Development of flaxseed fortified rice – corn flour blend based extruded product by response surface methodology

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Abstract Flaxseed imparted the evidence of health benefits in human being. Response surface methodology (RSM) was employed to develop flaxseed fortified rice – corn flour blend based extruded product using twin screw extruder. The effect of roasted flaxseed flour (RFF) fortification (15–25 %), moisture content of feed (12–16 %, wb), extruder barrel temperature (120–140 °C) and screw speed (300–330 RPM) on expansion ratio (ER), breaking strength (BS), bulk density (BD) and overall acceptability (OAA) score of extrudates were investigated using central composite rotatable design (CCRD). Increased RFF level decreased the ER and OAA score significantly while increased BS and BD of extrudates ($p < 0.01$). Moisture content of extruder feed was positively related to ER ($p < 0.01$) and OAA ($p < 0.05$) and negatively related to BD ($p < 0.01$). Extruder barrel temperature was found to be negatively related to ER and OAA ($p < 0.05$) and positively related to BD ($p < 0.1$). Quadratic effect of screw speed was significantly positively related to ER ($p < 0.01$), BS ($p < 0.05$) and negatively related to BD ($p < 0.01$). 15 % RFF fortification with rice flour, 16 % moisture content (wb) of extruder feed, 120 °C extruder barrel temperature and 330 RPM of screw speed gave an optimized product of high desirability with corresponding responses as 3.08 ER, 0.53 kgf BS, 0.106 g.cm⁻³ BD and 7.86 OAA.

Keywords BD · BS · ER · Extruded product · Flaxseed · OAA · RSM

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Introduction

Extrusion process offers the combination of high throughput rates, energy efficiency and versatility, results in the potential for improved cost effectiveness and process rationalization over traditional production methods. Extrusion combines a number of unit operations i.e. mixing, cooking, shearing, puffing, final shaping and drying in one energy efficient rapid continuous process (Harper 1989) and can be used to produce a wide variety of starchy foods including snacks, ready to eat (RTE) cereals, confectioneries and extruded crisp breads (Suknark et al. 1997). Guy (2001) found that the ability of extruders to blend diverse ingredients in novel foods can also be exploited in the developing functional food. Cereals are usually fortified with legumes to overcome the deficiency of certain amino acids. Several researchers reported on cereals-legumes blend based extruded products (Chakraborty and Banerjee 2009; Asare et al. 2012) and commercial products are also available. The most widely consumed extruded snacks are made primarily with cereals/grains due to their good expansion characteristics; however, they tend to be low in protein, fiber and other nutrients. Hence, there is an increasing consumer demand for more nutritious snacks (Meng et al. 2010). To develop nutritious snack food, food professionals are always trying to explore the different crops ability. Flaxseed is emerged as functional ingredient in last two decades owing to its higher alpha linolenic acid (ALA ω -3 fatty acid) dietary fiber, protein and lignan content (Ganorkar and Jain 2013; Oomah and Mazza 1999; Tarpila et al. 2005; Morris 2007). Whole flaxseed, defatted meal and its oil imparted health benefits like hypocholesterolaemic, hypoglycemic, atherosclerosis prevention (Ranhotra et al. 1992; Ratnayake et al. 1992; Cunnane et al. 1993; Arjmandi et al. 1998; Prasad et al. 2000; Lemay et al. 2002; Prasad 2005; Tzang et al. 2009). Flaxseed has been incorporated into baked goods (Pohjanheimo et al.

2006; Chetana et al. 2010; Rajiv et al. 2012), dairy products (Hall and Schwarz 2002; Hall et al. 2004), dry pasta and macaroni products (Lee et al. 2004; Hall et al. 2005), flaxseed chutney (Rao et al. 2013), flaxseed chikki (Chetana 2011). Moreover, effects of flaxseed meal incorporation on corn meal extrudates, lignan residue and physical properties were reported (Wu et al. 2007). However, there is a dearth of literature on utilization of flaxseed in rice - corn flour based extruded product and its effect on extrudates characteristics.

