Product Temperature Response of a Locally Developed Extruder to Maize Processing

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Abstract—Product temperature is a very important system parameter as well as an indicator of extrusion process. In this study, the product temperature response of a single screw extruder developed locally was investigated for the extrusion process of the flour and starch of maize. A factorial experiment in completely randomized design was employed to study the effect of extrusion variables: feed moisture (30, 40, 50 %), extruder temperature (40, 70, 100°C) built up by varying the duration of sampling and screw speed (100, 150, 200 rpm) on product temperature. Product temperature increased with increase in duration of operation. A maximum temperature of 150°C was attained in 30 minutes through viscous dissipation. Also, the study revealed that product temperature is strongly related to extrusion process parameters under study and the proximate composition of samples. Also, Product temperature increased at 100 and 150 rpm but decreased at 200 rpm. The equations relating the various dependent and independent variables were established to predict the extruder’s performance for maize processing. Quadratic coefficients fit the extrusion data very well, better than linear models.

Keywords—Extrusion, product temperature, maize starch, flour, wheat

1 INTRODUCTION

Maize (Zea mays) is a very important crop grown in many parts of the world that contributes to economic development and food security, most especially in low income food deficient countries because of their inherent characteristics. Maize as a popular staple food plays an important role in the diet of millions of people because of dry matter per hectare, its ease of cultivation, versatile food uses and storage characteristics (Mulege, 2011; Asiedu, 1992). Maize in its different processed forms is an important food for large numbers of people in the developing world, providing significant amounts of nutrients, in particular calories and protein. Its nutritional quality is particularly important for children.

Extrusion is a food processing operation that can increase the usefulness of starchy crops by producing a range of products with different shapes, nutrients, texture, colours, sizes, flavor etc, thereby increasing the varieties of food products in the diet (Fellows, 2003). In extrusion, product temperature is one of the dynamically controlled variables usually taken to reflect and predict product quality. Product temperature is related to the shear force and specific mechanical energy input of the extrusion system (Lin et. al. 2008; Olkku 1980). As a system parameter it can be used to connect extrusion cooking conditions such as screw speed, moisture content, screw configuration e.t.c and product conversion (Water Absorption index, Water Solubility Index) and thus to optimize and scale up the process appropriately (Bouvier, 2001). Also, many product properties including porosity, expansion, density depends on product temperature (Thymi et al 2005; Zweteyick 2008). Moreover, an important problem in extrusion process is the temperature control and regulation.

The present study was undertaken to determine the effects of different extrusion conditions from a locally developed extruder (screw speed, moisture content of feed, and extrusion time) on product temperature of maize extrudates. This will serve to define the product temperature profile of the locally developed extruder for maize under different conditions so as to be able to design a heat control system for the extruder.

2 MATERIALS AND METHODS

2.1 Sample Preparation

White maize, EV8363-5R QPM was sourced from the International Institute of Tropical Agriculture, Ibadan and processed into flour and starch respectively as described by Akanbi et al (2003). Maize samples were sourced from IITA breeder’s seed.

2.2 Extrusion

The extruder used in this study is a dry type made up of three (3) main units namely the feeding unit, the compression and melting unit and the die unit all fabricated using locally available materials. The extruder was developed as a test rig at the Agricultural Engineering Department, Federal University of Technology, Akure, Nigeria. A detailed report of the Extruder is contained in Fayose (2009) and Fayose et. al. (2009). 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, the screw configuration, feed rate, screw speed, die configuration and nozzle can be varied. Speed regulation 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 picture of the extruder while Figure 2 shows the isometric view of the extruder.

The screw is of single flight, increasing diameter and tapering/decreasing pitch with a compression ratio of 4.5:1, L/D: 1/12 and screw length: 750mm. The diameter of the final portion of the screw is reduced to a cone. This aid in pressure built up, easy conveyance of materials through the die and in reducing wear rate. The length to diameter ratio is 12:1. An electric motor drives the screw through a gear reducer, and the backward thrust of the screw is absorbed by a thrust bearing. The barrel and the screw/die configuration is typical of alimentary food
production equipment. The extrudates were extruded as ribbons and later cut into sizes manually.

