Effects of Extrusion Conditions on Physical Properties of Sorghum Based Extruded Products

Byreddy Naveena[1*] and Mohan Singh[1]

[1]*Department of Post Harvest Process & Food Engineering, Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur, Madhya Pradesh, India.*

Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

Original Research Article

ABSTRACT

Extrusion cooking is a high temperature short time multivariable unit operation. In this study, response surface methodology (RSM) was used to evaluate the effect of feed parameters i.e., feed moisture (8-16%), blend ratio of sorghum:barley:bengal gram, (70:15:15 to 50:35:15) and machine parameters of twin screw extruder i.e., barrel temperature (120-200°C) and screw speed (120-200 rpm) on physical properties of extrudates i.e., mass flow rate, bulk density and moisture content. The results showed that maximum mass flow rate (0.974 g/s) was observed with the blend ratio 60:25:15, having 8 percent moisture (w.b) extruded at 160°C barrel temperature and a screw speed of 160 rpm. The bulk density of extrudates was found minimum (0.08 g/cc) at 10% moisture content, 65:20:15 blend ratio, 180°C barrel temperature and 180 rpm screw speed and the moisture content of extrudates was found minimum (4.74%) at 10% moisture content, 55:30:15 blend ratio, 180°C barrel temperature and 140 rpm screw speed.

Keywords: Extrusion cooking; multivariable; response surface methodology; barley; mass flow rate.

1. INTRODUCTION

Extrusion is a food processing technology with high temperature and short time [1] features, and it is one of the most important processing techniques used in the production of food products. It involves mixing, shearing, cooking, puffing and drying in a single energy efficient,

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*Corresponding author: E-mail: naveenachittinavi@gmail.com;

rapid continuous process which brings about gelatinization of starch, denatures proteins, modifies lipids and inactivates enzymes, microbes and many anti-nutritional factors. Extrusion cooking has become a popular method in the cereal, snack, and pet food industries, where starch and protein are used as raw ingredients to create extremely valuable food products [2].

Traditionally, sorghums are preferred for many foods such as flat bread, thick and thin porridges, snacks, and other products [3]. However, low protein content and quality limit the widespread applications of sorghum in human foods. Starch is the main component of sorghum grain, followed by proteins, non-starch polysaccharides and fat [4]. Sorghum proteins contain more cross-linked prolamines than other cereals, which reduce digestibility and functionality of sorghum flour [5]. Therefore, there is a need for sorghum-based foods with higher protein content and digestibility. Incorporation of protein and carbohydrate sources could significantly increase the protein quality and expansion ratio of sorghum-based products and provide additional functional properties [6].

Barley (*Hordeum vulgare* L.) is regarded as a nutraceutical grain as it is a good source of bioactive compounds including β-glucan, phenolic compounds, B-complex vita- mins and minerals [7]. The nutritional profile of barley places it in a prime position for development of a new extruded–expanded snack food with health benefits. Intake of whole grain barley and oat is associated with a decreased risk for coronary heart disease and certain types of cancer, as well as a cholesterol-lowering effect [8].

Bengal gram contains 22% of protein on dry weight basis and 19–22.7% of dietary fibre. It also contains lectins and agglutinins which can be anticancer, immunomodulatory, anti-obesity in nature [9]. The chickpea flour possesses high antioxidant content and phenolic content. Bengal gram contains starch as the major polysaccharide constituent [10]. Food processing industries have been utilizing starch as a binder, thickening and emulsifying entity and also as a cloudifier [11].

RSM (response surface methodology) is a useful tool for improving processes and products. RSM is a set of experimental design and optimization approaches that allows the experimenter to figure out how the response and the independent variables are related. RSM is commonly used to map a response surface over a specified region of interest, optimise the response, or choose operating conditions in order to meet target specifications or client needs [12]. RSM can be used to improve extrusion processes [13].

2. MATERIALS AND METHODS

2.1 Material

The ingredients used for production of ready-to-eat extruded snacks were sorghum, barley and bengal gram and were procured from the Raichur local market, Karnataka, India. For preparing the samples, all the raw materials were grinded in a hammer mill separately, to reduce the size into fine particles.

