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Effect of extrusion cooking on functional properties of germinated buckwheat-corn based snacks using RSM

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Abstract

The present work was undertaken to study the utilization of corn flour (*Zea mays*) and germinated buckwheat (*Fagopyrum esculentum*) flour in preparation of extruded product using central composite rotatable design. The experiments were randomized in order to minimize the effects of unexplained variability in the observed responses due to extraneous factors. The effect of different extrusion parameters i.e. Feed rate (4 kg/h), Feed composition (Germinated Buckwheat: Maize:: 90:10, 80:20, 70:30, 60:40, 50:50 respectively), feed moisture (13–17%), screw speed (250– 350 rpm), and barrel temperature (100–140°C) on expansion, textural properties, water absorption index (WAI), and water solubility index (WSI) of an expanded buckwheat-corn snack was observed. Increasing feed rate results in extrudates with a higher hardness and lower energy to puncture the samples. Increasing feed moisture content results in extrudates with lower expansion, lower WAI, higher WSI, higher hardness and lower puncture energy. Increasing screw speed caused slight reduction in hardness of extrudate. Higher barrel temperature reduced WAI, and hardness, but increased the WSI and puncture energy of extrudate. Lateral expansion ranged from 130.36 to 189.39%, water absorption index from 3.73 to 9 g/g, water solubility index from 4.5% to 9%, hardness 29.49 to 36.83Nof extruded product. In experiment, optimization studies resulted in 129.69°C of barrel temperature, 275 rpm of screw speed, 14% of feed moisture and 34.52% of corn flour with 65.48% of germinated buckwheat flour.

Keywords: extrusion, corn, buckwheat, RSM

1. Introduction

Extrusion cooking is an important and popular food processing technique classified as a high temperature-short time process to produce fiber rich products (Gaosong and Vasanthan, 2000) [7]. It is the combination of number of unit operations *i.e*. mixing, cooking, shearing, puffing, final shaping and drying in one energy efficient rapid continuous process (Harper, 1989) [8]. In the extruder, food mix is thermo mechanically cooked to high temperature, pressure and shear stress which is generated in the screw-barrel assembly. The cooked melt is then texturized and shaped in the die (Arhaliass *et al.*, 2003) [1]. In extrusion technology nutrient losses are low than other thermal processing methods (Kharat, *et al.*, 2015) [9].

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. Buckwheat is a pseudocereal, in India two species of buckwheat are cultivated in the Himalayas (*F.esculentum* and *F. tataricum*). It is highly nutritive same time rich in lysine (Anonymous, 2002) [3]. The flour of buckwheat is rich in vitamins such as B1, B2 and niacin (Pomernaz, 1983) and minerals like zinc, copper and potassium (De Francischi *et al*., 1994) [4]. Buckwheat contains many flavonoid compounds which are known in reducing the blood cholesterol, keeping capillaries and arteries strong and flexible and assisting in prevention of high blood pressure. The germinated buckwheat flour used because of reduced the antinutritional factor and provides the high nutritive value.

Maize (Zea mays) is another important food providing many nutrients for humans and animals. With its high content of carbohydrates, fats, proteins and some of the important vitamins and minerals; maize acquired a well-deserved reputation as a ‘poor man’s diet. Maize has become an attractive ingredient in the extrusion industry due to its attractive yellow colour and great expansion characteristic as expansion is an important parameter in the production of a cereal-based extruded snack food in terms of the functional properties of the final product (Tahnoven *et al*., 1998) [18]. Maize grits are widely used to elaborate expanded products by extrusion cooking.

The fast changing life style of the consumer demands convenience in terms to save time and labour and to provide hygienic products of standard and uniform quality with enhanced shelf life. The present study was conducted to develop the extrudates product by application of maize flour and germinated buckwheat flour blends. The extrudates products obtained were analysed for their functional properties like expansion, textural properties, water absorption index (WAI), and water solubility index (WSI).

2. Materials and Methods

The study was carried out in the Department of Food Engineering and Technology, Sant Longowal Institute of Engineering and Technology, Longowal, Punjab. The experiment was consisting of varying proportion of maize flour and germinated buckwheat flour for development of extruded snack product.