2.3 Experimental Procedure
Samples were fed into the extruder at a feed rate 10 kg/h. The feeding section of the extruder was maintained at room temperature. The extruder was operated for 30 minutes for each set of condition. Steady state extrusion conditions is assumed to have been reached where there is no visible drifts in products temperature and torques required to turn the screw and by a steady extrusion rate. Temperature, both of the barrel and product were varied by continuous running of the machine, thereby building up the temperature. A major reason why heat is better generated through viscous dissipation than that added or removed through the barrel walls is that heat generated by drive unit (through viscous dissipation) is more dominant and cost efficient (Liang et al., 2002). However heat may be introduced into the system through the barrel walls if the heat generated by vicious generation is not sufficient for the product transformation. Since barrel temperature varies with duration of operation, duration of operation was observed as an independent variable. Heat generated by vicious dissipation on the extruder was cooled by removing and dipping the barrel and screw in a bath of cold water each time the extruder is to be fed with fresh samples. Temperature was monitored by using K type copper-constantan thermocouple inserted into the barrel immediately before entry of the mass into the die and with Portec CAI 001 thermometer probe (Portec instrumental, Milton Keynes, UK) inserted into the melt immediately before passage of the mass out of the die. The result was read from a read out digital meter.

2.4 Data collection and Analysis
Official methods of the Association of official Analytical chemists (1995) were used for moisture, ash, protein, fat and crude fibre. The carbohydrate content was determined by difference. Moisture contents of native starch samples and their extrudates were determined on a dry basis by an oven method using the AOAC (1995) method. The Proximate composition of the maize under study is presented in Table 1. Barrel and product temperatures were determined as described by Chessari and Sellahewa (2001) with K type copper-constantan thermocouple inserted into the barrel immediately before entry of the mass into the die and with Portec CAI 001 thermometer probe (Portec instrumental, Milton Keynes, UK) inserted into the melt immediately before passage of the mass out of the die. The result was read from a read out digital meter.

2.5 Statistical Analysis
This experiment was conducted using a factorial design comprising of two levels of product classification, three levels of initial moisture content, three levels of screw speed and five levels of duration of operation of machine. The four independent variable levels were pre-selected based on the results of preliminary tests (Fayose et al 2009). Each treatment was replicated thrice. Anova, least significant follow up tests, and stepwise multiple regression analysis were carried out using Statistical Package for Social Scientists (SPSS 13.0) software. Microsoft excel © 2007 was used for plotting graphs and generating regression equation. Regression analyses were employed to fit the experimental data to second-order polynomials. Also, variables were analyzed with and without their interaction to see if there will be any improvement in the model fit. Significance level was defined at P < 0.05.

Table 1. Proximate composition of the maize used

<table>
<thead>
<tr>
<th>Material</th>
<th>Moisture</th>
<th>Ash (%)</th>
<th>Fat (%)</th>
<th>Fibre (%)</th>
<th>Carbohydrate (%)</th>
<th>Protein (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ms</td>
<td>2.05</td>
<td>0.17</td>
<td>0.77</td>
<td>0.18</td>
<td>96.27</td>
<td>0.56</td>
</tr>
<tr>
<td>Mt</td>
<td>1.32</td>
<td>0.40</td>
<td>5.34</td>
<td>0.47</td>
<td>88.17</td>
<td>4.30</td>
</tr>
</tbody>
</table>
3 RESULT AND DISCUSSION

3.1 Effect of Extrusion on Products

The effect of extrusion variables (initial moisture content, duration of operation and screw speed) on product temperature for maize starch and maize flour are shown in Figures 3 and 4 respectively. The graphs show that product temperature varies directly with duration of operation. Product temperature increased with increase in duration of operation. The temperature of maize starch extrudate is higher than that of maize flour. The difference observed between the temperature of maize starch and maize flour might be due to the differences in proximate composition as shown in Table 1. For example, fat content of maize flour is higher than that of maize starch which may inhibit the frictional heating effect of the screws on maize flour products (Zweytick, 2008; Guy 2001).

