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Development of Model for Extrusion Cooking Based on Textural Properties of Extrudate Prepared From Sorghum, Horse Gram and Defatted Soy Flour Blends

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ABSTRACT

Extrusion cooking of sorghum, horse gram and defatted soy flour blends was done to prepare snacks by using a Brabender Single – Screw laboratory extruder. The effect of moisture content, feed blend ratio, barrel temperature and screw speed of extruder on textural characteristics of extrudates were studied by using Texture Analyzer. A central composite rotatable design of Response surface methodology was used to develop prediction model. Second order quadratic regression model was fitted in the variation. The significance was established at $p \leq 0.05$. The hardness of extrudates varied from 1.1 to 10.4 kg whereas the cutting strength of extrudates varied from 1.3 to 10.1 kg. It was observed that moisture content and blend ratio of feed, and barrel temperature gave significant role of textural characteristics of extrudates.

Key words: *Extrusion cooking, Textural properties, Hardness, Cutting strength, Extrudates*

INTRODUCTION

India has indeed a very good potential demand for cereals and pulses based ready–to–eat soy fortified extruded snacks. Extrusion has become an important processing technique and its application today cover a wide range of food products based on starch cereals protein and sugar. In recent years, there has been an increasing interest in the production of extruded foods such as snacks, pastas, breakfast cereals, baby foods, pet foods, etc. Snacks consist essentially of a cereal blend extruded with a certain amount of water. Extrusion cooking has advantages, including versatility, high productivity, low operating costs, energy efficiency and shorter cooking times[6]. Several legumes have been treated by extrusion and good expansion has been reported[2]. In addition, and as a result of high temperatures, high pressures, and several shear forces reached inside the barrel, chemical reactions and molecular modifications like gelatinization of starch, denaturation of proteins, inactivation of many food enzymes, and reduction of microbial counts can occur[6].

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Inside the extruder the cereal mixture is heated above the starch gelatinization temperature leading to a cooked product that may be directly enrobed and flavoured, or may need further processing such as frying or roasting. In the blend of flours made from starch and protein rich grains, the selection of machine and process parameters for extrusion becomes more important as the starch gets gelatinized and protein gets denatured at different process parameters. Hence a consorted effort is required to get optimum physical properties of the extrudate making to be more acceptable to the consumer. Product quality can vary considerably depending on the extruder type, screw configuration, feed moisture, and temperature profile in the barrel session, screw speed and feed rate[5]. In fact, the chemical and physical characteristics of products strongly depend upon process variables such as extrusion temperature, screw speed and moisture content[4]. In cereal-based products, the degree or proper processing of starch is important for major quality aspects such as taste, digestibility, texture, appearance and puffing. Extrusion operational parameters such as barrel temperature, and screw speed affect the snack quality. In addition to these, processing parameters like feed moisture content, blending ratio also play important role on the quality of extrudate. This study has been conducted to evaluate the effect of processing and operational parameters on textural properties of sorghum and horse gram at 10 % defatted soy flour blended extruded snacks. Simultaneously, models have been developed, which could be used to optimize parameters for best quality of ready-to-eat snack food product.

MATERIALS AND METHODS

Sorghum and horse gram grains were procured from local market of Jabalpur. After cleaning, these grains were milled in a laboratory scale Hammer Mill to obtain required quantity of flour. Defatted Soy Flour (DFS) was procured from Ruchi Soy industry, Indore, India. The moisture content of flour of different blend ratios was measured by hot air oven method. After getting the moisture content of blends, water was added to maintain desired moisture content levels in the blends i.e. 9, 12, 15, 18 and 21%, kept for conditioning for 24 hrs, calculated by using the formula:

$$W_w = W_d \left\{ \frac{(M_2 - M_1)}{(1 - M_1)(1 - M_2)} \right\}$$

Where,

W_w = Weight of water to be added,

W_d = Bone dry weight of raw flour

M_1 = Initial moisture content of flour, % wb in decimal,

M_2 = Desired moisture content of flour, % wb in decimal

In this study the laboratory - scale single - screw extruder (model Kompakt E-19/25 D Brabender Duisburg, Germaney) (length-to-dia 20:1; compression ratio 2:1 and die opening 5 mm) available at department of post harvest process & food engineering, college of agricultural engineering, Jabalpur, was used for extrusion cooking.

