

Effect of Temperature, Feed Moisture and Feed Composition on the Physical Properties of Corn Extrudates

V. H. Shruthi, Sharanagouda Hiregoudar, Udaykumar Nidoni,
C. T. Ramachandra, Kisan Jhadav

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Abstract Nutri-rich extruded products were prepared from corn flour fortified with rice bran and pigeon pea brokens using a twin screw extruder and the physical properties of the extruded product were evaluated and related to process variables: Temperature (110°C, 120°C and 130°C), Feed moisture (15%, 17.5% and 20%), Feed composition (92:4:4, 94:3:3 and 96:2:2) (Corn: Pigeon pea brokens: Rice bran). A Box-Behnken

experimental design and response surface methodology was used to evaluate the significance of independent and interaction effects of extrusion process variables. The independent variables had significant ($p \leq 0.05$) effects on physical properties of extrudates. The optimized condition for the preparation of corn based extruded product was found to be 127.66°C temperature, 18.96% of feed moisture and 92:4:4 feed composition at constant screw speed of 350 rpm. The optimized extrusion processing parameters showed higher value of expansion ratio (3.27), mass flow rate (4.38 g/s) and L^* value (66.06), and minimum values of bulk density (0.12 g/cc), moisture retention (22.25%) and specific mechanical energy (23.94 kJ/kg). As per the design expert software the selected optimized process condition was found to be desirability of 0.746.

V. H. Shruthi^{1*}, S. Hiregoudar², C. T. Ramachandra⁴,
U. Nidoni³, K. Jhadav⁵

¹PhD Scholar,

Department of Processing and Food Engineering,
College of Agricultural Engineering,
University of Agricultural Sciences,
Raichur 584104, India

^{2&4}Assistant Professor,

Department of Processing and Food Engineering,
College of Agricultural Engineering,
University of Agricultural Sciences,
Raichur 584104, India

³Head, Department of Processing and Food Engineering,
College of Agricultural Engineering,
University of Agricultural Sciences,
Raichur 584104, India

⁵Assistant Professor,

Department of Biotechnology,
College of Agriculture, University of
Agricultural Sciences, Raichur 584104, India
e-mail : shruthingowda@gmail.com

*Correspondence

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Introduction

Incorporation of by-products from the food industry using extrusion technology in order to improve the nutritional characteristics of ready-to-eat snacks is very well documented. These products significantly improved the total dietary fiber level but they also affected the textural characteristics of the extrudates [1, 2]. Among other materials, incorporation of legume flours has been shown to cause a positive impact on

Table 1. Proportion of composite flour (percent).

Sl. No.	Raw material	A	B	C
1	Corn, %	92.00	94.00	96.00
2	Pigeonpea brokens, %	4.00	3.00	2.00
3	Rice bran, %	4.00	3.00	2.00

levels of proteins and dietary fiber of corn starch-based extruded snacks. On the other hand, addition of high-fiber, high-protein alternate ingredients to starch has been demonstrated to significantly affect the texture, expansion and overall acceptability of extruded snacks [3, 4]. Extrudate expansion has been reported to be the most dependent on material moisture content and extrusion temperature. Several theoretical considerations for extrudate expansion have been published [5]. Several studies have reported chemical changes during extrusion cooking and related them to product functional qualities such as expansion volume, water solubility and product color. Most of these studies used radial expansion as a measure of quality for extrudate expansion [5, 6].

The objectives of the present study was to determine the possibility of application of agro-waste products such as pigeonpea brokens and rice bran for the production of snack food products and to determine the effect of temperature, feed moisture and feed composition on the physical properties of corn extrudates.

Materials and Methods

Raw materials

The raw material such as corn (Hema (NAH-1137), pigeonpea brokens (TS3R) and rice bran were procured from Seed Unit, University of Agricultural Sciences, Raichur. All raw materials were cleaned and ground separately in grinder and passed through 0.88 mm sieve.

Preparation of composite flour

The composite flour were prepared by mixing corn,

Table 2. Experimental design as per Box-Behnken for coded and un-coded variable levels.

