Chickpea is another legume, grown in tropical and subtropical areas that have a functional ingredient for the food industry. Chickpea is valued for its nutritive value with high protein content 25.3-28.9 % after dehulling (Hulse, 1991; Huisman and van der poel, 1994). Corn is staple food in all over the world, consumed in daily diet. Corn contains 39.08% protein, 3.88% fat, 0.03% ash, 76.80% carbohydrate, vitamin and amino acid (Santosa et al., 2005). Extrusion processing of corn and oatmeal has been very well studied (Bhattacharya and Hanna 1987) and well commercialized especially in the category of breakfast cereals.

The objective of this research was to study the effect of fenugreek seed powder and oat flour on macrostructure and physical properties of extrudates product.

Materials and Methods

Raw materials

Rice, Corn, Chickpea, fenugreek seed, oat, was purchased from local market. Rice, Corn, Chickpea, fenugreek seed and Oat grounded in mixture grinder or flour mill, particle size of all the flour were less than 60BSS screen. All chemicals used were of analytical grade.

Extruder

Extrusion was carried using a co-rotating twin-screw extruder (BASIC TECHNOLOGY PVT. LTD, KOLKATA, INDIA). The main drive has 7.5 HP motor (400 V, 3 ph, 50 cycles). The screw that was a standard design for processing cereals and flour-based products was used. Barrel (L/D) was 8:1. The barrel of the extruder received feed from a co-rotating variable feeder. The barrel with two electric band heaters and two water cooled jackets. A temperature sensor was fitted on the front die plate and direct connected to temperature control placed in the panel board. The die plate of the die fixed by a screw nut which is tightened by a special wrench provided. The initial experimental temperature was reached within 30 min and a sample was poured into feed hopper and then feed rate was adjusted to 8 kg/h for easy and non-choking operation. Then selected diameter of die was at 4 mm as recommended by the manufacturer for such product. The barrel zone temperature was kept constant at 118°C throughout the experiment and screw speed was maintained at 250rpm.

Experimental design

Response surface methodology (RSM) was accepted 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 2001). The main advantage of RSM is the reduced number of experimental runs needed to provide sufficient information for statistically acceptable results. A five-level, two-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 Bulk density, Lateral expansion, Water absorption index, Water solubility index, Specific length ad expansion ratio. The five levels of two independent variables were coded as −1.414, -1, 0, +1 and +1.414 (Montgomery 2001). Moisture content of feed was adjusted to14% as per CCRD design.

Table 1: Values of independent variables as per CCRD design

Independent variables	Coded	Levels in coded form				
		-1.414	-1	0	1	1.414
Fenugreek Seed Powder	A	1.586	2	3	4	4.414
Oat Flour	B	4.758	6	9	12	13.242

Product analysis

Bulk density

The bulk density (BD) g/cm^3 was calculated by measuring the actual dimensions of the extrudates (Thymi et al., 2005). 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.

$$BD = \frac{4\,m}{\pi d^2 L} \quad \text{.................................} \ (1)$$

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

Lateral expansion

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

$$LE = \frac{(\text{diameter of product} - \text{diameter of die hole})}{\text{diameter of die hole}} \times 100 \quad \ldots \ (2)$$

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

The WSI and WAI were measured using a technique developed for cereals (Ding et al., 2006) 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 4000 rpm for 15 min. (Shirani et al., 2008) 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 formulas,

$$WAI\ (g/g) = \frac{\text{Weight gain by gel}}{\text{Dry weight of extrudate}} \quad \text{...............} \ (3)$$

$$WSI\ (\%) = \frac{\text{Weight of dry solid in supernatent}}{\text{Dry weight of extrudate}} \times 100 \quad \ldots \ (4)$$

Macrostructure

Specific length (S.L.) and Expansion ratio (E.R.)

The length (le), diameter (De), (Dd) die diameter and mass (me) were measured for 20 pieces of dried product from each treatment, and used to obtain the radial expansion ratio (ER), specific length (lsp), (Alvarez-Martinez et al.,1988). The extrudates were cut by hand in pieces of about 5 cm in length. Each treatment was measured 15 times. (Karkle et al., 2011)

(Specific length) $lsp = le/me$ (mm/gm) ......(5)

(Expansion ratio) $ER = D^2e \ / \ D^2d$ ....(6)

Results and Discussion

The effect of fenugreek seed powder and oat flour on macrostructure and physical proportion reported on table 2.

