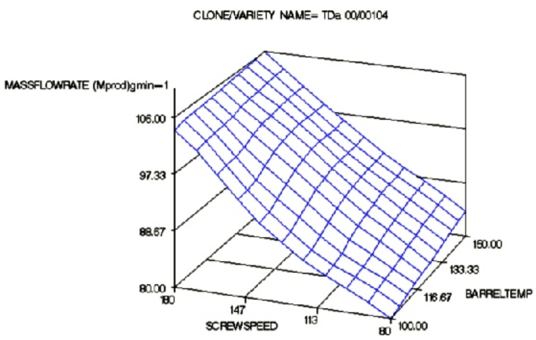
$$Y_{MFR\ TDa\ 00/00104\ flour} = -153.7 + 22.883FMC\ 0.572FMC^2 + 0.0014SS^2$$

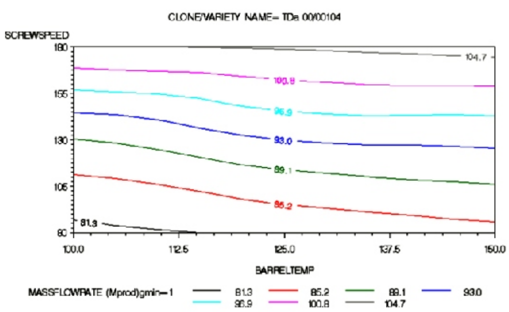
$$Y_{MFR\ TDa\ 00/00194\ flour} = -32.56 + 8.0622FMC\ 0.183FMC^2 + 0.002SS^2$$

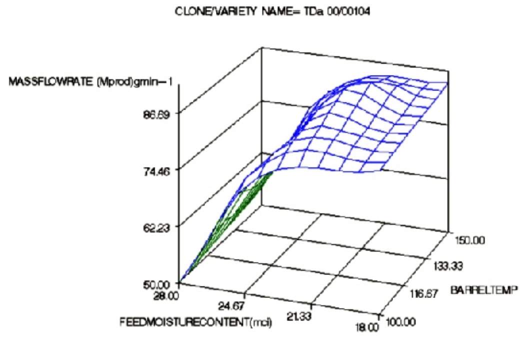
The response surface and contour plots generated for mass flow rate with feed moisture content, barrel temperature and screw speed are shown in Figs. 3-4 for the flour extrudates. The surface showed that higher feed moisture content lowered mass flow rate while higher screw speed resulted in higher mass flow rate. Hulya (1996) had reported that higher screw speed rate increased both the volumetric flow rate and mass flow rate by increasing extruder shear, raises extruder internal temperature and hence lowers the melt viscosity.











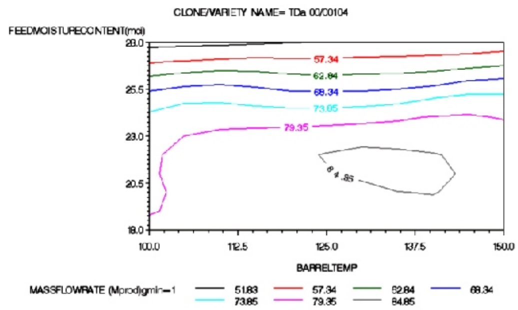
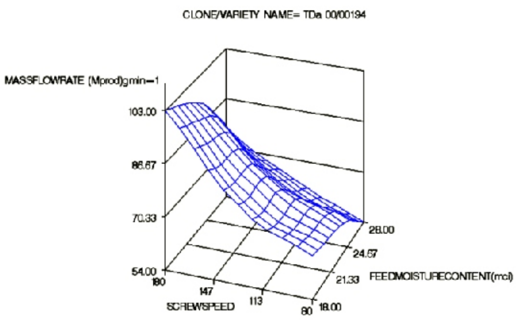
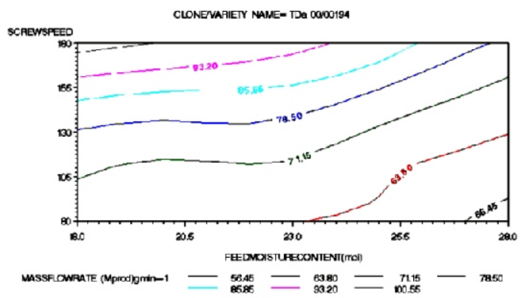


Fig. 3:Response surface and contour plots of effect of feed moisture content (%), screw speed (rpm) and barrel temperature (°C) on TDa 00/00104 flour extrudates mass flow rate





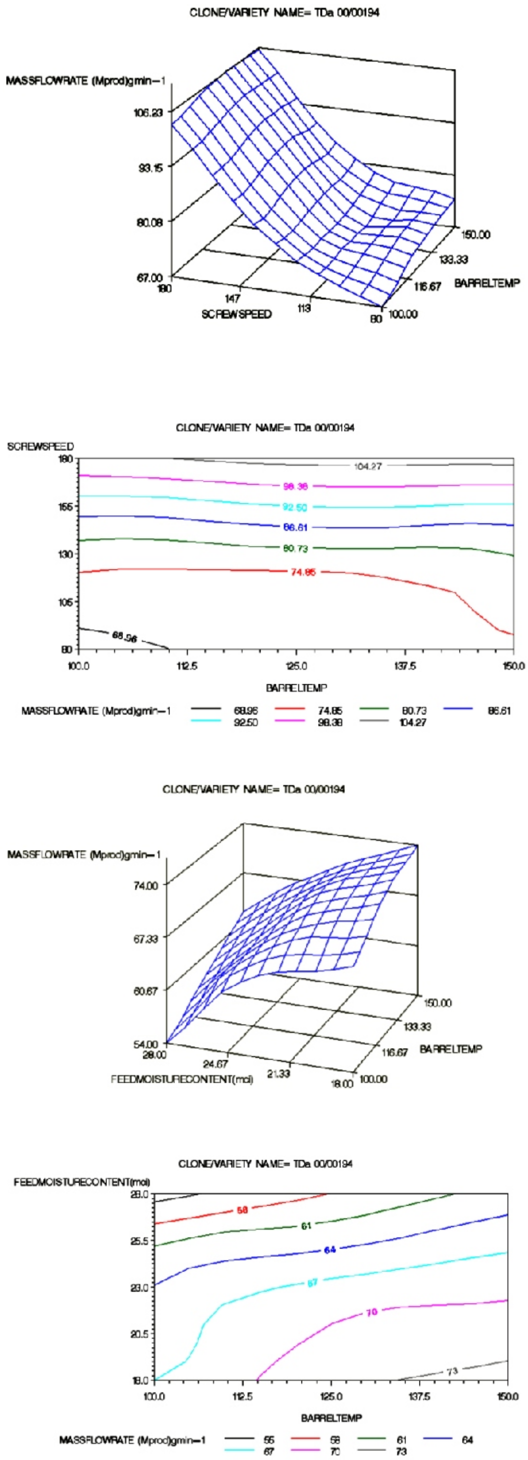


Fig. 4: Response surface and contour plots of effect of feed moisture content (%), screw speed (rpm) and barrel temperature (°C) on TDa 00/00194 flour extrudates mass flow rate

Residence Time

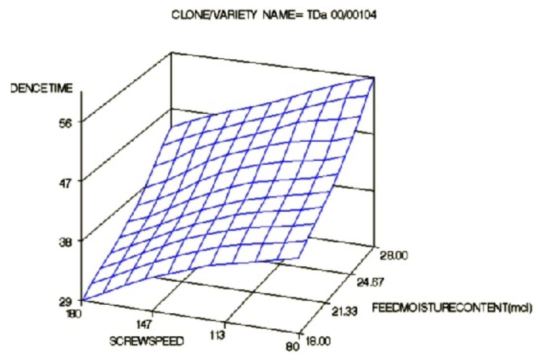
The results of effect of processing variables on residence time of extrudates showed that the linear effects of feed moisture content, screw speed and barrel temperature significantly ($p<0.05$) affected the residence time of all the varieties extrudates. Also, the cross product effects of FMC*SS, SS*BT and FMC*BT significantly ($p<0.05$) affected the residence time of extrudates all the varieties. The quadratic effect of the FMC^2 and SS^2, however, exerted the greatest effect on residence time. The R^2 of 0.80 or more (R^2=0.80) and the analysis of variance showed that there were significant ($p<0.05$), fitness of the model to the linear regression.