Run	Coded levels			Uncoded levels		
	X ₁	X ₂	X ₃	X ₁ Tempe- rature (°C)	X ₂ Feed moisture (%)	X ₃ Feed compo- sition (%)
1	0	-1	1	120	15.0	96:2:2
2	0	0	0	120	17.5	94:3:3
3	0	1	1	120	20.0	96:2:2
4	0	0	0	120	17.5	94:3:3
5	0	-1	-1	120	15.0	92:4:4
6	-1	-1	0	110	15.0	94:3:3
7	1	1	0	130	20.0	94:3:3
8	0	0	0	120	17.5	94:3:3
9	0	0	0	120	17.5	94:3:3
10	-1	0	-1	110	17.5	92:4:4
11	1	0	-1	130	17.5	92:4:4
12	-1	1	0	110	20.0	94:3:3
13	-1	0	1	110	17.5	96:2:2
14	0	0	0	120	17.5	94:3:3
15	0	1	-1	120	20.0	92:4:4
16	1	-1	0	130	15.0	94:3:3
17	0	0	0	120	17.5	94:3:3
18	1	0	1	130	17.5	96:2:2

pigeonpea brokens and rice bran with calculated amount of water and the flour were allowed to equilibrate for 15 min (Table 1). The blended samples were conditioned to achieve required moisture content per cent (w.b.) by spraying with a calculated amount of water and mixing uniformly. The samples were kept in container and stored at 4°C for 12 h [6].

Extrusion process

The experiments were performed using a co-rotating twin-screw extruder (Basic Technology Pvt Ltd, Kolkata, India). The screw speed of extruder was kept at constant of 350 rpm. The die diameter was selected at 3 mm. The barrel zone temperatures were kept constant (60°C) for all the experiments but die temperature was varied according to the experimental design. The speed of cutter was fixed at 150 rpm for all experiments. Extrudates were cut with a sharp knife, at the exit end of the die and left to cool at room temperature for about 20 min.

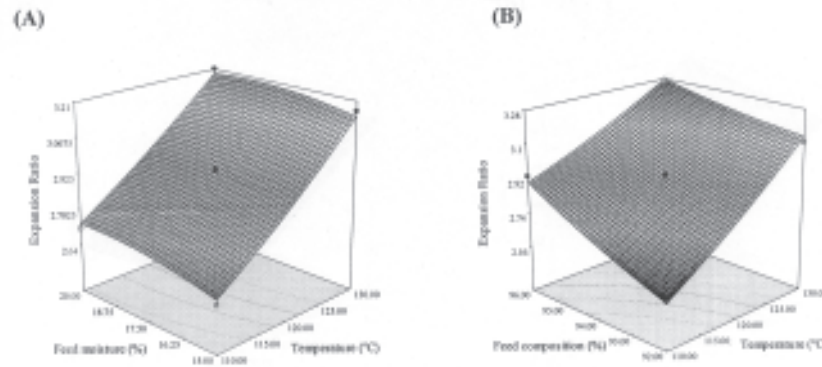


Fig. 1. Response surface plot for expansion ratio as a function of temperature, feed moisture and feed composition.

Physical properties

Expansion ratio

The ratio of diameter of extrudate and the diameter of die was used to express the expansion of extrudate [7].

$$\text{Expansion ratio} = \frac{\text{Diameter of extruded product (mm)}}{\text{Diameter of die hole (mm)}}$$

Moisture retention (%)

The moisture retention (%) was measured by using the following equation [6].

$$\text{Moisture retention (\%)} = \frac{\text{Moisture content of extrudate (\%)}}{\text{Moisture content of feed (\%)}} \times 100$$

Bulk density (g/cm³)

The bulk density (BD) was calculated by measuring the actual dimensions of the extrudates [8].

$$\text{Bulk density (g/cm}^3\text{)} = \frac{4m}{\pi d^2 L}$$

Where, m is the mass (g) of the extruded product, L is the length (cm) of extrudate and d is diameter (cm) of the extrudate.

Mass flow rate (g/s)

The mass flow rate was calculated by collecting the extrudates in a container for specific period of time as soon as it comes out of the die and weighed instantly after cooling to the ambient temperature [9].

$$\text{Mass flow rate (g/s)} = \frac{\text{Weight (g)}}{\text{Time (s)}}$$

Specific mechanical energy (SME) (kJ/kg)

It is the mechanical energy input per unit mass of extrudate. It was calculated by dividing the net power input to the screw by extrudate mass flow [10].

$$\text{SME (kJ/kg)} = \frac{\text{Screw speed (rpm)} \times \text{Torque (Nm)}}{\text{Die diameter (mm)} \times \text{Mass flow rate (kg/h)}}$$