Experiment design and analysis

Response surface methodology (RSM) was used in designing the experiment[3]. Independent variables such as moisture content, blend ratio of feed, barrel temperature and screw speed were coded as X_1, X_2, X_3 and X_4 respectively. Five levels of each of the four variables were chosen according to a central composite rotable design (CCRD). The coded and actual parameter values are presented in Table 1. The data obtained from the experiment was processed in trial Design Expert 7.0.1 (45 days). The observed data was analyzed, employing multiple regression technique. The best fitting model was chosen, based on lack of fit criteria[3].

Determination of textural properties

A Texture Analyzer TA – XT*2i* available at Department of Post Harvest Process and Food Engineering, CAE, Jabalpur is a highly scientific device was used to study the hardness and cutting strength of extrudates.

RESULTS AND DISCUSSION

The data obtained from the experiments for different combinations (Table 2) were analyzed by using multiple regression and second order polynomial model and fitted to the experimental data with coded values of independent variables and inter- treated with the help of models and graphs. From the tabulated values, three-dimensional graphs were prepared treating two independent variables to be constant and showing the effect of other two variables on textural properties i.e. hardness and cutting strength of extrudates. Adequacy of the model was tested using Fisher's F-test. The significance was established at $p \leq 0.05$. The effects of variables have been interpreted. The findings have been explained suitably with logical reasons wherever possible. The findings also have been discussed in the light of theories and with the literature support to the possible extent. The process parameters considered were moisture content and blend ratio of feed where as the operational parameters were temperature and screw speed. The experimental details are given in Table 2.

Effect of process and operational parameters on hardness of extrudate

The analysis of variance (ANOVA) is shown in Table 3, and it reveals that observed and predicted values (Table 5) are nearly the same, hence a second order model seems to be adequate to describe the effect of variables in the experimental zone. The test of significance of individual regression coefficients show that linear and square terms of moisture content and blend ratio of feed have significantly contributed towards the hardness of extrudate. The relationship developed for hardness with the coded values of independent variables is given in equation 1.

$$Y = 5.016 + 1.93758\,X_1 + 0.411\,X_2 + 0.032\,X_1X_2 + 0.41902\,X_1^2 - 0.54360\,X_2^2 \quad \ldots(1)$$

It is observed that when moisture content of feed and blend ratio increased (increasing protein content and decreasing starch), hardness of extrudate also increased. Previous studies also reported that the hardness of extrudate increased as the feed moisture content increased[1]. It might due to the reduced expansion caused by the increase in moisture content[7]. When barrel temperature and screw speed increased gradually, the hardness of extrudate decreased. It might due to more moisture was evaporated at high temperature causing better puffing. Therefore hardness reduced. Minimum value of hardness of extrudate observed at 15% moisture content of feed, 80:10:10 of blend ratio, 130 rpm screw speed and 130^{0}C barrel temperature. Effect of process and operational parameters on extrudate was shown in Figures 1 to 6.

Effect of process and operational parameters on cutting strength of extrudate

The analysis of variance (ANOVA) is shown in Table 4, and reveals that observed and predicted values (Table 6) are nearly the same, hence a second order model seems to be adequate to describe the effect of variables in the experimental zone. The test of significance of individual regression coefficients show that linear and square terms of moisture content and blend ratio of feed have significantly contributed towards the cutting strength of extrudate.

The relationship developed for cutting strength with the coded values of independent variables is given in equation 2.

$$Y = 5.43 + 1.88942\,X_1 + 0.414\,X_2 - 0.045\,X_1X_2 + 0.467\,X_1^2 - 0.54\,X_2^2 \quad \ldots\ldots(2)$$

It is observed that when moisture content of feed and blend ratio increased (increasing protein content and decreasing starch), cutting strength of extrudate also increased. It may be because the feed materials became hard due to increasing moisture content of feeding. Further it was observed that barrel temperature and screw speed increased gradually, the cutting strength of extrudate decreased. This may be because more moisture was evaporated at high temperature causing formation of bubbles and consequently puffing. Therefore cutting strength reduced. Effect of process and operational parameters on extrudate was shown in Figures 7 to 12. Minimum value of cutting strength of extrudate observed at 15% moisture content of feed, 80:10:10 of blend ratio, 130 rpm screw speed and 130 ^{0}C barrel temperature.

