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Preparation of Corn Flour Based Extruded Product and Evaluate Its Physical Characteristics

C. S. Saini

Abstract**—**The composite flour blend consisting of corn, pearl millet, black gram and wheat bran in the ratio of 80:5:10:5 was taken to prepare the extruded product and their effect on physical properties of extrudate was studied. The extrusion process was conducted in laboratory by using twin screw extruder. The physical characteristics evaluated include lateral expansion, bulk density, water absorption index, water solubility index, and rehydration ratio and moisture retention. The Central Composite Rotatable Design (CCRD) was used to decide the level of processing variables i.e. feed moisture content (%), screw speed (rpm), and barrel temperature (^{o}C) for the experiment. The data obtained after extrusion process were analyzed by using response surface methodology. A second order polynomial model for the dependent variables was established to fit the experimental data. The numerical optimization studies resulted in 127°C of barrel temperature, 246 rpm of screw speed, and 14.5% of feed moisture as optimum variables to produce acceptable extruded product. The responses predicted by the software for the optimum process condition resulted in lateral expansion 126%, bulk density 0.28 g/cm^3, water absorption index 4.10 g/g, water solubility index 39.90%, rehydration ratio 544% and moisture retention 11.90% with 75% desirability.

Keywords**—**Black gram, corn flour, extrusion, physical characteristics.

I. Introduction

EXTRUSION process for producing snack foods developed at a fast pace because the process improves the nutritional quality of carbohydrate-based products by diversification and fortification. Extrudate products are preferred by consumers because of their crispiness and good swelling properties [1]. Extrusion cooking technology is being used increasingly in the food industries for the development of new products, such as cereal-based snacks including dietary fiber, baby foods, and breakfast cereals and modified starch from cereals [2]. Extrusion combines a number of unit operations i.e. mixing, cooking, shearing, puffing, final shaping and drying in one energy efficient rapid continues process [3]. Extrusion technology is very useful from the standpoint of nutritional value as nutrient losses are low than other thermal processing methods.

Cereal grains are generally used as major raw material for development of extruded snack foods due to their good expansion characteristics because of their high starch content. Physical characteristics of an extruded snack product such as expansion, hardness and density are important parameters in terms of the consumer acceptability of the final product, as well as its functional properties [4]. Corn-based food products are easily found especially in the area with corn as staple foodstuff. Most people like specific and unique taste of corn, therefore, many snack foods are made from corn, either wet or dry products. Corn contains 355 cal of energy with 9.08% protein, 3.88% fat, 0.03% ash, 76.80% carbohydrate, vitamins and amino acids. Pulses belong to the family leguminosae. The use of pulses ranges from their forming a staple diet to their being used as condiments, milk, cheese and snacks [5]. Black gram (*Vigna mungo*) belongs to family Leguminoseae. Black gram or urd is one of the important pulse crops in India. It contains about 26% protein, which is almost three times than that of cereals. Black gram supplies a major share of protein requirement of vegetarian population of the country. It is consumed in the form of split pulse as well as whole pulse, which is an essential supplement of cereal based diet. Pearl millet is the most important of all millets. Major areas where pearl millet is cultivated are India and northern Africa. It is also cultivated in eastern and southern Africa. Wheat bran is the byproduct of flour milling which consists of 17% protein, and 70% carbohydrates, about 80% of which is cellulose and hemicelluloses [6].

Response surface methodology (RSM) is a statistical method used to describe the relationship between process variables and product quality characteristics. RSM has been effectively used in several extrusion studies to relate the product characteristics to extrusion variables. The objective of the present work was (a) development of extruded snack by using corn, black gram, pearl millet and wheat bran and (b) to study the effect of different variables on the physical characteristics of extruded snack.

II. Materials and Methods

Corn flour, pearl millet flour, black gram flour and wheat bran was procured from local market of Sangrur. The moisture content of the flour was measured before mixing. The flour was mixed using food processor to give corn flour: pearl millet flour: black gram flour: wheat bran in the ratio of 80:5:10:5. After mixing samples were stored in polyethylene bags at room temperature for 24 hrs. The moisture content of all the samples was estimated using the hot air oven [7].

A. Extrusion Process

Extrusion trials were performed using a co-rotating twin-screw extruder (Basic Technology Pvt. Ltd. Kolkata, India). The main drive was provided with 7.5 HP motor (400 V, 3 ph, 50 cycles).

C.S. Saini is with the Department of Food Engineering and Technology, Sant Longowal Institute of Engineering and Technology (SLIET), Longowal-148106, Sangrur, Punjab, India (Phone: 91-1672-280044; e-mail: charanjiv_cjs@yahoo.co.in).