Color value

Color of the prepared extruded product samples was measured using a Hunter Lab Colorimeter. It provides reading in terms of L^* , a^* and b^* . The luminance (L^*)

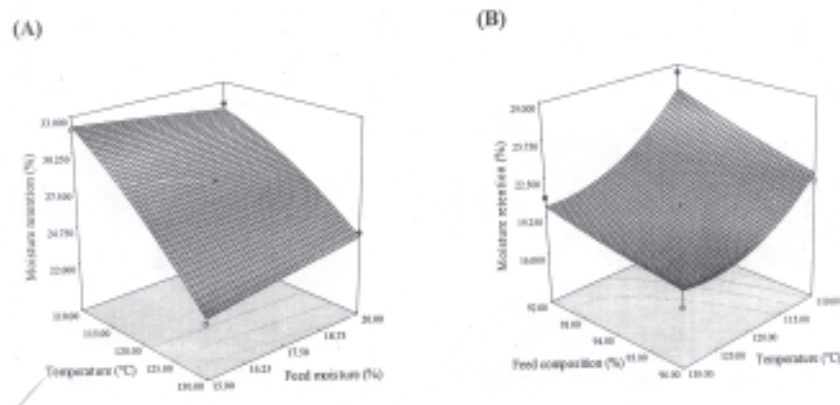


Fig. 2. Response surface plot for moisture retention as a function of temperature, feed moisture and feed composition.

forms the vertical axis, which indicates whiteness (+) to darkness (-). In the same way, a^* indicates redness (+) to greenness (-) and b^* indicates yellowness (+) to blueness (-).

Experimental design

Response surface methodology (RSM) was adopted in the design of experimental combinations [11]. Box-Behnken experimental design was employed for best experiment combination. To examine the combined effect of the three independent variables on rotatable design $2^3 = 8$ plus 4 center points and $(2 \times 3 = 6)$ star

points leading to a total of 18 experiments were performed. The details of the experiments are given in Table 2. The experiments were designed using Design Expert Software, Version 7.7.0. The coded variables (A, B and C) were evaluated using second degree polynomial equation.

$$Y = \beta_0 + \beta_1 A + \beta_2 B + \beta_3 C + \beta_{11} A^2 + \beta_{22} B^2 + \beta_{33} C^2 + \beta_{12} AB + \beta_{13} AC + \beta_{23} BC + \epsilon$$

The coefficients of the polynomial were represented by β_0 (constant), β_1 , β_2 and β_3 (linear effects); β_{12} , β_{13} and β_{23} (interaction effects); β_{11} , β_{22} and β_{33} (quadratic

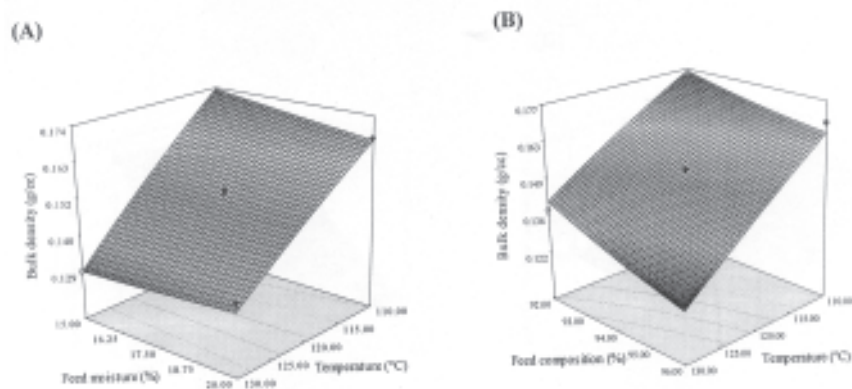


Fig. 3. Response surface plot for bulk density as a function of temperature, feed moisture and feed composition.

