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Effect of Extrusion Parameters on Physio-Chemical Properties of Extruded Products Prepares by Rice and Pigeon Pea Dal Broken Flour Blends

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ABSTRACT

The traditional milling processing practices used in rice and pulses milling, yields significant amounts in the form of brokens from rice and dal mill industries. That brokens do not find appropriate market and are listed as losses of the milling industries, generally disposed off cheaply, whereas they have equally rich in the nutrition as comparable to whole grain. In developing countries protein malnutrition is a big issue for most of the population. The objective of this study was to develop a novel snack made with rice and pigeon pea dal brokens, yields from milling industries commonly considered as wastage, by using extrusion cooking technology. The effect of process parameters i.e. moisture content of feed and feed blend ration, as well as the operational parameters i.e. barrel temperature, die head temperature and screw speed of extruder on physio-chemical properties of extrudates were studied. A central composite rotatable design (CCRD) 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≤ 0.05. The results suggested that the extrusion variables (i.e. process and operational parameters) were found significance influence on the extrudate physio-chemical properties as well as both independently and interactively. The feed blend ratio and extruder barrel temperature were observed to be the most significant factors that affected the extrudate properties. The best extrusion conditions was obtained at screw speed of 135 rpm, barrel temperature of 130 ^{0}C and die head temperature 190 ^{0}C based on moisture content, expansion ratio, bulk density, and protein content of the extruded products. This study demonstrated that extruded products could be prepared from blends of rice broken flour and pigeon pea dal broken flour under different ranges of extrusion conditions.

Keywords: *Extrusion cooking, Textural properties, Hardness, Expansion ratio, Response surface*

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INTRODUCTION

Extrusion is one of the most dynamic, versatile, and well-established industrial processes used in the food and feed industry today. It is being extensively used worldwide to produce an ever-expanding list of food and feed products including snacks, cereals, pastas, TVPs (texturized vegetable proteins), pet foods, animal feeds, instant beverages, meat analogs, and a range of ethnic foods (Shah, 2003). India has indeed a very good potential demand for cereals and pulses based ready–to–eat soy fortified extruded snacks. Extrusion technologies are used for cereal and protein processing in the food and closely related pet foods and feed sectors. 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. Now-a-days extrusion cooking technology is one of a most significance manufacturing tool for food and feed processing industries. The significance of it should not be underestimated since the technology is relatively new as well as during the last some years it is one of the successful unit operations for food processing industries in India that is still developing rapidly. India has indeed a very good potential demand for cereals and pulses based ready–to–eat extruded snacks. Extrusion cooking has advantages, including versatility, high productivity, low operating costs, energy efficiency, and shorter cooking times (Harper, 1981). Several legumes have been treated by extrusion and good expansion has been reported (Balandran et al., 1998). 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 (Harper, 1981). 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 (Ding et al., 2005). In fact, the chemical and physical characteristics of products strongly depend upon process variables such as extrusion temperature, screw speed and moisture content (De Cindio et al., 2002). 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 physio-chemical properties of extrudates. In addition to these, processing parameters like feed moisture content, blending ratio also play important role on the quality of extrudates. Therefore, the effects of various operational and processing parameters and their interaction on physio-chemical characteristics of extrudates has studied and established. Present study has been conducted to investigate and standardized various operational and process parameters and their interaction on physio-chemical properties of extrudated snacks prepared from by-products of rice and dal milling industries i.e. brokens. Simultaneously, models have been developed, which could be used to optimize parameters for best textural quality of ready-to-eat snack food product.

MATERIALS AND METHODS

The raw material for the study i.e. rice and dal broken were procured from Department of Agricultural Engineering, AKS University, Satna (M.P.). After initial removal of foreign materials, flour was prepared by grinding in the hammer mill. The moisture content of flour at different blend ratio was then measured by standard oven drying method. After getting the moisture content of rice broken flour and dal broken flour blends, additional water required to raise the moisture content to desired levels of blends i.e. 9, 12, 15, 18 and 21% (wb) was calculated. Then calculated amount of water plus an additional 10% of calculated water was added to supplement the evaporation losses during mixing and conditioning. Tempering of samples was done by keeping the moistened samples for 24 h at room temperature (25^0C) so as to get uniform distribution of moisture throughout the mass of blends. The conditioned sample was then feed to the laboratory-scale single-screw extruder (model Kompakt E-19/25 D Brabender Duisburg, Germaney) at pre set operational conditions (length-to-dia 20:1; compression ratio 2:1 and die opening 5 mm) for extrusion cooking. The product after coming out of the extruder discharge end through round die, expanded due to sudden release of pressure. The extrudates were collected and packed in laminated polythene bags and properly labelled for the analysis purpose.

