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Modelling of system parameters of extruded sorghum–cowpea breakfast cereal using response surface methodology

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Abstract

Blends of sorghum and cowpea flour (10%, 20% and 30%) were extruded at 20%, 22.5% and 25% moisture and 120 °C, 140 °C and 160 °C barrel temperatures respectively, using a single-screw extruder. A central composite face-centered (CCF) design was used to model the specific power consumption (SPC), torque, mass flow rate (MFR) and apparent specific volume (ASV) of the sorghum–cowpea extrudates. The SPC, torque, MFR and ASV varied from 201.71 to 229.28 Kw h^{-1} kg^{-1}, 85 to 97 Nm, 1.94 to 2.31 g s^{-1} and 4.01 to 6.36 cm^3, respectively. The SPC was significantly ($p < 0.05$) influenced by the linear effect of feed composition and the interaction effects of feed moisture and extrusion temperature. The torque was however significantly ($p < 0.05$) influenced by the linear effect of feed moisture and the interaction effects ($p < 0.01$) of feed moisture and extrusion temperature. The ASV was significantly ($p \leq 0.01$) influenced by the linear effect of extrusion temperature and the quadratic effect of extrusion temperature as well as the interaction effects of feed composition and feed moisture. The coefficients of determination were 0.78, 0.79, 0.63 and 0.86 for SPC, torque, MFR and ASV, respectively. There was no significant lack of fit for the SPC, torque, and MFR of the extrudates. The correlation coefficients (r^2) for the observed and predicted values were 0.88, 0.75, 0.78 and 0.93 for SPC, torque, MFR and ASV, respectively, indicating a good fit for the model. The CCF was found appropriate in predicting the SPC, torque, MFR and ASV of the extrudates.

Keywords: Blends; Optimum; Extrudates; Regression; Torque

1. Introduction

The major cereals cultivated in Nigeria are sorghum, millet, rice and maize. Nigeria is the largest producer of millet and sorghum in Africa and the second largest the world over (FAO, 2004). Sorghum however is still a crop of the small farmer, consumed largely where it is produced (National Academy of Science (NAS), 1996). Another constraint on sorghum utilization has been the lack of processed foods like flour, meal, breads, or other materials for use by those who cannot devote hours making flour from the raw grain. The development of a sorghum-based food processing industry would do much to offset Africa's shift in demand towards imported rice and wheat (NAS, 1996). Extrusion cooking, which is advocated for the production of snack foods, breakfast cereals and texturized vegetable protein (TVP) (Fellows, 2000; Bouvier, 2001 and Anuonye, 2012), is appropriate under this circumstance. Extrusion is reported (Filli et al., 2014) to be central to value addition of agricultural commodities, especially cereals and legumes, to enhance food security and sustainable development.

The main purpose of extrusion is to increase variety of foods in the diet by producing a range of products with different shapes, textures, colours, and flavours from basic ingredients (Lewis, 1987). It exhibits several advantages, the principal one being that the ingredients undergo a number of unit operations, e.g. mixing, shearing, shaping, cooking, drying and texturization, in one energy

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efficient and rapid process (Stanley, 1986). The food is at a distinct advantage when working with fabricated foods, since it is possible, within technological limits, to adjust both the composition of starting material and duration of the process to maximize structure and therefore, quality.

Extrusion cookers are extremely difficult to model due to the complex rheological properties and flow behaviour of the processed material, the poorly understood chemical reactions and the almost limitless screw and die configurations possible (Elsey et al., 1997; Filli et al., 2012). Extrusion of foods demands close control of many variables such as feed moisture, feed composition, feed particle size, feed rate, barrel temperature, screw speed, screw configuration and die geometry (Meng et al., 2010; Filli et al., 2012). Fluctuations in torque and hence in energy indicate erratic feeding, surging, and plugging of the extruder (Fichtali and van de Voort, 1989). This could cause variations in the quality of the extrudates. Modelling the torque, specific power consumption (SPC) and mass flow rate (MFR) of the process will stabilize the system and also produce extrudates with consistent quality.

It has been realized by several authors (Tayeb et al., 1992; Iwe, 2001, 2010) that the one-variable-at-a-time method of experimentation is inappropriate in many circumstances. Response surface methodology (RSM) is useful in particular situations such as extrusion cooking, where several input variables potentially influence some performance measure or quality characteristic of the process (Carley et al., 2004).