Barrel length to diameter ratio (L/D) was 8:1. The barrel of the extruder received the feed from a co-rotating variable speed feeder. The barrel was provided with two electric band heaters and two water cooling jackets. A temperature sensor was fitted on the front die plate which was connected to temperature control placed on the panel board.

The initial experimental temperature was reached within 30 min and samples were then poured into feed hopper and the feed rate was adjusted to 8 kg/h for easy and non-choking operation. The die diameter was selected at 4 mm as recommended by the manufacturer for such product. The barrel zone temperatures were kept constant at 60°C throughout the experiments but die temperature varied according to the experimental design. Extrudates were cut with a sharp knife and left to cool at room temperature for about 20 min.

B. Experimental Design

Response surface methodology (RSM) was used in the design of experimental combination. This design required 20 experiments by using three variables. The main advantage of RSM is the reduced number of experiments. The independent variables include moisture content (12 to 16%), screw speed (207 to 292 rpm) and temperature (103 to 136°C) (Table I).

TABLE I
VALUES OF INDEPENDENT VARIABLES AT VARIOUS LEVELS IN CCRD DESIGN

Independent variables	Un-coded	Levels in coded form				
		-1.68	-1	0	+1	+1.68
Feed moisture (%)	X_1	12.32	13	14	15	15.68
Screw speed (rpm)	X_2	207	225	250	275	292
Temperature (°C)	X_3	103	110	120	130	136

C. Physical Properties

The following physical characteristics were selected to describe the properties of corn based extruded snack.

Lateral expansion: The ratio of diameter of extrudate and the diameter of die was used to express the expansion of extrudate [8], [9]. Six lengths of extrudate (approximately 120 mm) was selected at random during collection of each of the extruded samples, and allowed to cool to room temperature. The diameter of the extrudates was then measured at 10 different positions along the length of each of the six samples using a vernier caliper. Lateral expansion (LE) was then calculated using the mean of the measured diameters:

$$LE\,(\%) = \frac{diameter\ of\ product - diameter\ of\ die\,hole}{diameter\ of\ die\,hole} x100 \quad (1)$$

Bulk density: The bulk density (BD) was calculated by measuring the actual dimensions of the extrudates [10]. The diameter and length of the extrudates were measured using digital vernier caliper (model CD-12"C, Mitutoyo Corp. Japan) with least count of 0.1 mm. The weight per unit length of extrudate was determined by weighing measured lengths (about 1 cm). The bulk density was then calculated using the following formula, assuming a cylindrical shape of extrudate. Ten pieces of extrudate were randomly selected and average was taken.

$$BD\,(g/cm^3) = \frac{4m}{\pi d^2 L} \quad (2)$$

where, m is the mass (g) of a length L of extrudate, d is diameter of the extrudate (cm), and L is the length of the extrudate (cm).

Water solubility index (WSI) and water absorption index (WAI): The WSI and WAI were measured using a technique developed for cereals [11]. 2.5 gm of ground extrudate was suspended in 25 ml water at room temperature for 30 min, with intermediate stirring, and then centrifuged at 3000 rpm for 15 min. The supernatant was decanted into an evaporating dish with a known weight.

The WSI is the weight of dry solids in the supernatant expressed as a percentage of the original weight of sample, whereas WAI is the weight of gel obtained after removal of the supernatant per unit weight of original dry solids. These were calculated using following formulae:

$$WAI\,(g/g) = \frac{weight\ gain\ by\ gel}{dry\ weight\ of\ extrudate} \quad (3)$$

$$WSI\,(\%) = \frac{weight\ of\ dry\ solid\ in\ supernatant}{dry\ weight\ of\ extrudate} x100 \quad (4)$$

Rehydration Ratio (RR): Rehydration ratio (RR) was measured at 30°C. The extrudate was cut to obtain 35 mm long strands and around 10 strands were weighed (M_1) and placed in 250 ml of water at 30°C for 15 min. The water was drained and the rehydrated samples were weighed (M_2). RR is defined as:

$$Rehydration\ ratio = \frac{M_2 - M_1}{M_1} x\ 100 \quad (5)$$

Moisture retention (MR): The moisture content (w.b.) of the feed and extruded samples was determined. Moisture retention (%) was calculated as:

$$Moisture\ retention\ (\%) = \frac{product\ moisture}{feed\ moisture} x100 \quad (6)$$

Statistical Analysis:

Results were analyzed using Design expert 6.0 and the second order polynomial model was used to predict the dependent variable.

$$Y = \beta_o + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_{11} x_1^2 + \beta_{22} x_2^2 + \beta_{33} x_3^2 + \beta_{12} x_1 x_2 + \beta_{13} x_1 x_3 + \beta_{23} x_2 x_3 + \varepsilon \quad (7)$$

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

Data were modeled by multiple regression analysis and the statistical significance of the terms was examined by analysis of variance for each response.