Experiment design and analysis

Design experiments were conducted following Response Surface Methodology (RSM) (Myres, 1976). This is a combination of mathematical and statistical techniques that are useful for the modeling and analysis of problems, in which response of interest is influenced by several variables and objective is to optimize the response. In the present study, Central Composite Rotatable Design (CCRD) of five independent variables with five level of each was used. In this study the effect of processing parameters i.e. bland ratio of rice broken flour and dal broken flour (90:10, 80:20, 70:30, 60:40 and 50:50), moisture content (w.b.) of feed (9, 12, 15, 18 and 21%), die head temperature (180, 190, 200, 210 and 220 ^{0}C), barrel temperature (120, 125, 130, 135 and 140 ^{0}C) and screw speed (120, 125, 130, 135 and 140 rpm) was optimized against the following physio-chemical properties of extrudate responses i.e. moisture content, expansion ratio, bulk density, and protein content of the extruded products. Prediction models were developed for each of the responses, followed by the model analysis which included checking the validity of the model with the help of various prescribed statistical aids. Optimum values were obtained for all the processing variables by keeping the response either in range at minimum or at maximum.

Data analysis was done for optimization of operational and processing parameters of extruder on textural properties of extrudates prepared out of rice broken flour and dal broken flour blends using software, Design expert 11.1.2.0 (32bit). Based on the executed statistics, such as p-values, lack of fit and R^2, PRESS values for comparing the models, software executed statistics and suggested linear and Quadratic model significant at $p<0.0001$ with R^2 = 0.999 and R^2=0.975, lowest PRESS and insignificant lack of fit was selected. Coefficients of the model were estimated for each response. Best-fit regression equations were also developed. Response surface graphs were drawn with the help of Design expert 11.1.2.0 to know the effect of independent variables on the responses. The observed data was analyzed, employing multiple regression technique. The best fitting model was chosen, based on lack of fit criteria (Cochran & Cox 1957).

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	90:10	80:20	70:30	60:40	50:50
Barrel Temperature (^{o}C)	120	125	130	135	140
Screw Speed (rpm)	120	125	130	135	140

Physio-Chemical Properties of Extruded Products

Physiochemical properties of extruded snacks are important especially for the acceptability by the consumers. Process parameters play a very important role on the physical properties of the snack. Effect of blend ratio, moisture content, screw speed and temperature was studied on physical attributes *viz.*, moisture content of extrudates (MCE), mass sectional expansion index of extruder (SEI), bulk density (BD) and protein content of extrudates.

Determination of Moisture Content of Extrudates (Hot air oven method, 44:19 AACC 1983)

Two grams of the sample was weighed, placed into the oven in aluminum pans and heated at 135^0C for two hours. The percentage moisture content was calculated using this formula: The percentage moisture content was determined on wet basis.

$$\text{Moisture Content of Extrudate (\%)} = \frac{\text{Initial wt.of sample}}{\textit{Final wt.of sample}} \text{x } 100$$

Determination of Sectional Expansion Index of Extrudates (SEI)

The method of Fan and others (1996) was used to determine the expansion ratio. The mean of 10 random measurements of the extrudate diameter was determined using a vernier caliper.

$$\text{Sectional Expansion Index (SEI)} = \left(\frac{Diameter\ of\ Extrudate}{Diameter\ of\ Die}\right)^2$$

Determination of Bulk Density of Extrudates (BD)

The method of Deshpande and Poshadri (2011) was followed to determine the bulk density. The average diameter and average length of 25 readings of extrudates were measured and the volume of the extrudates computed as: vol. (cm^3) = $\pi d^2 L/4$

Where, d= average diameter of extrudates in m

L= average length of extrudates in m

The bulk density was obtained as:

$$\text{Bulk Density (B.D.), kg/m}^3 = \frac{\text{Weight of sample}}{\text{Volume of sample}}$$

Mass of extrudate (kg)

Volume of extrudates (m^3)

Determination of Protein Content of Extrudates (Kjeldahl method, 46:10 AACC 1983, Vol 1)

A 0.2 g of sample was added into 350 mL digestion tubes in triplicate. Ten milliliters of concentrated H2S04 and one Kjeldahl tablet (CuSO4 + K2SO4) were added into the digestion tubes and digested for one hour at 420oC in a fume hood to hydrolyse the protein. The digested products were cooled to ambient temperature and distilled using the Keltec 2000 analyzer (Foss 34Inc.) with 40% NaOH titrated with 0.1 N HCl and the nitrogen content was measured. Conversion factor of 6.25 was used for titrable nitrogen to convert it to crude protein percentage.