2.1 Procurement of Raw Material

Buckwheat and maize were procured from the local market of Sangrur, Punjab. These grains were freshly harvested having good germination capacity. The grains were cleaned in unit operation laboratory by using instruments like aspirator & sieving etc. as well as manually.

2.2 Preparation of extrudates product

2.2.1 Preparation of sample

Ingredient formulations for extrusion products are given in Table 2 In the blend preparation corn flour at levels of 10%, 20%, 30%, 40% and 50% were used. The moisture was adjusted by sprinkling the distilled water in all the dry ingredients. All the ingredients were weighed and then mixed in the Food Processor with mixer attachment for 20 min. This mixture was then passed through a 2 mm sieve to reduce the lumps formation due to addition of moisture. After mixing samples were stored in polyethylene bags at room temperature for 24h (Stojceska *et al*., 2008) [17]. The moisture content of all the samples was estimated using the Hot air oven method (Ranganna, 2003) [16].

2.2.2 Extrusion components

Extrusion trials were performed using a co-rotating twin-screw extruder (Basic Technology Pvt. Ltd. Kolkata, India). The main drive is provided with 7.5 HP motor (400 V, 3 ph, 50 cycles). The output shaft of worm reduction gear was provided with a torque limiter coupling. The screw configuration that was a standard design for processing cereals and flour-based products was used.

2.2.3 Extrusion of samples

The twin screw extruder was kept running for suitable period of time to stabilize the set temperatures and samples were then poured in to feed hopper and the feed rate was adjusted to 4 kg/h for easy and non-choking operation. The die diameter of 4 mm was selected as recommended by the manufacturer for such product. The product was collected at the die end and packed in already numbered zipped lock packs and kept for proper storage.

2.2.4 Stabilization of moisture

All the samples were kept in high precision ($\pm$ 0.1°C) incubator (Macro Scientific works, New Delhi) at 60°C for 12 hour duration for the stabilization of moisture.

2.3 Evaluation of extrudates product characteristics

2.3.1 Lateral expansion

The ratio of diameter of extrudate and the diameter of die was used to express the expansion of extrudate (Fan *et. al*, 1996; Ainsworth *et.al*, 2006) [6, 2]. 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:

$$LE = \frac{(diameter\ of\ product - diameter\ of\ dia\ hole)}{diameter\ of\ dia\ hole} \times 100$$

2.3.2 Water absorption index (WAI) and water solubility index (WSI)

WAI and WSI were determined according to the method developed for cereals (Stojceska. V *et al*., 2008) [17]. The ground extrudate was suspended in water at room temperature for 30 min, gently stirred during this period, and then centrifuged at 3000g for 15 min. The supernatant was decanted into an evaporating dish of known weight. The WAI was the weight of gel obtained after removal of the supernatant per unit weight of original dry solids. The WSI was the weight of dry solids in the supernatant expressed as a percentage of the original weight of sample.

$$WAI\ (g/g) = \frac{Weight\ grain\ by\ gel}{Dry\ weight\ of\ extrudate}$$

$$WSI(\%) = \frac{Weight\ of\ dry\ solid\ in\ supernatent}{Dry\ weight\ of\ extrudate} \times 100$$

2.3.3 Hardness

Mechanical properties of the extrudates were determined by a crushing method using a TA – XT2 texture analyzer (Stable Micro Systems Ltd., Godalming, UK) equipped with a 500 kg load cell. An extrudate 40 mm long was compressed with a probe SMS – P/75 – 75mm diameter at a crosshead speed 5 mm/sec to 3 mm of 90% of diameter of the extrudate. The compression generates a curve with the force over distance. The highest first peak value was recorded as this value indicated the first rupture of snack at one point and this value of force was taken as a measurement for hardness (Stojceska.V *et.al*. 2008) [17].

2.3.4 Experimental design

Response surface methodology (RSM) was adopted in the experimental design as it emphasizes the modeling and analysis of the problem in which response of interest is influenced by several variables and the objective is to optimize this response (Montgomery, D.C., 2001) [13]. A five-level, four-factor central composite rotatable design was employed. Table 1 shows independent variables selected for the experiments. The variables and their levels were chosen by taking trials of samples. The ranges having good expansion are taken. Response variables were Lateral expansion, Water absorbtivity index, Water solubility index, Hardness.