Table 1: Level of coded variables

Independent variable	Code levels				
	-2	**-1**	**0**	**1**	**2**
Moisture Content (% w.b.)	9	12	15	18	21
Blend ratio	80:10:10	75:15:10	70:20:10	65:25:10	60:30:10
Barrel Temperature (^{o}C)	120	125	130	135	140
Screw Speed (rpm)	120	125	130	135	140

Table 2: Experimental design matrix for parameter levels

Run	Coded values				Actual values (uncoded)			
	X_1	X_2	X_3	X_4	X_1	X_2	X_3	X_4
1	-1	-1	-1	-1	12	75:15:10	125	125
2	1	-1	-1	-1	18	75:15:10	125	125
3	-1	1	-1	-1	12	65:25:10	125	125
4	1	1	-1	-1	18	65:25:10	125	125
5	-1	-1	1	-1	12	75:15:10	135	125
6	1	-1	1	-1	18	75:15:10	135	125
7	-1	1	1	-1	12	65:25:10	135	125
8	1	1	1	-1	18	65:25:10	135	125
9	-1	-1	-1	1	12	75:15:10	125	135
10	1	-1	-1	1	18	75:15:10	125	135
11	-1	1	-1	1	12	65:25:10	125	135
12	1	1	-1	1	18	65:25:10	125	135
13	-1	-1	1	1	12	75:15:10	135	135
14	1	-1	1	1	18	75:15:10	135	135
15	-1	1	1	1	12	65:25:10	135	135
16	1	1	1	1	18	65:25:10	135	135
17	-2	0	0	0	9	70:20:10	130	130
18	2	0	0	0	21	70:20:10	130	130
19	0	-2	0	0	15	80:10:10	130	130
20	0	2	0	0	15	60:30:10	130	130
21	0	0	-2	0	15	70:20:10	120	130
22	0	0	2	0	15	70:20:10	140	130
23	0	0	0	-2	15	70:20:10	130	120
24	0	0	0	2	15	70:20:10	130	140
25	0	0	0	0	15	70:20:10	130	130
26	0	0	0	0	15	70:20:10	130	130
27	0	0	0	0	15	70:20:10	130	130
28	0	0	0	0	15	70:20:10	130	130
29	0	0	0	0	15	70:20:10	130	130
30	0	0	0	0	15	70:20:10	130	130
31	0	0	0	0	15	70:20:10	130	130
32	0	0	0	0	15	70:20:10	130	130

Table 3: ANOVA for hardness of extrudate

Source	Sum of square	df	Mean square	F-value	p-value prob>F	Remark
Model	112.03	14	8.00	13.15	0.0001	S
X_1	90.10	1	90.10	148.01	0.0001	S
X_2	4.05	1	4.05	6.65	0.0209	S
X_3	0.98	1	0.98	1.62	0.2227	NS
X_4	0.30	1	0.30	0.50	0.4905	NS
X_1X_2	0.016	1	0.016	0.026	0.8739	NS
X_1X_3	0.100	1	0.100	0.16	0.6916	NS
X_1X_4	0.59	1	0.59	0.97	0.3403	NS
X_2X_3	0.014	1	0.014	0.023	0.8803	NS
X_2X_4	0.27	1	0.27	0.44	0.5156	NS
X_3X_4	0.049	1	0.049	0.081	0.7799	NS
X_1^2	4.82	1	4.82	7.91	0.0131	S
X_2^2	8.11	1	8.11	13.32	0.0024	S
X_3^2	0.64	1	0.64	1.05	0.3211	NS
X_4^2	0.024	1	0.024	0.040	0.8439	NS
Residual	9.13	15	0.61			
Lack of Fit	4.88	10	0.49	0.57	0.7878	NS
Pure Error	4.25	5	0.85			

Table 4: ANOVA for cutting strength of extrudate

Source	Sum of square	df	Mean square	F-value	p-value prob>F	Remark
Model	112.99	14	8.07	9.26	0.0001	S
X_1	85.68	1	85.68	98.29	0.0001	S
X_2	4.11	1	4.11	4.72	0.0463	S
X_3	1.11	1	1.11	1.27	0.2772	NS
X_4	3.21	1	3.21	3.68	0.0743	NS
X_1X_2	0.032	1	0.032	0.037	0.8501	NS
X_1X_3	0.0055	1	0.0055	0.00636	0.9375	NS
X_1X_4	0.27	1	0.27	0.31	0.5872	NS
X_2X_3	0.046	1	0.046	0.053	0.8206	NS
X_2X_4	0.36	1	0.36	0.42	0.5275	NS
X_3X_4	0.068	1	0.068	0.078	0.7844	NS
X_1^2	5.98	1	5.98	6.86	0.0194	S
X_2^2	8.03	1	8.03	9.21	0.0084	S
X_3^2	1.38	1	1.38	1.58	0.2279	NS
X_4^2	0.71	1	0.71	0.81	0.3815	NS
Residual	13.08	15	0.87			
Lack of Fit	12.38	10	1.24	8.90	0.4131	NS
Pure Error	0.70	5	0.14			