Table 2: Experimental design matrix for parameter levels

Run	Coded Values				Actual Values			
	F - 1	F - 2	F - 3	F - 4	F - 1	F - 2	F - 3	F - 4
	A	B	C	E	A	B	C	D
1	1	-1	-1	-1	40	12	125	125
2	1	-1	-1	1	40	12	125	135
3	-1	1	1	-1	20	18	135	125
4	1	-1	1	-1	40	12	135	125
5	-2	0	0	0	10	15	130	130
6	0	0	-2	0	30	15	120	130
7	-1	1	-1	1	20	18	125	135
8	2	0	0	0	50	15	130	130
9	0	0	0	0	30	15	130	130
10	0	0	2	0	30	15	140	130
11	-1	-1	1	1	20	12	135	135
12	1	1	-1	1	40	18	125	135
13	0	0	0	2	30	15	130	140
14	0	0	0	0	30	15	130	130
15	0	0	0	0	30	15	130	130
16	0	0	0	0	30	15	130	130
17	1	1	1	-1	40	18	135	125
18	0	0	0	-2	30	15	130	120
19	1	-1	1	1	40	12	135	135
20	-1	-1	1	-1	20	12	135	125
21	0	0	0	0	30	15	130	130
22	0	0	0	0	30	15	130	130
23	-1	-1	-1	-1	20	12	125	125
24	0	0	0	0	30	15	130	130
25	1	1	1	1	40	18	135	135
26	0	-2	0	0	30	9	130	130
27	-1	-1	-1	1	20	12	125	135
28	0	2	0	0	30	21	130	130
29	-1	1	1	1	20	18	135	135
30	1	1	-1	-1	40	18	125	125
31	0	0	0	0	30	15	130	130
32	-1	1	-1	-1	20	18	125	125

A:Blend Ratio (%), B:Feed Moisture Content (%), C:Barrel Temperature (°C), D:Screw Speed (RPM)

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 variables on physiochemical properties i.e. crispness, 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 barrel temperature, die head temperature and screw speed. The experimental details are given in Table-2.

Effect of process and operational parameters on moisture content of extrudate

The multiple regression analysis for moisture content of extrudates (MCE) versus feed moisture content (FMC), blend ratio (BR), barrel temperature (BT) and screw speed (SS) was done using CCRD and fitting of second degree polynomial equation for representative response surface of data resulted in the development of following model;

$$\mathbf{M.C.E.} = 29.2034 + 1.4226 \times FMC - 0.589432 \times BR + 1.19235 \times BT - 0.677652 \times SS - 0.00458333 \times FMC \times BR + 0.0108333 \times FMC - 0.0125 \times FMC \times BT - 0.0125 \times FMC \times SS + 0.003125 \times BR - 0.002 \times BR \times BT + 0.002 \times BR \times SS - 0.00075 \times BT + 0.00125 \times SS + 0.001 \times BT \times SS - 0.00542929 \times FMC^2 + 0.000511364 \times BR^2 - 0.00345455 \times BT^2 + 0.00154545 \times SS^2 \quad \text{..........}(\mathbf{1})$$

The R^2 had a value of 0.9940 for the model. The results of analysis of variance (ANOVA) for model 1 are presented in Table-3.

Table 3: Analysis of variance for moisture content (MCE) of extrudates

Source	DF	SS	MSS	F	P
Regression	20	7.49	0.3743	90.74	0.02
Residual	11	0.0454	0.0041		
Total	31	7.5354	0.3784		

The F-value 90.74 implies that the model is significant. In this case, linear term of moisture content of feed, interaction term of barrel temperature and die head temperature, quadratic terms of moisture content of feed, blend ratio and barrel temperature are highly influencing variables on the moisture content of extrudates.

Moisture content of extrudates (MCE) varied from 4.60 to 6.00 %. It was observed that as moisture content of extrudates increases and the rate of increase are almost uniform with increase in moisture content of feed. Also the moisture content of extrudates decreases with increase in the proportion of dal broken flour in blend. Further, it was also observed that barrel temperature increased gradually, the moisture content of extrudate decreased and screw speed increased then the moisture content of extrudate also increased. Minimum value of moisture content of extrudate was observed at 12 % feed moisture content, 80:20 of blend ratio, 125 rpm of screw speed, 125 ^{0}C barrel temperature.

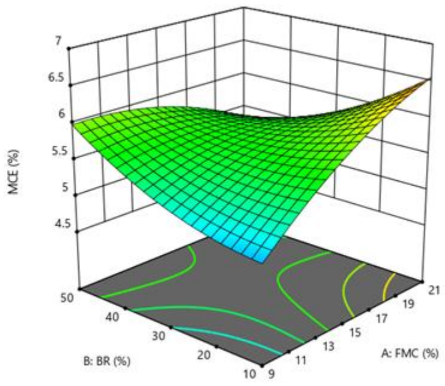

Fig. 1: Effect of feed moisture content and blend ratio on moisture content of extrudates