Table 1: Values of independent variables at five levels of the CCRD design

Independent Variables	Uncoded	Levels in coded form				
		-2	-1	0	+1	+2
Feed composition (%)	X_1	90:10	80:20	70:30	60:40	50:50
Feed moisture (%)	X_2	13	14	15	16	17
Screw speed (rpm)	X_3	250	275	300	325	350
Die temperature (℃)	X_4	100	110	120	130	140

Table 2: Experiment combinations in Coded and Uncoded levels for extruded snacks.

Sr No.	Coded variables				Uncoded variables			
	x_1	x_2	x_3	x_4	X_1 Feed Proportion (Germinated buckwheat flour:corn flour)	X_2 Moisture content (%)	X_3 Screw speed (rpm)	X_4 Temperature (^{0}C)
1	-1	-1	-1	-1	80:20	14	275	110
2	1	-1	-1	-1	60:40	14	275	110
3	-1	1	-1	-1	80:20	16	275	110
4	1	1	-1	-1	60:40	16	275	110
5	-1	-1	1	-1	80:20	14	325	110
6	1	-1	1	-1	60:40	14	325	110
7	-1	1	1	-1	80:20	16	325	110
8	1	1	1	-1	60:40	16	325	110
9	-1	-1	-1	1	80:20	14	275	130
10	1	-1	-1	1	60:40	14	275	130
11	-1	1	-1	1	80:20	16	275	130
12	1	1	-1	1	60:40	16	275	130
13	-1	-1	1	1	80:20	14	325	130
14	1	-1	1	1	60:40	14	325	130
15	-1	1	1	1	80:20	16	325	130
16	1	1	1	1	60:40	16	325	130
17	-2	0	0	0	90:10	15	300	120
18	2	0	0	0	50:50	15	300	120
19	0	-2	0	0	70:30	13	300	120
20	0	2	0	0	70:30	17	300	120
21	0	0	-2	0	70:30	15	250	120
22	0	0	2	0	70:30	15	350	120
23	0	0	0	-2	70:30	15	300	100
24	0	0	0	2	70:30	15	300	140
25	0	0	0	0	70:30	15	300	120
26	0	0	0	0	70:30	15	300	120
27	0	0	0	0	70:30	15	300	120
28	0	0	0	0	70:30	15	300	120
29	0	0	0	0	70:30	15	300	120
30	0	0	0	0	70:30	15	300	120

Code '0' is for centre point of the parameter range investigated '$\pm$1' for factorial points, and '$\pm$2' for star points; X_1 - Feed composition (%), X_2 - Feed moisture (%), X_3 - Screw speed (rpm) and X_4 - Barrel temperature (̊c)

2.3.5 Statistical analysis of responses

The responses (lateral expansion, WAI, WSI and hardness) for different experimental combinations were related to the coded variables (x_i, i=1, 2, 3 and 4) by a second degree polynomial equation

$$Y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_4 x_4 + \beta_{11} x_1^2 + \beta_{22} x_2^2 + \beta_{33} x_3^2 + \beta_{44} x_4^2 + \beta_{12} x_1.x_2 + \beta_{13} x_1.x_3 + \beta_{14} x_1.x_4 + \beta_{23} x_2.x_3 + \beta_{24} x_2.x_4 + \beta_{34} x_3.x_4 + \varepsilon$$

The coefficients of the polynomial were represented by β_0 (constant), β_1, β_2, β_3, β_4 (linear effects); β_{12}, β_{13}, β_{14} β_{23}, β_{24}, β_{34} (interaction effects); β_{11}, β_{22}, β_{33}, β_{44} (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.

2.2.5 Analysis of data

Design Expert 6.0 (version 6.0, by STAT-EASE Inc., USA) was used for optimization of selected parameters.