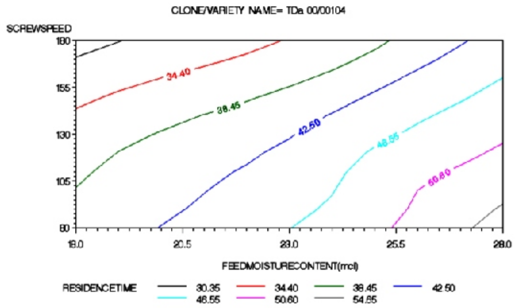
The model equations after elimination of non-significant terms became:

$$Y_{RT\,TDa\,00/00104\,flour} = 54.16\ 2.742FMC + 0.106FMC^2$$

$$Y_{RT\,TDa\,00/00194\,flour} = 33.018 + 0.0759FMC^2$$

The response surface and contour plots generated for extrudates residence time with feed moisture content, barrel temperature and screw speed are shown in Figs. 5-6 for the flour extrudates. The plots showed that increasing feed moisture content and screw speed led to increases in the residence time. In the same way, increasing the feed moisture content and barrel temperature led to increase in residence time. Jager *et al.* (1992) and Anuonye *et al.* (2007) observed that residence time was a function of at least the moisture content, feed rate, screw speed, barrel temperature and screw geometry. The results obtained from this work confirmed this observation. Moreover, indications from the results obtained showed that moisture content exerted a great effect on residence time than temperature.





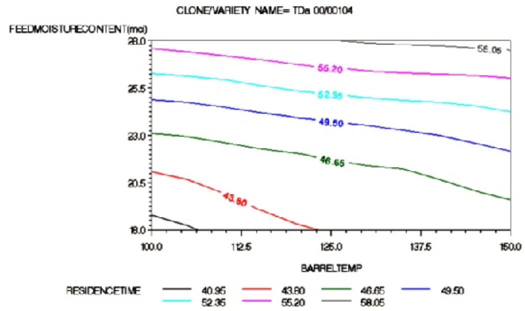
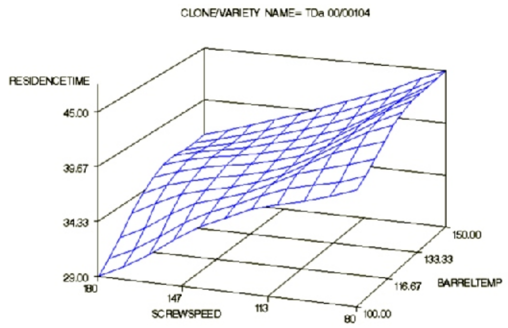
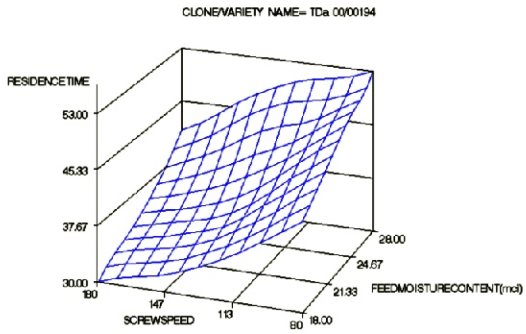
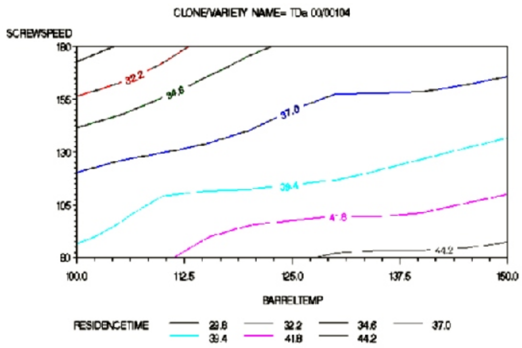
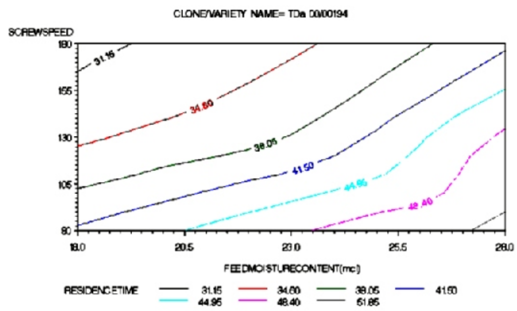


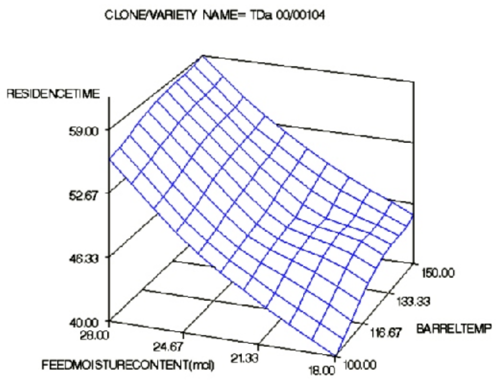
Fig. 5: Response surface and contour plots of effect of feed moisture content (%), screw speed (rpm) and barrel temperature (^{o}C) on TDa 00/00104 flour extrudates residence time

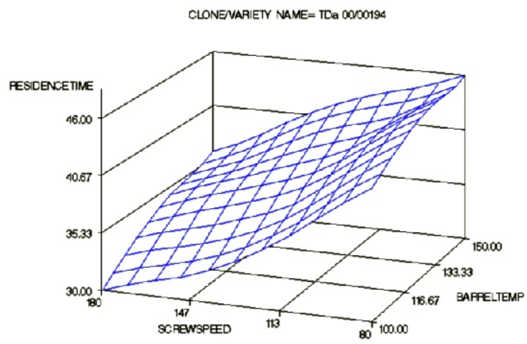












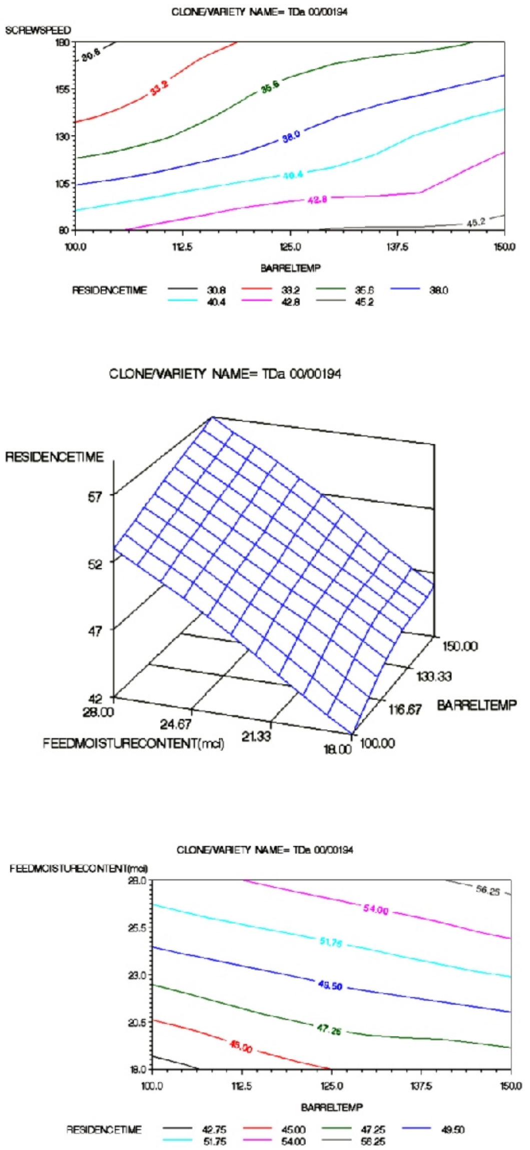


Fig. 6: Response surface and contour plots of effect of feed moisture content (%), screw speed (rpm) and barrel temperature (°C) on TDa 00/00194 flour extrudates residence time

Specific Mechanical Energy

Monitoring the specific mechanical energy (SME) is for a common way to quantify the fragmentation of starch molecules (Gomez and Aguilera, 1984; Wen *et al.*, 1990; Politz *et al.*, 1994; Rosentrator et al., 2009) during processing. Specific mechanical energy integrates extrusion responses, such as net torque, screw speed and the product mass flow rate (Onwulata *et al.*, 1998; Onwulata *et al.*, 2001a).