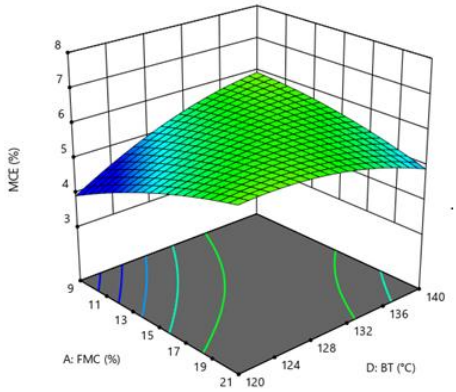

Fig. 2: Effect of feed moisture content and barrel temperature on moisture content of extrudates

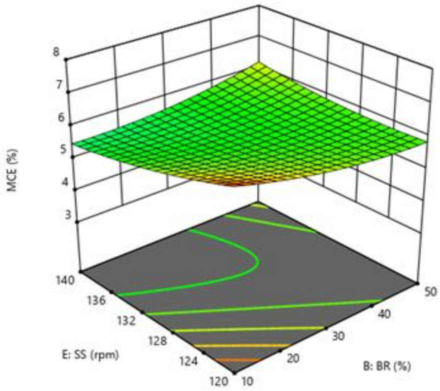

Fig. 3: Effect of blend ratio and screw speed on moisture content of extrudates

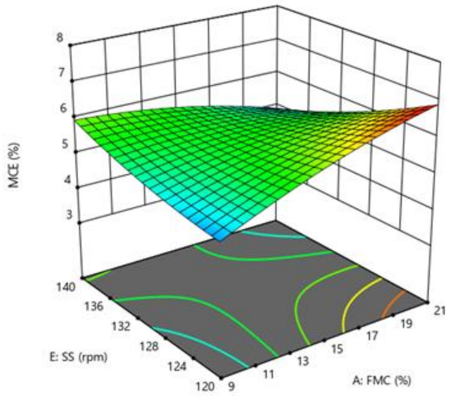

Fig. 4: Effect of feed moisture content and screw speed on moisture content of extrudates

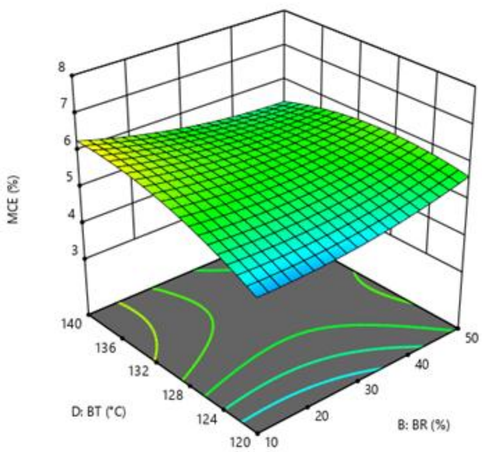

Fig. 5: Effect of blend ratio and barrel temperature on moisture content of extrudates

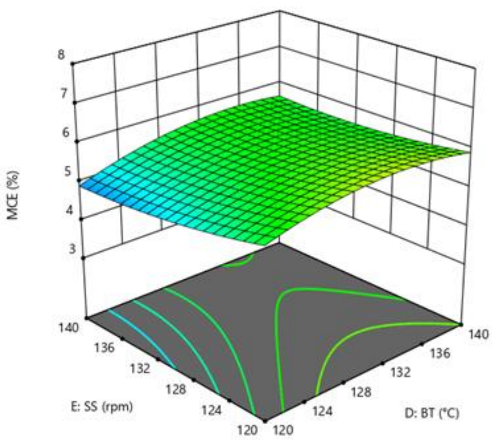

Fig. 6: Effect of barrel temperature and screw speed on moisture content of extrudates

Effect of process and operational parameters on Sectional Expansion Index of Extrudates (SEI)

The multiple regression analysis for the sectional expansion index (SEI) of extrudates versus feed moisture content (FMC), blend ratio (BR), barrel temperature (BT) and screw speed (SS) was done using CCRD and fitting of second degree polynomial equation for representative response surface of data resulted in the development of following model;

$$\text{S.E.I.} = 31.2742 - 0.324861 \times FMC - 0.316375 \times BR - 0.108167 - 0.552 \times BT + 0.404833 \times SS - 0.00529167 \times FMC \times BR - 0.0015 \times FMC - 0.00025 \times FMC \times BT + 0.00516667 \times FMC \times SS - 0.0004 \times BR + 0.004975 \times BR \times BT - 0.0009 \times BR \times SS + 0.00515 \times DHT \times BT - 0.000925 \times SS + 0.0018 \times BT \times SS + 0.00430556 \times FMC^2 - 0.000825 \times BR^2 - 0.00325 \times BT2 - 0.00195 \times SS^2 \quad \text{.......}\mathbf{(2)}$$

The R^2 had a value of 0.8583 for the model. The results of analysis of variance (ANOVA) for model 2 are presented in Table- 4.

