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Physical properties of extruded sorghum-barley-chickpea blends: A response surface analysis

Byreddy Naveena and Mohan Singh

Abstract
A twin-screw extruder was used to produce extrudates from sorghum, barley and chickpea flour blends (70:15:15 to 50:35:15) at 8, 10, 12, 14 and 16% moisture levels at 120, 140, 160, 180 and 200 °C barrel temperatures with screw speeds in the range of 120-200 rpm. The moisture content, bulk density and mass flow rate were modelled using response surface methodology with a central composite rotatable design (CCRD). According to the findings, extrudate moisture content ranged from 4.74 to 8.18 percent, bulk density was 0.08 to 1.19 g/cc and mass flow rate was 0.702 g/s to 0.974 g/s. Feed moisture and extrusion temperature had the greatest impact on the physical properties of the extrudates, followed by blend ratio and screw speed.

Keywords: Extrusion cooking, barley grain, response surface methodology, mass flow rate, puffing

1. Introduction

Extrusion is a food processing technology with high temperature and short time features (De Cruz *et al*., 2015) [5], and it is one of the most important processing techniques used in the production of food products (Tiwari & Jha, 2017; Masatcioglu *et al*., 2014; Moscicki & van Zuilichem, 2011) [25, 16, 18]. Mixing, cooking, kneading, shearing, shaping, and moulding are some of the unit processes included (Stojceska *et al*., 2009) [24]. The short residence duration should limit adverse reactions like bioactive component breakdown (Hirth *et al*., 2014) [9]. As a result, extrusion cooking is becoming a more popular method of manufacturing snack foods and breakfast cereals. Cereals, starches, and/or vegetable proteins make up the majority of extruded foods. Several studies have shown that starch-based materials are appropriate for extrusion processing (Yu *et al*., 2012; Moad, 2011) [27, 17], because their primary function is to build the structure, texture, mouth feel, and a variety of other qualities sought in finished goods (Li *et al*., 2014; Anton *et al*., 2009) [14, 1].

Sorghum is a prominent grain crop in the world's semi-arid regions, where it is used as a food and feed source. Sorghum species (such as Sorghum vulgare and Sorghum bicolor) are members of the grass family. Great millet and guinea corn are two West African names for sorghum; kafir corn is a South African name; dura is a Sudanese name for sorghum; mtama is an Eastern African name for sorghum; jowar is an Indian name for sorghum; and kaoliang is a Chinese term for sorghum (Purseglove, 1972) [21]. In North America, it is commonly referred to as milo or milo-maize. Although the United States is a major producer of sorghum, the grain is mostly used as animal feed in the semi-arid tropics of Africa and India, where it provides the primary diet for enormous populations. Sorghum, like other cereals, is a good source of protein and starch. It is a gluten-free cereal that is important in today's world, where the prevalence of Celiac Disease (CD), an immunological reaction to gluten sensitivity, is on the rise. Grain sorghum contains phenolic compounds called flavonoids (Shahidi and Naczk 1995) [22], which have been shown to slow tumour growth (Huang and Ferraro 1992) [10]. Because sorghum's starches and sugars are released more slowly than those in other cereals (Klopfenstein and Hoseney 1995) [13], it may be advantageous to diabetics (Toomey 1988) [26]. Sorghum is used in baked bread, porridge, tortillas, couscous, gruel, steam-cooked items, alcoholic, and non-alcoholic beverages all over the world.

Barley grain is a desired component in baked goods and it is a good source of soluble and insoluble dietary fibres, phenolic compounds, vitamin B complex and minerals. β-glucans, the primary fibre elements of barley, have been linked to the highest nutritional value. Lowering plasma cholesterol, increasing lipid metabolism, lowering the glycemic index, and stimulating the immune system are all suggested health benefits of β-glucans.