3. Results and Discussion

Extruded snack product was developed from corn flour and germinated buckwheat flour. Germinated buckwheat flour was replaced by corn flour at different levels. Designed experiments were conducted to study the effect of incorporation of corn flour into germinated buckwheat flour on extrudate functional properties i.e., lateral expansion, water absorption index, water solubility index, and hardness

3.1 Diagnostic checking of fitted model and surface plots of experiment

3.2.1 Effect of process variables on product lateral expansion ratio

The measured expansion of the extrudate (germinated buckwheat flour and corn flour) varied from 130.36% to 189.39%. Table 3 and Table 4 show the coefficients of the model and other statistical attributes of lateral expansion. Regression model fitted to experimental results of LER shows that Model F-value of 4.00 was significant ($P < 0.0058$). Whereas, lack-of-Fit F-value of 3.03 was not significant ($P > 0.05$). The chance of large model F-value due to noise was only 0.58%. The fit of model was also expressed by the coefficient of determination R^2, which was found to be 0.7886 the Adj R^2 was 0.5912 and Adequate Precision was 7.058 showed 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 (Eq.1) 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 was as follows:

Table 3: Analysis of variance for lateral expansion ratio

Factor	Coefficient Estimate	Sum of Squares	Mean Square	DF	F Value	Prob > F
Model	166.17	6498.02	464.14	14	4.00	<0.0058**
x_1	5.43	707.85	707.85	1	6.09	0.0261**
x_2	-5.33	680.96	680.96	1	5.86	0.0286**
x_3	5.63	761.18	761.18	1	6.55	0.0218**
x_4	9.01	1947.24	1947.24	1	16.76	0.0010**
x_1^2	2.66	194.50	194.50	1	1.67	0.2152
x_2^2	1.91	100.37	100.37	1	0.86	0.3673
x_3^2	-2.17	129.70	129.70	1	1.12	0.3074
x_4^2	-2.34	150.13	150.13	1	1.29	0.2734
x_1x_2	-4.79	367.30	367.30	1	3.16	0.0956
x_1x_3	-5.48	479.83	479.83	1	4.13	0.0602
x_1x_4	1.32	27.98	27.98	1	0.24	0.6307
x_2x_3	4.36	304.50	304.50	1	2.62	0.1263
x_2x_4	1.08	18.71	18.71	1	0.16	0.6939
x_3x_4	5.77	531.99	531.99	1	4.58	0.0492**

*Significant at P < 0.1, **Significant at P < 0.05, ***Significant at P < 0.001, df: degrees of freedom

Table 4: Analysis of variance results of equation 1

Response	Source	Sum of squares	Df	Mean squares	F-value	P-value
LE	Regression	6498.02	14	464.14	4.00	< 0.0058**
	Lack of fit	1495.61	10	149.56	3.03	0.1164
	Pure error	246.83	5	49.37		
	Residual	1742.44	15	116.16		
	Total	8240.47	29			
	R^2-value	0.7886				
	Adjusted R^2	0.5912				
	Adeq. Precision	7.058				

*significant at P < 0.05, df: degrees of freedom

$$LE = 166.17 + 5.43x_1 - 5.33x_2 + 2.66x_3 + 9.01x_4 + 2.66x_1^2 + 1.91x_2^2 - 2.17x_3^2 - 2.34x_4^2 - 4.79x_1x_2 - 5.48x_1x_3 + 1.32x_1x_4 + 4.36x_2x_3 + 1.08x_2x_4 + 5.77x_3x_4 \quad \ldots (1)$$

Where x_1, x_2, x_3 and x_4 are the coded values of feed composition, germinated buckwheat flour: corn flour, moisture content (%), screw speed (rpm) and temperature (°C). Following observations can be made from equation (1), the coefficient of feed composition i.e. corn flour (x_1) are positive and moisture content (x_2) is negative therefore increase in corn flour and decrease in moisture content, increase lateral expansion ratio. Out of these, temperature and screw speed is most significant, Coefficient of x_3 (screw speed) are positive and coefficient of x_4 (temperature) is also positive indicating that lateral expansion ratio of product increase. The increase in temperature will increase the degree of superheating of the water in the extruder and would increase at higher temperature, leading to the slightly greater expansion. Similar finding have been reported by Ding *et al.* (2005) [5]. The reduced viscosity effect would favor the bubble growth during extrusion which leads to increased expansion of extrudates.