Table 2: Effect of fenugreek seed powder and oat flour on macrostructure and physical proportion of extruded product

Sr.No.	Fenugreek seed powder	Oat flour	B.D.	L.E.	W.A.I.	W.S.I.	S.L.	E.R.
1	+1	+1	0.064	201	1.114	4.1	78.2	0.0784
2	+1	-1	0.0653	199	1.101	4.15	75.5	0.084
3	-1	+1	0.0614	192	1.294	4.3	70.1	0.088
4	-1	-1	0.0711	194	1.125	4.12	72.2	0.088
5	+1.414	0	0.0659	199.5	1.246	4.1	75.9	0.088
6	-1.414	0	0.0711	194	1.125	4.2	72.2	0.088
7	0	+1.414	0.0737	200.5	1.402	4.01	76.5	0.082
8	0	-1.414	0.0646	199	1.208	4.3	74.7	0.075
9	0	0	0.0717	189	2.54	4.45	89.5	0.085
10	0	0	0.0862	189	2.668	4.43	89.6	0.079
11	0	0	0.0825	188.5	2.062	4.43	89.5	0.082
12	0	0	0.0829	188.5	2.684	4.43	89.5	0.080

Bulk Density (Table 3 Figure.1)

Bulk density of extruded product ranged from 0.0098 to 0.0825 g/cm^3 .The resulting polynomial equation (7). B.D 14% =+0.083 -0.0010*A +0.00047* B - 0.0079* A^2 -0.0076* B^2 +0.0018*A*B ....equ.(7). In linear term, fenugreek seed powder (A) and oat flour (B) were found to be significant ($P<0.05$). F- value for linear terms fenugreek seed powder (A) and Oat flour (B) were 0.47and 0.089 and P-value was found to be 0.5191 and 0.7756 ($P<0.05$) respectively form table 3, validating that terms were significant. Quadratic terms of fenugreek seed powder (A^2) and oat flour (B^2) had shown significant effect. F-value for quadratic terms fenugreek seed powder (A^2) and oat flour (B^2) were 20.25 and 18.63 and p- value was found to be 0.0041 and 0.0050 ($P>0.05$) respectively. The interaction term form fenugreek seed powder and oat flour (AB) gave non-significant effect P-value was found to be 0.4453 ($P<0.05$) and it shows the positive effect on the interaction term. F-value found to be 0.67 in table 3.

Counter plots shows the effect of fenugreek seed powder and oat flour on bulk density is showed in Figure.1 as fenugreek seed powder increased then bulk density decreased and oat flour content of the extruded product was increased then bulk density of the extruded product was increased.

Table 3: Anova of bulk density showing effect of fenugreek seed powder and oat flour

Response	Source	DF	Sum of squares	Mean squares	F-value	P-value
Bulk Density	Regression	5	0.00067	0.000134	6.73**	0.0190
	A	1	0.0000093	0.0000093	0.47	0.5191
	B	1	0.0000017	0.0000017	0.089	0.7756
	A^2	1	0.0004045	0.0004045	20.25**	0.0041
	B^2	1	0.0003721	0.0003721	18.63**	0.0050
	AB	1	0.0000133	0.0000133	0.67	0.4453
	Pure error	3	0.00002827	0.0000094		
	Lack of fit	3	0.00009156	0.0000305	3.24*	0.1801
	Residual	6	0.0001198	0.0000199		
	Total	1	0.0007916			
R^2 0.8486, *Significant at P < 0.1, **Significant at P < 0.05,						

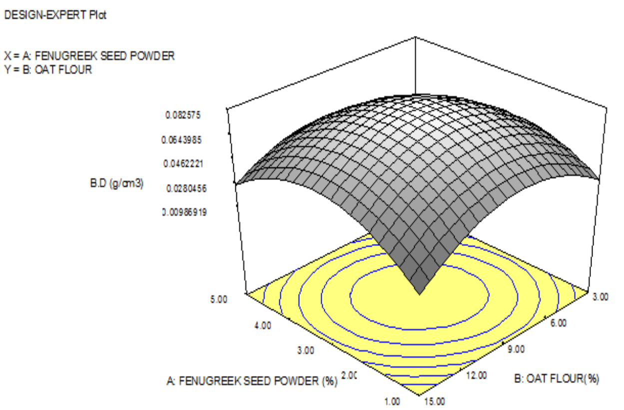

Figure 1: Counters plot for bulk density of extruded product as affected by propration of fenugreek seed powder and oat flour.

Lateral expansion (Table 4, Figure.2)

Lateral exapansion of extruded product ranged from 187.10% to 232.72%. The resulting polynomial equation (8).

