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Effect of process variables on physical properties of corn (variety: popcorn: sugar baby) extrudates

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Abstract
As the world population continues to grow, the demand for human food and animal feed grows exponentially. Corn flour fortified with rice bran and pigeon pea brokens was extruded using a twin-screw extruder. Blends were prepared with three levels of feed composition (92:4:4, 94:3:3 and 96:2:2; corn: rice barn: pigeonpea broken), feed moisture (15, 17.5 and 20%) and extrusion condition three-barrel temperatures (110, 120, and 130 °C). The extruded products were evaluated for their physical properties like expansion ratio, moisture retention, bulk density, mass flow rate, specific mechanical energy, colour value (L^* value). 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 130 °C temperature, 20 % 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 (3.21), mass flow rate (4.01 g/s) and L^* value (65.42), and minimum values of bulk density (0.13 g/cc), moisture retention (24.55%) and specific mechanical energy (25.29 kJ/kg). As per the design expert software the selected optimized process condition was found to be desirability of 0.698.

Keywords: Twin screw extrusion, physical properties, temperature, feed moisture, feed composition, response surface methodology.

Introduction
Extrusion cooking is one of the most promising techniques in the field of food technology developed in the recent times. Its advantages are many, which have been well documented in the literature. However, practice of this technology, has remained more an art than the science. Knowledge and database on extrusion cooking is however growing fast. Extrusion cooking is associated with partial or complete gelatinisation of the starch, complex formation, transformation and interactions involving bio-polymers (Anderson *et al*., 1970) [3].
Extruders are classified according to the method of operation (cold extruders or extruder-cookers) and the method of construction (single or twin-screw extruders). The principles of operation are similar in all types: raw materials are fed into the extruder barrel and the screw then convey the food along it. Further down the barrel, smaller flights restrict the volume and increase the resistance to movement of the food. As a result, it fills the barrel and the spaces between the screw flights and becomes compressed. As it moves further along the barrel, the screw kneads the material into a semi-solid, plasticized mass. If the food is heated above 100ºC the process is known as extrusion cooking (or hot extrusion). Here, frictional heat and any additional heating that is used cause the temperature to rise rapidly. The food is then passed to the section of the barrel having the smallest flights, where pressure and shearing is further increased. Finally, it is forced through one or more restricted openings (dies) at the discharge end of the barrel as the food emerges under pressure from the die, it expands to the final shape and cools rapidly as moisture is flashed off as steam. A variety of shapes, including rods, spheres, doughnuts, tubes, strips, squirls or shells can be formed. Typical products include a wide variety of low density, expanded snack foods and ready-to-eat (RTE) puffed cereals (Baraiya *et al.*, 2015) [6].
Of the two types of extruders (single screw and twin-screw), twin-screw extruder permits a greater flexibility of operation to achieve the desired time, temperature, and shear range for the processed material because of an additional independent variable, viz., screw configuration. Cereal grains lend themselves as good raw material for preparation of ready to eat snack foods and other products on account of high starch content in them. Extensive work has been reported on extrusion of corn (maize), in comparison to that for wheat and rice.

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 fibre level but they also affected the textural characteristics of the extrudates (Ainsworth *et al*., 2007; Stojceska *et al*., 2008; Shruthi *et al*., 2017) [2, 22, 20]. Among other materials, incorporation of legume flours has been shown to cause a positive impact on levels of proteins and dietary fibre of corn starch based extruded snacks. On the other hand, addition of high-fibre, high-protein alternate ingredients to starch has been demonstrated to significantly affect the texture, expansion and overall acceptability of extruded snacks (Veronica *et al*., 2006; Anton *et al*., 2009) [24, 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 (Thymi *et al*., 2005) [23]. Several studies have reported chemical changes during extrusion cooking and related them to product functional qualities such as expansion volume, water solubility and product colour. Most of these studies used radial expansion as a measure of quality for extrudate expansion (Thymi *et al*., 2005; Deshpande and Poshadri, 2011) [23, 9].
The objectives of the present study were 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 (Popcorn: Sugar baby), 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.
The composite flour were prepared by mixing corn, 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 (Deshpande and Poshadri, 2011) [9].