Table 5: Observed and predicted values for hardness of extrudate

Run	Y_{ob}	Y_{pred}	X_1	X_2	X_3	X_4
1	1.989	1.807	-1	-1	-1	-1
2	6.393	5.846	1	-1	-1	-1
3	3.379	2.765	-1	1	-1	-1
4	6.265	6.932	1	1	-1	-1
5	2.265	2.109	-1	-1	1	-1
6	6.827	6.460	1	-1	1	-1
7	3.279	3.041	-1	1	1	-1
8	7.904	7.520	1	1	1	-1
9	3.336	2.785	-1	-1	-1	1
10	6.022	6.056	1	-1	-1	1
11	2.919	3.2276	-1	1	-1	1
12	7.252	6.626	1	1	-1	1
13	3.589	2.867	-1	-1	1	1
14	6.625	6.450	1	-1	1	1
15	3.664	3.496	-1	1	1	1
16	7.012	7.207	1	1	1	1
17	2.115	2.816	-2	0	0	0
18	10.426	10.567	2	0	0	0
19	1.112	2.019	0	-2	0	0
20	3.728	3.663	0	2	0	0
21	3.670	3.552	0	0	-2	0
22	4.296	4.816	0	0	2	0
23	4.329	4.896	0	0	0	-2
24	4.621	4.896	0	0	0	2
25	4.215	5.016	0	0	0	0
26	4.690	5.016	0	0	0	0
27	5.644	5.016	0	0	0	0
28	5.770	5.016	0	0	0	0
29	6.010	5.016	0	0	0	0
30	3.769	5.016	0	0	0	0

Table 6: Observed and predicted values for cutting strength of extrudate

Run	Y_{ob}	Y_{pred}	X_1	X_2	X_3	X_4
1	2.172	1.626	-1	-1	-1	-1
2	6.092	5.789	1	-1	-1	-1
3	2.199	2.954	-1	1	-1	-1
4	6.161	6.937	1	1	-1	-1
5	2.383	2.330	-1	-1	1	-1
6	6.220	6.421	1	-1	1	-1
7	2.527	3.740	-1	1	1	-1
8	8.586	7.651	1	1	1	-1
9	2.383	3.046	-1	-1	-1	1
10	7.391	6.693	1	-1	-1	1
11	3.753	3.770	-1	1	-1	1
12	7.754	7.237	1	1	-1	1
13	4.051	3.490	-1	-1	1	1
14	8.387	7.065	1	-1	1	1
15	4.267	3.849	-1	1	1	1
16	6.628	7.244	1	1	1	1
17	4.155	3.519	-2	0	0	0
18	10.086	11.076	2	0	0	0
19	1.304	2.442	0	-2	0	0
20	4.874	4.098	0	2	0	0
21	4.353	3.114	0	0	-2	0
22	4.360	5.434	0	0	2	0
23	4.485	4.786	0	0	0	-2
24	4.735	4.786	0	0	0	2
25	5.053	5.430	0	0	0	0
26	5.083	5.430	0	0	0	0
27	5.195	5.430	0	0	0	0
28	5.610	5.430	0	0	0	0
29	5.675	5.430	0	0	0	0
30	5.964	5.430	0	0	0	0

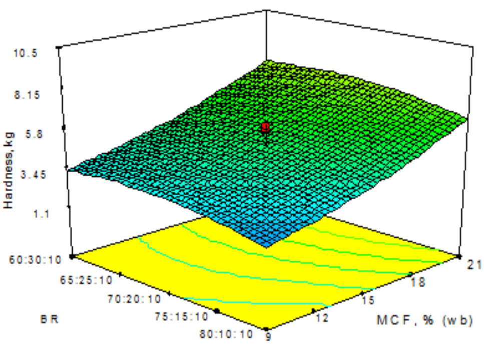

Fig 1: Effect of moisture content of feed and blend ratio on hardness of extrudate

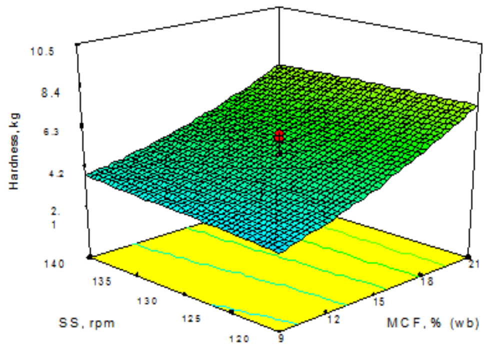

Fig 2: Effect of moisture content of feed and screw speed on hardness of extrudate