Many Nigerians do not have enough access to animal protein. The utilization of extrusion cooking and supplementation of sorghum flour with plant protein such as cowpea flour in the production of a breakfast cereal is likely to increase protein consumption of the consumers. Cowpea, being richer in lysine than cereal grains, is also valued for its flavour and short cooking time and can be used in a wide variety of ways principally as a nutritious component in human diet. In Nigeria the beans are either eaten as boiled beans or consumed in other forms such as moin-moin, akara or kosai, and danwake.

Traditional snack items are being replaced by fabricated alternatives usually produced using an extruder (Lasekan et al., 1996). The production of breakfast cereals in Nigeria currently underutilizes extrusion technology and locally available raw materials like sorghum and cowpea. Breakfast cereals available in the Nigerian market such as Golden Morn, Fast-O-Meal, and corn flakes are all produced using maize as basic raw material. This work was intended to model the effect of blending of sorghum and cowpea flour, and variation of feed moisture and extrusion temperature on the torque, specific power consumption, mass flow rate and apparent specific volume of the extruded breakfast cereal using response surface methodology (RSM).

2. Materials and methods

2.1. Procurement of raw materials

The red sorghum variety (Chakalari red) was obtained from Maiduguri Monday market. Cowpea (var kananede) was obtained from the Mubi main market, Adamawa State, Nigeria.

2.2. Preparation of sorghum flour

About 15 kg of sorghum grains was cleaned using a laboratory aspirator (Vegvari Ferenc Type OB125, Hungary) to remove stalks, chaff, leaves and other foreign matter. They were then washed with treated tap water in plastic basins and sun dried on mats for 2 days (at 38 °C and relative humidity of 27.58%) to 12% moisture. This was then dehulled using a commercial rice dehuller (Konching 1115, China) and milled using an attrition mill (Imex GX 160, Japan) to an average particle size of 0.599 mm. The flour was packed in polythene bags and stored for further use.

2.3. Preparation of cowpea flour

About 3 kg of cowpea was soaked in water for 10 min to loosen the seed coat. The kernels were then cracked in a mortar with pestle. The seed coat was then washed off in excess water. The beans were oven dried (Model: Chirana HS 201A, Hungary) at 80 °C to 12% moisture content and milled into flour (Imex GX 160, Japan) to an average particle size of 0.422 mm before packing in polythene bags for further use (Filli et al., 2010).

2.4. Blending of sorghum flour with cowpea flour and moisture adjustment

Sorghum flour was blended with cowpea flour in varying proportions (10%, 20%, 30% cowpea). The individual moisture contents of the cowpea and sorghum flours were determined (on dry weight basis) using the hot air oven method (Egan et al., 1981) and then the total moisture of the blends adjusted to the desired level according to Zasypkin and Tung-Ching (1998), using the formula below. The blends were mixed and the moisture allowed to equilibrate for 1 h before extrusion.

$$C_{cf} = [r_{cf} \times M \times (100 - w)]/[100 \times (100 - W_{cf})]$$
$$C_{sf} = [r_{sf} \times M \times (100 - w)]/[100 \times (100 - W_{sf})]$$
$$W_x = M - C_{cf} - C_{sf}$$

where C_{cf} is the mass of cowpea flour (g); $C_{sf,}$ the mass of sorghum flour (g); S_f and C_f are sorghum flour and cowpea flour, respectively; r_{cf} and r_{sf} are the cowpea flour (%) and sorghum flour (%), respectively; M, the total mass of the blend (g); w is the moisture content of final blend (%); W_x is weight of water added (g); W_{cf},the moisture content of cowpea flour (%); while W_{sf} is the moisture content of sorghum flour (%).

2.5. Specific power consumption

This is defined as power consumed per unit feed rate (Sopade and Le Grys, 1991) where power consumption is given by

$$\frac{1.85 \times R \times Q}{500x100}$$

where R and Q are the screw speed (rev min^{-1}) and torque (Nm), respectively, while 500 is the maximum screw speed (rev min^{-1}) and 18.5, the drive motor power (kW).