The Food and Drug Administration (FDA) found that soluble β-glucan (3 g/day) from oat bran and rolled oats, dry milled barley and wholegrain barley products is effective in decreasing concentrations of total and LDL-cholesterol serum (Food and Drug Administration, 2003).
Numerous previous studies (Hegazy *et al*., 2017 and Nithya *et al*., 2016) [8, 19] have described mixing cereals with legumes for the formation of extruded goods. Chickpeas are high in protein, have readily available carbohydrates, and a lot of fibre (Shevkani *et al*., 2019) [23]. The aim of this study was to use extrusion cooking to develop nutritionally superior snacks with improved functional and sensory features. The impact of feed moisture, blend ratio, barrel temperature, and screw speed on the physical properties of sorghum-barley-chickpea based expanded products is examined.

2. Materials & Methods

2.1 Raw material

According to the experimental design, flour samples were weighed in precise amounts and the moisture content of the blends was determined through pre-conditioning. The extrusion process was completed with a BTPL lab model twin screw extruder.

2.2 Statistical design

The selected independent variables i.e., moisture content, blend ratio, barrel temperature and screw speed were investigated using Response Surface Methodology.

2.3 products characteristics

2.3.1 Moisture content

The moisture content of the samples was determined using the hot air oven method. A 5 gm sample was carefully measured into clean and dry moisture boxes of known weight, then dried for 12-15 hours at 105 °C in a hot air oven, cooled in a dessicator, and weighed (AOAC, 1990) [2].

$$\text{Moisture content (w.b)} = \frac{\text{Initial weight} - \text{Final weight}}{\text{Sample weight}} \quad \text{.. eqn. 1}$$

2.3.2 Bulk density

Bulk density is defined as the mass per unit bulk volume of a substance, including the volume of voids. The bulk density of the sample was calculated by measuring the extrudate actual dimensions. After the extrudate was weighed, the diameter and length of the extrudate were measured with a digital vernier calliper with a least count of 0.01 mm. The bulk density was determined using the formula 2, assuming an extrudate with a cylindrical shape.

$$\text{Bulk density (g/cc)} = \frac{4 \times \text{mass (g)}}{\pi \times \text{length (cm)} \times (\text{diameter})^2\ \text{(cm)}} \text{... eqn 2}$$

2.3.3 Mass flow rate

The mass flow rate of extrudates is expressed in gram per second. The extrudate was collected in a polyethylene bag for a specified amount of time (typically 10 seconds) as soon as it came out of the extruder, and its weight was taken.

3. Results & Discussion

3.1 Effect of extrusion conditions on physical parameters

3.1.1 Moisture content of extrudates

MCE stands for moisture content of extrudates and indicates how much moisture is lost during extrusion cooking. The moisture content of extrudates (MCE) assessed for all of the samples ranged from 4.74 to 8.18 percent based on the results of the experiment. 3-D surface plots depict the effect of extrusion parameters on extrudate moisture content (Fig. 1 to 3). The various regression model's coefficient of determination (R^2) for predicting the moisture content of extrudates was 0.88. The effect of processing parameters on moisture content of extrudates in coded values is represented by the following second order model, which produces a multiple regression equation.
Moisture content = $-$ 37.95594 + 2.80531 x MC + 0.17337 x BR + 0.16257 x BT + 0.13105 x SS + 9.37500 x 10^{-4} x MC x BR $-$ 1.01563 x 10^{-3} x MC x BT $-$ 3.59375 x 10^{-4} x MC x SS $-$ 3.68750 x 10^{-4} x BR x SS $-$ 0.085547 x MC^2 - 2.88750 x 10^{-3} x BR^2 $-$ 4.74219 x 10^{-4} x BT^2 $-$ 3.11719 x 10^{-4} x SS^2 eqn.3

Where;
MC = Moisture Content, BR= Blend Ratio, BT = Barrel Temperature, SS = Screw Speed
Positive coefficients of the first order terms of SS, MC, interaction terms, and quadratic terms in equation 1 indicate that the moisture content of extrudates (MCE) increases as these variables are increased, whereas negative coefficients of the first order terms of BT, BR, quadratic terms, and interaction terms indicate that the MCE of extrudates decreases as these variables are increased.