Table 4 Analysis of variance for sectional expansion index of extrudates

Source	DF	SS	MSS	F	P
Regression	20	3.67	0.1835	3.33	0.0222
Residual	11	0.6060	0.0551		
Total	31	4.2760	0.2386		

The F-value of 3.33 implies that the model is significant but the lack of fit 2.40 is non significant.

The sectional expansion index (SEI) decreased sharply with increasing feed moisture. Also as it is seen that, increase in amount of rice broken flour increases the SEI because as rice broken flour increases it has reduces dal broken flour which has high value protein content which reduces the SEI. It can be observed that SEI increase with increase in the barrel temperature of Zone III. The sectional expansion index ranged from 2.91 to 4.72 of the extrudates. Similar finding were reported by Nelson (2003) and Berrios (2010) that increasing the proteins levels will lead to decrease in diameter and expansion ratio of the extrudates. All the processing variables were significantly affecting the sectional expansion index in linear, interactive and quadratic terms. The individual effect of all the processing parameters was also significant.

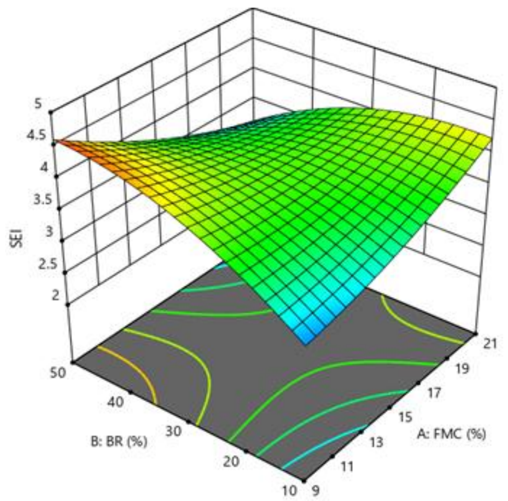

Fig. 7: Effect of feed moisture content and blend ratio on sectional expansion index of extrudates

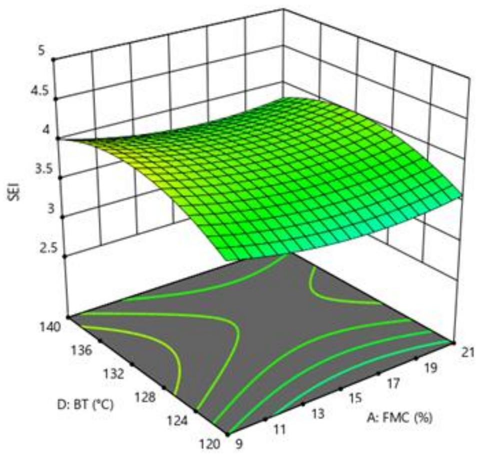

Fig. 8: Effect of feed moisture content and barrel temperature on sectional expansion index of extrudates

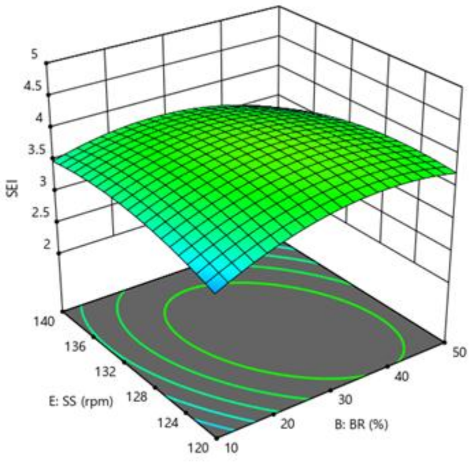

Fig. 9: Effect of blend ratio and screw speed sectional expansion index of extrudates

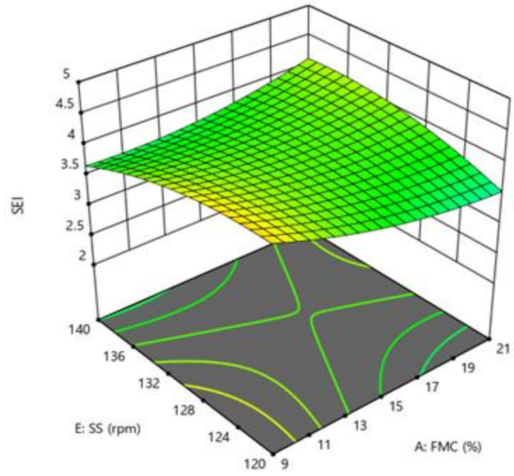

Fig. 10: Effect of feed moisture content and screw speed sectional expansion index of extrudates