III. Results and Discussion

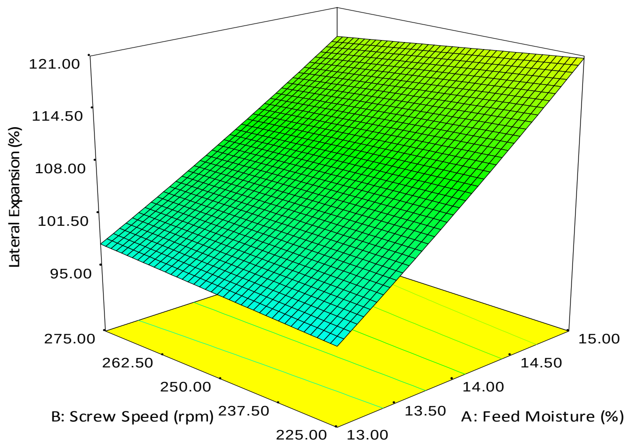
A. Effect of Process Variables on Lateral Expansion of Extruded Product

Expansion is the most important physical property of a snack food. Starch is the main component of cereal which plays major role in expansion process. The measured expansion of the extrudate prepared from corn flour, pearl millet, black gram and wheat bran varied from 81.11 to 135.78%. The regression model fitted to experimental result of lateral expansion showed the model F value of 5.74 which was significant (P<0.05), whereas the lack of fit F value is 1.30, which was not significant. The R^2 was found to be 0.83 and Adj R^2 was 0.69 and Adequate precision was 6.98 which showed an adequate signal. The quadratic model obtained from regression analysis for lateral expansion in terms of coded levels of the variables is as:

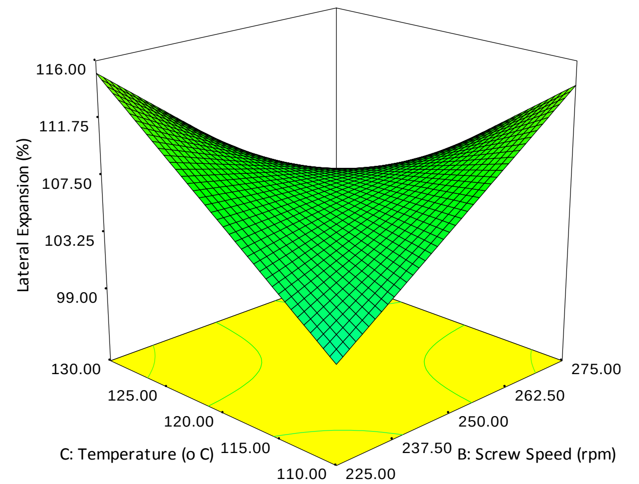
$$LE = 109.03 + 11.04\,x_1 - 0.43x_2 + 9.17x_3 + 0.31x_1^2 - 7.49x_2^2 - 2.01x_3^2 - 1.36x_1x_2 + 6.33x_1x_3 + 2.08x_2x_3 \quad (8)$$

where, x_1, x_2 and x_3 are the coded value of moisture content, screw speed and temperature, respectively. Quadratic equation (8) showed that the coefficient of x_1 and x_3 was positive. Therefore lateral expansion increased with increasing the moisture content and temperature. The coefficient of x_2 is indicating the negative effect on lateral expansion, which means lateral expansion increased with decreasing screw speed. In linear terms, moisture content (x_1) and temperature (x_3) were found to be significant (P<0.05). F-value for linear terms of moisture content (x_1) and temperature (x_3) were 21.30 and 14.71 and P-value was found to be 0.0010 and 0.0033 (P<0.05) respectively, validating that terms were significant. Quadratic terms of screw speed (x_2^2) had significant effect (P<0.05) and gives negative quadratic effect. F-value for quadratic terms of screw speed (x_2^2) was found to be 10.35 and P-value was found to be 0.0092 (P<0.05) respectively. The interaction terms of moisture content and temperature ($x_1 . x_3$) was found to be significant terms and gave positive effect on lateral expansion. F-value for interaction terms moisture content and temperature ($x_1 . x_3$) was 4.10 and P-value was found to be 0.0703.