L.E.= +187.75 +3.16* A +0.70* B +3.84* A^2 +5.34* B^2 +0.13*A*B ....(8)

In linear term, fenugreek seed powder (A) and oat flour (B) were found to be significant (P<0.05). F-value for linear terms fenugreek seed powder (A) and Oat flour(B) were 13.28 and 0.65 and P-value was found to be 0.0108 and 0.4486(P<0.05) respectively form table 4, validating that terms were significant. Quadratic terms of fenugreek seed powder (A^2) and oat flour (B^2) had shown significant effect (P<0.05) .F-value for quadratic terms fenugreek seed powder (A^2) and oat flour (B^2) were 15.72 and 30.38 and p-value was found to be 0.0074 and 0.0015 (P<0.05) respectively. The interaction term form fenugreek seed powder and oat flour (AB) gave significant effect P-value was found to be 0.9221 (P<0.05) and it shows the negative effect on the interaction term and F-value found to be 0.010 in table 4.

Counter plots shows the effect of fenugreek seed powder and oat flour on L.E.R. is showed in Figure.2 as fenugreek seed powder content product was increased then lateral expansion of the extruded product was found to be increased and oat flour content of the extruded product was increased then lateral expansion of the extruded product was found to be increased.

Table 4: Anova of lateral expansion effects of fenugreek seed powder and oat flour

Response	Source	DF	Sum of Squares	Mean squares	F-value	P-value
L.E.R.	Regression	5	317.97	63.59	10.57**	0.0062
	A	1	79.87	79.87	13.28**	0.0108
	B	1	3.94	3.94	0.65	0.4486
	A^2	1	94.55	94.55	15.72**	0.0074
	B^2	1	182.75	182.75	30.38**	0.0015
	AB	1	0.062	0.062	0.010	0.9221
	Pure error	3	10.25	3.416		
	Lack of fit	3	25.83	8.611	2.52	0.2339
	Residual	6	36.08	6.013		
	Total	11	354.06			
R^2=0.9124 *Significant at P < 0.1, **Significant at P < 0.05,						

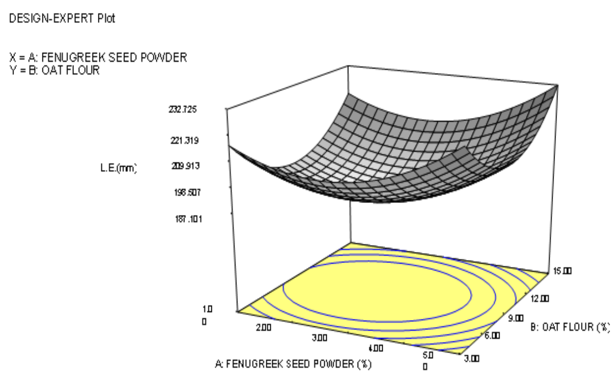

Figure 2: Counters plot for L.E. of extruded product as affected by propration of fenugreek seed powder and oat flour.

Water Absorption index (WAI) (Table 5, Figure.3)

W.A.I. of extruded product ranged from 1.1077 to 2.6885%. The resulting polynomial equation (9).

W.A.I. =+2.49 -0.006485* A +0.055* B -0.67 *A^2 -0.61* B ^{2}-0.034*A*B ………(9)

Fenugreek seed powder (A) and oat flour (B) were found to be non-significant ($P<0.05$) respectively F-value for linear terms fenugreek seed powder (A) and Oat flour (B) were 0.0069 and 0.50 and P-value was found to be 0.9362 and 0.5078 shows non-significant effect respectively with ($P<0.05$) respectively table 5. Quadratic terms of fenugreek seed powder (A^2) and oat flour (B^2) had shown significant model ($P<0.05$). F-value for quadratic terms fenugreek (A^2) and oat (B^2) were 59.92 and 49.74 and p- value was found to be 0.0002 and 0.0004 shown significant ($P<0.05$) respectively. The interaction term form fenugreek seed powder and oat flour (AB) gave significant effect P-value was found to be 0.7657 ($P<0.05$) and it shows the positive effect on the interaction term. F-value found to be 0.097 in table 5.

Counter plots shows the effect of fenugreek seed powder and oat flour on W.A.I. is showed in Figure.3 as fenugreek seed powder content of extruded product increased then W.A.I. decreased and oat flour of the extruded product increased W.A.I. increased.