Extrusion cooking modeling for quality changes involves numerous process input parameters and multiple product output properties. The response surface methodology (RSM) is a mathematical and statistical approach which has been widely used for optimizing the response of multivariate parameters during modeling of extrusion processing (Ganjyal et al. 2003; Shihani et al. 2006; Seth and Rajamanickam 2012). Considering the potential of flaxseed as functional ingredient, the present investigation is undertaken with the objective to develop nutritionally enhanced flaxseed fortified extruded product by RSM.

Materials and methods

Raw materials Flaxseed (Variety NL 260) were obtained from College of Agriculture, Nagpur, India and used for this investigation. Rice flour and corn flour were procured from local market.

Preparation of flours and blending Flaxseed were roasted in Kenstar microwave oven (Model OM-34 ECR) at 480 W for 5 min to reduce cyanogenic glycosides (CG) content and to develop nutty flavour. Roasted flaxseed were ground to powder in domestic mixer (M/s Sumeet Mixer Model DXE plus) for 2 min and sieved through 40 mesh screen to obtain RFF. Chemical composition like moisture content, ash, crude protein, crude fat and crude fiber of RFF, rice and corn flour were carried out by standard methods (AOAC 2000). CG content in RFF was determined by AOAC official method 915.03 (part B, alkaline titration method). Carbohydrate content is estimated by difference method. Extruder feed blends were obtained according to the experimental design at three level combinations. RFF was fortified with the substitution of rice flour in rice—corn flour blend (3:1). All the flour blends were mixed in ribbon type blender. The moisture content of each flour blend was estimated by Infra-red moisture analyzer (M/s Advance Research Equipment Co., New Delhi). The flour blend was hydrated to achieve required moisture content level (Table 1) by adding calculated amount of water to the feed. Mass of water to be added was calculated by using following equation (Oluwale and Olapade 2011 modified for wet basis). The flour blend

was then kept in polyethylene bags for 24 h at 4 °C for uniform distribution of moisture.

$$Q = \frac{A(M_f - M_i)}{(1 - M_f)} \quad (1)$$

Where, A = Initial mass of the blend; M_i = Initial fraction of moisture content (wb) of the blend; M_f = Desired fraction of moisture content (wb) of the blend; Q = Mass of water to be added (kg)

Extrusion The prepared RFF- rice – corn flour blends were extruded in a co-rotating intermeshed twin screw extruder (M/s Basic Technology Pvt. Ltd., Kolkata, India). Two screws were 30 mm in diameter and 350 mm long. Thus, the length to diameter ratio of the screws was 11.66:1. The screw had constant pitch of 20 and 3.5 mm flight. Parameters i.e. feeder rpm 25, second heater temperature 60 °C and extruder die of 4 mm diameter were kept constant throughout the investigation. During each extruder run, the machine was allowed to stabilize for 5 min until a stable torque was achieved. Extrudates were collected on stainless steel plate to allow excess steam flash off.

Response surface methodology RSM was used to generate the experimental designs, statistical analysis and regression model with the help of Design Expert Software Version 8 (Statease Inc.). The CCRD with a quadratic model (Box and Draper 1987) was employed. Four independent variables namely RFF fortification (%), moisture content of extruder feed (%), temperature of extruder barrel (°C) and screw speed (RPM) were chosen. Preliminary trials were conducted to decide the level of each independent variable. Each independent variable had 3 levels which were −1, 0 and +1. A total of 30 different combinations including six replicates of the centre point each signed the coded value (0) were chosen in random order according to a CCRD configuration for three factors divided in three blocks (Cochran and Cox 1957). The α - values in the design outside the ranges were selected for rotability of the design (Thompson 1982). The experimental design in the coded (x) and actual (X) levels of variables is shown in Table 1. The responses function (y) measured were expansion ratio (ER), breaking strength (BS), bulk density (BD) and overall acceptability (OAA) of extruded product. Results were means of three replicates. These values were related to the coded variables (x_i , $i = 1, 2, 3$ and 4) by a second degree polynomial using the equation below.