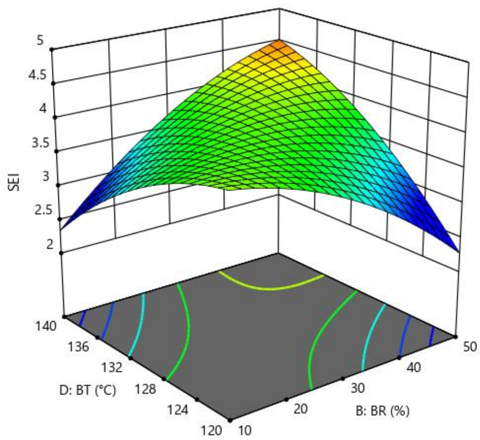

Fig. 11: Effect of blend ratio and barrel temperature sectional expansion index of extrudates

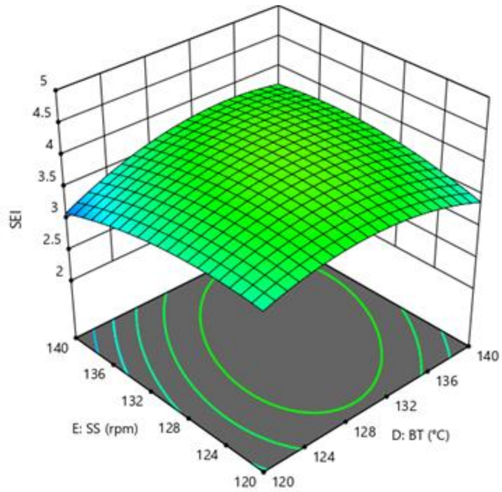

Fig. 12: Effect of barrel temperature and screw speed sectional expansion index of extrudates

Effect of process and operational parameters on bulk density of extrudate (BD)

The multiple regression analysis for bulk density (BD) of extrudates versus feed moisture content (FMC), blend ratio (BR), barrel temperature (BT) and screw speed (SS) was done using CCRD and fitting of second degree polynomial equation for representative response surface of data resulted in the development of following model;

$$\textbf{B.D.} = -1211.9 + 58.8908 \times FMC + 5.23201 \times BR + 2.08144 + 36.2242 \times BT - 28.2424 \times SS + 0.04375 \times FMC \times BR - 0.0729167 \times FMC - 0.3625 \times FMC \times BT - 0.0125 \times FMC \times SS + 0.018125 \times BR - 0.05375 \times BR \times BT - 0.04375 \times BR \times SS - 0.04875 \times BT + 0.06625 \times SS - 0.0575 \times BT \times SS + 0.160354 \times FMC^2 + 0.0544318 \times BR^2 - - 0.0472727 \times BT^2 + 0.0977273 \times SS^2 \quad \ldots\ldots \textbf{(3)}$$

The R^2 had a value of 0.9137 for the model; the results of analysis of variance (ANOVA) for model 3 are presented in Table-5

Table 5: Analysis of variance for bulk density of (BD) extrudates

Source	DF	SS	MSS	F	P
Regression	20	4268.44	213.42	5.82	0.0023
Residual	11	403.03	36.64		
Total	31	4671.47	250.06		

The F-value 5.82 implies that the model is significant but the lack of fit 1.14 is non significant.

The bulk density of extrudates increases with increase in moisture content of feed. It is because with increase in moisture content the mass per unit volume of extrudates increases which is ultimately responsible for increase in density. The bulk density of extrudates achieved maximum value of 157 kg/m3 whereas the minimum value of 115 kg/m3. It has been observed that when barrel temperature and die head temperature increases the bulk density decreases. It was found that bulk density in extrudates varied due to the screw speed, is well supported by Suknark et al. (1998), which produces smaller diameter extrudates with increased length and volume. The die head temperature is directly and barrel temperature is indirectly responsible for vaporization of moisture from extrudates therefore it reduces the density as well as reduction of bulk density of the extrudates was due to the enhancement of gelatinization also. Extrudates density is inversely related to overall expansion. It also can be seen that bulk density increases with increase in proportion of dal broken flour in the blend.

Effect of process and operational parameters on protein content of Extrudates

The multiple regression analysis for protein content of extrudates versus feed moisture content (FMC), blend ratio (RB), barrel temperature (BT) and screw speed (SS) was done using CCRD and fitting of second degree polynomial equation for representative response surface of data resulted in the development of following model;

$$\text{Protein} = -49.4916 + 2.07218 \times FMC - 0.27839 \times BR + 0.0749318 \times BT - 0.357902 \times SS + 0.00595833 \times FMC \times BR - 0.00166667 \times FMC + 0.0035 \times FMC \times BT - 0.01425 \times FMC \times SS + 0.0030625 \times BR - 0.004575 \times BR \times BT + 0.0001 \times BR \times SS - 0.0014 \times BT - 0.000725 \times SS + 0.00045 \times BT \times SS - 0.0164015 \times FMC^2 + 0.00568636 \times BR^2 + 0.000795455 \times BT^2 + 0.00269545 \times SS^2 \quad \ldots\ldots(4)$$

The R^2 had a value of 0.9558 for the model. The results of analysis of variance (ANOVA) for model 4.6 are presented in Table-6

Table 6: Analysis of variance for protein content of extrudates

Source	DF	SS	MSS	F	P
Regression	20	97.29	4.86	11.89	< 0.0001
Residual	11	4.50	0.4090		
Total	31	101.79	5.2690		

The F-value 11.89 implies that the model is significant.