Table 5: Anova of hardness showing effect on fenugreek seed powder and oat flour

Response	Source	DF	Sum of Squares	Mean squares	F-value	P-value
W.A.I.	Regression	5	4.44	0.89	18.42**	0.0014
	A	1	0.00033	0.00033	0.0069	0.9362
	B	1	0.024	0.024	0.50	0.5078
	A^2	1	2.89	2.89	59.92**	0.0002
	B^2	1	2.40	2.40	49.74**	0.0004
	AB	1	0.00469	0.00469	0.097	0.7657
	Pure error	3	0.25	0.085		
	Lack of fit	3	0.034	0.011	0.13	0.9329
	Residual	6	0.29	0.048		
	Total	11	4.73			

R^2=0.9388 *Significant at P < 0.1, **Significant at P < 0.05

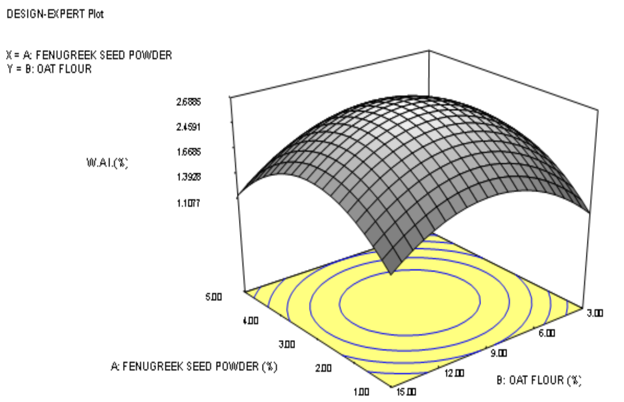

Figure 3: Counters plot for WAI of extruded product as affected by proportion of fenugreek seed powder and oat flour

Water Solubility Index (WSI) (Table 6, Figure.4)

W.S.I. of extruded products ranged from 2.967 to 4.4372 The resulting polynomial equation (10).

W.S.I.14% = +4.44 -0.039*A -0.035*B -0.14*A^2 -0.14*B^2 -0.057*A*B ……(10)

Fenugreek seed powder (A) and oat flour (B) were found to significant ($P<0.05$). F- value for linear terms fenugreek seed powder (A) and Oat flour (B) were 1.95 and 1.58 and P-value was found to be 0.2122 and 0.2559 shows non-significant effect respectively with ($P<0.05$) table 6. Quadratic terms of fenugreek seed powder (A^2) and oat flour (B^2) had shown significant model ($P<0.05$) .F-value for quadratic terms fenugreek (A^2) and oat (B^2) were 19.81 and 19.10 and p- value was found to be 0.0043 and 0.0047 respectively shown significant ($P<0.05$) effect. The interaction term for fenugreek seed powder and oat flour (AB) gave non-significant effect since P-value was found to be 0.1951($P<0.05$) and it shows the negative effect on the interaction term. F-value found to be 2.13.

Counter plots shows the effect of fenugreek seed powder and oat flour on W.S.I. is showed in Figure.4 as fenugreek seed powder content of the extruded product was increased then water solubility index of the extruded product was decreased and oat flour content of the extruded product was increased then water solubility index of the extruded product was decreased.

Table 6: Anova of hardness showing effect on fenugreek seed powder and oat flour

Response	Source	DF	Sum of square	Mean squares	F-value	P-value
W.S.I.	Regression	5	0.24	0.012	7.62**	0.0141
	A	1	0.012	0.012	1.95	0.2122
	B	1	0.0098	0.0098	1.58	0.2559
	A^2	1	0.12	0.12	19.81**	0.0043
	B^2	1	0.12	0.012	19.10**	0.0047
	AB	1	0.013	0.013	2.13*	0.1951
	Pure error	3	0.0003	0.0001		
	Lack of fit	3	0.037	0.012	123.40**	0.0012
	Residual	6	0.037	0.0062		
	Total	11	0.27			
R^2=0.9780 *Significant at P < 0.1, **Significant at P < 0.05						

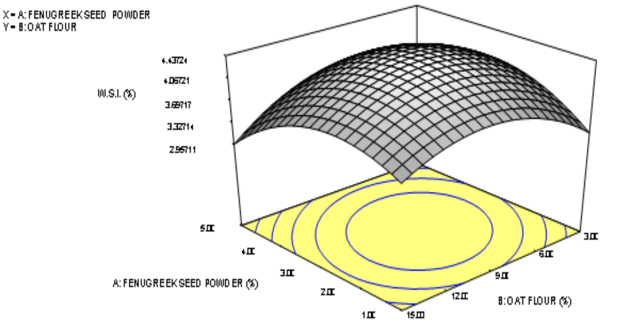

Figure 4: Counter plot for W.S.I. of extruded product as affected by proportion of fenugreek seed powder and oat flour

Specific length (Table 7, Figure.5)

Sp. length of extruded products ranges from 17.75 to 89.525 mm. The resulting polynomial equation (11).