It has been observed that when the screw speed increased, there was increase in lateral expansion and reached at maximum level at 255 rpm (Fig. 1 (a)). With further increase in screw speed, there was decrease in lateral expansion. With increasing screw speed, it will reduce the residence time of material, which could reduce the energy received by the material in the barrel, and therefore could result in lower the expansion [12]. Similarly with increasing moisture content, there was increase in lateral expansion. Because 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 and so increases the expansion [13]. With increase in temperature, there was increase in lateral expansion (Fig. 1 (b)). Expansion increased due to the higher degree of super heating of water in the extruder encountering the bubble formation [11]. Similarly with increasing the screw speed, there was increase in lateral expansion and then decrease with further increase in screw speed. Expansion increased with increase in screw speed due to high mechanical shear [14].



(a)



(b)

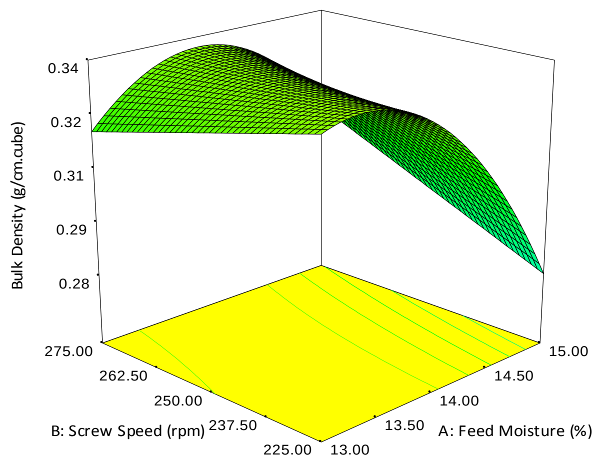
Fig. 1 Response surface plot for lateral expansion ratio as a function of (a) feed moisture and screw speed (b) screw speed and temperature

B. Effect of Process Variables on Bulk Density

Bulk density is the most important physical property of extrudate product. The bulk density, which considers expansion in all direction, ranged from 0.22 to 0.40 g/cm^3 for the extrudate. The regression model fitted to experimental result of bulk density showed model F-value of 6.38 which was significant (P<0.05) whereas the lack of fit F value is 2.50, which was not significant. The R^2 was found to be 0.85 and Adj R^2 was 0.71 and Adequate precision was 8.23 which showed an adequate signal. Considering all the above criteria, following model was selected for representing the variation of bulk density. Bulk density increased with decreasing the moisture content and temperature. Coefficient of x_2 was positive, therefore bulk density increased with increasing screw speed.

$$BD = 0.34 - 0.017\ x_1 + 0.002923x_2 - 0.038x_3 - 0.020x_1^2 - 0.017x_2^2 - 0.009776x_3^2 + 0.014x_1x_2 - 0.004850x_1x_3 - 0.013x_2x_3 \quad (9)$$

Quadratic equation (9) showed that the coefficient of x_1 and x_3 was negative. In linear terms, moisture content (x_1) and temperature (x_3) was found to be significant (P<0.05). F-value for linear terms of moisture content (x_1) and temperature (x_3) was 6.34 and 31.03 and P-value was found to be 0.0304 and 0.0002 (P<0.05) respectively, validating these terms were significant. Quadratic terms of moisture content (x_1^2) and screw speed (x_2^2) had given negative quadratic effect. F-value for quadratic terms of moisture content (x_1^2) and screw speed (x_2^2) was found to be 8.98 and 6.64 and P-value was found to be 0.0134, 0.0276 (P<0.05).



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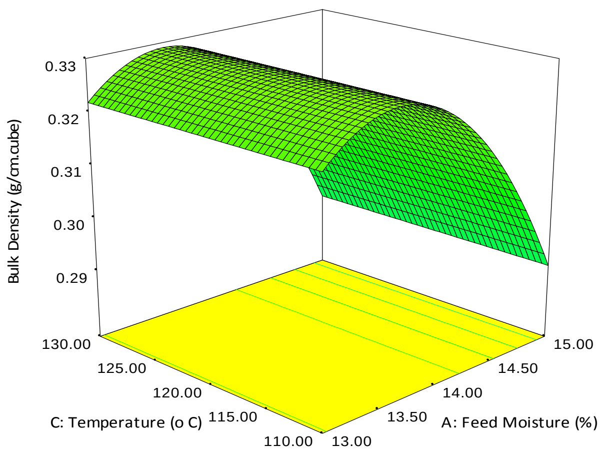