F-value for the interaction term $x_3.x_4$ is 4.58 and P-value is 0.0492. It indicates that this interaction term is significant. As the interaction term is positive one can concluded that lateral expansion will show concave shaped variation with the change in value of variables. It can be observed that lateral expansion ratio increases with increase in temperature and increases with increase in screw speed. The variation is in agreement with the findings of Ding *et al.* (2005) [5], Iwe, M.O. (1998) [11]. An increase in the barrel temperature will decrease the melt viscosity Mercier and Feillet, (1975) [12].

3.2.2 Effect of process variables on product Water Absorptivity 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, Ding *et al*. (2005) [5]. The WAI ranged from 3.73 to 4.31g/g for germinated buckwheat flour and corn flour extrudate. Table 5 and Table 6 shows the coefficient of the model and other statistical attributes of WAI. The Model F-value of 3.07 implies the model is significant. In this case x_4, x_1^2, x_2^2 *and* x_2x_3 are significant model terms. Values of R^2 0.7411, Adj R^2 0.4995 and Adeq precision is 5.588 suggest than the equation 6 can be selected for further analysis.

$$WAI = 4.33 - 0.012.x_1 - 0.007083.x_2 - 0.050.x_3 + 0.075.x_4 - 0.13.x_1^2 - 0.059.x_2^2 - 0.023.x_3^2 - 0.058.x_4^2 - 0.031.x_1.x_2 - 0.008125.x_1.x_3 + 0.021.x_1.x_4 - 0.077.x_2.x_3 - 0.013.x_2.x_4 - 0.005625.x_3.x_4 \quad \ldots (2)$$

It is clear from Table 5 that the coefficient of x_1, x_2 x_3, are negative, therefore, as corn flour feed composition increases water absorption index decreases, increase in extrusion temperature and decrease in screw speed will increases WAI. Similar finding have been reported by Pardhi *et al.* (2017) [15].

F-value for interaction term of screw speed and temperature ($x_2.x_3$) is 4.57 and P value is 0.0494. It means that the term is significant. Since coefficient of $x_2.x_3$ is negative. WAI will decrease with the screw speed and decrease with decrease in feed moisture.

Table 5: Analysis of variance table for WAI

Source	Coefficients of model terms	Sum of Squares	Df	Mean Square	F – Value	Prob > F
Model	4.33	0.89	14	3.07	3.07	0.0195**
x_1	-0.012	3.504E-003	1	3.504E-003	0.17	0.6865
x_2	-7.083E-003	1.204E-003	1	1.204E-003	0.058	0.8126
x_3	-0.050	0.059	1	0.059	2.85	0.1119
x_4	0.075	0.13	1	0.13	6.45	0.0226**
x_1^2	-0.13	0.49	1	0.49	23.83	0.0002**
x_2^2	-0.059	0.096	1	0.096	4.62	0.0482**
x_3^2	-0.023	0.014	1	0.014	0.69	0.4192
x_4^2	-0.058	0.092	1	0.092	4.43	0.0526
$x_1.x_2$	-0.031	0.015	1	0.015	0.73	0.4078
$x_1.x_3$	-8.125E-003	1.056E-003	1	1.056E-003	0.051	0.8243
$x_1.x_4$	0.021	6.806E-003	1	6.806E-003	0.33	0.5748
$x_2.x_3$	-0.077	0.095	1	0.095	4.57	0.0494**
$x_2.x_4$	-0.013	2.756E-003	1	2.756E-003	0.13	0.7202
$x_3.x_4$	-5.625E-003	5.062E-004	1	5.062E-004	0.024	0.8778

*significant at P < 0.1, **significant at P < 0.05, ***significant at P < 0.001 df: degrees of freedom

Table 6: Analysis of variance of equation 2

Response	Source	Sum of squares Squares	Df	Mean square squares	F-value	P-value
WAI	Regression	0.89	14	0.063	3.07	0.0195*
	Lack of fit	0.22	10	0.022	1.13	0.4753
	Pure error	0.095	5	0.019		
	Residual	0.31	15	0.021		
	Total	1.20	29			
	R^2-value	0.7411				
	Adjusted R^2	0.4995				
	Adeq. Precision	5.588				