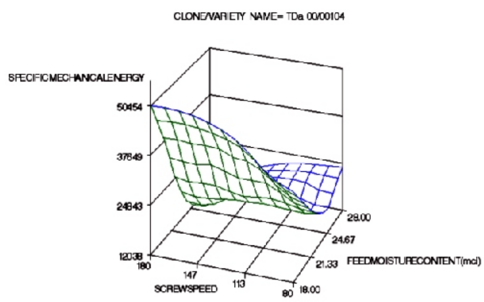
There were no clear effects on SME consumption due to the changes in processing barrel temperature, except for the results due to the changes in feed moisture content and the screw speed. Increasing the feed moisture content from 18-28% db resulted in substantial increase in SME values. Similar results were discussed by Chevanan *et al.* (2008) in their extrusion studies. Often, as screw speed increases, SME generally increases as well. The model equations after elimination of non-significant terms became:

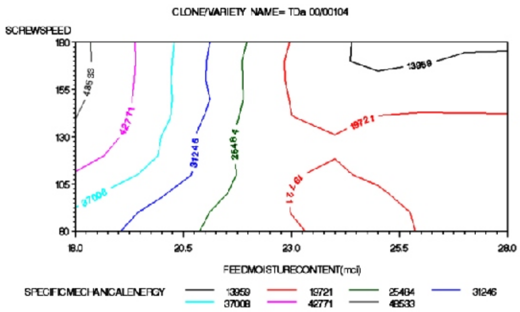
$$Y_{\text{SME TDa 00/00104 flour}} = 189359 - 16823FMC + 373.27FMC^2 - 1.075SS^2$$

$$Y_{\text{SME TDa 00/00194 flour}} = 18665 - 1483FMC + 334.7SS + 20.282FMC^2 - 1.696SS^2$$

The response surface and contour plots generated for extrudates specific mechanical energy with feed moisture content, barrel temperature and screw speed are shown in Figs. 7-8 for flour extrudates.

The specific mechanical energy input (SME) is a good quantitative descriptor in extrusion processes, since it allows the direct comparison of different combinations of extrusion conditions such as screw speed, feeding rate, and torque. The amount of mechanical energy delivered to the extruded material determines the extent of macromolecular transformations and interactions that take place; that is, starch conversion and, consequently, the rheological properties of the melt. Increased SME leads to lower viscosity, which promotes mobility and thus may lead to an increase in the rate of bubble growth (Mitchell and Areas, 1992).





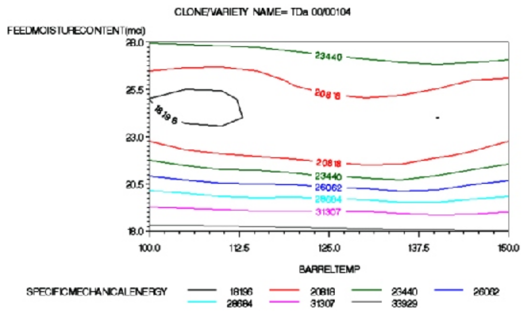
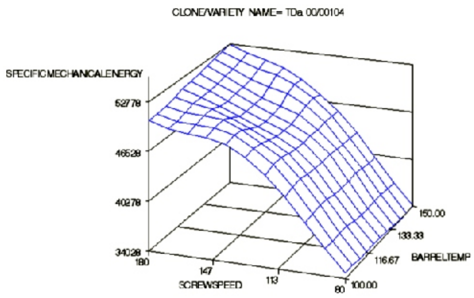
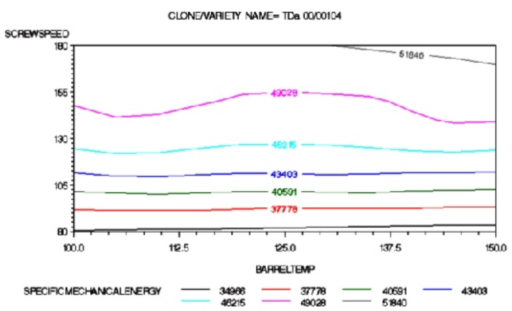
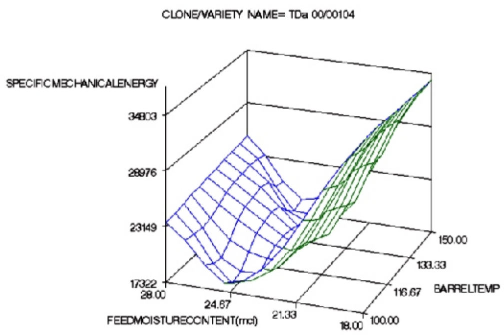
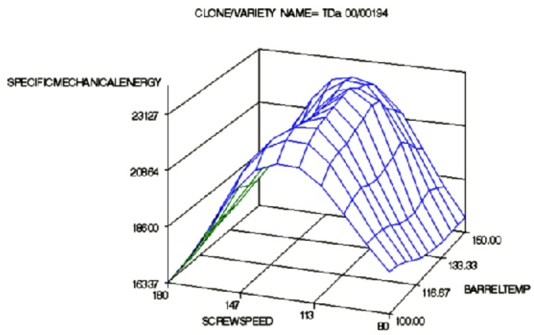


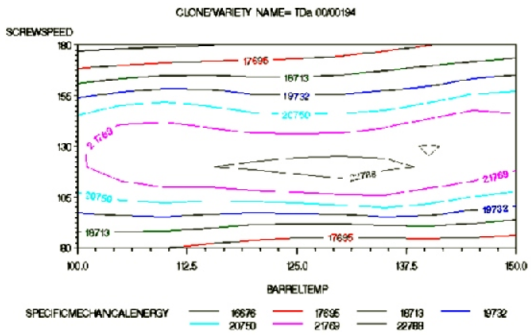
Fig.7: Response surface and contour plots of effect of feed moisture content (%), screw speed (rpm) and barrel temperature (°C) on TDa 00/00104 flour extrudates specific mechanical energy

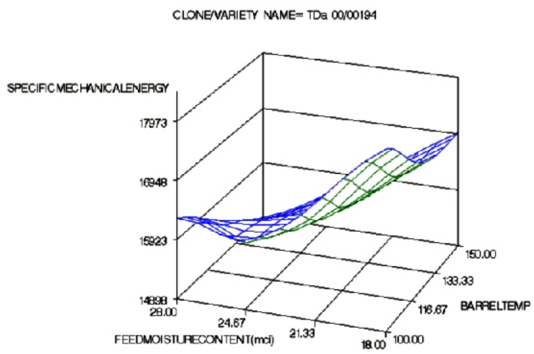












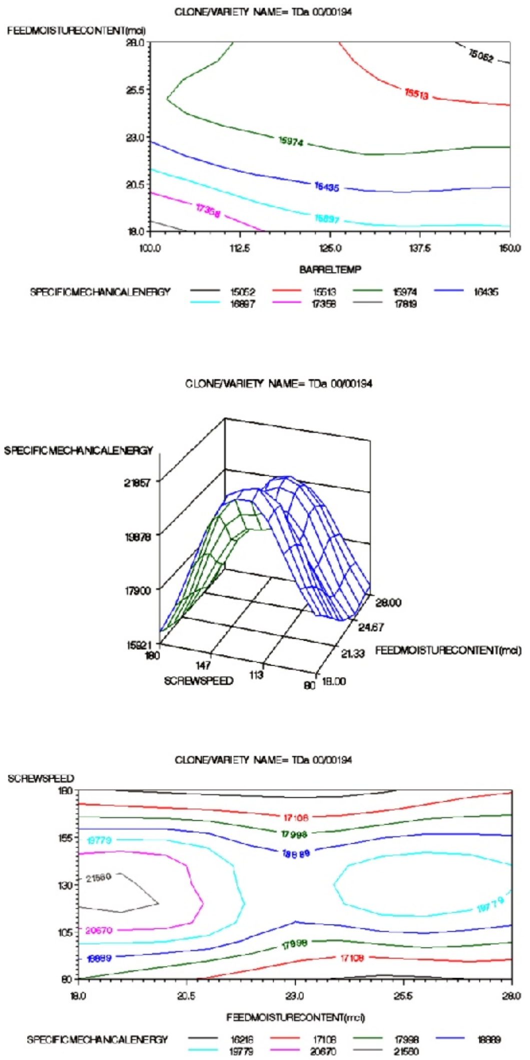


Fig. 8: Response surface and contour plots of effect of feed moisture content (%), screw speed (rpm) and barrel temperature (°C) on TDa 00/00194 flour extrudates specific mechanical energy

Expansion Ratio

Processing conditions and equipment-related variables have the ability to influence the degree of expansion significantly, since they dictate the type and extent of physical and chemical modifications that take place during extrusion which, in turn, affect expansion. Following the studies reviewed by Guy and Horne (1988) and Chinnaswamy (1993), several recent studies continued to investigate the effects of process parameters on extrudate expansion: extrusion variables (Avin *et al.* 1992; Kim and Maga 1993; Arora *et al.* 1993; Bhattacharya *et al.* 1994; Ilo *et al.* 1996; Pan *et al.* 1998; Lee *et al.* 1999; Giri and Bandyopadhyay 2000; Liu *et al.* 2000; Oluwole, 2008), temperature and moisture content (Bhattacharya *et al.,* 1994; Prinyawiwatkul *et al.,* 1995; Cha *et al.,* 2001), and extruder configuration (Sokhey *et al.,* 1994; Bhattacharya *et al.,* 1994; Sokhey *et al.,* 1996; 1997; Choudhury and Gautam 1998, 1999).