Table 1: Proportion of composite flour

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

Extrusion Process

The experiments were performed using a co-rotating twin-screw extruder (Basic Technology Pvt. Ltd., 3711-12, Kolkata, India). The ratio of barrel length to diameter ratio (L/D) was 8:1 and 3 mm diameter die was selected. The barrel zone temperatures were kept constant at 60°C throughout the experiments. 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.

Physical properties of extruded product

The physical properties of the extruded product are important in designing particular equipment or determining the behavior of the product for its handling. The methodology followed for determining various physical properties of the extruded product are discussed here under.

Bulk density (g/cm^3)

The bulk density (BD) was calculated by measuring the actual dimensions of the extrudates (Chinnaswamy and Bhattacharya, 1986) [8]. The diameter and length of the extrudates were measured by using digital vernier calliper (Mitutoyo Corp., CD-6 CSX, Japan) with least count of 0.1 mm. The weight per unit length of extrudate was determined by weighing measured lengths (1 cm). The bulk density was then calculated by using the following formula, assuming a cylindrical shape of extrudate. Ten pieces of extrudate were randomly selected and the average was taken (Ding *et al.*, 2005) [10]. The experiments were repeated thrice and the bulk density was calculated by using the following equation;

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

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 (Singh *et al*., 1996) [21]. The experiments were repeated thrice and mass flow rate was calculated by using the following equation;

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

Moisture retention (%)

The hot air oven (Kalavil Electro Mechanical Industries, KOS.6FD, Ernakulam, Kerala) method (AOAC, 2005, 925.10) [5] was used to determine the moisture content of extruded samples. Extruded samples of approximately 2 g were placed in pre-dried moisture box in an oven. The operating temperature was 105 ºC for 5-6 h. The samples were taken out of the oven, cooled in a desiccator and weighed by using electronic balance (Wensar Weighing Scales Limited, DAB220, Chennai) having a sensitivity of 0.01 g. The fresh and bone dried weights were used to calculate the moisture content on wet basis.

$$\text{Moisture content (\% w.b.)} = \frac{W_2 - W_3}{W_2 - W_1} \times 100$$

Where, W_1, W_2 and W_3 are weights of empty moisture box, moisture box + sample before drying and moisture box + sample after drying, respectively.
The experiment was repeated thrice and the moisture retention (%) was measured by using the following equation (Deshpande and Poshadri, 2011) [9].

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

Expansion ratio

The ratio of diameter of extrudate and the diameter of die was used to express the expansion of extrudate (Fan *et al.*, 1996 and Ainsworth *et al.*, 2006) [12, 1]. Six lengths of extrudate (approximately 120 mm) were selected at random during collection of each of the extruded samples and allowed to cool at room temperature. The diameter of the extrudates was measured at three different positions along the length of each sample, using a digital Vernier caliper (Mitutoyo Corp., CD-6 CSX, Japan) with a least count of 0.1 mm and their average was taken as the mean diameter of the extrudate. The experiments were repeated thrice and the expansion ratio was calculated by using the following equation (Fan *et al.*, 1996) [12].

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

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. The experiments were repeated thrice and expansion ratio was calculated by using the following equation (Robin *et. al.*, 2011).

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

Color value (L^* value)

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

Statistical Design

Box-Behnken design of Response surface methodology was employed for optimization of process parameters (Montgomery 2001) [15]. The experiments were designed using Design Expert Software, Version 7.7.0 (State-Ease, Minneapolis, MN). The same software was used for statistical analysis of experimental data. The detail of experimental design is shown in Table 2.

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 Temperature (°C)	X_2 Feed moisture (%)	X_3 Feed composition (%)
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

Results and Discussion

Bulk density (g/cm^3)

The bulk density, which considers expansion in all directions, ranged from 0.12 to 0.15 g/cm^3 for corn based extrudates (Popcorn: Sugar baby). It is observed that the minimum bulk density (0.12 g/cm^3) was observed for treatment $T_3M_2F_3$ *i.e.*,130 °C temperature, 17.5 per cent feed moisture and 96:2:2 feed composition whereas, maximum bulk density (0.15 g/cm^3) was observed for treatment $T_2M_1F_1$ *i.e.*,120 °C temperature, 15 per cent feed moisture and 92:4:4, as given in Table 3. Average value of bulk density was 0.14 g/cc.