*significant at P < 0.05, df: degrees of freedom

3.2.3 Effect of process variables on product water solubility index (WSI)

WSI used as an indicator of degradation of molecular components. It measures the amount of soluble polysaccharide released from the starch component after extrusion Ding *et al*. (2005) [5]. The WSI ranged from 4.5% to 9% for the germinated buckwheat flour corn flour extrudates. Table 7 and Table 8 shows the coefficient of the model and other statistical attributes of WSI (g/g). The Model F-value of 4.66 implies the model is significant. In this case model terms x_1, x_2, x_3, x_1^2, x_3^2, x_2x_3, x_2x_4 are significant at P<0.05.

The "Lack of Fit F-value" of 1.22 implies that the Lack of Fit is not significant. R^2 value is 0.8904, Adj R^2 0.8132 and Adeq precision is 8.581. Considering all the above criteria, the following model was selected for further analysis.

$$WSI = 7.25 + 0.32.x_1 - 0.24.x_2 + 0.48x_3 + 0.067x_4 - 0.049x_1^2 + 0.22.x_2^2 - 0.28x_3^2 - 0.094x_4^2 + 0.050.x_1x_2 - 0.27.x_1x_3 + 0.025.x_1.x_4 - 0.39.x_2x_3 + 0.39x_2x_4 + 0.34x_3x_4 \quad \ldots (3)$$

From table 7 it is evident that the coefficient of x_1, x_3, and x_4 are positive, therefore, as corn flour proportion of feed composition increases, WSI increases. Increase in extrusion temperature and screw speed will also increase WSI. The most significant factor is x_3 as it is having highest coefficient value.

Table 7: Analysis of variance table for WSI

Source	Coefficients of model terms	Sum of Squares	Df	Mean Square	F – Value	Prob > F
Model	7.25	28.14	14	28.14	4.66	0.0027**
x_1	0.32	2.54	1	2.54	5.88	0.0284**
x_2	-0.24	1.40	1	1.40	3.25	0.0914*
x_3	0.48	5.41	1	5.41	12.57	< 0.0029**
x_4	0.067	0.11	1	0.11	0.25	0.6260
x_1^2	-0.049	6.69	1	6.69	15.52	0.0013**
x_2^2	0.22	1.31	1	1.31	3.05	0.1014
x_3^2	-0.28	2.17	1	2.17	5.03	0.0404**
x_4^2	-0.094	0.24	1	0.24	0.56	0.4661
$x_1.x_2$	0.050	0.040	1	0.040	0.093	0.7648
$x_1.x_3$	-0.27	1.21	1	1.21	2.81	0.1145
$x_1.x_4$	0.025	1.000E-002	1	1.000E-002	0.023	0.8810
$x_2.x_3$	-0.39	2.40	1	2.40	5.57	0.0322**
$x_2.x_4$	0.39	2.40	1	2.40	5.57	0.0322**
$x_3.x_4$	0.34	1.82	1	1.82	4.23	0.0576

*significant at P < 0.1, **significant at P < 0.05, ***significant at P < 0.001 df: degrees of freedom

Table 8: Analysis of variance of equation 3

Response	Source	Sum of square Squares	df	Mean Squares	F-value	P-value
WSI	Regression	28.14	14	2.01	4.66	0.0027*
	Lack of fit	4.59	10	0.46	1.22	0.4359
	Pure error	1.88	5	0.38		
	Residual	6.46	15	0.43		
	Total	34.60	29			
	R^2-value	0.9428				
	Adjusted R^2	0.8895				
	Adeq. Precision	19.63				

*significant at P < 0.05, df: degrees of freedom

F-value for interaction term of feed moisture and screw speed (x_2 x_3) is 5.57 with P value of 0.0322, indicates the term is significant. WSI will decrease with the Feed moisture and barrel screw speed

F-value for interaction term of feed moisture and barrel temperature ($x_2.x_4$) is 5.57 with P value of 0.0322, indicates the term is significant. WSI will increase with the Feed moisture and barrel temperature. The result is in agreement with the findings of Ding *et al.* (2005) [5].