(b)

Fig. 2 Response surface plot for bulk density as a function of (a) feed moisture and screw speed (b) feed moisture and temperature

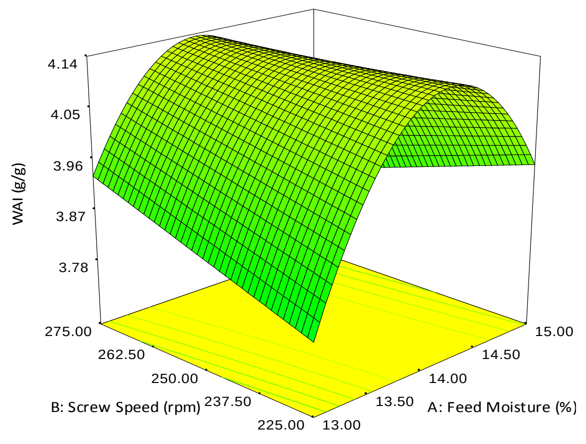
With increasing the screw speed, there was increase in bulk density and reached at maximum level at 252 rpm. With further increase in screw speed , there was decrease in bulk density (Fig. 2 (a)). Bulk density increased with increase in screw speed [15]. Similarly with increase in moisture content, there was increase in bulk density up to 0.28 g/cm^3 and with further increase in moisture content, there was decrease in bulk density. Fig. 2 (b) showed the effect of moisture content on product bulk density. Bulk density increased with increasing the moisture content up to 14%, and with further increase in moisture content bulk density decreased. Bulk density increases with increase in feed moisture at low barrel temperature whereas opposite effect occurred at high temperature [16].

C. Effect of Process Variables on Water Absorption Index (WAI)

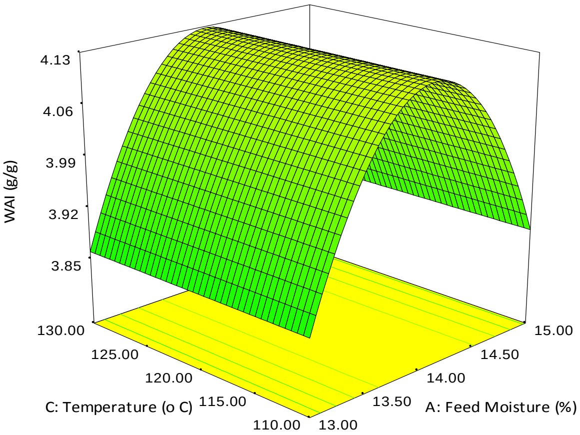
WAI measures the amount of water absorbed by starch that can be used as an index of gelatinization and it is generally agreed that barrel temperature and feed moisture exert greatest effect on the extrudate by promoting gelatinization [17]. The WAI ranged from 3.09 to 4.55 g/g for extrudates. The regression model fitted to experimental results of water absorption index shows model F-value of 16.65 which was significant, whereas the lack of fit F value is 0.44, which was not significant. The R^2 was found to be 0.93 and Adj R^2 was 0.88 and Adequate precision was 11.78, which showed an adequate signal. The quadratic model obtained from regression analysis for **w**ater absorption index in terms of coded levels of the variables is as:

$$WAI = 4.37 + 0.015\ x_1 + 0.005225x_2 + 0.15x_3 - 0.28x_1^2 - 0.29x_2^2 - 0.30x_3^2 - 0.067x_1x_2 - 0.16x_1x_3 - 0.023x_2x_3 \quad (10)$$

Quadratic equation (10) showed that the coefficient of x_1, x_2 and x_3 was positive. Therefore water absorption index increased with increasing moisture content, screw speed and temperature. Quadratic terms of moisture content (x_1^2), screw speed (x_2^2) and temperature (x_3^2) gave negative quadratic effect. The interaction terms were found to be not significant except between ($x_1.x_3$) moisture content and temperature. It was observed that when the screw speed increased, there was increase in water absorption index (Fig. 3 (a)).



(a)



(b)

Fig. 3 Response surface plot for water absorption index as a function of (a) feed moisture and screw speed (b) feed moisture and temperature

Similarly with increasing moisture content, there was increase in water absorption index and reached at maximum level at 14.10% moisture content.