2.2 Determination of Moisture Content of Raw Material

By using the oven drying method, the moisture content of raw materials was evaluated for each ingredient. A sample of grains flour was dried for 16 hours at 80 °C for this purpose. The mass of the sample was measured before and after drying and the loss of mass was calculated. The following formula was used to calculate the moisture content:

$$\text{Moisture Content (\% w.b)} = \frac{\text{Initial mass of sample (g)} - \text{Final mass of sample (g)}}{\text{Initial mass of sample (g)}}$$

2.3 Preparation of Samples

The samples were prepared using process parameters such as five distinct sorghum, barley and bengal gram blends (70:15:15, 65:20:15, 60:25:15, 55:30:15, 50:35:15) at feed moisture content (8, 10, 12, 14, 16%) and extruder operational parameters such as barrel temperature (120, 140, 160, 180 and 200 ºC) and screw speed (120, 140, 160, 180 and 200 rpm). All of the flours were weighed and the moisture content was adjusted by sprinkling water into the flours and mixing them together to make a homogeneous mixture. After mixing, the samples were kept at room temperature for 12 to 24 hours in aluminium laminated polyethylene bags. The samples were sieved and placed into a feed hopper, where they were extruded with a 7 mm die diameter and collected at the die end.

2.4 Extruder

In present study, the BTPL lab model twin screw extruder was used for extrusion of barley,

sorghum and bengal gram. The extruder was made out of a grooved barrel with heating components and cooling jackets that were covered. The motor, gear unit, loading unit, coupling, extruder barrel with screw and control cabinet are the extruder's structural elements. A temperature controller regulates the temperatures in each zone. The extruder's feeding zone is water-cooled, while the compression and metering zones are air-cooled. The barrel's end was fitted with a round die head. Above the feed aperture, the feed screw-feeding apparatus was installed. Within the extruder and die head, electronic equipment and sensors are provided for sensing melt pressure and melt temperature. A highly engineered component is the opening that lets feed material to form particular forms. In this experiment, a circular die with a diameter of 7 mm was employed.

2.5 Statistics Design

Design expert software was used to create a design matrix with 30 runs. Central composite rotatable design (CCRD) was used to analyze the influence of four independent variables i.e., Moisture Content of Feed (MCF), Blend Ratio (BR), Barrel Temperature (°C) and Screw Speed (rpm) on properties of extrudates i.e., mass flow rate, bulk density and moisture content. A second order polynomial equation was used to fit the measured dependent variables (mass flow rate, bulk density and moisture content) as a function of independent extrusion variables.

2.6 Physical Properties of Extrudates

2.6.1 Mass flow rate

Mass flow rate is expressed in gram per second and it was measured by collecting the extrudate in a polyethylene bag for a certain amount of time (usually 10 seconds) as soon as it came out of the extruder and its weight was taken.

2.6.2 Bulk density

The mass per unit bulk volume of a substance, including the volume of voids, is known as bulk density. The sample's bulk density was determined by measuring the actual dimensions of the extrudates. The diameter and length of the extrudate were measured with a digital vernier calliper with a least count 0.01 mm after the extrudate was weighed. Assuming a cylindrical shape of extrudate, the bulk density was calculated using the formula 2.1.

Bulk density (g/cc)

$$= \frac{4 \text{ x mass (g)}}{\pi \text{ x length (cm) x (diameter)}^2 \text{ (cm)}} \qquad \text{eqn.1}$$

2.6.3 Moisture content

The hot air oven method was used to determine the moisture content of the samples. A 5gm sample was carefully measured into clean and dry moisture boxes of known weight, dried in a hot air oven at 105 °C for 12-15 hours, cooled in a dessicator, and weighed [14].

Moisture content (w.b) **=**
$$\frac{\text{Initial weight} - \text{Final weight}}{\text{Sample weight}} \qquad \text{eqn.2}$$

3. RESULTS AND DISCUSSION

3.1 Mass Flow Rate of Extrudates

Mass flow rate was calculated to determine the extrudate output rate. It refers to the rate at which extrudates exited the die. The Mass flow rate of sorghum-barley-bengal gram blend extrudates varied between 0.702 g/s to 0.974 g/s. The mass flow rate of extrudates was found maximum (0.974) at 8% moisture content, 60:25:15 blend ratio, barrel temperature 160 °C and screw speed 160 rpm. Minimum (0.702 g/s) value of mass flow rate was found at 16% moisture content, 60:25:15 blend ratio, barrel temperature 160 °C and screw speed 160 rpm. The effect of extrusion parameters on mass flow rate of extrudates are shown in 3-D surface plots (Fig. 1 to 3).

The coefficient of determination (R^2) of the various regression models for predicting the mass flow rate of extrudates was 0.95. The following second order model provides a multiple regression equation that represents the effect of processing factors on mass flow rate in coded values.