$$y = b_0 + b_1x_1 + b_2x_2 + b_3x_3 + b_4x_4 + b_{12}x_1x_2 + b_{13}x_1x_3 + b_{14}x_1x_4 + b_{23}x_2x_3 + b_{24}x_2x_4 + b_{34}x_3x_4 + b_{11}x_1^2 + b_{22}x_2^2 + b_{33}x_3^2 + b_{44}x_4^2 \quad (2)$$

The coefficients of the polynomial were represented by b_0 (constant terms), b_1 , b_2 , b_3 and b_4 (linear effects), b_{11} , b_{22} , b_{33}

Table 1 The effect of independent variables on the response functions for developing flaxseed fortified extruded product

Run	Type	RFF (%) $X_1 (x_1)$	Moisture content (% wb) $X_2 (x_2)$	Temp. (°C) $X_3 (x_3)$	Screw speed (RPM) $X_4 (x_4)$	(ER)	BS (kgf)	BD (g/cm ³)	OAA
1	Axial	20 (0)	10 ($-\alpha$)	130 (0)	315 (0)	2.434	0.783	0.138	6.7
2	Factorial	15 (-1)	12 (-1)	140 ($+1$)	330 ($+1$)	2.649	1.151	0.123	6.9
3	Factorial	25 ($+1$)	12 (-1)	140 ($+1$)	300 (-1)	2.143	0.631	0.146	5.6
4	Axial	10 ($-\alpha$)	14 (0)	130 (0)	315 (0)	3.265	0.688	0.095	8.2
5	Center	20 (0)	14 (0)	130 (0)	315 (0)	2.31	0.681	0.141	6.7
6	Factorial	15 (-1)	16 ($+1$)	120 (-1)	300 (-1)	3.061	0.899	0.103	7.8
7	Axial	20 (0)	14 (0)	110 ($-\alpha$)	315 (0)	2.564	0.730	0.127	6.8
8	Factorial	15 (-1)	12 (-1)	120 (-1)	330 ($+1$)	2.651	1.142	0.124	6.7
9	Factorial	25 ($+1$)	12 (-1)	140 ($+1$)	330 ($+1$)	2.543	1.137	0.135	5.8
10	Center	20 (0)	14 (0)	130 (0)	315 (0)	2.187	0.913	0.146	6.6
11	Factorial	15 (-1)	16 ($+1$)	140 ($+1$)	330 ($+1$)	2.815	0.519	0.109	6.8
12	Factorial	25 ($+1$)	12 (-1)	120 (-1)	330 ($+1$)	2.523	1.279	0.136	5.9
13	Factorial	15 (-1)	12 (-1)	140 ($+1$)	300 (-1)	2.79	0.661	0.115	7
14	Axial	20 (0)	18 ($+\alpha$)	130 (0)	315 (0)	2.872	0.921	0.114	7.2
15	Center	20 (0)	14 (0)	130 (0)	315 (0)	2.211	0.749	0.140	6.7
16	Axial	20 (0)	14 (0)	130 (0)	345 ($+\alpha$)	2.758	0.914	0.118	7.3
17	Axial	30 ($+\alpha$)	14 (0)	130 (0)	315 (0)	2.587	1.313	0.125	5.8
18	Factorial	15 (-1)	12 (-1)	120 (-1)	300 (-1)	2.701	0.641	0.119	6.9
19	Axial	20 (0)	14 (0)	150 ($+\alpha$)	315 (0)	1.7	0.669	0.171	5.3
20	Center	20 (0)	14 (0)	130 (0)	315 (0)	2.21	0.801	0.142	7.1
21	Factorial	25 ($+1$)	16 ($+1$)	120 (-1)	330 ($+1$)	2.775	0.968	0.121	6
22	Center	20 (0)	14 (0)	130 (0)	315 (0)	2.485	0.765	0.131	6.8
23	Factorial	15 (-1)	16 ($+1$)	120 (-1)	330 ($+1$)	3.226	0.562	0.104	8.1
24	Factorial	25 ($+1$)	16 ($+1$)	120 (-1)	300 (-1)	2.809	1.283	0.110	6.4
25	Factorial	25 ($+1$)	16 ($+1$)	140 ($+1$)	330 ($+1$)	2.73	0.793	0.119	6.6
26	Axial	20 (0)	14 (0)	130 (0)	285 ($-\alpha$)	2.725	1.000	0.119	6.2
27	Factorial	25 ($+1$)	16 ($+1$)	140 ($+1$)	300 (-1)	2.755	0.991	0.124	6.1
28	Factorial	25 ($+1$)	12 (-1)	120 (-1)	300 (-1)	2.029	0.621	0.162	6.1
29	Center	20 (0)	14 (0)	130 (0)	315 (0)	2.207	0.665	0.142	6.4
30	Factorial	15 (-1)	16 ($+1$)	140 ($+1$)	300 (-1)	2.91	0.848	0.105	7.1