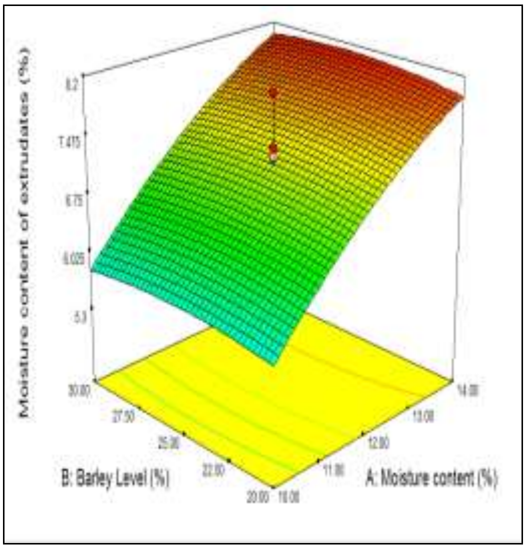

Fig 1: Effect of moisture content and barley level on moisture content of extrudates

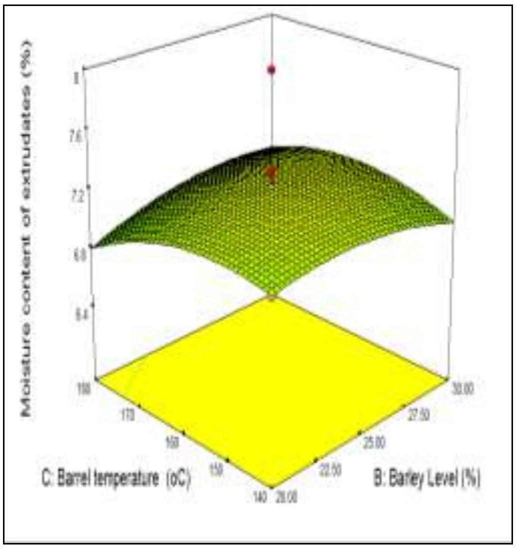

Fig 2: Effect of barley level and barrel temperature on moisture content of extrudates

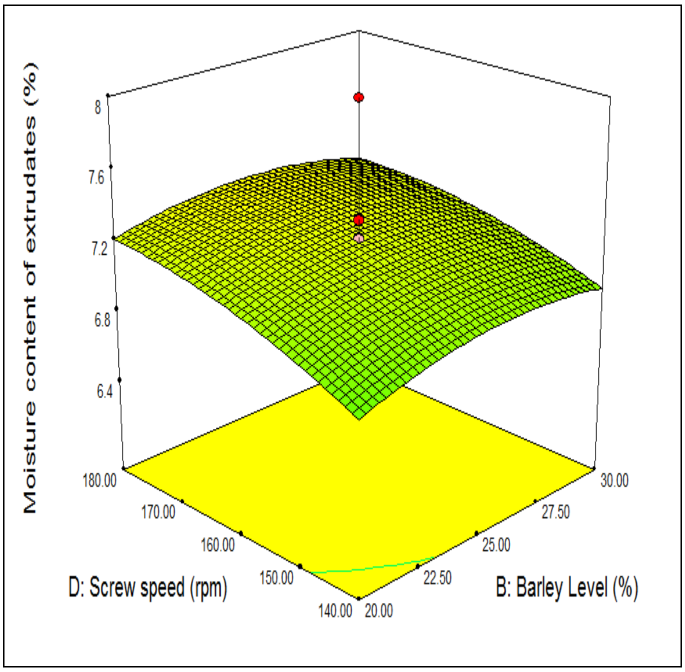

Fig 3: Effect of barley level and screw speed on moisture content of extrudates

It is observed in fig.1 that at higher moisture levels, there was an increase in the moisture content of extrudates, owing to the fact that when feed moisture content rises, so does the quantity of moisture retained in extrudates. Figure 2 shows that when the barrel temperature rises, the moisture content of the extrudates reduces.