Mass Flow Rate = + 0.57939 − 0.016969 x MC + 3.19583 x 10^{-3} x BR + 2.30312 x 10^{-3} x BT + 4.39687 x 10^{-3} x SS + 5.43750 x 10^{-4} x MC x BR − 1.26562 x 10^{-4} x MC x SS − 5.70312 x 10^{-4} x MC^2 　　　　eqn.3

Where;
MC = Moisture Content, BR= Blend Ratio,
BT = Barrel Temperature, SS = Screw Speed

Positive coefficients of the first order terms of BL, SS, interaction terms and quadratic terms in equation 1 indicate an increase in mass flow rate

(MFR) of extrudates as these variables are increased, whereas negative coefficients of the first order terms of MC, BT, quadratic terms and interaction terms indicate a decrease in mass flow rate of extrudates as these variables are increased.
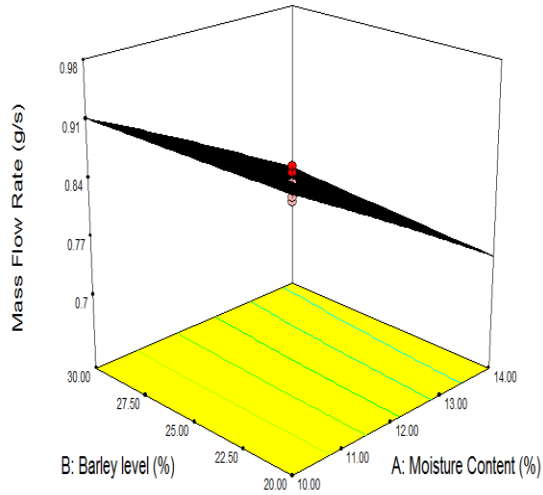

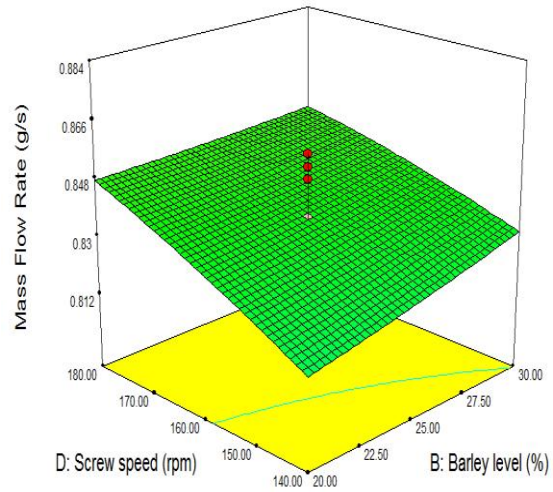**Fig. 1. Effect of moisture content and barley level on mass flow rate of extrudates**

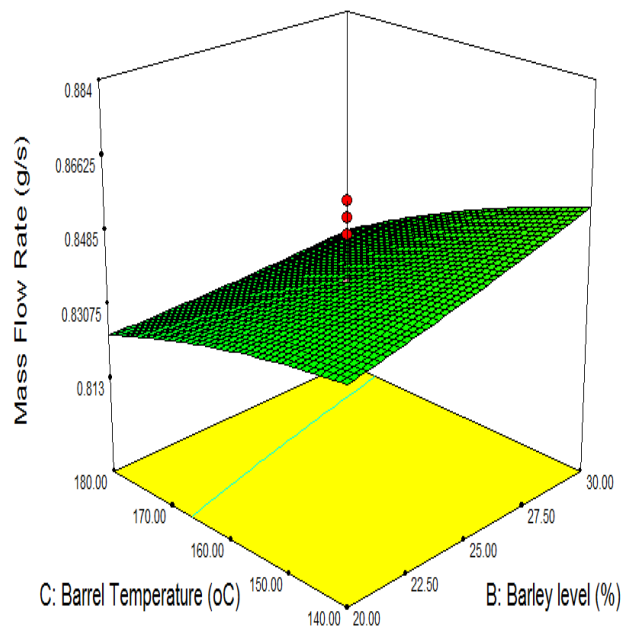**Fig. 2. Effect of barley level and screw speed on mass flow rate of extrudates**

Fig. 3. Effect of barley level and barrel temperature on mass flow rate of extrudates

Increasing the feed moisture content resulted in decreased mass flow rate as shown in Fig. 1. Similar results were reported by [15,16]. The amount of heat given during extrusion by shearing as well as direct heating did not create enough vapour pressure 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 the mass of extrudates. There was a positive correlation of mass flow rate with screw speed as shown in Fig. 2. This is in agreement with the results of [15,16]. As residence time is inversely proportional to screw speed, the high screw speed reduced extrusion material residence time in the heating chamber, resulting in an increase in mass flow rate.