The expansion ratio of the two extrudates considered in this study ranged from 0.935-1.934. It increased with decrease in moisture content of the feeds. This is due to the fact that low moisture feeds exhibit more drag and therefore exert more pressure at the die resulting into greater expansion at the exit of the die than high moisture feeds (Arora *et al.,* 1993; Bhattacharya *et al.,* 1994; Oluwole, 2008). Moisture is the main plasticizer of the cereal flours, which enables them to undergo a glass transition during the extrusion process and thus facilitates the deformation of the matrix and its expansion.

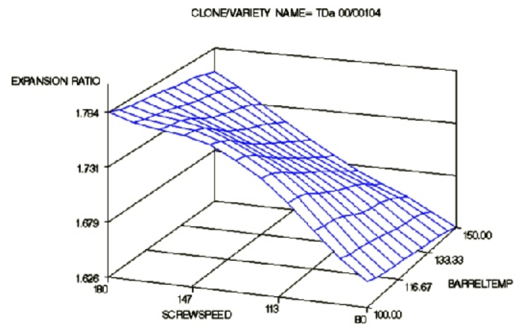
According to Ilo *et al.* (1996), an increase in moisture content during extrusion decreases the SME, apparent viscosity, and radial expansion ratio during extrusion of maize grits. Parsons *et al.* (1996) reported a decrease in the expansion ratio of cornmeal when the extrusion moisture content was increased from 19.5 to 21.5% (w/ w). The reduction of expansion at high moisture content was later confirmed by the findings of Chinnaswamy and Hanna (1990), Garber *et al.* (1997), Liu *et al.* (2000), Onwulata *et al.* (2001b). Screw speed has generally a positive effect on extrudate expansion due to the increase in shear, and thus decrease in melt viscosity induced by high screw speeds (Kokini *et al.* 1992; Ali *et al.* 1996). This was confirmed by this study. In the study of Bhattacharya (1997), screw speeds of 100 to 400 rpm imparted curvilinear effects on the characteristics of rice and green gram extrudates. For that particular formulation, high barrel temperatures combined with low screw speeds were suitable for obtaining expanded products. However, at higher screw speed, radial expansion is expected to reduce while axial expansion increases due to reduced residence time (Hsieh *et al.*, 1990), reduced degree of gelatinization of starch and hence reduce expansion (Chinnaswamy and Hanna, 1988; Padmanabhan and Bhattacharya, 1989; Oluwole, 2008).

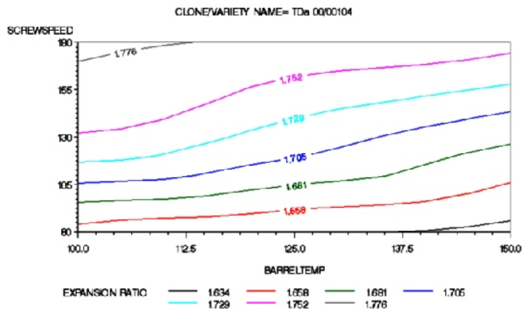
Other workers have reported, however, that screw speed had no significant effect on the expansion ratio: Liu *et al.* (2000) for extruded oat-corn puff and Giri and Bandyopadhyay (2000) for fish muscle-rice flour extrudates. Such differences may be explained by significant differences in the extrusion conditions, such as type of extruders and screw configuration, temperature, and composition of the feed. The regression analysis indicated that barrel temperature as an independent variable had little significant ($p<0.05$) effect only at the interactions (FMC*BT; SS*BT; FMC*SS*BT) on the expansion ratio. The analysis of variance, however, showed significant ($p<0.05$) model fitnesses. Removing the non significant terms, the resulting polynomial equations became:

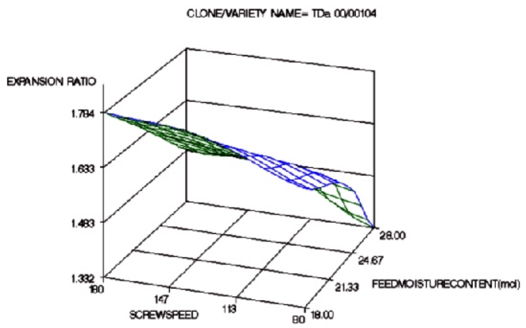
$$Y_{ER\ TDa\ 00/00104\ flour} = 1.5322\ \ 0.002FMC^2$$

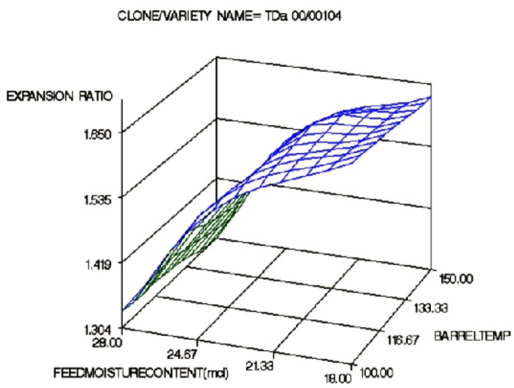
$$Y_{ER\ TDa\ 00/00194\ flour} = -0.113 + 0.1644FMC + 0.0095SS - 0.003FMC^2 + 1E\text{-}05SS^2 - 5E\text{-}04FMC*SS - 5E\text{-}04FMC*BT - 8E\text{-}05SS*BT + 4E\text{-}06FMC*SS*BT$$

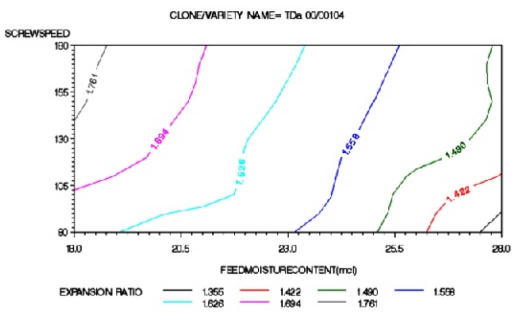
The response surface and contour plots generated for extrudates expansion ratio with feed moisture content, barrel temperature and screw speed are shown in Figs. 9-10 for flour extrudates.











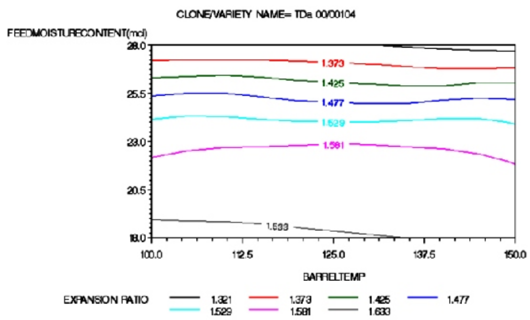
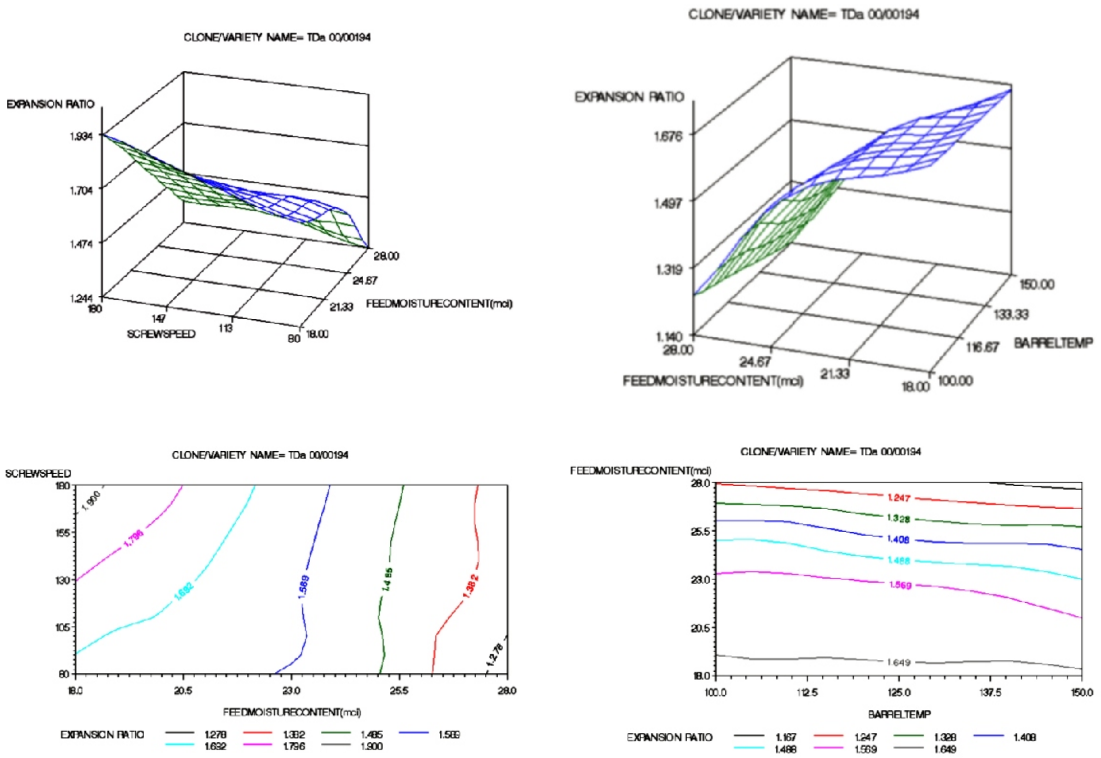