Increasing level of temperature resulted decrease in bulk density of extrudate. High temperature resulted in the larger extent of starch gelatinization thus the volume of the extrudate increased and the bulk density decreased (Case *et al.*, 1992) [7]. In addition, Mercier and Feillet (1975) [14] suggested that an increase in temperature will decrease the melt viscosity. The reduced viscosity would favor the bubble growth during extrusion leading to increased expansion of extrudates and ultimately reduction in the bulk density. Similar findings were reported by Park *et al.* (1993) [17] for single screw extrusion of defatted soy flour, corn starch and raw beef blends and Iwe (2000) [13] for extrusion of mixtures of defatted soy flour and sweet potatoes. 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 by Ding *et al.* (2006) [11] for wheat based expanded snacks. There is solid evidence in the literature that as high-fiber, high-protein materials are added to starch-based extruded products, density would increase (Onwulata *et al.*, 2001) [16]. In the present study, increasing pigeonpea and rice bran content in the feed material and decreasing corn content resulted in increased bulk density. This is due to the fact that legume flour has 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 (Ruiz *et al.*, 2008) [19]
.

The coefficients of the model and other statistical attributes of bulk density were analyzed. The regression model fitted to experimental results of bulk density which indicates model 'F' value of 63.98 was significant ($p < 0.0001$)whereas, lack-of-fit 'F' value of 377.27 was significant ($p < 0.05$). The R^2 value was found to be 0.9863, indicating that 98.63 per cent of the variability of the response could be explained by the model. The adjusted R^2 was 0.9709 and adequate precision was 29.64 showing an adequate signal. A ratio greater than 4 is desirable and hence this model may be used to navigate the design space. Considering all the above criteria, the model with coded levels selected for representing the variation of bulk density is as follows;

Bulk density = $0.14 - 9.567E\text{-}003x_1 - 2.189E\text{-}003x_2 - 5.056E\text{-}003x_3 - 3.742E\text{-}004x_1x_2 + 4.787E\text{-}003x_1x_3 + 2.496E\text{-}003x_2x_3 - 9.239E\text{-}005x_1^2 + 1.005E\text{-}003x_2^2 + 7.627E\text{-}004x_3^2$

Where, x_1, x_2 and x_3 are the coded values of temperature (°C), moisture content (%) and feed composition (%), respectively.

Mass flow rate (g/s)

The average value of mass flow rate was 3.87 g/s and it ranged from 3.62 to 4.31 g/s for corn based extrudates (Popcorn: Sugar baby). The maximum mass flow rate (4.31 g/s) was observed for treatment $T_3M_2F_1$ *i.e.*,130 °C temperature, 17.5 per cent feed moisture and 92:4:4 whereas, minimum mass flow rate (3.62 g/s) was observed for treatment $T_1M_1F_2$ *i.e.*,110 °C temperature, 15 per cent feed moisture and 94:3:3 feed composition as given in Table 3. The results show that the mass flow rate of extrudates increased as the temperature increased. 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 by Deshpande and Poshadri (2011) [9] for foxtail millet based composite flour extruded snacks. Mass flow rate of extrudate decreased with increased content of pigeonpea and rice bran in the feed composition. This may be due to increased stickiness and bulk density of product upon addition of these materials in the composite mixture. The experimental results of mass flow rate for regression model shows that, the model 'F' value of 19.60 was significant at $p < 0.05$ whereas, lack-of-fit 'F' value of 650528.07 was significant ($p < 0.0001$). The coefficient of determination R^2 indicates 95.66 per cent variability of the response could be explained by the model. The adjusted R^2 was 0.9078 and adequate precision was 16.66 showing an adequate signal. A ratio greater than 4 is desirable and hence this model may be used to navigate the design space. Considering all the above criteria, the model is selected for representing the variation of mass flow rate as shown here under;

Mass flow rate = $3.84 + 0.19x_1 + 0.052x_2 + 0.088x_3 - 0.026x_1x_2 + 0.049x_1x_3 + 88E003x_2x_3 + 0.082x_1^2 - 3.804E\text{-}003x_2^2 + 3.435E\text{-}003x_3^2$

Where, x_1, x_2 and x_3 are the coded values of temperature (°C), moisture content (%) and feed composition (%), respectively.