X_1 , X_2 , X_3 and X_4 represents uncoded values and values in bracket i.e. x_1 , x_2 , x_3 and x_4 represents the coded values for respective factors

and b_{44} (quadratic effects) and b_{12} , b_{13} , b_{14} , b_{23} , b_{24} and b_{34} (interaction effects). The analysis of variance (ANOVA) tables were generated and the effect and regression coefficients of individual linear, quadratic and interactions terms were determined. The significances of all terms in the polynomial were judged statistically by computing the F- value and compared with standard significance level of 0.1 %, 1 % and 5 %.

All generated models adequately explain the variation of responses with R^2 values, non-significant lack of fit that is a measure of failure of a model to represent data in the experimental design at which points were not include in the regression.

Extrudate Product characteristics

Expansion ratio (ER) ER was measured as the ratio of cross sectional area of the cylindrical extrudate to that of the die (4 mm) (Chakraborty et al. 2009). The diameter of the extrudates was the average of ten random measurements.

Bulk density (BD) Cylindrical section was weighed and the diameter measured using vernier caliper. BD was then calculated as the ratio of the weight of extrudate to the volume of extrudate (Barret and Peleg 1992).

$$BD = \frac{4w}{\pi d^2 L} \quad (3)$$

Where w is weight in gram, d is diameter of the extrudate (cm) and L is length (cm). Ten pieces of extruded product were randomly selected and average was reported.

Breaking strength (BS) BS was measured by using Texture analyzer (M/s Lloyd Instruments Ltd., Hampshire UK, Model TA Plus). Warner—Bratzler cutting blade in snap test setup was used. Probe speed of 2 mm/s, trigger force of 0.1 N and limit of 15 mm were set parameters in snap test. Breaking strength can be well correlated with textural attributes of the product. Breaking strength in kgf was then calculated as mean of ten random determinations (Ilo et al. 1999).

Overall acceptability score (OAA) OAA was given on 9-point hedonic scale ranging from extremely dislike (1) to extremely like (9) (Ranganna 2000). Ten semi trained panelist evaluated each extruder run product. Mean value of each sample score was reported.

Results and discussion

The proximate composition of RFF, rice and corn flour are presented in Table 2. The reported values are mean of triplicate samples with standard deviations.

Model fitting The effects of independent variables on response variables ER, BS, BD and OAA are presented in Table 1. The independent and response variables were fitted to the second order model and examined for the goodness of fit. Coefficient of determination or R^2 is the proportion of variation in the response due to the model than to random error and was suggested that for good fit model. R^2 should be at least 80 % (Gan et al. 2007). The obtained R^2 in all response variables were adequate as they are found to be more than 80 %. There is no significant lack of fit in all response variables. Therefore, the proposed models can be suitably used for the prediction at any values of the parameters within experimental range.