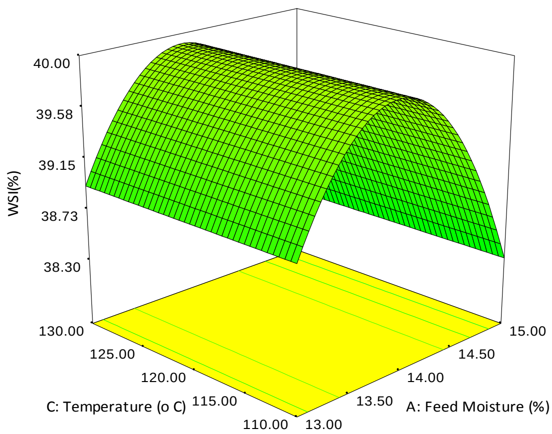
With further increase in moisture content, there was decrease in water absorption index. Feed moisture has significant effect on water absorption index. The available moisture was absorbed by starch during gelatinization which causes increase in expansion. Also it might be due to the fact that moisture content acting as a plasticizer during extrusion cooking reduces the degradation of starch granule, resulting in increased capacity for water absorption [16]. With increasing the temperature, there was increase in water absorption index and reached at maximum level of 3.86% (Fig. 3 (b)). WAI decreased with increasing temperature if dextrinization or starch melting prevails over the gelatinization phenomenon [11]. Similarly, moisture content had significant effect on water absorption index i.e. with increasing moisture content, there was increase in water absorption index and was maximum at 14.25% moisture. With further increase in moisture content, water absorption index decreased. Barrel temperature and feed moisture are found to exert the greatest effect on gelatinization. The maximum gelatinization occurs at high moisture and low temperature or vice versa [13].

D. Effect of Process Variables on Water Solubility Index (WSI)

WSI is used as an indicator of degradation of molecular components. The WSI measures the amount of soluble polysaccharide released from the starch component after extrusion [17]. The WSI ranged from 34 to 42.9% in extrudates. The regression model fitted to experimental result of water solubility index shows model F-value of 15.53 which was significant, whereas the lack of fit F value is 0.55, which was not significant. The R^2 was found to be 0.93 and Adj R^2 was 0.87. The quadratic model obtained from regression analysis for **w**ater solubility index in terms of coded levels of the variables is as:

$$WSI = 41.39 - 0.31\,x_1 + 0.59\,x_2 + 0.80\,x_3 - 1.45\,x_1^2 - 1.09\,x_2^2 - 1.82\,x_3^2 - 0.030\,x_1x_2 + 0.0100\,x_1x_3 - 0.18\,x_2x_3 \quad (11)$$

Quadratic equation (11) showed that the coefficient of $\boldsymbol{x_2}$ and $\boldsymbol{x_3}$ is positive. Therefore water solubility index increased with increasing the screw speed and temperature. The coefficient of $\boldsymbol{x_1}$ indicates the negative effect on water solubility index, which means water solubility index increased with decreasing moisture content. Water solubility index is not only due to starch content but also due to water-soluble components like protein which are present in raw material i.e. black gram, pearl millet, and corn and wheat bran. Water solubility index is an indicator of degradation of molecular components [18]. Fig. 4 (a) indicates that water solubility index increased with increasing the die temperature. The influence of high temperature, pressure and shearing forces intensifies the starch chain depolymerisation process which in turn contributes to an increase in water solubility index value of the extrudates [19]. Similarly water solubility index increased with increasing the moisture content at 14% moisture and then decrease with increasing moisture above 14%. A significant increase in water solubility index with increase in extrusion temperature for the high starch fraction of different beans was reported [20]. Fig. 4 (b) showed that with increasing the temperature, there was increase in water solubility index. With further increase in temperature there was decreased in water solubility index. Gelatinization, the conversion of raw starch to a cooked and digestible material by the application of water and heat is one of the important effects that extrusion has on the starch component of foods. Water is absorbed and bound to the starch molecule with a resulting change in the starch granule structure. Barrel temperature and feed moisture are found to exert the greatest effect on gelatinization. The increase in water solubility index with increasing screw speed was consistent with the result reported for corn meal and corn and wheat extrudate [21], [22]. Increase of screw speed induced a sharp increase of specific mechanical energy, the high mechanical shear degraded the macromolecules, so the molecular weight of starch granules decreased and hence increased WSI [22].