Moisture retention (%)

The moisture retention of the corn based extrudates (Popcorn: Sugar baby) varied from 16.56 to 28.27 per cent. The average moisture retention was recorded as 20.87 per cent. Table 3 shows that the minimum moisture retention (16.56 %) was observed for treatment $T_3M_2F_3$ *i.e.*, 130 °C temperature, 17.5 per cent feed moisture and 96:2:2 feed composition whereas, maximum moisture retention (28.27 %) was observed for treatment $T_1M_2F_1$ *i.e.*, 110 °C temperature, 17.5 per cent feed moisture and 92:4:4 feed composition. The retention of moisture in extrudates largely depends on the temperature and feed moisture. The moisture retention decreases with the increase in temperature and it may be because more moisture has been utilized during cooking process. Furthermore, there is decrease in moisture retention as the feed moisture decreases. The highest moisture retention was found in the extruded product prepared using composite flour containing high amount of pigeonpea and rice bran. This may 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 by Deshpande and Poshadri (2011) [9] for extrusion of composite flours containing foxtail millet, rice, chick pea, amaranth seed and cow pea.

The coefficients of the model and other statistical attributes of moisture retention are presented. Quadratic model fitted to the experimental results of moisture retention shows that the model 'F' value of 8.79 implied that the model was significant ($p < 0.05$) whereas, lack of fit 'F' value of 131645474.05 was significant ($p < 0.0001$). The coefficient of determination R^2, which was found to be 0.9082, indicated that 90.82 per cent of the variability of the response could be explained by the model. The adjusted R^2 was 0.8049 and adequate precision was 10.29. Equation shows the coefficients of model selected for representing the variation of moisture retention. The quadratic model obtained for moisture retention in terms of coded levels of the variables is as follows;

Moisture retention = $19.93 - 2.80x_1 - 0.42x_2 - 1.61\ x_3 + 0.86x_1x_2 + 0.48x_1x_3 + 0.24x_2x_3 + 1.82x_1^2 + 0.11x_2^2 + 0.$

Where, x_1, x_2 and x_3 are the coded values of temperature (°C), moisture content (%) and feed composition (%), respectively.

Table 3: Physical properties of corn (Popcorn: Sugar baby) based extruded product

Treatments	BD (g/cc)	MFR (g/s)	MR (%)	ER	SME (kJ/kg)	L^*
$T_2M_1F_3$	0.14	3.86	19.72	2.95	32.92	63.27
$T_2M_2F_2$	0.14	3.84	19.93	2.94	33.12	62.88
$T_2M_3F_3$	0.13	3.97	19.66	2.95	32.12	63.47
$T_2M_2F_2$	0.14	3.84	19.93	2.94	33.12	62.88
$T_2M_1F_1$	0.15	3.76	21.27	2.91	38.42	56.97
$T_1M_1F_2$	0.15	3.62	25.71	2.72	37.21	58.17
$T_3M_3F_2$	0.13	4.13	19.75	3.06	27.82	65.42
$T_2M_2F_2$	0.14	3.84	19.93	2.94	33.12	62.88
$T_2M_2F_2$	0.14	3.84	19.93	2.94	33.12	62.89
$T_1M_2F_1$	0.14	3.63	28.27	2.76	35.79	60.83
$T_3M_2F_1$	0.13	4.31	19.15	3.11	26.41	67.27

$T_1M_3F_2$	0.15	3.85	22.86	2.84	34.26	59.69
$T_1M_2F_3$	0.14	3.78	21.94	2.86	34.87	60.05
$T_2M_2F_2$	0.14	3.84	19.93	2.94	33.12	62.88
$T_2M_3F_1$	0.15	3.81	20.24	2.92	34.04	61.47
$T_3M_1F_2$	0.13	4.03	20.95	2.98	30.41	65.13
$T_2M_2F_2$	0.14	3.84	19.93	2.94	33.12	62.88
$T_3M_2F_3$	0.12	3.92	16.56	2.97	30.75	63.59
Mean	0.14	3.87	20.87	2.92	32.98	62.37
Std. Dev.	1.324E-003	0.049	1.15	0.033	0.71	0.35
C.V. (%)	0.95	1.25	5.50	1.12	2.15	0.55
Adj. R^2	0.9709	0.9078	0.8049	0.8713	0.9405	0.9813
R^2	0.9863	0.9566	0.9082	0.9394	0.9720	0.9912
Adeq. precision	29.64	16.66	10.29	13.26	19.88	36.65
'F' value	63.98	19.60	8.79	13.79	30.87	100.29
Lack of fit	377.27	6.505E+005	1.316E+08	4637.15	1549E+007	38975.94
$p < 0.01$	S	S	S	S	S	S