Table 2 Proximate composition of RFF, rice and corn flour

Parameter	RFF	Rice flour	Corn flour
Moisture (%), wb	3.62±0.76	11.25±0.56	9.88±0.48
Ash (%)	4.10±0.31	0.08±0.02	1.04±0.06
Crude fat content (%)	44.33±0.73	1.10±0.26	1.63±0.04
Crude protein (%)	21.10±0.75	6.23±0.18	11.76±0.57
Crude fiber (%)	12.33±0.55	0.26±0.06	3.84±0.46
Carbohydrate* (%)	26.84±1.87	82.08±1.08	71.85±1.61
CG content (mg/100 g)	36.10±0.90	—	—

*Carbohydrate content is estimated by difference method

Expansion ratio (ER) Expansion is an important characteristic of extruded product being developed as a snack and RTE by food industries (Asare et al. 2012). The ER measured for all experimental samples ranged from 1.7 to 3.265 for RFF – rice – corn blend systems (Table 1). The data presented in Table 3 showed that ER was negatively related to linear effects of roasted flaxseed flour (RFF) fortification level and positively related to linear effect of moisture content ($p<0.01$). Similarly it is positively related to quadratic effects of RFF level, moisture content and screw speed ($p<0.01$) and negatively related to linear effect of barrel temperature ($p<0.05$). The regression models developed to predict the ER could explain 87.52 % of the variations (Table 3). RFF and moisture content were found to be more effective variable as their linear and quadratic effect are significant at $p<0.01$. It is evident from Fig. 1 that as RFF fortification increased, ER of extruded product decreased. This could be due to high fibre, and protein content of flaxseed that may affect the starch gelatinization. Non starch polysaccharides in the fibre may bind water more tightly during extrusion than do protein and starch. This binding may inhibit water loss at the die and thus reduces the expansion. These findings are well in line with the results reported by Seth and Rajamanickam (2012), Mahasukhonthachat et al. (2010) and Pai et al. (2009). Moreover, fat content of flaxseed provides a lubricant effect in extrusion which reduces the mechanical energy dissipation and tends to protect the dispersal of starch granules of low moisture foods. This reduces the amount of gelatinised starch in the melted material and prevents extrudate expansion (Ilo et al. 1999). The response surface plot (Fig. 1) revealed that as the moisture content increased from 12 to 16 %, ER increased. This is attributed to the viscosity of the starch would be low at high moisture content, allowing for extensive internal mixing and uniform heating which would account for enhanced starch gelatinization (Lawton and Handerson 1972). Similar results are reported for extrusion of rice with pea grit by Singh et al. (2007). The negative effect of temperature on ER can be attributed to the decrease in melt viscosity with increasing temperature (Launay and Lisch 1983) and also to dextrinization and weakening of starch structure (Mendonca et al. 2000).

Breaking strength (BS) The BS indicating texture of the extrudates varied between 0.519 and 1.313 kgf (Table 1). The regression models developed to predict the BS could explain 90.16 % of the variations (Table 3). BS was positively significantly related to the linear and quadratic effect of RFF fortification at $p<0.01$ (Table 3). It is negatively related to the interaction effect of moisture content and screw speed ($p<0.01$). Quadratic effect of screw speed and interaction effect of flaxseed and moisture content were found significantly positively related ($p<0.05$). It is evident from Fig. 2 that BS was increased as the RFF fortification level increased. This might be due to high fiber and protein content of flaxseed

Table 3 Results of regression analysis of extruded product

Parameters	Estimated regression coefficients			
	ER	BS (kgf)	BD ($\text{g}\cdot\text{cm}^{-3}$)	OAA
Intercept (b_0)	2.27	0.7624	0.1403	6.7166
RFF, % (b_1)	−0.160*	0.0105*	0.0087*	−0.5666*
Moisture content, % (b_2)	0.163*	−0.0050	−0.0088*	0.2083**
Temperature, °C (b_3)	−0.090**	−0.0326	0.0035***	−0.2083**
Screw speed, RPM (b_4)	0.033	0.0334	−0.0006	0.0833
b_{11}	0.180*	0.0604*	−0.0081*	0.0583
b_{22}	0.110*	0.0233	−0.0041**	0.0458
b_{33}	−0.021	−0.0148	0.0015	−0.1791**
b_{44}	0.130*	0.0496**	−0.0060*	−0.0041
b_{12}	0.038	0.0707**	−0.0028	−0.0375
b_{13}	0.032	−0.0334	−0.0004	0.0875
b_{14}	0.060	0.0203	−0.0030	0.0250
b_{23}	−0.055	−0.0285	0.0025	−0.0875
b_{24}	−0.043	−0.2082*	0.0021	0.0250
b_{34}	−0.027	−0.0023	0.0003	0.05
R^2	0.8752	0.9016	0.8545	0.8448
P -value for quadratic model	0.0002	<0.0001	0.0005	0.0008
P -value for model lack of fit	0.1264	0.4234	0.0519	0.0933
Mean	2.59	0.86	0.130	6.65
SD	0.17	0.098	0.0092	0.37