S.L.14% = +89.53 +1.29* A -0.39* B -7.55* A^2 - 6.77* B^2 +2.78*A*B ....(11)

Fenugreek seed powder (A) and Oat flour (B) were found to significant (P<0.05). F- value for linear terms of fenugreek seed powder (A) and Oat flour (B) were 8.31 and 0.77 and P-value was found to be 0.0279 and 0.4126 shows significant effect respectively at (P<0.05) table 7. F-value for quadratic terms fenugreek (A^2) and oat (B^2) were 227.22 and 182.97 and p- value was found to be <0.0001 and <0.0001 respectively which shown significant effect (P<0.05). The interaction term for fenugreek seed powder and oat flour (AB) have p-value 0.0047 gave significant effect (P<0.05) and it shows the negative effect on the interaction term. F-value found to be 19.18. Counter plots shows the effect of fenugreek seed powder and oat flour on S.L. is showed in Figure.5 as fenugreek seed powder content of extruded product increases and oat flour content of the extruded product was increased then specific length of the extruded product was decrease significantly.

Table 7 Anova of hardness showing effect on fenugreek seed powder and oat flour

Response	Source	DF	Sum of Squares	Mean squares	F-value	P-value
Sp.Length	Regression	5	595.01	119.00	74.12**	< 0.0001
	A	1	13.35	13.35	8.31**	0.0279
	B	1	1.24	1.24	0.77	0.4126
	A^2	1	364.82	364.82	227.22**	< 0.0001
	B^2	1	293.76	293.76	182.97**	< 0.0001
	AB	1	30.80	30.80	19.18**	0.0047
	Pure error	3	0.0075	0.0025		
	Lack of fit	3	9.63	3.21	1283.45**	< 0.0001
	Residual	6	9.63	1.61		
	Total	11	604.64	957.96		
R^2=0.9841 *Significant at P < 0.1, **Significant at P < 0.05						

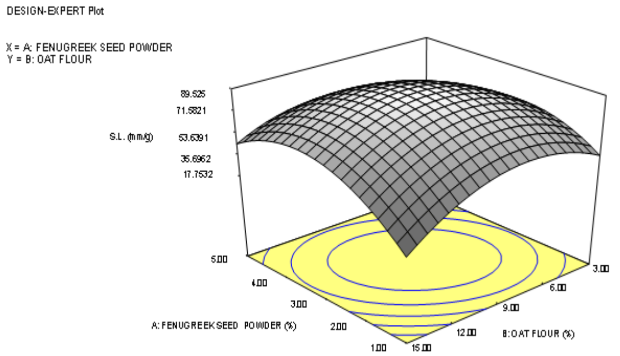

Figure 5: Counters plot for SL of extruded product as affected by proportion of fenugreek seed powder and oat flour.

Expansion ratio (Table 8, Figure.6)

Expansion ratio of extruded products ranges from 0.0075 to 0.0088mm. The resulting polynomial equation (12).

E.R.= +0.080 -0.00082*A +0.0014*B +0.0039*A^2 - 0.00078*B -0.003150*A*B .....(12)

Fenugreek seed powder (A) and Oat flour (B) were found to significant (P<0.05). In linear term, fenugreek seed powder (A) and Oat flour (B) were found to be significant (P<0.05). F- value for linear terms fenugreek seed powder (A) and Oat flour (B) were 1.49 and 4.36 and P-value was found to be 0.2686 and 0.0819 (P<0.05) respectively. Form table 8, validating that terms were significant. Quadratic terms of fenugreek seed powder (A^2) and oat flour (B^2) had shown non-significant effect. F-value for quadratic terms fenugreek seed powder (A^2) and oat flour (B^2) were 27.43 and 1.08 and p- value was found to be 0.0019 and 0.3381 (P>0.05) respectively. The interaction term form fenugreek seed powder and oat flour (AB) gave significant effect P-value was found to be 0.0166 (P<0.05) and it showed the positive effect on the interaction term. F-value found to be 10.83.