3.2.4 Effect of process variables on product hardness

The textural property of germinated buckwheat flour, corn flour extrudate was determined by measuring the force required to break the extrudate. The higher the value of maximum peak force required in Newton, which means the more force required to breakdown the sample, the higher the hardness of the sample to fracture Li *et al*. (2001) [10]. Hardness of geminated buckwheat flour, corn flour extrudate varied between 29.49 and 36.83 N. Table 9 and Table 10 shows the coefficient of the model and other statistical attributes of Hardness. The Model F-value of 5.53 implies the model is significant. In this case x_1, x_2, x_4, x_3^2, x_1x_4, *and* $x_2.x_3$, are significant model terms at (P<0.05). The "Lack of Fit F-value" of 29.40 implies the Lack of Fit is not significant. R^2 is 0.8376, Adj R^2 0.6860 and Adeq precision is 8.346. Justifies that the equation (8) can be selected for further analysis.

$$H = 34.33 + 1.61x_1 + 1.09x_2 + 0.47x_3 - 0.62x_4 - 0.48x_1^2 + 2.3x_2^2 - 1.38x_3^{\ 2} - 0.35x_4^2 - 0.79x_1x_2 - 0.074.x_1x_3 - 1.39.x_1x_4 + 0.98x_2x_3 - 0.020.x_2x_4 + 0.12.x_3x_4 \quad .... (4)$$

From the equation, it is observed that, positive co-efficient of x_1, x_2, and x_3 direct relationship between these variables with hardness while a negative co-efficient of x_4 indicates inverse relationship with hardness.

Table 9: Analysis of variance table for hardness

Source	Coefficients of model terms	Sum of Squares	Df	Mean Square	F – Value	Prob > F
Model	34.33	15.95	14	15.95	5.53	< 0.0011**
x_1	1.61	62.27	1	62.27	21.57	0.0003**
x_2	1.09	28.38	1	28.38	9.83	0.0068**
x_3	0.47	5.34	1	5.34	1.85	0.1939
x_4	-0.62	9.20	1	9.20	3.19	0.0944*
x_1^2	-0.48	6.29	1	6.29	2.18	0.1605
x_2^2	0.23	1.48	1	1.48	0.51	0.4850
x_3^2	-1.38	52.44	1	52.44	18.17	0.0007**
x_4^2	-0.35	3.44	1	3.44	1.19	0.2925
$x_1.x_2$	-0.79	9.92	1	9.92	3.44	0.0835
$x_1.x_3$	-0.074	0.087	1	0.087	0.030	0.8645
$x_1.x_4$	-1.39	30.75	1	30,75	10.65	0.0052**
$x_2.x_3$	0.98	15.44	1	15.44	5.35	0.0353**
$x_2.x_4$	-0.020	6.400E-003	1	6.400E-003	2.217E-003	0.9631
$x_3.x_4$	0.12	0.24	1	0.24	0.081	0.7792

*Significant at P < 0.1, **Significant at P < 0.05, ***Significant at P < 0.001 df: degrees of freedom

Table 10: Analysis of variance of equation 4

Response	Source	Sum of Squares	Df	Mean squares	F-value	P-value
Hardness (H)	Regression	223.31	14	15.95	5.53	< 0.0011*
	Lack of fit	29.40	10	2.94	1.06	0.5073
	Pure error	13.90	5	2.78		
	Residual	43.30	15	2.89		
	Total	266.61	29			
	R^2-value	0.8376				
	Adjusted R^2	0.6860				
	Adeq. Precision	8.346				

*significant at P < 0.05, df: degrees of freedom

The F-values for square term of moisture content (x_3^2) is 18.*17* with (P 0.0007) is significant. Since coefficient of x_3^2 is negative, it will show convex shaped variation with the change in value of variables.