Figure 3 shows that as the quantity of barley flour was increased, the moisture content of the extrudates increased. Gluten, present in cereals, has a stronger ability to hold water even at higher temperatures (Harper, 1981) [7]. During extrusion cooking, barley includes gluten, which has a high water binding capacity. As a result, the moisture content of extrudates increased as barley level increased.

3.2 Bulk density of extrudates

The degree of puffing in the dough as it passes through the extruder die is referred to as bulk density of extrudates. The bulk density (BD) of extrudates assessed for all samples ranged from 0.08 to 1.19 g/cc based on the results of the experiment. In 3-D surface plots, the effect of extrusion parameters on extrudate bulk density is depicted (Fig. 4 to 6). The various regression model's coefficient of determination (R^2) for estimating the bulk density of extrudates was 0.95. The effect of processing parameters on bulk density in coded values is represented by the following second order model, which offers a multiple regression equation.

$$\text{Bulk Density} = + 2.61073 - 0.15740 \times MC - 0.067625 \times BL - 0.023719 \times BT + 0.013385 \times SS + 0.00976563 \times MC^2 \quad \text{eq. 4}$$

Positive coefficients of the first order terms of BL, MC, interaction terms, and quadratic terms in equation 4 indicate an increase in extrudate bulk density (BD) as these variables are increased, whereas negative coefficients of the first order terms of BT, SS, quadratic terms, and interaction terms indicate a decrease in extrudate bulk density as these variables are increased.

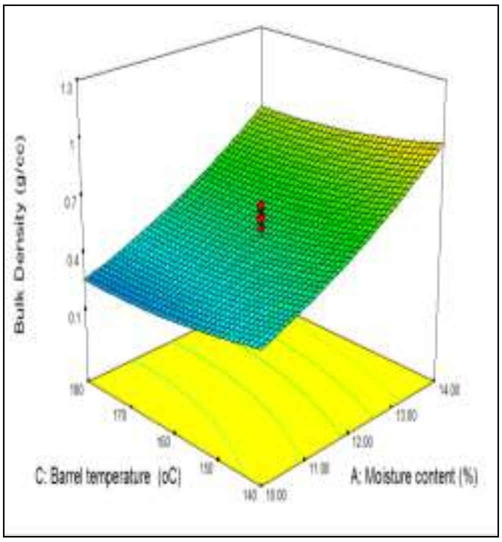

Fig 4: Effect of moisture content and barrel temperature on bulk density of extrudates

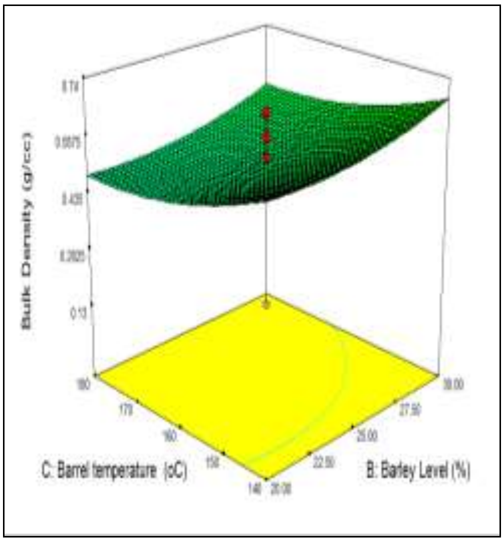

Fig 5: Effect of barley level and barrel temperature on bulk density of extrudates