ER : Expansion ratio; BD : Bulk density; MFR : Mass flow rate; SME : Specific mechanical energy; MR : Moisture retention; S : Significant
T : Temperature, °C (T_1-110 °C, T_2-120 °C, T_3-130 °C); M : Feed moisture (w.b.), % (M_1-15 %, M_2-17.5 %, M_3-20 %); F : Feed composition, % (F_1-92:4:4, F_2-94:3:3, F_3-96:2:2)

Expansion ratio

The expansion ratio of the corn based extrudates (Popcorn: Sugar baby) varied from 2.72 to 3.11 as given in Table 3. The average value of expansion ratio was 2.92. The maximum expansion ratio (3.11) was observed for treatment $T_3M_2F_1$ *i.e.*,130 °C temperature, 17.5 per cent feed moisture and 92:4:4 feed composition whereas, minimum expansion ratio (2.72) was observed for treatment $T_1M_1F_2$ *i.e.*,110 °C temperature, 15 per cent feed moisture and 94:3:3 feed composition. The extruded product expansion increased with increase in the temperature. High temperature results in larger starch gelatinization. Case *et al.* (1992) [7] indicated that with increase in starch gelatinization, the volume of the extrudate increases. The increase in temperature increased the degree of superheating of water in the extruder and would increase at higher temperature, leading to slightly greater expansion. Similar findings were reported by Ding *et al*. (2006) [11] for wheat based expanded snacks and Camire and King (1991) [25] for corn meal based extruded products. Mercier and Feillet (1975) [14] suggested that an increase in temperature would decrease the melt viscosity. The reduced viscosity would favor the bubble growth during extrusion process, which leads to increase the expansion of extrudates. However, increasing the level of feed moisture content resulted increase in expansion of extrudate as sufficient water available for expansion of the extrudate and also water in the extruder works as a heat sink/trap and lubricant and reduces shear strength. This can be explained by the fact that when materials are forced through an extruder die their water content vaporizes, and the simultaneous vapour flash-off expands their starch content, producing a porous, sponge-like structure in the extrudate (Ruiz *et al*., 2008) [19]. Similar findings were reported by Park *et al*. (1993) [17] for single screw extrusion of blends containing defatted soy flour, corn starch and raw beef. Sun and Muthukumarappan (2002) [26] prepared extruded product by using corn flour and soy flour blends in a single-screw extruder and reported that expansion ratio increased with increasing feed moisture. It is also noticed that the lateral expansion increased with increasing corn content and decreasing rice bran 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. This coincides with Ruiz *et al*. (2008) [19] for extruded product prepared using hard-to-cook beans and quality protein maize. Perez *et al*. (2008) [27] reported also that by decreasing the amount of corn starch in the mixtures and increasing the concentration of protein and fiber through addition of bean flour, less expanded products were formed due to interactions between these components and the starch. This lower expansion can also be explained on the basis that fiber can rupture cell walls and prevent air bubbles from expanding to their maximum potential. The coefficients of the model and other statistical attributes of lateral expansion are presented. The model 'F' value of 13.79 was significant ($p < 0.05$) for lateral expanison ratio according to regression model fitted to experimental results. The lack-of-fit 'F' value 4637.15 was also significant ($p < 0.0001$). The regression model for expansion ratio was highly correlated ($R^2 = 93.94$ %) with the actual observations. The adjusted R^2 was 0.8713 and adequate precision was 13.26 showing an adequate signal. A ratio greater than 4 is desirable and hence this model may be used to navigate the design space. The model was selected for representing the variation of lateral expansion ratio and for further analysis. The quadratic model obtained from regression analysis for lateral expansion in terms of coded levels of the variables is as follows;

Expansion ratio = $2.94 + 0.12x_1 + 0.022x_2 + 0.044x_3 - 5.583\text{E-}005x_1\ x_2 - 1.583\text{E-}003x_1\ x_3 - 9.167\text{E-}004x_2\ x_3 - 0.024x_1^2 - 6.369\text{E-}003x_2^2 + 1.990\text{E-}003x_3^2$

Where, x_1, x_2 and x_3 are the coded values of temperature (°C), feed moisture content (%) and feed composition (%), respectively.