F-value for interaction term of feed composition and barrel temperature (x_1 x_4) is 10.65 with P value of 0.0052, indicates the term is significant. Since coefficient of $x_1.x_4$ is negative, it will show convex shaped variation with the change in value of variables, as shown in fig. 1 hardness will decrease with the Feed composition and barrel temperature. Hardness will decrease with increase in temperature. The result is in agreement with the findings of Ding *et al.* (2005) [5], Pardhi *et al.* (2017) [15].

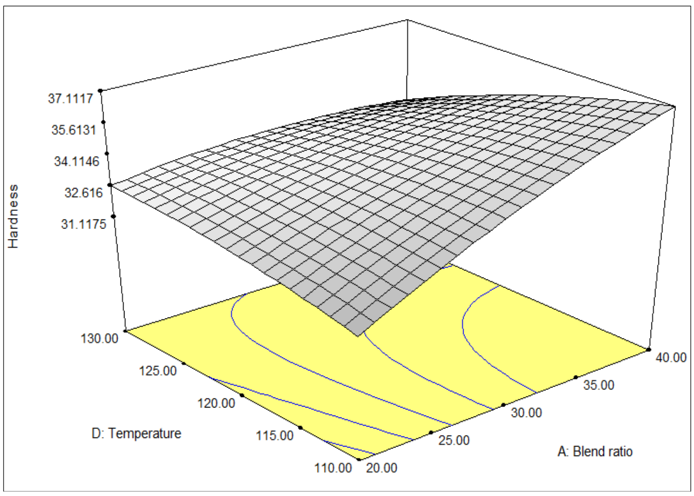

Fig 1: Effect of temperature: blend composition on hardness

F-value for interaction term of feed moisture and screw speed (x_2 x_3) is 5.35 with P value of 0.0353, indicates the term is significant. Since coefficient of $x_2.x_3$ is positive, it will show concave shaped variation with the change in value of variables, as shown in fig. 2 hardness will increase with the Feed moisture and screw speed.

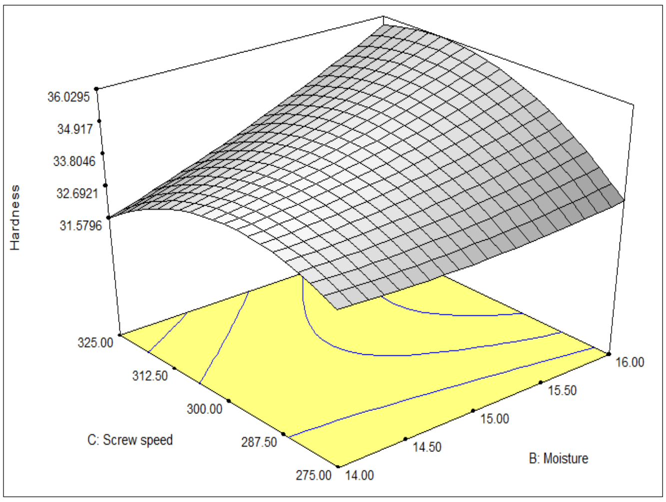

Fig 2: Effect of screw speed: feed moisture on hardness

3.2.5 Compromised Optimum Conditions

The compromised optimum condition for the development of extruded snack with geminated buckwheat flour and corn flour was determined using the following criteria by Design Expert software Package (Design Expert Software "DE-6"). The product should get the maximum expansion, maximum water absorption index and other parameter should be within range.

Table 11 and Table 12 show parameters to be selected for optimization and actual experimentation results respective.

4. Summary and Conclusion

Significant effects were observed on the product response by varying level of corn flour & germinated buckwheat flour, moisture content, temperature and screw speed. Increase in barrel temperature resulted in maximum expansion, minimum hardness and maximum WSI (water solubility index). Higher corn flour proportion in feed composition showed higher expansion, minimum WAI (water absorption index) and maximum WSI (water solubility index) of developed extrudates.

Lateral expansion ranged from 130.36 to 189.39 0.244 g/cm^3, water absorption water solubility index from 4.5% to 9%, hardness 29.49 to 36.83N of extruded product. Optimized product was obtained using the combination of corn flour: germinated buckwheat flour (34.52:65.48), moisture content 14%, barrel temperature 129.69°C, screw speed 275 rpm.

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