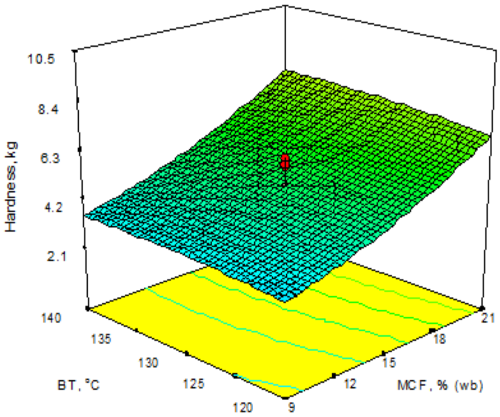

Fig 3: Effect of moisture content of feed and barrel temperature on hardness of extrudate

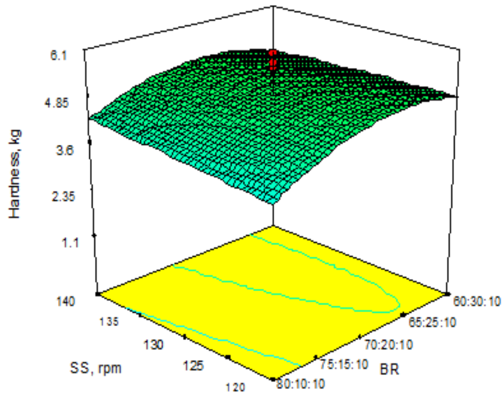

Fig 4: Effect of blend ratio of feed and screw speed on hardness of extrudate

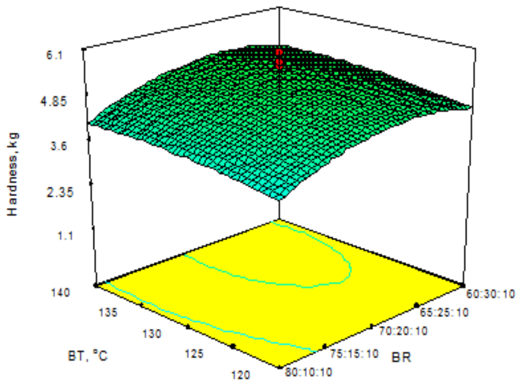

Fig 5: Effect of blend ratio of feed and barrel temperature on hardness of extrudate

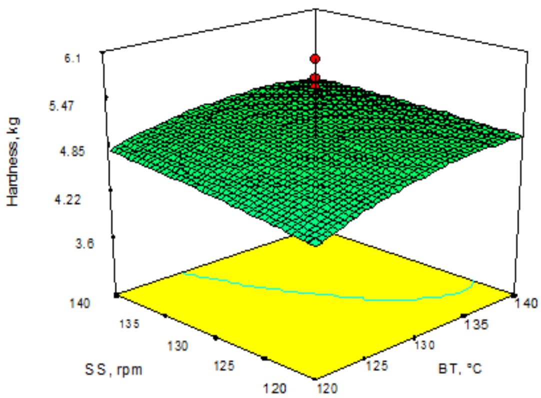

Fig 6: Effect of screw speed and barrel temperature on hardness of extrudate

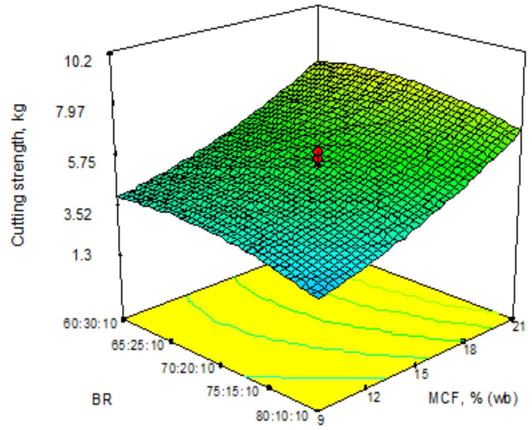

Fig 7: Effect of moisture content of feed and blend ratio on cutting strength of extrudate