Counter plots shows the effect of fenugreek seed powder and oat flour on E.R. is showed in Figure.6 as fenugreek seed powder content of the extruded product was increased then expansion ratio of the extruded product was decreased and oat flour increased then the expansion ratio of extruded product was increased.

Table 8: Anova of hardness showing effect on fenugreek seed powder and oat flour

Response	Source	DF	Sum of square	Mean squares	F-value	P-value
E.R.	Regression	5	0.000178	0.0000356	9.729106	0.0076
	A	1	0.0000054	0.0000054	1.48617	0.2686
	B	1	0.000016	0.000016	4.356109	0.0819
	A^2	1	0.0001	0.0001	27.42769	0.0019
	B^2	1	0.0000039	0.0000039	1.083308	0.3381
	AB	1	0.000039	0.000039	10.83308	0.0166
	Pure error	3	0.0000071	0.0000024		
	Lack of fit	3	0.0000148	0.0000049	2.058459	0.2842
	Residual	6	0.000022	0.0000036		
	Total	11	0.0002			
R^2=0.8902 *Significant at P < 0.1, **Significant at P < 0.05						

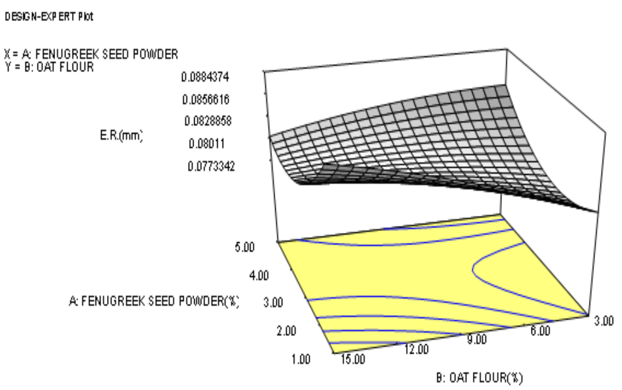

Figure 6: Counters plot for E.R. of extruded product as affected by proportion of fenugreek seed powder and oat flour

Optimization

A numerical multi-response optimization technique was applied (Park *et al.,* 1993) to determine the optimum combination of fenugreek seed powder and oat flour.

Compromised optimum condition for experiment

The assumptions were to develop a product which would have maximum score in Overall acceptability so as to get market value and acceptance, minimum bulk density, maximum lateral expansion, minimum WAI, minimum WSI, maximum specific length and maximum expansion ratio. Therefore, among responses, these parameters were attempted to be maintained whereas other parameters were kept within range. Under these criteria, the uncoded optimum operating conditions for development of fenugreek seed powder and oat flour extruded snack were 118°C of barrel temperature, 250 rpm of screw speed, 14% of feed moisture 2.28% fenugreek seed powder and 4.76 oat%. The responses predicted by the design expart-6 software for these optimum process conditions.

Table 9: Multi response optimization constraints of experiment

Parameters	Goal	Lower limit	Upper limit	Lower Weight	Upper Weight	Importance
Fenugreek seed powder	is in rang	1.586	40414	1	1	3
Oat flour	is in range	4.758	13.242	1	1	3
BD	minimize	0.0614	0.0862	1	1	3
LER	maximize	188.5	201	1	1	3
WAI	minimize	1.101	2.284	1	1	3
WSI	minimize	4.01	4.84	1	1	3
S.L	Maximize	70.1	89.6	1	1	3
E.R.	Maximum	0.075	0.088	1	1	3

Verification of Results

The suitability of the model developed for predicting the optimum response values was tested using the recommended optimum conditions of the variables and was also used to validate experimental and predicted values of the responses.

Table 10: Optimized condition for experiment

Process variable	Fenugreek seed flour	Oat flour	Screw speed	Tempera ture
Uncoad ed	2.28 %	4.76 %	250 rpm	118°C

Table 11: Predicted and actual values of the responses at the optimized condition of experiment

Responses	Predicted value	Actual value	Variation %
BD	0.06520	0.059	9.50%
LER	197.021	185.000	6.10%
WAI	0.81136	1.58	9.47%
WSI	4.01015	3.665	8.60%
S.L	74.5413	71.1	4.61%
E.R.	0.079	0.0756	4.30%

Conlusion

By applying RSM to find out the effects of fenugreek seed flour and oat flour on different responses used in RSM, As fenugreek seed powder and oat flour contents increases then similarly, lateral expansion increased and water solubility index decreased and show a significant effects ($P<0.05$). Similarly developed antioxidants rich extruded product by supplement with fenugreek seed powder and oat flour.

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