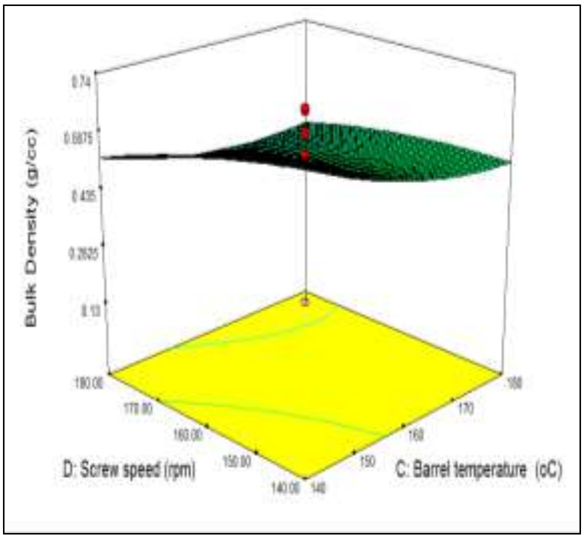

Fig 6: Effect of barrel temperature and screw speed on bulk density of extrudates

The bulk density of the feed increased as the moisture content of the feed increased, as seen in fig. 4. Similar findings have been reported by others (Peluola-Adeyemi and Idowu 2014) [20]. Extrusion cooking is insufficient to enable adequate moisture evaporation, resulting in moisture retention, and as a result, product puffing is reduced. Thus, a denser product is developed.

Bulk density of extrudate increased as the amount of barley in the feed increased, as shown in Fig. 5. Barley which is a member of the grass family, has 17 grams of dietary fibre. Because of the fibre particles tended to breach the cell walls before the gas bubbles had fully inflated, the extruded snacks had a higher density (Lue *et al*., 1991) [15]. Figure 6 shows that the influence of barrel temperature on extrudate bulk density was negative. The bulk density of extrudates reduced as the barrel temperature increased. A similar decrease in density of rice extrudates has been seen when barrel temperature rises (Ilo *et al*., 1999) [11].

3.3 Mass flow rate

The extrudate output rate was determined using the mass flow rate. The rate at which extrudates exited the die is known as mass flow rate and it ranged from 0.702 g/s to 0.974 g/s. In 3-D surface plots, the effect of extrusion parameters on mass flow rate of extrudates is shown (Fig. 7 to 9). The coefficient of determination (R^2) for estimating the mass flow rate of extrudates was 0.95. The effect of processing parameters on mass flow rate in coded values is represented by the following second order model, which offers a multiple regression equation.

Mass Flow Rate = + 0.57939 – 0.016969 x MC + 0.00319583 x BL + 0.00230312 x BT + 0.00439687 x SS .. eqn. 5

In equation 5, Positive coefficients of the first order terms of BL, SS, interaction terms, and quadratic terms indicate an increase in extrudate mass flow rate (MFR) as these variables are increased and negative coefficients of the first order terms of MC, BT, quadratic terms, and interaction terms indicate a decrease in extrudate mass flow rate as these variables are increased.

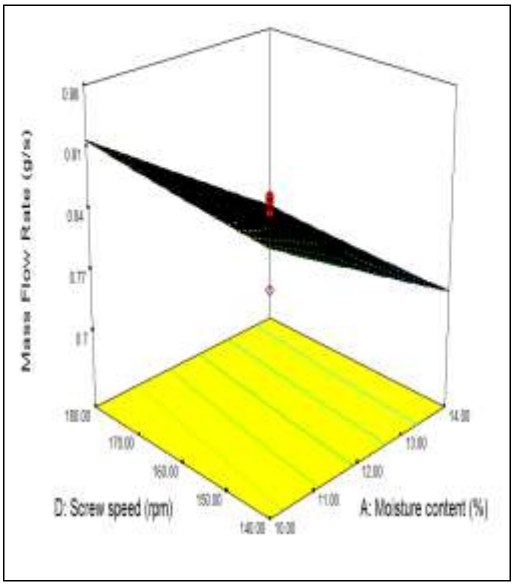

Fig 7: Effect of moisture content and screw speed on mass flow rate of extrudates