Specific mechanical energy (SME) (kJ/kg)

The specific mechanical energy during extrusion process ranged from 26.41 to 38.42 kJ/kg for corn based extrudates (Popcorn: Sugar baby). The average value of SME was 32.98 kJ/kg. The minimum SME (26.41 kJ/kg) was observed for treatment $T_3M_2F_1$ *i.e.*,130 °C temperature, 17.5 per cent feed moisture and 92:4:4 feed composition whereas, maximum SME (38.42 kJ/kg) was observed for treatment $T_2M_1F_1$ *i.e.*,120 °C temperature, 15 per cent feed moisture and 92:4:4 feed composition as given in Table 3.

The decrease in SME value was observed as the temperature increased. Similar result was obtained by Onwulata *et al*. (2001) [16] for co-extrusion of dietary fiber and milk proteins in expanded corn products and Meng *et al*. (2010) [28] for chickpea flour-based snack. According to Ilo and Berghofer (1999) [29] an increase in feed moisture content decreased the SME. Higher temperature facilitated the transformation from solid flow to viscoelastic flow and higher moisture produced a lubricating effect, resulting in less energy use. Starch gelatinization is positively influenced by SME during extrusion. The higher the SME the higher the degree of gelatinization since mechanical energy favours gelatinization by promoting rupture of intermolecular hydrogen bonds (Gropper *et al*., 2002) [30]. Also, an increase in pigeonpea and rice bran content in the composite flour increased SME.

The coefficients of the model and other statistical attributes of SME were analyzed. The significant ($p < 0.0001$) model 'F' value of 30.87 implied regression model best fitted to experimental results of SME. Whereas, the lack of fit 'F' value of 15493082.73 implied that the lack of fit was significant ($p < 0.0001$). The coefficient of determination R^2, which was 0.9720, indicating that 97.20 per cent of the variability of the response could be explained by the model. The adjusted R^2 was 0.9405 and adequate precision was 19.876. Considering all the above criteria, the model was selected for representing the variation of SME and for further analysis. The magnitude of p-value indicates that the linear terms of all process variables was significant at 5 per cent level ($p < 0.05$). Other interaction and quadratic terms were not significant ($p > 0.05$). The quadratic model for specific mechanical energy in terms of coded levels of the variables is as follows;

Specific mechanical energy = $33.12 - 3.86x_1 - 0.63x_2 - 1.39x_3 - 0.29x_1x_2 - 0.20x_1x_3 - 0.14x_2x_3 + 0.52x_1^2 + 0.20x_2^2 + 0.011x^3$

Where, x_1, x_2 and x_3 are the coded values of temperature (°C), feed moisture (%) and feed composition (%), respectively.

Colour value (*L value)**

Colour (L^* value) of corn based extrudates (Popcorn: Sugar baby) prepared under different experimental parameters, varied from 56.97 to 67.27 whereas, the average colour L^* was 62.37 as shown in Table 3. The maximum colour L^* (67.27) was observed for treatment $T_3M_2F_1$ *i.e.,* 130 °C temperature, 17.5 per cent feed moisture and 92:4:4 feed composition whereas, minimum colour L^* (56.97) was observed for treatment $T_2M_1F_1$ *i.e.*, 120 °C temperature, 15 per cent feed moisture and 92:4:4 feed composition (Table 3). The coefficients of model and other statistical attributes of colour, L^* value was analyzed statistically. Regression model fitted to experimental results of colour indicates that the model 'F' value of 100.29 was significant ($p < 0.0001$) whereas, lack-of-fit 'F' value of 38975.94 was also significant ($p < 0.0001$). The coefficient of determination R^2 used to describe the best fit model was 0.9912, indicating that 99.12 per cent of the variability of the response could be explained by the model. The adjusted R^2 value was 0.9813 and adequate precision was 36.652, which is greater than 4. Considering all the above criteria, the model was selected for representing the variation of colour L^* value and for further analysis. The quadratic model for colour value (L^*) in terms of coded levels of the variables is as follows;

Colour value (L^*) = $62.88 + 3.32x1 + 0.33x_2 + 1.40x_3 - 0.31x_1x_2 + 0.15x_1x_3 - 0.11x_2x_3 - 1.54x_1^2 - 0.25x_2^2 - 0.38x^3$

Where, x_1, x_2 and x_3 are the coded values of temperature (°C), feed moisture (%) and feed composition (%), respectively.