From Fig. 3 it can be depicted that the mass flow rate was decreased with increasing the barrel temperature. The more moisture evaporates at higher barrel temperature, the more porous structures are created, and the mass flow rate of extrudates is reduced.

3.2 Bulk Density of Extrudates

Bulk density of extrudates describes the degree of puffing in the dough as it passes through the extruder die. From the experiment, the bulk density (BD) of extrudates measured for all the samples ranged from 0.08 to 1.19 g/cc. Maximum BD was observed at 60 per cent sorghum, 25 per cent barley, 15 per cent bengal gram level, 16 per cent (w.b.) feed moisture content extruded at 160 °C barrel temperature

and 160 rpm while the variable values for the lower BD were 65:20:15 blend ratio, 10% moisture content, 180 °C and 180 rpm respectively. The effect of extrusion parameters on bulk density of extrudates are shown in 3-D surface plots (Fig. 4 to 6).

The coefficient of determination (R^2) of the various regression models for predicting the bulk density of extrudates was 0.95. The following second order model provides a multiple regression equation that represents the effect of processing factors on bulk density in coded values.

Bulk Density = + 2.61073 − 0.15740 x MC − 0.067625 x BR − 0.023719 x BT + 0.013385 x SS + 5.62500 x 10^{-4} x MC x BR − 1.71875 x 10^{-4} x MC x BT + 6.09375 x 10^{-4} x MC x SS + 3.12500E + 9.76563E − 003 x MC^2 + 9.12500 x 10^{-4} x BR^2 eqn.4

Where;
MC = Moisture Content, BR= Blend Ratio, BT = Barrel Temperature, SS = Screw Speed

Positive coefficients of the first order terms of BL, MC, interaction terms, and quadratic terms in equation 2 indicate an increase in bulk density (BD) of extrudates 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 bulk density of extrudates as these variable is increased.
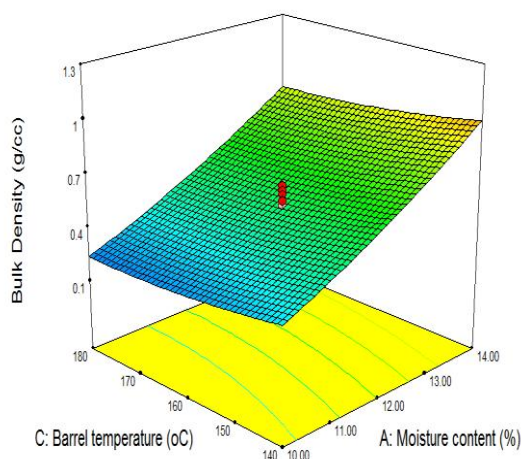

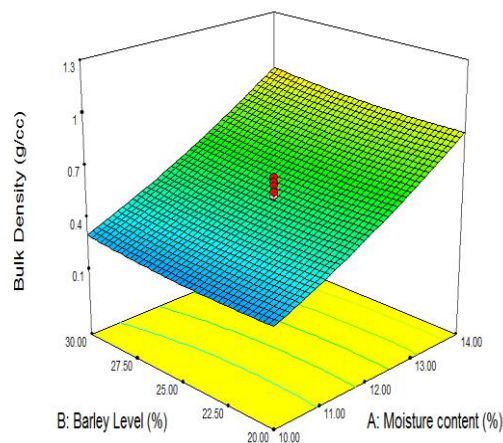**Fig. 4. Effect of moisture content and barrel temperature on bulk density of extrudates**