Fig. 9: Response surface and contour plots of effect of feed moisture content (%), screw speed (rpm) and barrel temperature (°C) on TDa 00/00104 flour extrudates expansion ratio



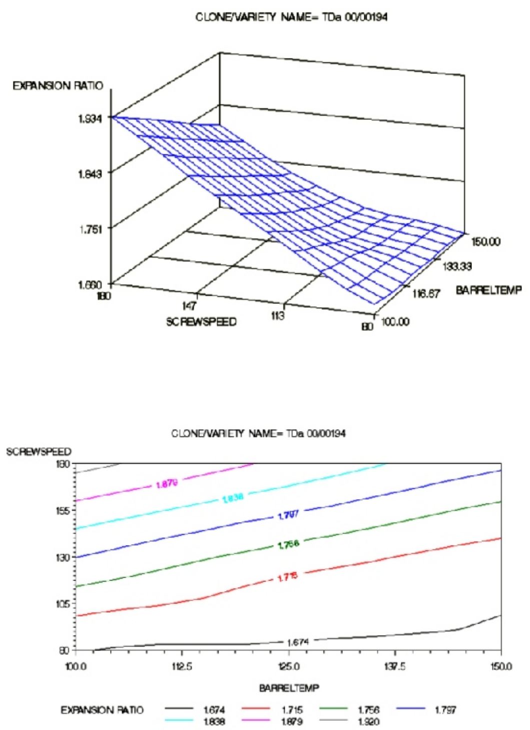


Fig. 10: Response surface and contour plots of effect of feed moisture content (%), screw speed (rpm) and barrel temperature (°C) on TDa 00/00194 flour extrudates expansion ratio

Conclusion

There is currently scanty information on the general application of response surface analysis in food research in Nigeria while there is dearth of information on specific application of extrusion technology (HTST) in yam species processing, especially *D. alata*. The objectives of this study was to develop predictive models that relate extrusion process variables to extrudates variables- expansion ratio, torque, mass flow rate, residence time, specific mechanical energy. This was accomplished by varying the feed moisture content and extruder parameters which include barrel temperature, screw speed and determine their effects on resulting extrudates properties.

Therefore, It was generally observed that the changing of the feed moisture content, barrel temperature and screw speed significantly ($p<0.05$) affected expansion ratio, torque, mass flow rate, residence time and specific mechanical energy of the two extrudates studied. Increasing the feed moisture content (18-28% db) and screw speed (80-180rpm) resulted in a substantial decrease in expansion ratio (46.6%), residence time (27.5%), and specific mechanical energy (83.6%); whereas, increasing the screw speed significantly increased the mass flow rate (64.5%) of extrudates.

Recommendation

Further studies on the effect of different ratio of *D. alata* and other ingredients for the production of noodles in large-scale single and twin screw extrusion will provide a broader understanding of these feed moisture content and extruder variables studied.

References

Akinwande, B.A.,adeyemi, I.A., Akande, E.O. and Ogundipe, O.D. 2004. Effect of substituting flour with yam starch and yam flour on pasting property of composite flour and sensory quality of noodle. NIFST Proceeding of the 28th Annual Conference, Ibadan.Pp. 257-258.

Ali, Y., Hanna, M.A. and Chinnaswamy, R. 1996. Expansion characteristics of extruded corn grits. Lebensm-Wiss Technol 29(8):702-7.

Anuonye, J.C., Badifu, G.I.O., Inyang, C.U. and Akpapunam, M.A. 2007. Effect of extrusion process variables on the amylase and pasting characteristics of acha/soybean extrudates using response surface analysis. American journal of Food Technology 2(5):354-365

Arora A., Zhao J. and Camire, M.E. 1993. Extruded potato peels functional properties affected by extrusion conditions. J Food Sci 58(2):335-337.

Avin D., Kim C.H. and Maga, J.A. 1992. Effect of extrusion variables on the physical characteristics of red bean (Phaseolis vulgaris) flour extrudates. J Food Proc Preserv 16(5):327-35.

Bhattacharya, S. and Prakash, M. 1984. Extrusion of blends of rice and chickpea flours: A response surface analysis. J. Food Eng. 21:315 330.

Bhattacharya, S, Kodiak, A.K. and Choudhury, G.S. 1994. Twin-screw extrusion of rice flour: effect of extruder length-to-diameter ratio and barrel temperature on extrusion parameters and product characteristics. J of Food Proc and Preserv 18(5):389-406.

Bhattacharya, S. 1997. Twin-screw extrusion of rice-green gram blend: extrusion and extrudate characteristics. J Food Eng 32(1):83-99.

Bhattacharya, D., Singhal, R.S. and Kulkarni, P.R. 1996. Carboxymethyl starch: an extrusion aid. Carbohydr Polymers 31(1/2):79-82.

Cha, J.Y., Chung, D.S., Seib, P.S., Flores, R.A. and Hanna, M.A. 2001. Physical properties of starch-based foams as affected by extrusion temperature and moisture content. Industr Crops Prod 14(1):23-30.

Changi, Y.K., Martinez- Bustos, F. and Larai, H. 1998. Effect of some extrusion variables on rheological properties and physicochemical changes of cornmeal extruded by twin screw extruder. Braz. J.Chem. Eng. 15 (4):796-801.

Chevanan, N., Muthukumarappan, K., Rosentrater, K.A. and Julson, J.L. 2007b. Effect of die dimensions on extrusion processing parameters and properties of DDGS Cereal Chem., 84(4):389-398.

Chevanan, N., Rosentrater, K.A. and Muthukumarappan, K. 2007c. Effect of DDGS, moisture content and screw speed on physical properties of extrudates. Cereal Chem., 85(2):132-139.

Chevanan, N., Rosentrater, K.A. and Muthukumarappan, K. 2008. Effects of processing conditions on feed ingredients containing DDGS in single screw extrusion. Food Bioprocess Technol. Pp 1-10.

Chinnaswamy, R. and Hanna, M. A. 1988. Optimum extrusion-cooking conditions for maximum expansion of corn starch. J Food Sci 53(3):834-6, 840.

Chinnaswamy, R. and Hanna, M.A. 1990. Macromolecular and functional properties of native and extrusion-cooked corn starch. Cereal Chem 67(5):490-9.

Choudhury, G.S. and Gautam, A. 1998. Comparative study of mixing elements during twin-screw extrusion of rice flour. Food Research International 31, 717.

Choudhury, G.S. and Gautam, A. 1999. Screw configuration effects on macroscopic characteristics of extrudates produced by twin-screw extrusion of rice flour. J Food Sci 64(3):479-87.

Conway, H.F. and Anderson, R.A. 1973. Protein fortified extruded food products. Cereal Sci. Today, 18:94-97

Coursey, D.G. 1976. The origins and domestication of yams in Africa. In: Origins of African plant domestication. J.R. Harlan, J.M.J. de Wet and A.B.L. Stenler, (eds.) Mouton, The Hague. Pp 3383-403.

Coursey, D.G. 1983. Yams. In: Chan, H.T. (ed.) Handbook of Tropical Foods. New York, Marcel Dekker. Pp 555-601

Garber, B.W., Hsieh, F. and Huff, H.E. 1997. Influence of particle size on the twin-screw extrusion of corn meal. Cereal Chem 74(5):656-61.

Giri, S.K. and Bandyopadhyay, S. 2000. Effect of extrusion variables on extrudate characteristics of fish muscle-rice flour blend in a single-screw extruder. J Food Proc and Preserv 24(3):177-90.

Gomez, M.H., and Aguilera, J.M. 1984. A physicochemical model of corn starch. J Food Sci. 49:40-3.

Gonzalez, R.J., Torres, R.L., Greef, D.M.D. and GUADALUPE, B.A. 2005. Effects of extrusion conditions and structural characteristics on melt viscousity of starchy materials. J. Food Eng. 74(1):96-107.

Guy, R.C.E and Horne, A.W. 1988. Extrusion and co-extrusion of cereals. In: Blanshard JMV, Mitchell JR, editors. Food structureits creation and evaluation. London, U.K.: Butterworth. Chpt. 1 8 , p 331-50.