The results suggested that there was increase in L^* value as moisture content increased. 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 by Chaiyakul *et al*. (2009) [31] for rice-based snack and Ilo and Berghofer (1999) [29] for extrusion of maize grits. Increased 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 finding were reported by Ding *et al*. (2006) [11] for rice-based snack and Camire and King (1991) [25] for expanded corn meal. It has been also noticed 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 observed by Costa *et al*. (2009) [32] for lycopene and soy protein incorporated extruded product and Altan *et al*. (2008) [33] for extrusion of barley-tomato pomace blends.

Conclusion

The independent process variables had significant (p£0.05) effects on physical properties of corn (variety: Popcorn: Sugar baby) extrudates. The optimized condition for the preparation of corn based extruded product was found to be 130 °C temperature, 20 % 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 (3.21), mass flow rate (4.01 g/s) and L^* value (65.42), and minimum values of bulk density (0.13 g/cc), moisture retention (24.55%) and specific mechanical energy (25.29 kJ/kg). As per the design expert software the selected optimized process condition was found to be desirability of 0.698. This work has shown evidence for the potential use of pigeonpea brokens and rice bran in food formulation as well as in the development of acceptable product from agro-industries by-products.

References

1. Ainsworth P, Ibanoglu S, Plunkett A and Ozer EA. Physical and sensory evaluation of a nutritionally balanced gluten free extruded snack. J Food Engg. 2006; 75(4):469-472.
2. Ainsworth P, Ibanoglu S, Plunkett A, Ibanoglu E and Stojecesks V. Effect of brewers spent grain addition and screw speed on the selected physical and nutritional properties of an extruded snack. J Food Engg. 2007; 81:702-709.
3. Anderson RA, Conway HF and Peplinski AJ. Gelatinization of corn grits by roll cooking, extrusion cooking and steaming. Starch. 1970; 22(4):130-135.
4. Anton AA, Fulcher RG and Arntifield SD. Physical and nutritional impact of fortification of corn starch based extruded snacks with common bean (*Phaseolus vulgaris* L.) flour: Effects of bean addition and extrusion cooking. Food Chem. 2009; 113:989-996.
5. Association of Official Analytical Chemists (AOAC), 2005, Official Methods of Analysis of the AOAC International. 18th Edn. Gaithersburg, MD, USA.
6. Baraiya KG, Lende SR, Khileri RA, Shrivastava V and Vikas. Extrusion technology and its application in seafood system: a review. J Agric. Engg. Food Technol. 2015; 2(3):213-216.
7. Case SE, Hamann DD and Schwartz SJ. Effect of starch gelatinization on physical properties of extruded wheat