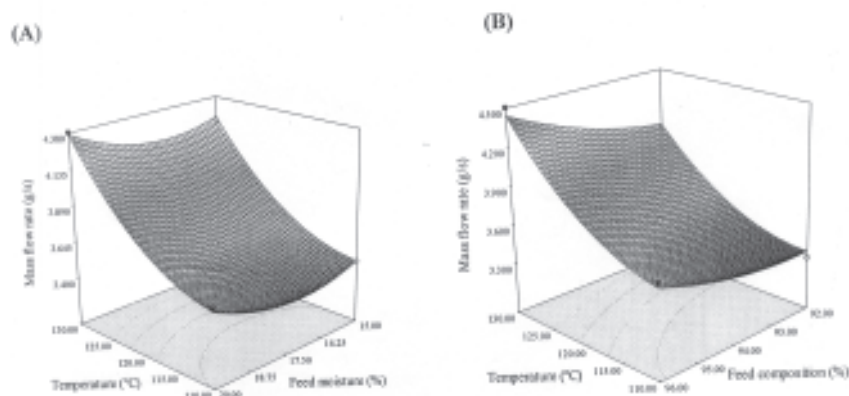


Fig. 4. Response surface plot for mass flow rate as a function of temperature, feed moisture and feed composition.

effects); and ε (random error).

Results and Discussion

Expansion ratio

The expansion ratio of the corn based extrudates varied from 2.57 to 3.27. The average expansion ratio was 2.94. The extruded product expansion increased with increase in the temperature (Fig. 1A). High temperature results in larger starch gelatinization. It was explained that melt viscosity decreased with increased temperature and the reduced viscosity effect would favor the bubble growth during extrusion [12]. Similar findings were reported [13–16]. However, increasing the level of feed moisture content resulted increase in expansion of extrudate as sufficient water available for expansion of the extrudate. This could be explained by the fact that when materials are forced through an extruder die their water content vaporizes, and simultaneous vapour flash-off expands their starch content, producing a porous, sponge-like structure in the extrudate [17]. Figure 1B shows that lateral expansion increased with increasing corn content and decreasing rice barn and pigeonpea content in the feed composition. This can be explained by the fact that when feed material with high per cent corn (having more starch) results in increasing in starch gelatinization during extrusion thereby increases extrudate

volume. Similar behavior was also observed by the researchers with increase in starch [17, 18].

Moisture retention

The moisture retention of the corn based extrudates varied from 21.08 to 33.47%. The average moisture retention was recorded as 27.85%. The retention of moisture in extrudates largely depends on the temperature and feed moisture. The moisture retention decreases with the increase in temperature (Fig. 2A) and it might be because more moisture has been utilized during cooking process. Furthermore, there was decrease in moisture retention as the feed moisture decreased. The highest moisture retention was found in the extruded product prepared using composite flour containing high amount of pigeonpea and rice bran (Fig. 2B). This might be because of the increase in protein content due to maximum utilization of pigeonpea and rice bran in the composite flour sample. Similar tendencies were recorded [6].

Bulk density

The bulk density, which considers expansion in all direction, ranged from 0.12 to 0.18 g/cm³ whereas, the average bulk density of corn based extrudates was 0.15 g/cc. Increasing level of temperature resulted decrease in bulk density of extrudate (Fig. 3A). Higher temperature provided a higher potential energy for

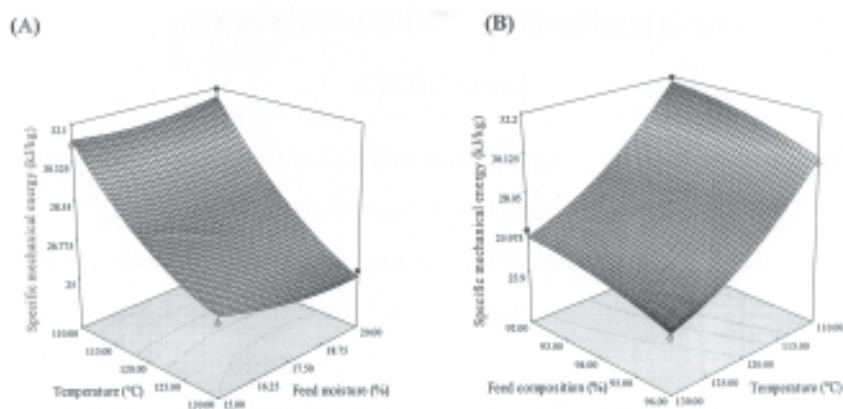


Fig. 5. Response surface plot for specific mechanical energy as a function of temperature, feed moisture and feed composition.

flesh-off of super-heated water from extrudates as they left the die. With higher melt temperatures, the extrudates exiting the die lose more moisture and become lighter in weight [19]. Similar findings were reported [14]. The high dependence of bulk density on feed moisture would reflect its influence on elasticity characteristics of the starch-based material. Increased feed moisture content during extrusion may reduce the elasticity of the dough through plasticization of the melt, therefore increasing the density of extrudate. Similar findings were reported [13, 15, 16, 20, 21]. In the present study, increasing pigeonpea and rice bran content in the feed material and decreasing corn content resulted in increased bulk density (Fig. 3B). This is due to the fact that legume flour have high protein content, which can influence density since friction and shear during extrusion cause extensive interlacing between proteins and lead to their texturization. High protein content extrudates are denser and more rigid [17].