Fig. 5. Effect of moisture content and barley level on bulk density of extrudates
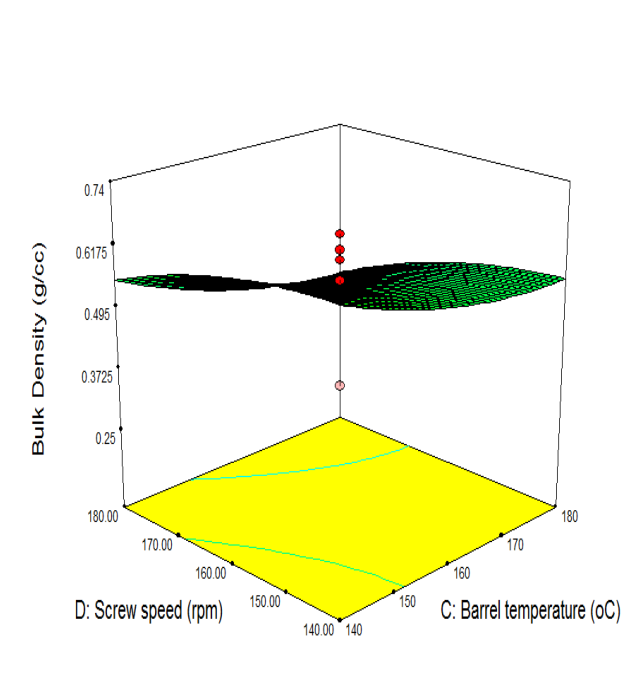
Fig. 6. Effect of barrel temperature and screw speed on bulk density of extrudates

It is observed in Fig. 4 that the bulk density increased as the moisture content of the feed increased. Similar results were reported by [17]. Because extrusion cooking is insufficient to provide sufficient evaporation of moisture, resulting in moisture retention, as a result, product puffing is decreased. Finally, a denser product is produced. Fig. 5 shows that extrudate bulk density increased as the amount of barley level in the feed increased. Barley, a member of the grass family, contains 17 g dietary fiber. The fibre particles tended to burst the cell walls before the gas bubbles had fully expanded, resulting in higher density extruded snacks [18].

It is observed in Fig. 6 that effect of barrel temperature was negative on bulk density of extrudates. As the barrel temperature increased, the bulk density of extrudates was decreased. Similar reduction of density of rice extrudates with increase in barrel temperature has been reported by [19].

3.3 Moisture Content of Extrudates

Moisture content of extrudates (MCE) give an idea of moisture loss during extrusion cooking. From the experiment, the moisture content of extrudates (MCE) measured for all the samples ranged from 4.74 to 8.18%. The moisture content of extrudates was maximum (8.18%) at 14% moisture content, 65:20:15 blend ratio, 140°C

barrel temperature and 180 rpm screw speed. Minimum (4.74%) value of MCE was found at 10% moisture content, 55:20:15 blend ratio, 180 °C barrel temperature and 140 rpm screw speed. The effect of extrusion parameters on moisture content of extrudates are shown in 3-D surface plots (Fig. 7 to 9).

The coefficient of determination (R^2) of the various regression models for predicting the moisture content of extrudates was 0.88. The following second order model provides a multiple regression equation that represents the effect of processing factors on moisture content of extrudates in coded values.

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.5

Where;
MC = Moisture Content, BR= Blend Ratio, BT = Barrel Temperature, SS = Screw Speed

Positive coefficients of the first order terms of MC, SS, interaction terms and quadratic terms in equation 3 indicate an increase in moisture content of extrudates (MCE) as these variables

are increased, whereas negative coefficients of the first order terms of BT, BR, quadratic terms and interaction terms indicate a decrease in MCE of extrudates as these variable is increased.
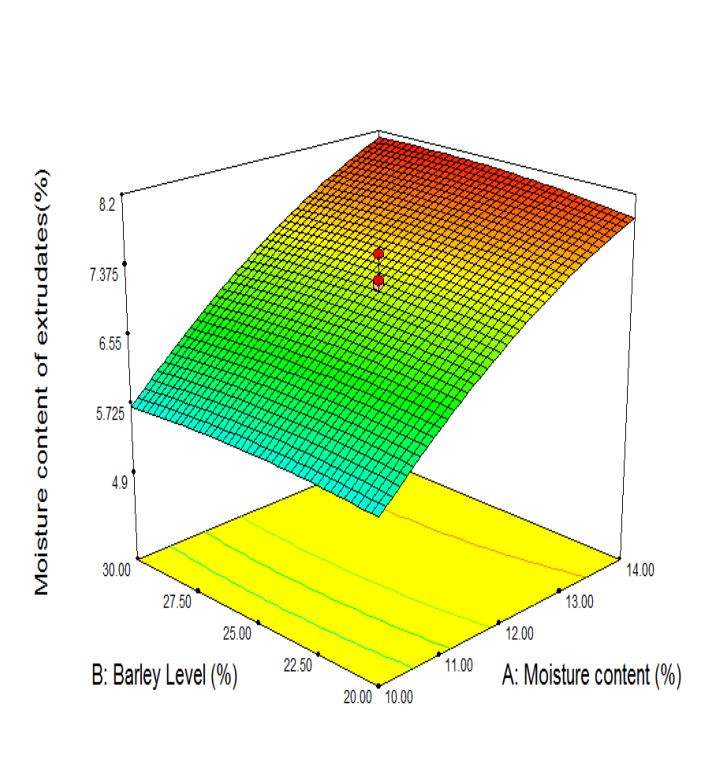