Hsieh, F., Peng, I.C. and Huff, H.E. 1990. Effects of salt, sugar and screw speed on processing and product variables of corn meal extruded with a twin screw extruder. J. Food Sci., 55: 224-227.

Hulya, A. 1996. Pressure, torque and energy responses of a twin screw extruder at high moisture content. Food Res. Int., 29:423-429.

Ilo S., Tomschik, U., Berghofer, E. and Mundigler, N. 1996. The effect of extrusion operating conditions on the apparent viscosity and properties of extrudates in twin-screw extrusion cooking of maize grits. Lebensm Wiss Technol 29(7):593-8.

Iwe, M.O. 2000. Effects of extrusion cooking on some functional properties of soysweet potato mixtures: a response surface analysis. Plant Foods Human Nutr 55(2):169-84.

Iwe, M.O., Vanzuilichem, D.J. and Ngoddy, P.O. 2001. Extrusion cooking of blends of soy flour and sweet potato flour on specific mechanical energy (SME), extrudate temperature and torque. J. Food Sci., 53:450-454.

Jager, T., Van Zuilichem, D.J. and Stolp, W. 1992. Residence time distribution, mass flow and mixing in a co-rotating, twin screw extruder. In: Food extrusion science and technology. Kokini, J.L., Ho, C. and Karwe, M.V. (Eds.), Dekker Inc., pp 71-78

Kalentunc, G. and Breslauer, K.J. 1993. Glass transitions of extrudates: Relationship with processing - induced fragmentation and end- product attributes. Cereal Chemistry. 70:548-552

Kim, C.H. and Maga, J.A. (1993). Influence of starch type, starch/protein composition and extrusion parameters on resulting extrudate expansion. Devel Food Sci 32:957- 64.

Kim, Y. S., Wiesenborn, D. P., Orr, P.H. and Grant, L.A. 1995. Screening potato starch for novel properties using differential scanning calorimetry. Journal of Food Science 60:1060-1065.

Kokini, J. L., Chang, C. N. and Lai, L. S. 1992. The role of rheological properties on extrudate expansion. In: Kokini JL, Ho C-T, Karwe MV, editors. Food extrusion science and technology. New York, N.Y. Marcel Dekker Inc. p 631-53.

Lee, E.Y., Ryu, G.H. and Lim, S.T. 1999. Effects of processing parameters onphysical properties of corn starch extrudates expanded using supercritical CO2 injection. Cereal Chem 76(1):63-9.

Linko, Y Y., Vourien, V., Olkku, J. and Linko, P. 1980. The effect of HTST-extrusion on retention of cereal a-amylase activity and on enzymatic hydrolysis of barley starch. In: Linko, P. and Larinkari, J. (eds), Food process engineering, Vol. 2, Enzyme engineering in food processing. Applied Science publishers London. Pp. 210-223.

Linko, P., Linko, Y Y. and Olkku, J. 1984. Extrusion cooking and bioconversions. In: Jowitt, R. (eds), Extrusion cooking technology, Elsevier Applied Science publishers, London. Pp. 143-157.

Liu, Y., Hsieh, F., Heymann, H. and Huff, H. E. 2000. Effect of process conditions on the physical and sensory properties of extruded oat-corn puff. J Food Sci. 65(7):1253- 9.

Mercier, C., Linko, P. and Harper, J.M. 1989. Extrusion cooking. American Association of Cereal Chemists, St Paul, MN, USA. pp 1-471.

Mitchell, J.R., and Areas, J.A.G. 1992. Structural changes in biopolymers during extrusion. In: Food extrusion science and technology. New York, N.Y.: Marcel Dekker.

Myers, R.H. 1971. Response Surface Methodology. Allyn and Bacon, Boston, MA. pp. 26106.

Oluwole, O.B. 2008. Effect of thermo extrusion cooking on physicochemical, textural and sensory qualities of yam (*Dioscorea rotundata*) and bambara groundnut (*Voandezeia subterranean L. Thou*) blends. Unpublished Ph.D thesis, UNAAB, Abeokuta, Nigeria. Pp 117-213.

Onwulata, C.I., Konstance, R.P., Smith, P.W., and Holsinger, V.H. 1998. Physical properties of extruded products as affected by cheese whey. J Food Sci 63(5):814-18.

Onwulata, C.I., Konstance, R.P., Smith, P.W., and Holsinger, V.H. 2001a. Co-extrusion of dietary fiber and milk proteins in expanded corn products. Lebens Wiss Technol 34:424- 429.

Onwulata, C.I., Smith, P.W., Konstance, R.P., and Holsinger, V.H. 2001b. Incorporation of whey products in extruded corn, potato or rice snacks. Food Res Intl 34(8):679-687.

Osagie, A.U. 1992. The Yam in Storage. Post harvest Research Unit, University of Benin, AMBIK press. Pp 22-24.

Padmanabhan, M. and Bhattacharya, M. 1989. Extrudate expansion during extrusion cooking of foods. Cereal Foods World 34(11):945.

Pan, Z., Zhang, S. and Jane, J. 1998. Effects of extrusion variables and chemicals on the properties of starch-based binders and processing conditions. Cereal Chem 75(4):541-546.

Parsons, M.H., Hsieh, F., and Huff, H.E. 1996. Extrusion cooking of cornmeal with sodium bicarbonate and sodium aluminum phosphate. J Food Proc Preserv 20(3):221-34.

Politz, M.L., Timpa, J.D., White, A.R., and Wasserman, B.P. 1994. Nonaqueous gel permeation chromatography of wheat starch in dimethylacetamide (DMAC) and LiCl: extrusion- induced fragmentation. Carbohydr Polym 24(2):91-9.

Prinyawiwatkul, W., Beuchat, L.R., Phillips, D., and Resurreccion, A.V.A. 1995. Modeling the effects of peanut flour, feed moisture content, and extrusion temperature on physical properties of an extruded snack product. Intl J Food Sci Technol 30(1):37-44.

Rosentrater, K.A. Muthukumarappan, K. and Kannadhason, S. 2009. Effects of ingredients and extrusion parameters on aquafeeds containing DDGS and tapioca starch. Journal of Aquaculture feed science and nutrition 1(1):6-21.

Sokhey, A.S., Kollengode, A.N. and Hanna, M.A. 1994. Screw configuration effects on corn starch expansion during extrusion. J Food Sci. 59(4):895-8.

Sokhey, A.S., Rizvi, S.S.H. and Mulvaney, S.J. 1996. Application of supercritical fluid extrusion to cereal processing. Cereal Foods World 41(1):29-34.

Sokhey, A.S., Ali, Y. and Hanna, M.A. 1997. Effects of die dimensions on extruder performance. J Food Engr 31(2):251-61.

Tadmor, Z. and Gogos, C.G. 1979. Principles of polymer processing. John Wiley sons, New York

Tetteh, J.P. and Saakwa, C. 1994. Prospects and constraints to yam production in Ghana. In: Ofori, F. and Hahn, S.K. (eds). Tropical Root Crops in a Developing Economy. Proceedings of the ninth symp. of the International Society for Tropical Root Crops, 20-26 Oct.,1991. Accra, Ghana.

Wen, L.F., Rodis, P. and Wasserman, B.P. 1990. Starch fragmentation and protein insolubilization during twin-screw extrusion of corn meal. Cereal Chem., 67(3):268-275.

Zhang, T., and Oates, C. G. 1999. Relationship between amylase degradation and physicochemical properties of sweet potato starches. Food Chemistry, 65, 157163.

Functional and pasting characteristics of cassava sweet potato starch blends

***Adebowale A.A., Sanni L.O. and Fadahunsi E.L.**
Department of Food Science and Technology, University Of Agriculture, P.M.B. 2240, Abeokuta, Nigeria
*Corresponding Author: deboraz2002@yahoo.com

Abstract

Starch is an important constituent in many foods and plays an obvious role in achieving the desired viscosity in products like sauces, pie fillings, salad dressings, puddings, etc. Blending different starches have been reported to results in desirable functional properties which help to overcome some end use limitations of native starches. Therefore, the purpose of this study was to determine the functional and pasting characteristics of cassavasweet potato starch blends with the aim of improving the utilization of these starches in food and non-food applications. Starches were isolated from cassava roots and sweet potato tubers using standard procedures. The starches were dried, milled and blended in different proportions. The functional and pasting characteristics of the starch blends were determined using standard analytical procedures and instruments. The functional properties of the starch blends were significantly different (P<0.05) from 100% cassava and sweet potato starch except bulk density and pH. Bulk density ranged from 0.64-0.67g/ml, Water absorption index and dispersibility ranged from 69.07-87.00% and from 64.80-87.60%, respectively while least gelation concentration ranged between 2.00% and 3.73%. The pH of the starch blends were between 6.70 and 6.80. Swelling power of the starch blends increased with increasing temperature and considerably higher than that of 100% sweet potato starch but lower than that of 100% cassava starch. Total titratable acidity of the starch blends was lower than that of 100% cassava and sweet potato starches. The pasting profile of the starch blends was significantly different from that of the 100% cassava and sweet potato starches. Peak viscosity, trough, breakdown viscosity and final viscosities of the starch blends were lower than that of 100% cassava and sweet potato starches, and ranged from 310.05-379.29 RVU, 162.67-203.42 RVU, 169.13-177.46, RVU and from 200.50-274.50 RVU, respectively. Set back viscosity ranged between 66.30 and 82.00 RVU. Time to attain peak viscosity ranged from 4.47-4.97 min, while the starches pasting temperature ranged from 73.65 91.60°C. In conclusion, blending sweet potato starch with cassava starch significantly improves some functional properties of sweet potato starch. The blend containing 75% cassava starch and 25% sweet potato starch showed higher paste stability than 100% cassava and sweet potato starches due to its low setback viscosity.