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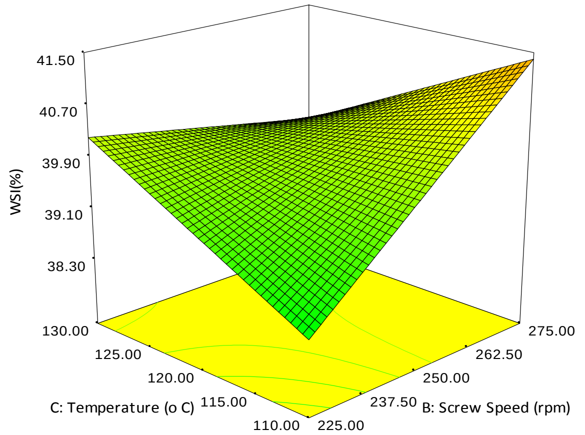


(b)

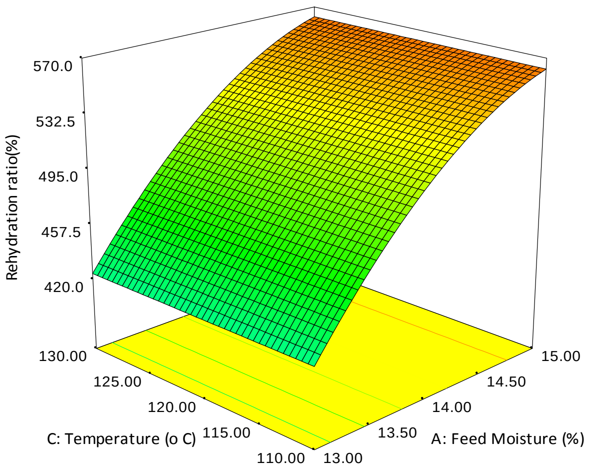
Fig. 4 Response surface plot for water solubility index as a function of (a) feed moisture and temperature (b) screw speed and temperature

E. Effect of Process Variables on Rehydration Ratio (RR)

The rehydration ratio is an important parameter for snack food and it defines the ability of how much liquid the product can be absorbed. The RR ranged from 320 to 595% for extrudate. The regression model fitted to experimental result of rehydration ratio shows model F-value of 17.95. The following model was selected for representing the variation of rehydration ratio:

$$RR = 500.04 + 69.42\ x_1 - 17.88\,x_2 - 2.64\,x_3 - 20.78\,x_1^2 - 16.15\,x_2^2 + 19.87\,x_3^2 - 3.50\,x_1x_2 - 18.00\,x_1x_3 - 22.25\,x_2x_3 \quad (12)$$

Rehydration ratio increased with decreasing the screw speed and temperature. The coefficient of $\boldsymbol{x_1}$ indicates the positive effect on rehydration ratio, which means rehydration ratio increased with increasing moisture content. Quadratic terms of moisture content ($\boldsymbol{x_1^2}$), and screw speed ($\boldsymbol{x_2^2}$) had significant effect at (P<0.05) and presented negative quadratic effect. The temperature ($\boldsymbol{x_3^2}$) was found to be having significant effect (P<0.05).



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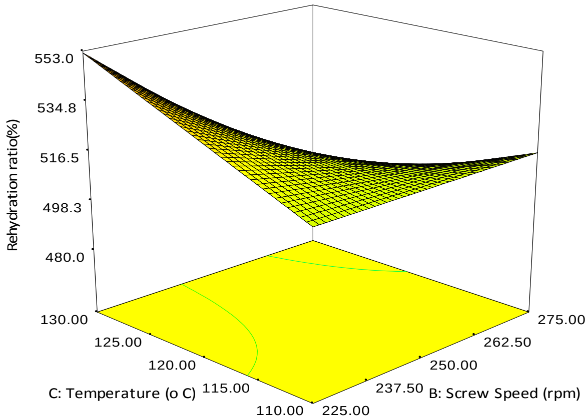


(b)

Fig. 5 Response surface plot for rehydration ratio as a function of (a) feed moisture and temperature (b) screw speed and temperature

When the temperature increased, there was increase in rehydration ratio. Similarly with increasing moisture content, there was increase in rehydration ratio (Fig. 5 (a)). Similarly, with increasing screw speed there was steadily increased in rehydration ratio (Fig. 5 (b)).

F. Effect of Process Variables on Moisture Retention (MR)

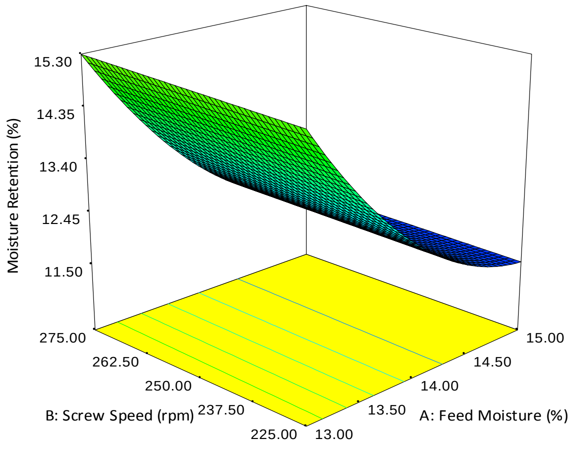
The moisture retention is an important physical property of snack food. The moisture retention ranged from 11.19 to 18.12% for extrudate. The R^2 was found to be 0.93 and Adj R^2 was 0.87. The quadratic model obtained from regression analysis for moisture retention in terms of coded level of the variables is as:

$$MR = 12.46 - 1.82\ x_1 + 0.059\,x_2 - 0.061x_3 + 0.81\,x_1^2 + 0.16\,x_2^2 + 0.17\,x_3^2 - 0.030\,x_1x_2 + 0.66\,x_1x_3 - 0.028\,x_2x_3 \quad (13)$$

Quadratic equation (13) showed that the coefficient of $\boldsymbol{x_1}$ and $\boldsymbol{x_3}$ is negative. Therefore moisture retention increased with decreasing the moisture content and temperature. The coefficient of $\boldsymbol{x_2}$ indicated the positive effect on moisture retention, which means moisture retention increased with increasing screw speed. The interaction terms of moisture content and temperature ($\boldsymbol{x_1.x_3}$) was found to be significant at (P<0.05). F-value for interaction terms of moisture content and temperature ($\boldsymbol{x_1.x_3}$) was found to be 8.66 and P- value was found to be 0.0147(P<0.05).

In Fig. 6 (a), it was found that when the screw speed increased, there was increase in moisture retention. With increasing moisture content, there was decrease in moisture retention. With increasing the temperature, there was decrease in moisture retention (Fig. 6 (b)).

Optimization: The optimization was done to develop a product which would have maximum expansion, minimum bulk density, maximum water absorption index, maximum water solubility index, maximum rehydration ratio and minimum moisture retention.



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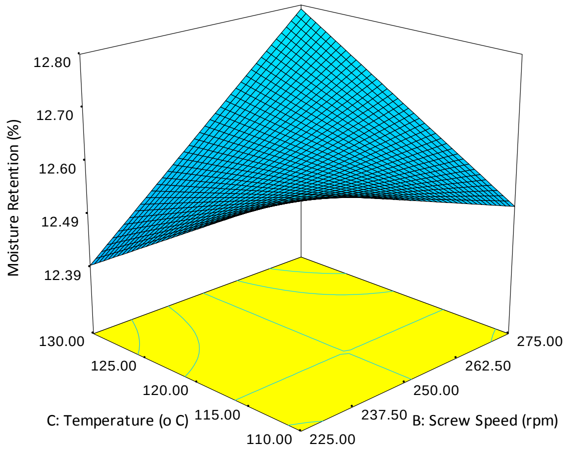

(b)

Fig. 6 Response surface plot for moisture retention as a function of (a) feed moisture and screw speed (b) screw speed and temperature

Under these criteria, the optimum operating conditions for development of corn flour, pearl millet, black gram and wheat bran powder extrudates were found to be 14.5% of moisture content, 246 rpm of screw speed and 127°C temperature. The responses predicted by the software for the optimum process condition resulted in lateral expansion 126%, bulk density 0.28 g/cm^3, water absorption index 4.10 g/g, water solubility index 39.90%, rehydration ratio 544% and moisture retention 11.90% with 75% desirability. The results were verified by conducting the experiment at the predicted values and the experimental value of optimum product was found to be nearly close to the predicted value.

IV. Conclusion

The present study was conducted to develop a high protein rich snack food based on corn flour, pearl millet flour, black gram flour and wheat bran powder. The experiment was conducted with three processing variables i.e. feed moisture, screw speed and die temperature. A second order model was used for optimization of process parameters. The product responses were mostly affected by temperature and moisture content. Increasing in barrel temperature resulted in maximum lateral expansion, WAI and WSI. Similarly, increasing the moisture content resulted in maximum lateral expansion, water absorption index, rehydration ratio and minimum moisture retention. The optimization of parameters resulted in barrel temperature of 127°C, screw speed of 246 rpm, and feed moisture of 14.5%. The optimized value obtained for the final product was 126 % lateral expansion, 0.28 g/cm^3 bulk density, 4.10 g/g water absorption index, 39.90% water solubility index, 544% rehydration ratio and 11.90 % moisture retention of extruded product. The findings of this study demonstrate the feasibility of developing value added extruded products from corn flour, black gram flour, pearl millet flour and wheat bran by extrusion processing.

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