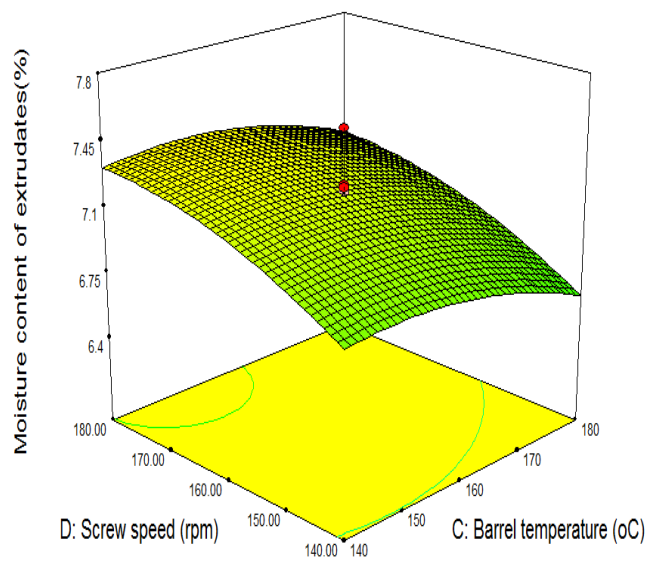**Fig. 7. Effect of moisture content and barley level on moisture content of extrudates**

Fig. 8. Effect of barrel temperature and screw speed on moisture content of extrudates
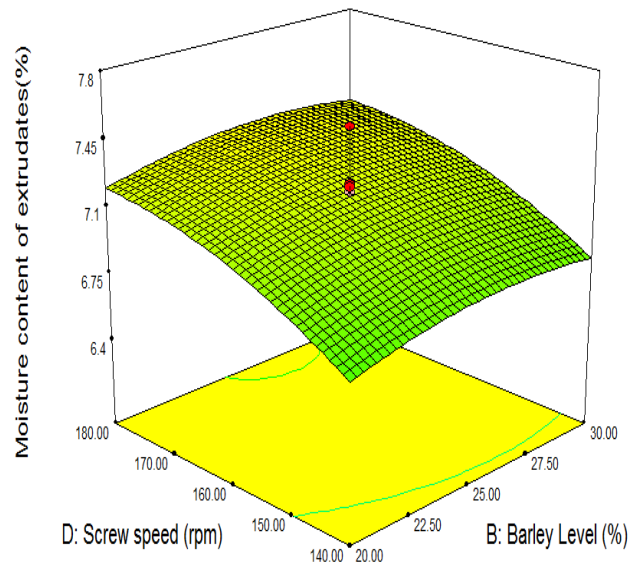
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Fig. 9. Effect of barley level and screw speed on moisture content of extrudates

The increase in moisture content of extrudates at higher moisture values was noted in the Fig. 7, owing to the fact that when the moisture content of feed increases, the amount of moisture retained in extrudates also increases. From Fig. 8 it can be depicted that moisture content of extrudates decreases with the increase in barrel temperature.

It was observed from the Fig. 9 that there was an inrease in moisture content of extrudates on increasing the proportion of barley flour. Gluten, which is found in cereals, has a greater ability to retain water even at higher temperatures [20]. Barley contains gluten, with good water binding capacity during extrusion cooking. Therefore moisture content of extrudates increased with increase in barley level.

4. CONCLUSION

The optimum extrusion conditions that resulted in extrudate snacks with the best physical properties i.e., high mass flow rate, low bulk density and low moisture content were: 10% feed moisture with the higher range of screw speed (180 rpm), barrel temperature (180°C) and 20% of barley flour. It was confirmed in this study that there was a positive correlation of mass flow rate with screw speed and a negative correlation with barrel temperature. Increasing barley flour and moisture content of the feed increased the bulk density. Because the fibre particles present in

barley tended to burst the cell walls before the gas bubbles had fully expanded, thus a denser product is obtained. Barrel temperature showed the negative effect for bulk density of extrudates.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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