*Significant at 0.01 level, **Significant at 0.05 level, ***Significant at 0.1 level

which reduces the expansion; product became less porous and perhaps due to aggregation of protein molecules. Moreover, microstructure of extruded product would have been strengthening for better understanding of ER and BS.

Fig. 1 Response Surface for Expansion Ratio as a function of flaxseed fortification and moisture content at Barrel temperature 130 °C and screw speed of 315 RPM

Generally, product cell wall thickness appears to correspond well with product texture; the thicker the cell walls, the higher the shear force (Jin et al. 1995). Increased RFF produced more compact extrudates with thick cell walls and small air cell size, hence higher BS was observed. Wu et al. (2007) also reported the increase in the hardness of the product as flaxseed increased from 5 to 15 % in flaxseed-corn puff. . A

Fig. 2 Response Surface for Breaking strength as a function of flaxseed fortification and moisture content at Barrel temperature 130 °C and screw speed of 315 RPM

more expanded product would take less force to shear and hence had a lower BS and vice versa. Ilo et al. (1999) reported similar results for rice and amaranth blend extrusion. Increasing amaranth content caused an enormous decrease in expansion and an increase in the BS. Figure 3 shows the interaction effect of moisture content and screw speed. This interaction effect is found significant ($p<0.01$). This interaction is negatively affected on the BS of extruded product. As the moisture content and screw speed increased, BS value also increased. This might be due to higher moisture content drops down the blend temperature (Liu et al. 2000). Higher screw speed reduces the retention time of the blend in the extruder cooking zone. Moreover, increasing the screw speed increased the shear rate and the potential for mechanical damage to food molecules. These damaged starches were characteristically less cohesive than gelatinized, undamaged starch. Consequently, they expanded less, creating products with small pores. Consequently, it affected on BS (Jin et al. 1995).

Bulk density (BD) BD has been linked with the expansion ratio in describing the degree of puffing in extrudates. A high bulk density is associated with a low expansion index (Rayas-Duarte et al. 1998; Suknark et al. 1997) because more compact material is obtained after milling a less expanded product (Onyango et al. 2004). The BD measured for all experimental extrudates ranged from 0.095 to 0.171 g.cm⁻³ in RFF – rice – corn blend systems (Table 1). The regression models developed to predict the BD could explain 85.45 % of the variations (Table 3). It is evident from the data (Table 3) that bulk density was influenced by linear effect of RFF fortification and moisture content ($p<0.01$). It is also influenced by linear effect of barrel temperature ($p<0.10$). Negative significant quadratic effect of RFF fortification and screw speed were observed

($p<0.01$). Moreover, BD is also negatively affected by the quadratic effect of moisture content ($p<0.05$). As the RFF fortification level increased, BD increased (Fig. 4). RFF fortification was an important variable in the response surface model of product BD as its linear and quadratic terms was significant at $p<0.01$ level. The minimum BD (0.095 g.cm⁻³) of product was observed at lowest flaxseed fortification level (10 %). This is due to the negative impact on the starch gelatinization and also protein aggregation. These results are well in agreement with the results reported by Yagci and Gogus (2008) for extruded snack food products developed from fruit waste fibers. As the value of feed moisture content increased the value of bulk density decreased and vice versa. The dependence of product density on feed moisture reflects its influence on the rheological characteristics of the starch based material. This is attributed to the higher of amount of non starch polysaccharides tightly bounds the water and do not allow to vaporize at the exit of die. Similar results are reported by Kulkarni and Joshi (1992).