The protein content of extrudates increases with increase in percentage of dal broken flour in the blend as it contains highest percentage of protein. It has been observed that with increase in barrel temperature the amount of protein content decreases whereas the protein content of extrudates increases with increase in screw speed because the destruction of protein is directly related to time and temperature interaction. The protein content of extrudates ranged from 8.84 to 17.94%. Less changes in the nutritional value of proteins of cereal based blends after processing in single screw extruders was reported by Harper and Jansen (1981).

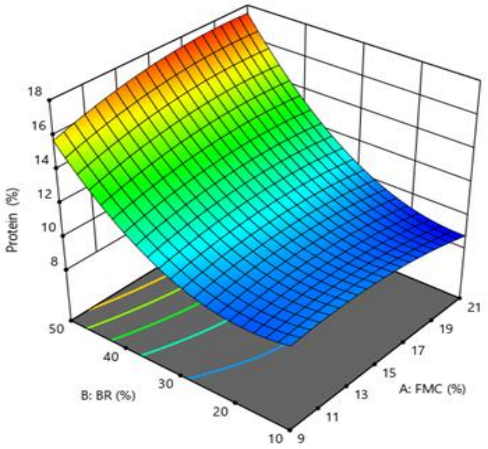

Fig. 13: Effect of feed moisture content and blend ratio on protein content of extrudates

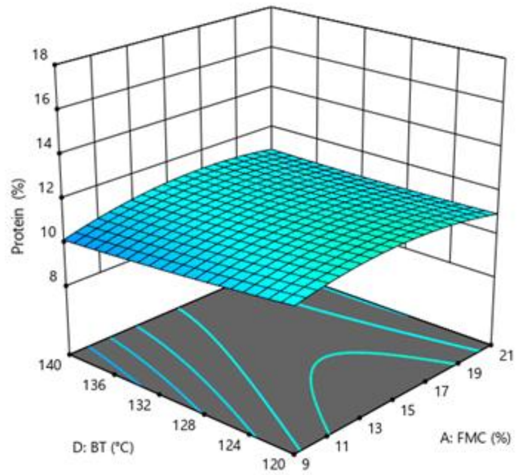

Fig. 14: Effect of feed moisture content and barrel temperature on protein content of extrudates

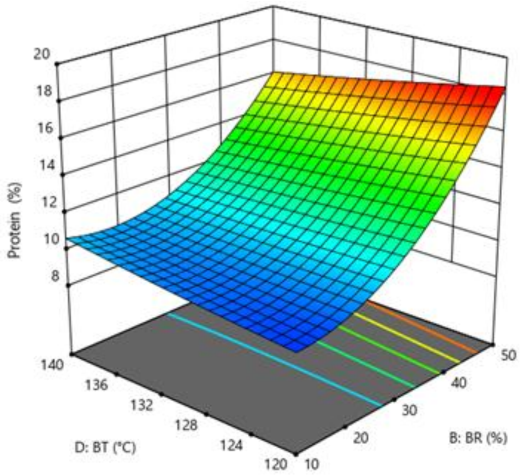

Fig. 15: Effect of blend ratio and barrel temperature on protein content of extrudates

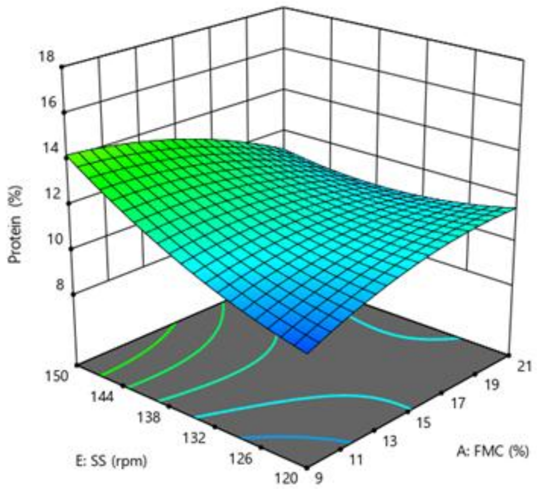

Fig. 16: Effect of feed moisture content and screw speed on protein content of extrudates