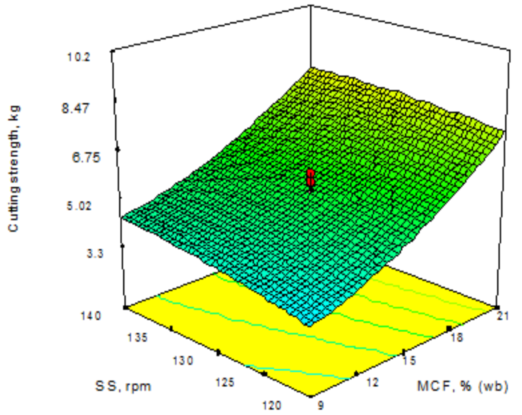

Fig 8: Effect of moisture content of feed and screw speed on cutting strength of extrudate

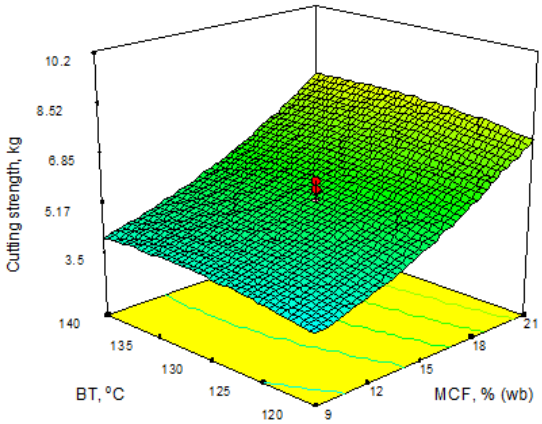

Fig. 9. Effect of moisture content of feed and barrel temperature on cutting strength of extrudate

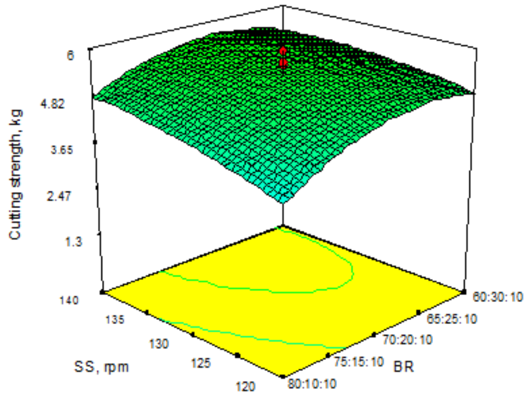

Fig 10: Effect of blend ratio and screw speed on cutting strength of extrudate

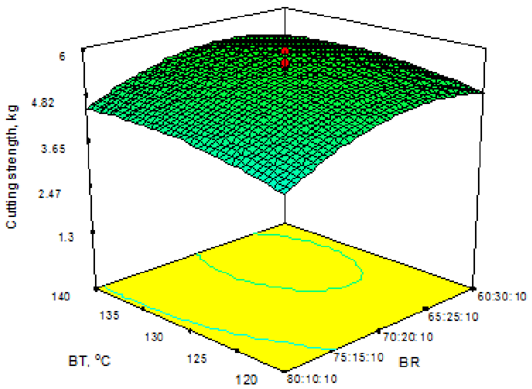

Fig 11: Effect of blend ratio and barrel temperature on cutting strength of extrudate

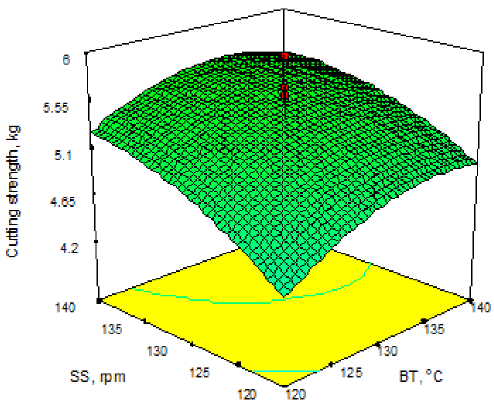

Fig 12: Effect of screw speed and barrel temperature on cutting strength of extrudate

CONCLUSION

The hardness of extrudates varied from 1.112 to 10.426 kg. Minimum value of hardness of extrudates observed at 15% moisture content of feed, 80:10:10 of blend ratio, 130 rpm screw speed and 130^0C barrel temperatures. The cutting strength and compressive strength of extrudates varied from 1.304 to 10.086 kg and 13.390 to 46.950 kg respectively. Minimum value of cutting strength of extrudate observed at 12 % moisture content of feed, 75:15:10 of blend ratio, 135 rpm screw speed and 135 ^{0}C barrel temperature.

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