For maize starch, a maximum temperature of 150°C was attained in 30 minutes through viscous dissipation at 150 rpm and 30% moisture content. The product temperature at 30% moisture content was higher than at 25 and 40% moisture content. Steady state condition was attained within 15 minutes for samples 30% moisture content while it took longer time for samples with 25% and 40% moisture contents. This may be because feed moisture ≤ 25% blocked the rotation of the screw and there was no transition from the original floury nature to a melted state typical of most extrusion processing. Also, beyond 35%, there was adherence of dough to the walls of the extruder. However for maize flour, restriction to flow started at feed moisture ≤ 30%. This experience can be avoided by introducing heat into the extruder through the barrel walls so as to enhance the melting of the dough.

This result agrees with those of Fletcher et al. (1985). Generally for the two products, product temperature increased at screw speeds 100 to 150 rpm and then decreased at 200 rpm. The decrease in temperature may be due to the decrease of mean residence time due to increase in screw speed. The shorter the time the feed material stays in the extruder, the less energy it receives from the process at constant feed rate. The feed rate must be optimized with screw speed to maintain uniform pressure, temperature, throughput and extrudate expansion (Zweytick, 2008; Badrie and Mellows, 1991).

This was what brought about specific feeding load (SFL) in previous studies (Frame, 2004; Lo et al., 1998). The final products of the extrusion studies are shown in Figures 5-8.
3.2 Statistical Analysis

The result of the statistical analysis is presented in Tables 2 and 3 for maize starch and maize flour respectively. The analysis showed the order of importance of the variables considered in this study. From Table 2, duration of sampling has the highest contribution, 67.9%, to R2 of Product temperature. The interaction term of screw speed and moisture content (sm) improved the model R2 by 1.2%. The Variance Inflation Factor (VIF) value for all parameter estimates were 1.0. Therefore, it can be concluded that multicollinearity is not a problem in this case. The more strongly correlated the independent variables are, the greater the need for controlling the confounding effects. However, the greater the intercorrelation of the independent variables, the less the reliability of the relative importance indicated by the partial regression coefficients.

The estimated coefficients reflect how changes in the predictors affect the response. T test value in the tables show the extent (%) of the influence of the independent variable on the performance of the response variable. An increase in each of the independent variables is contributing a positive percentage to the response variable. However, a unit increase in duration of extrusion dt is contributing 17.21% to product temperature while a unit increase in the interaction of screw speed and moisture content sm is decreasing product temperature by 2.5%. The F value indicates the significance of the total model.

In a similar study by Chang and Halek (1991) for corn meal, dough temperature studied at various extrusion conditions increased with increased barrel wall temperature zone 5, the most important factor that accounted for nearly 0.96 of the total R2. Food moisture or screw speed showed a slight effect. Also, moisture content and screw speed did not represent high R2 but are yet significant. It was speculated that since increase in screw speed reduced residence time, degree of fill and filled length, increases in viscous heating would be balanced by reduced barrel heat transfer. This may be the reason why the dough temperature in this present study for screw speed 200 rpm only differed from that for 100 rpm slightly. For wheat starch, Van Zuilichem and Stolp (1987) reported a similar case that a temperature of 95°C was attained in 44 minutes with an extruder of the following configuration: screw L/D: 1/12, compression ratio: 2.94 screw speed: 100 rpm and moisture content: 15.9 - 16.7%. However when the time of operation was extended beyond one hour to one hundred and three minutes, the temperature decreased. Also, a decrease in die diameter as well as in the moisture content led to an increase in product temperature for wheat starch (Meuser et al., 1987; O’ Connor, 1987). All these studies buttressed the reason
for a decreased temperature when screw speed is increased. The final products of the extrusion studies are shown in Figures 5-8.

4 CONCLUSION AND RECOMMENDATION

The product temperature response of maize to processing with a locally developed single screw extruder has being determined. The result shows good agreement with previous studies. Product temperature varies directly with duration of operation. Maize starch had the maximum temperature of 150°C attained in 30 minutes through viscous dissipation at a moisture content of 30 % while that of maize was 122°C. Product temperature is strongly related to the extrusion process parameters under study and the proximate composition of samples. Also, Product temperature increased at 100 and 150 rpm but decreased at 200 rpm. With the adoption of these results, data base for extruded products would be provided and more food with balanced diet will be produced at reduced costs from basic ingredients in most developing countries. The study can be carried out in the future considering to include introduction of heat through the barrel walls.

REFERENCES

FAO (1992), Maize in Human Nutrition, FAO Food and Nutrition Series, No. 25.