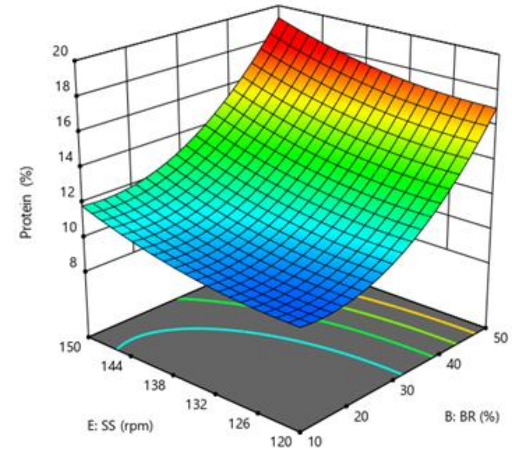

Fig. 17 Effect of blend ratio and screw speed protein content of extrudates

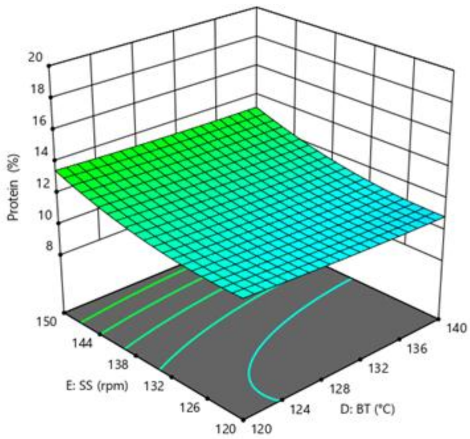

Fig. 18 Effect of barrel temperature and screw speed on protein content of extrudates

Table 7: Summary sheet values obtained by CCRD for different responses (dependent variables) under study of different blends

Response	Name	Units	Observ ations	Analysis	Min.	Max.	Mean	Std. Dev.	Transform	Model
R_1	Moisture Content of Extrudates (MCE)	%	32	Polynomial	4.6	6.8	5.73	0.4929	None	Quadratic
R_2	Sectional Expansion Index (SEI)		32	Polynomial	2.91	4.72	3.75	0.3714	None	Quadratic
R_3	Bulk Density (BD)	Kg/ m^3	32	Polynomial	115	157	134.22	12.28	None	Quadratic
R_4	Protein Content	%	32	Polynomial	8.84	17.94	11.60	1.81	None	Quadratic

Table 8: The standard error, mean, coefficient of variation, predicted residual error of sum squares (PRESS), coefficient of determination, adjusted and predicted R-Squared and adequate precision values for developed models

Model No.	Process order	Mean	Std. Deviation	C.V.%	PRESS	R^2	R^2 Adj.	R^2 Pred.	Adeq. Precision
1 (MCE)	Quadratic	5.73	0.0642	1.12	1.15	0.9940	0.9830	0.8474	42.4424
2 (SEI)	Quadratic	3.75	0.2347	6.25	12.28	0.8583	0.6005	-1.8720	8.9497
3 (BD)	Quadratic	134.22	6.05	4.51	6150.08	0.9137	0.7569	-0.3165	8.6163
4 (Prot)	Quadratic	11.60	0.6395	5.51	87.91	0.9558	0.8754	0.1363	15.1189

CONCLUSION

Rice and pigeon pea are grown in appreciable amount in most of the part of India; the traditional milling process yields significant amounts in the form of brokens from rice and dal mill industries. That brokens do not find appropriate market and are listed as losses of the milling industries, generally disposed off cheaply, only to be used as animal feed or to acts as raw material for manufacturing other complementary products. The broken part of rice and pulses, are equally rich in the nutrition as comparable to whole grain. Moreover, high protein by-product of industry offer scope for their use as supplement but all these require heat processing to make them suitable for human consumption. Extrusion cooking is one of the most important food processing technologies which have been used for the production of breakfast cereals, ready to eat snack foods and other textured foods. Effects of extrusion cooking on the physiochemical characteristics are ambiguous. As a complex multivariate process, extrusion cooking requires careful control if product quality is to be maintained. In this study it has to be mainly focused on the relationships between process and operation parameters on physiochemical properties of extrudates which were prepared by flour of rice and dal milling industry's by-products i.e. brokens. The moisture content (MCE) of the extrudates varied between 4.60 to 6.00 %. The sectional expansion index (SEI) of the extrudates ranged from 2.91 to 4.72, the bulk density of extrudates achieved maximum value of 157 kg/m^3 whereas the minimum value of 115 kg/m^3. The protein content of extrudates ranged from 8.84 to 17.94%. Optimum values of desired physiochemical extrudates were observed at

15% and 18 % moisture content of feed respectively, 80:20 of feed blend ratio, 135 ^{0}C barrel temperature 190 ^{0}C die head temperature and 135 rpm screw speed.

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