Mass flow rate

The mass flow rate, ranged from 3.31 to 4.50 g/s for corn based extrudates whereas, average mass flow rate was 3.85 g/s. The results show that the mass flow rate of extrudates increased as the temperature increased (Fig. 4A). This may be because as the temperature increases the melt viscosity of the dough

inside the barrel decreases hence product is coming out easily. The increased moisture in feed increases the mass flow rate as it increases moisture available for melting hence reducing viscosity. Similar findings were recorded for foxtail millet based composite flour extruded snacks [6]. Mass flow rate of extrudate decreased with increased content of pigeonpea and rice bran in the feed composition (Fig. 4B). This may be due to increased stickiness and bulk density of product upon addition of these materials in the composite mixture. In cases of scaling-up and transferring processes to different extruder geometrics, the residence time is a useful parameter for comparison since it is measured easily and is a result of mass flow patterns [22]. Similar findings were reported [16].

Specific mechanical energy

The specific mechanical energy (SME) during extrusion process ranged from 23.94 to 32.14 kJ/kg for corn based extrudates. The average value of SME was 27.80 kJ/kg. The decrease in SME value was observed as the temperature increased (Fig. 5A). Similar findings were reported [16, 21, 23]. Also an increase in pigeonpea and rice bran content in the composite flour increased SME (Fig. 5B). Researchers reported that increasing the amount of fish solids in the hydrolyzated fish muscle and rice blend resulted in lowering the SME input, reducing mixing and increas-

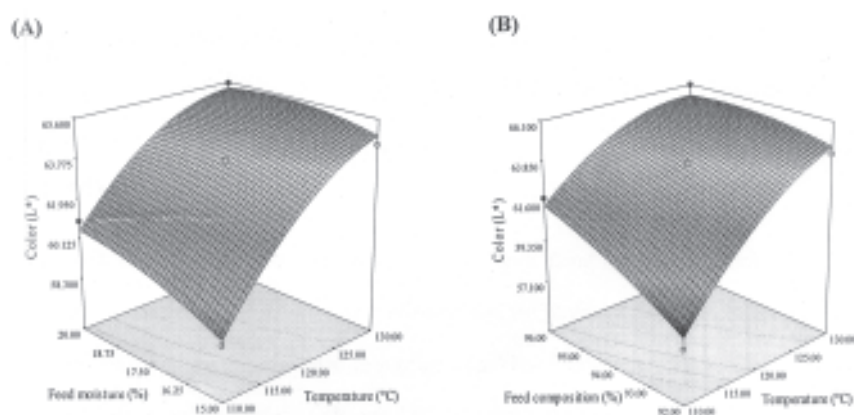


Fig. 6. Response surface plot for color (L^*) as a function of temperature, feed moisture and feed composition.

ing the mean residence time [24]. The specific mechanical energy reported was found to be dependent on feed moisture, feed rate, screw speed and temperature; and among them feed moisture was found to be the most significant factor [20].

Color (L^* value)

Color of corn based extrudates prepared under different experimental parameters, varied from 57.11 to 66.06. The average color L^* was 62.98. The results suggested that there was increase in L^* value as moisture content increased (Fig. 6A). The increase in whiteness of the extrudates with increased moisture content was due to increased expansion ratio and increased color (L^*) of the extrudate resulting in a more puffed and a porous product with better appearance. Similar findings were observed [12]. Increase in L^* value was observed as temperature increased. The increase in temperature increased the degree of superheating of water in the extruder, leading to slightly greater expansion which in turn led to lighter colored product. Similar findings were reported [13, 15]. Figure 6B shows that there was decrease in L^* value with increase in pigeonpea and rice bran content in the feed composition. It might be due to dark colored pigment present in pigeonpea and rice bran. Similar findings were reported [18, 25].

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