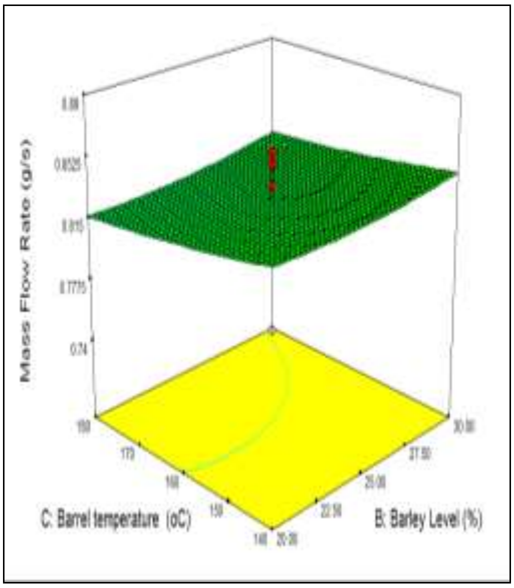

Fig 8: Effect of barley level and barrel temperature on mass flow rate of extrudates

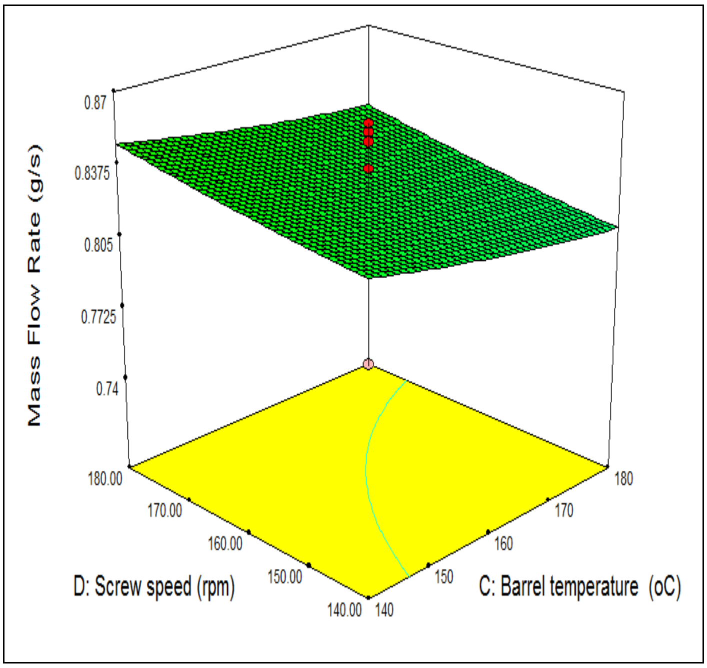

Fig 9: Effect of barrel temperature and screw speed on mass flow rate of extrudates

As demonstrated in fig 7, increasing the feed moisture content resulted in a decrease in mass flow rate. Similar findings have been reported by others (Chevanan *et al*, 2008) [3]. The amount of heat applied during extrusion, both by shearing and direct heating, was insufficient to evaporate all of the moisture by flash off as it came out of the die at higher levels of feed moisture, resulting in an increase in extrudate mass. Figures 8 and 9 shows that as the barrel temperature was raised, the mass flow rate was reduced. More porous structures are formed as moisture evaporates at higher barrel temperatures, and the mass flow rate of extrudates is lowered.
Figure 9 shows a relationship between mass flow rate and screw speed. This is in line with the findings of (Chevanan *et al*., 2008) [3]. Because screw speed is inversely proportional to resident time in the heating chamber, the high screw speed reduced extrusion material residence time, resulting in an increase in mass flow rate.

Conclusion
The snack quality attributes were strongly modified by extrusion processing parameters such as blend moisture level, barley inclusion, barrel temperature and screw speed. Of all the independent variables studied, feed moisture content had the greatest impact on dependent variables. Using response surface methodology, the best extrusion processing parameters predicted for the development of sorghum based extruded snacks were 10 percent feed moisture, 180 °C barrel temperature, 180 rpm screw speed, and a feed composition of 60:25:15 percent sorghum:barley:chickpea flour.

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