Keyword: Cassava, sweet potato, starch, pasting, functional, characteristics.

Introduction

Starch is not only one of the most abundant biopolymeric assemblies in nature but a major food component at world-wide scale and one of the main food ingredients, both in native or modified forms. The range of food products containing starch in one form or another is almost limitless. But the utility of starches is almost entirely based upon their natural or synthesized functional characteristics. The particular physical and chemical characteristics of individual starches are the keys to their commercial success. Starch plays an obvious role in achieving the desired viscosity in products like sauces, pie fillings, corn starch pudding, etc. In food systems, starch is used to influence or control such characteristics as aesthetics, moisture, consistency, and shelf stability. It can be used to bind, expand density, clarify or opacify, attract or inhibits moisture as well as stabilize emulsion and act as texturizing agent.

Starches are extracted from several different starchy raw materials such as barley, maize, rice, sweet potato, cassava, etc. Sweet potato and cassava are two major starchy root and tuber crops used in many tropical countries (Osundahunsi *et al.*, 2003). Sweet potato starch has been used as an ingredient in bread, biscuits, cakes, juice, ice cream and noodles or converted to glucose and isomerized glucose syrup (Zhang *et al.*, 1999). Cassava starch is used to produce variety of value added products such as sweeteners, alcohol, acids and other chemicals (Klanarongs *et al.* 2001). Cassava starch is used in industries due to its high yield, very low cost and unique characteristics such as clear viscous paste (Klanarongs *et al* ., 2001).

Starches from different plant sources exhibit different variety of characteristics functional properties like specific viscosity, flow properties, swelling and resistance to swelling, gel texture, etc. Starch functional properties are dependent on variety, environment and the extraction process and can also be altered by subsequent enzymatic or chemical modification (Stephen, 2008). Cassava starch, has low gelatinization temperature (65-70°C), rapid viscosity increase after gelatinization, forms clear and soft gel with better cold stability, but with a very cohesive texture. It is ranked very high among starchy staples because it gives a carbohydrate production which is about 40% higher than rice and 25% more than maize (Nyerhorvwo, 2004). Sweet Potato starch has been found to be easier to cook, had a lower potential for retrogradation, but was less stable during heating than starches from cassava.

One way to overcome some functional limitations of native starches is by blending different starches. Obanni and Bemiller (1997) reported that blend of native starches may be formulated to achieve some desired characteristics of modified starches. Scientific information available on the functional and pasting properties of cassava and sweet potato starches cannot be compared with that from the major cereal starches such as wheat and corn starches. It is therefore necessary that significant amount of research needs to be conducted on the functional characteristics of native as well as modified tropical roots and tubers starches for them to become competitive with corn and wheat starches, locally and internationally. Therefore, this study was conducted to determining the functional and pasting properties of cassavasweet potato starch blends with a view to provide information that will improve the utilization of these starches in food and non-food applications.

Methodology

Cassava and sweet potato starches were extracted according to the methods described by Oyewole and Obieze (1995) and Lilia and Collando (1999), respectively. Five different starch blends were obtained as shown below:

Cassava starch	75%	25%	50%	-	100%
Sweet potato starch	25%	75%	50%	100%	-

Determination of functional properties

Bulk density was determined by the method of Wang and Kinsella (1976), least gelation concentration by Coffman and Garcia (1977) and dispersibility by the method of Kulkarni *et al* (1991). Swelling power at different temperatures was determined according to Takashi and Sieb (1988), and water absorption index as described by the modified method of Anderson (1982). Total titratable acidity was determined by Pearson's (1985) method while pH was measured using a digital pH meter (AOAC, 1990).

Determination of pasting properties

Pasting properties were determined using a Rapid Visco Analyser (RVA) (model RVA 3D+; Network Scientific, Australia). The sample was turned into slurry by mixing 3 g starch powder with 25 ml of water inside the RVA can and inserted into the tower, which was then lowered into the system. The slurry was heated from 50 to 95°C and cools back to 50°C within 12 min, rotating the content at a speed of 160 rpm with continuous stirring of the content with a plastic paddle. Parameters estimated were peak viscosity, trough, setback viscosity, final viscosity, pasting temperature and time to reach peak viscosity.

Statistical analysis

All data obtained were subjected to One-Way Statistical Analysis of variance (ANOVA) using SPSS (version 17, 2010). Means were separated using Duncan's Multiple Range Test (DMRT).

Results and Discussion

Functional properties of cassava - sweet potato starch blends: The result of the functional properties of the starch blends are presented in Table 1. The functional properties of the starch blends were significantly different ($P<0.05$) from 100% cassava and sweet potato starch except bulk density and pH. Bulk density ranged from 0.64-0.67 g/ml. The bulk density is an important parameter that determines the ease of packaging and transportation of powdery or particulate foods. Bulk density is an important functional property in many food applications. For instance, it has been found to affect starch noodles sensory acceptability, handling and packaging requirements as well as transport cost (Nwabueze *et al*. 2009). Water absorption index and dispersibility ranged from 69.07-87.00% and from 64.80-87.60%, respectively while least gelation concentration (LGC) ranged between 2.00% and 3.87%. Dispersibility is a measure of the degree of reconstitution of flour or flour blends in water, the higher the dispersibility the better the flour reconstitutes in water (Adebowale *et al*., 2005). A higher dispersibility value exhibited by all the starches is indicative of their ability to produce smooth or consistent paste. LGC is a measure of the minimum amount of starch or blends of starch powder that is needed to form a gel. The LGC of the starch blends were higher than that of 100% cassava and sweet potato hence, less amount of the starch blend would be required to form paste during processing (Adebowale *et al.* 2005) compared to 100% cassava and sweet potato starch. The pH of the starch blends were between 6.70 and 6.80. Total titratable acidity (TTA) of the starch blends was lower than that of 100% cassava and sweet potato starches while the pH of the starch blends were similar to 100% cassava and sweet potato starches. The TTA when related with the pH values shows that the starch has low acid content characteristics of root and tuber starches (Onitilo *et al.* 2007).

The swelling power of the starch samples at different temperature is presented Figure 1. Swelling power of the starch blends increased with increasing temperature and considerably higher than that of 100% sweet potato starch but lower than that of 100% cassava starch. All the starches showed gradual increase in swelling power with increase in temperature and this suggested that these starches had weaker internal associative forces maintaining the granule structure.

Pasting properties of cassava - sweet potato starches: The pasting properties of cassava sweet potato starch blends are presented in Table 2. The pasting profile of the starch blends was significantly different from that of the 100% cassava and sweet potato starches. Peak viscosity, trough, breakdown viscosity and final viscosities of the starch blends were lower than that of 100% cassava and sweet potato starches, and ranged from 310.05-379.29 RVU, 162.67-203.42 RVU, 169.13-177.46, RVU and from 200.50-274.50 RVU, respectively. Peak viscosity is the maximum viscosity attained during or soon after the heating portion of the amylograph pasting test. Peak viscosity indicates the water binding capacity of the starch or mixture. It is often correlated with final product quality (Maziya-Dixon *et al.* 2007). The peak viscosity occurs at the equilibrium point between swelling causing an increase in viscosity and rupture and alignment causing its decrease. Set back viscosity ranged between 66.30 and 82.00 RVU. Setback has been correlated with texture of various products and high setback is also associated with syneresis or weeping during freeze/thaw cycles (Maziya-Dixon *et al.* 2007). The higher the setback value, the lower the retrogradation during cooling and the lower the staling rate of the products made from the starch (Adeyemi and Idowu, 1990). The set back viscosity of the blend of 75% cassava with 25% sweet potato starch was considerably lower than 100% starches indicative of the potential of the blend to form much stable starch paste than 100% cassava and sweet potato starches. Time to attain peak viscosity ranged from 4.47-4.97 min, while the starches pasting temperature ranged from 73.65 91.60°C. The ability of starch to imbibe water and swell is primarily dependent on the pasting temperature. The higher the pasting temperature the faster the tendency for paste to be formed (Dreher and Berry, 1983). The starch blends exhibited a higher pasting temperature compared to 100% cassava and sweet potato starches.