and corn based products. Cereal Chem. 1992; 69:401-409.
8. Chinnaswamy R and Bhattacharya KR. Characteristics of gel chromatographic fractions of starch in relation to rice and expanded rice-products qualities. Starch. 1986; 38(2):51-57.
9. Deshpande HW and Poshadri A. Physical and sensory characteristics of extruded snacks prepared from foxtail millet based composite flours. Int. Food Res. J. 2011; 18:751-756.
10. Ding Q, Ainsworth P, Gregory T, Hayley M. The effect of extrusion conditions on the physicochemical properties and sensory characteristics of rice-based expanded snacks. J. Food Engg. 2005; 66:283-289.
11. Ding QB, Ainsworth P, Plunkett A, Tucker G and Marson H. The effect of extrusion conditions on the functional and physical properties of wheat-based expanded snacks. J Food Engg. 2006; 73:142-148.
12. Fan J, Mitchell JR and Blanshard JMV. The effect of sugars on the extrusion of maize grits: The role of the glass transition in determining product density and shape. Int. J. Food Sci. Technol. 1996; 31:55-65.
13. Iwe MO. Effects of extrusion cooking on some functional properties of soy-sweet potato mixtures: a response surface analysis. Plant Foods Hum. Nutri. 2000; 01:169-184.
14. Mercier C and Feillet P. Modification of carbohydrate component by extrusion cooking of cereal product. Cereal Chem. 1975; 52:283-297.
15. Montgomery DC. Design and Analysis of Experiments. Wiley, New York, 2001, 416-419.
16. Onwulata CI, Konstance RP, Smith PW and Holsinger VH. Co-extrusion of dietary fiber and milk proteins in expanded corn products. Lebensm. Wiss. Technol. 2001; 34:424-429.
17. Park J, Rhee KS, Kim BK and Rhee KC. Single-screw extrusion of defatted soy flour, corn starch and raw beef blends. J Food Sci. 1993; 58(1):124-132.
18. Robin F, Dubois C, Pineau N, Schuchmann HP and Palzer S. Expansion mechanism of extruded foams supplemented with wheat bran. J Food Engg. 2011; 107:80-89.
19. Ruiz JR, Ayala AM, Drago S, Gonzalez R, Ancona DB and Guerrero LC. Extrusion of a hard-to-cook bean (*Phaseolus vulgaris* L.) and quality protein maize (*Zea mays* L.) flour blend. LWT - Food Sci. Technol. 2008; 41:1799-1807.
20. Shruthi VH, Sharanagouda H, Udaykumar N, Ramachandra CT and Kisan J Effect of temperature, feed moisture and feed composition on the physical properties on corn extrudates. Environ. Ecol. 2017; 35(3):1610-1617.
21. Singh N, Singh, B, Sandhu KS, Bawa AS and Sekhon KS. Extrusion behaviour of wheat, rice and potato blends. J Food Sci. Technol. 1996; 33(4):291-294.
22. Stojceska V, Ainsworth P, Plunkett A and Ibanoglu S. The recycline of brewers processing by-product into ready-to-eat snacks using extrusion technology. J Cereal Sci. 2008; 47:469-479.
23. Thymi S, Krokida MK, Papa A and Maroulis ZB. Structural properties of extruded corn starch. J Food Engg. 2005; 68:519-526.
24. Veronica AG, Olusola OO and Adebowale EA. Qualities of extruded puffed snacks from maize. soybean mixture. J Food Process Engg. 2006; 29:149-161.
25. Camire ME King CC. Protein and fiber supplementation effects on extruded corn meal snack quality. J Food Sci. 1991; 56: 760-763.
26. Sun Y and Muthukumarappan K. Changes in functionality of soy-based extrudates during single-screw extrusion processing. Int. J Food Prop. 2002; 5(2):379-389.
27. Perez AA, Drago SR, Carrara CR, Greef DM, Torres RL and Gonzalez RJ. Extrusion cooking of a maize/soybean mixture: Factors affecting expanded product characteristics and flour dispersion viscosity. J Food Engg. 2008; 87:333-340.
28. Meng X, Threinen D, Hansen M and Driedger D. Effect of extrusion condition on system parameters and physical properties of a chickpea flour based snack. Food Res. Int. 2010; 43:650-658.
29. Ilo S and Berghofer E. Kinetics of color changes during extrusion cooking of maize grits. J Food Engg. 1999; 39:73-80.
30. Gropper M, Moraru CI and Kokini JL. Effect of specific mechanical energy on properties of extruded protein–starch mixtures. Cereal Chem. 2002; 79(3):429-433.
31. Chaiyakul S, Jangchud K, Jangchud A, Wuttijumnong P and Winger P. Effect of extrusion conditions on physical and chemical properties of high protein glutinous rice-based snack. LWT-Food Sci. Technol. 2009; 42:781–787.
32. Costa DA, Mariano J, Bueno M, Valquiria F, Quast E, Paula F, Queiroz C and Steel CJ. Functional extruded snacks with lycopene and soy protein. Sci. Technol. Aliment., Campinas 2009; ISSN, 0101-2061.
33. Altan A, McCarthy KL and Maskan M. Evaluation of snack foods from barley-tomato pomace blends by extrusion processing. J Food Engg. 2008; 84(2):231-242.