Conclusion

In conclusion, blending sweet potato starch with cassava starch significantly improves some functional properties of sweet potato starch. The blend containing 75% cassava starch and 25% sweet potato starch showed higher paste stability than 100% cassava and sweet potato starches.

References

Adebowale, A.A., Sanni, L.O. and Awonorin, S.O. (2005). Effect of Texture Modifiers on the Physicochemical and Sensory Properties of Dried Fufu. Food Science and Technology International, 11(5): 373382.

Adeyemi I. A. and Idowu, M.A. (1990). Sensory evaluation and nutrient composition of weaning food from pregelatinized maize-sweet potato mixtures. Plant Foods for human Nutrition, 44:149-155

Anderson R.A. (1982). Water absorption and solubility and amylograph characteristics of roll cooked small grain products. Cereal Chemistry 59: 265270.

Coffman C.W. and Garcia. (1977). Functional properties and amino acid content of a protein isolated from mung bean flour. Food Technology, 12: 473484.

Dreher, M.L and Berry, J.W. 1983. Buffalo gourd root starch. Part I. Properties and structure. Starch/Starke 35:76-81

Kulkarni K.D., Kulkarni D.N. and Ingle U.M. (1991). Sorghum malt-based weaning formulations: preparation, functional properties, and nutritive value. *Food and Nutrition Bulletin,* 13(4): 322 327.

Lilia, S and Collando, R.C.J (1999). Genetic variation in the physical properties of sweet potato starch. *Journal of Agriculture and Food Chemistry*, 47, 4195 4201.

Maziya-Dixon. B.; A. G. O. Dixon and A. A. Adebowale (2007). Targeting different end uses of cassava: genotypic variations for cyanogenic potentials and pasting properties. *International Journal of Food Science and Technology*, 42(8): 969 976.

Nyerhovwo, J.T (2004). Cassava and the future of starch. Electronic Journal of Biotechnology ISSN:0717-3458

Nwabueze, T.U. Glory, A. and Anoruoh, G.A. (2009). Evaluation of flour and extruded noodles from eight cassava mosaic disease (CMD)- resistant varieties. *Food Bioprocess Technology,* DOI 10.1007/ s11947-009-02000-4.

Obanni M and Bemiller J.N (1997). Properties of some starch blends. *Cereal chemistry*, 74, 431-436

Onitilo, M.O., Sanni, L.O., Daniel, I., Maziya-Dixon, B and Dixon, A. (2007). Physicochemical and functional properties of native starches from cassava varieties in Southwest Nigeria. *Journal of Food, Agriculture & Environment, 5 (3&4) : 1 0 8 - 1 1 4.*

Oyewole, O.B. and Obieze, N. (1995), Processing and Characteristics of "Tapioca" meal from cassava. *Tropical Science*, 35: 19-22

Takashi S. and Seib P.A. (1988). Paste and gel properties of prime corn and wheat starches with and without native lipids. *Cereal chemistry* 65: 474480.

Wang, J.C. and Kinsella, J.E. 1976. Functional properties of novel proteins; alfalfa leaf protein. *Journal of Food Science,* 41:286289.

Table 1: Functional properties of cassava sweet potato starch blends

Sample	Bulk density (g/ml)^{ns}	Water absorption index (%)	Dispersibility (%)	pH^{ns}	Least gelation concentration (%)	Total titratable acidity
100% cassava	0.65	86.80^{d}	85.40^{b}	6.80	2.00^{a}	2.07^{b}
75% cassava : 25% sweet Potato	0.67	69.07^{a}	84.80^{b}	6.78	2.00^{a}	2.07^{b}
25% cassava : 75% sweet Potato	0.65	77. 60^{c}	64.80^{a}	6.70	3.38^{b}	1.38^{a}
50% cassava : 50% sweet Potato	0.67	70.40^{b}	87.60^{b}	6.70	3.73^{b}	1.73^{ab}
100% sweet potato	0.64	87.00^{d}	71.80^{a}	6.75	2.07^{a}	2.07^{b}

Values are means of three replicates.
Mean values having different superscript within column are significantly different (P<0.05)
ns not significantly different (P>0.05)

Table 2: pasting properties of cassava sweet potato starch blends

Sample	Peak (RVU)	Trough (RVU)	Break Down (RVU)^{ns}	final Viscosity (RVU)	Set Back (RVU)	Peak Time (min)^{ns}	Pasting temperature (^{0}C)
100% cassava	379.29^{d}	201.83^{d}	177.46	274.50^{c}	72.67^{ab}	4.47	81.68^{b}
75% cassava : 25% sweet Potato	310.05^{a}	134.21^{a}	175.84	200.50^{a}	66.30^{a}	4.77	73.65^{a}
25% cassava : 75% sweet Potato	360.21^{c}	187.84^{c}	172.38	269.84^{c}	82.00^{b}	4.90	88.88^{c}
50% cassava : 50% sweet Potato	331.79^{ab}	162.67^{b}	169.13	239.50^{b}	76.83^{ab}	4.97	91.60^{d}
100% sweet potato	376.29^{d}	203.42^{d}	172.75	273.50^{c}	70.09^{ab}	4.57	82.55^{b}

Values are means of three replicates.
Mean values having different superscript within column are significantly different (P<0.05)
ns not significantly different (P>0.05)

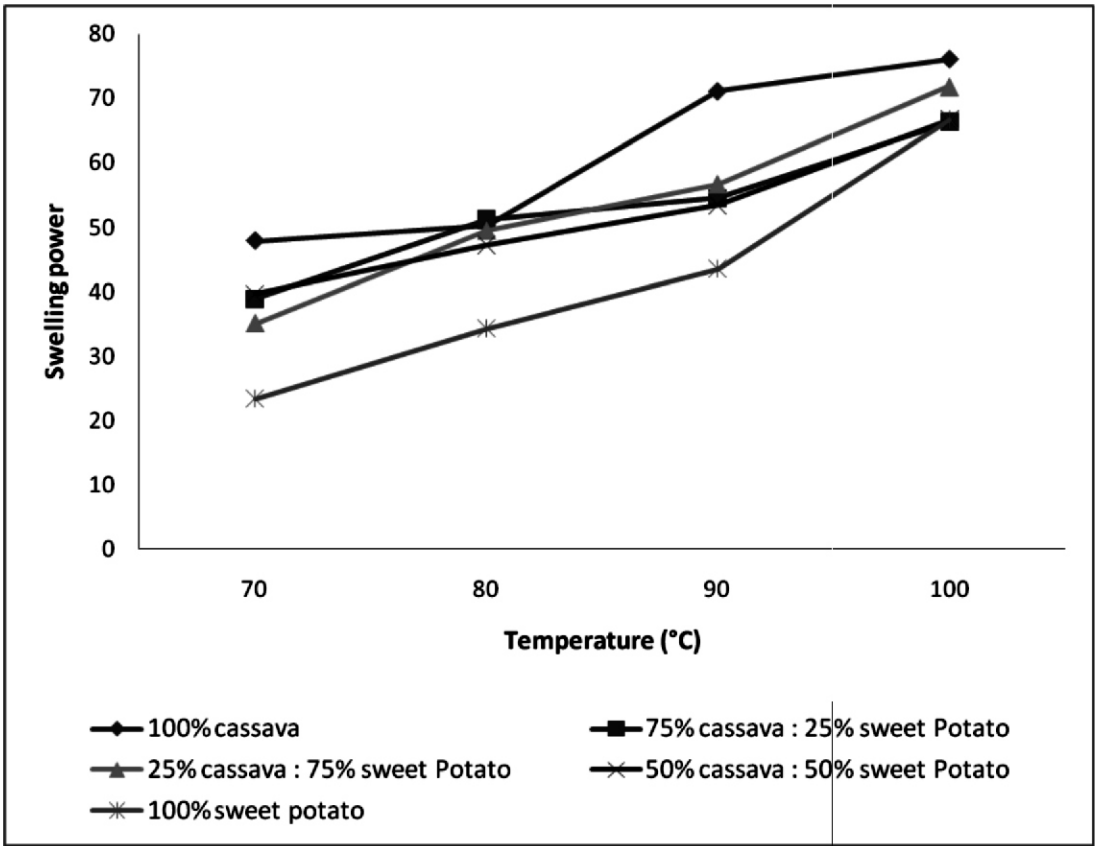


Figure 1: Swelling power of cassava-sweet potato starch blends at different temperature