The maximum BD (1.171 g.cm⁻³) of product was observed at higher barrel temperature (150 °C). As the barrel temperature increased, BD was found to increase marginally at 0.10 significant level (Fig. 5). Bulk density increase and porosity decrease at higher extruder temperatures can be attributed to increased dextrinization and weakening of structure (Mendonca et al. 2000). This can also be attributed to decrease in the elasticity of extrusion cooked melts with increasing temperature (Ilo et al. 1999). Results are well in line with the results reported by Chakraborty and Banerjee (2009) for production of expanded product from green gram and rice.

Overall acceptability (OAA) Overall acceptability (OAA) scoring is subjective evaluation (sensory evaluation) for confirming the product acceptability by the consumer. The

Fig. 3 Response Surface for Breaking strength as a function of moisture content and screw speed at Flaxseed fortification 20 % & Barrel temperature 130 °C

Fig. 4 Response Surface for Bulk density as a function of flaxseed fortification and moisture content at Barrel temperature 130 °C and screw speed of 315 RPM

Fig. 5 Response Surface for Bulk density as a function of flaxseed fortification and Barrel temperature at moisture content 14 % and screw speed of 315 RPM

OAA of all obtained extrudates in experimental runs varied from 5.3 to 8.2 (Table 1). The regression models developed to predict OAA could explain 84.48 % of the variations (Table 3). OAA was negatively related to the linear effect of RFF fortification at 0.01 % significant level (Table 3). It was positively related to the linear effect of moisture content ($p < 0.05$). It is negatively related to the linear effect of the barrel temperature ($p < 0.05$). It is also negatively related to the quadratic effect of barrel temperature ($p < 0.05$). It is evident from Fig. 6 that OAA score decreased with increase in RFF level. However, it increased with increase in moisture content. The highest OAA score of 8.2 was found at lowest flaxseed

Fig. 6 Response Surface for OAA as a function of flaxseed fortification and moisture content at Barrel temperature 130 °C and screw speed of 315 RPM

incorporation (10 %) while lowest OAA score of 5.8 at highest RFF fortification (30 %). Porosity / expansion are the dominant quality attributes in extruded product.

Fortification of higher flaxseed and lowering moisture content reduced ER and hardened the product and consequently lowered OAA score. Other reason is nutty flavour of flaxseed which increased at its higher incorporation level. Moisture content was found significantly affecting OAA score at 0.05 significant level. It is evident from Fig. 7 that as the barrel temperature increased, OAA score decreased. This can be attributed to higher dextrinization and formation of mallard reaction end products which ultimately reduced OAA score.

Optimization

Numerical optimization of independent variable levels was carried out for the development flaxseed fortified extruded product. Design Expert (Version 8) of STAT EASE software was used for simultaneous optimization of the responses. All the levels of independent variables were kept in range. Desired goals were assigned for all the parameters for obtaining the numerical optimum values for the responses. Response parameters like ER and OAA were kept maximum while BS and BD were kept minimum. The process variables for the best combination of the responses (Desirability – 0.90) were 15 % RFF fortification with rice flour, 16 % moisture content (wb) of extruder feed, 120 °C extruder barrel temperature and 330 RPM of screw speed. The response functions were calculated from the final polynomial and the response at this optimized combination were ER (3.08), BS (0.53 kgf), BD (0.106 g.cm⁻³) and OAA (7.86).

Fig. 7 Response Surface for OAA as a function of flaxseed fortification and moisture content at Barrel temperature 130 °C and screw speed of 315 RPM

Conclusion

Extrusion of RFF – rice – corn flour blend using RSM – CCRD exhibited the effect of independent variables (RFF level, moisture content, temperature and screw speed) on the response variables (ER, BS, BD and OAA) of extrudates. Among studied independent variables, RFF fortification level was found to be most important variable to varied levels on extrudates characteristics as its linear effect significantly affected on all responses at 0.01 level and then followed by moisture content and barrel temperature. Quadratic effect of screw speed and its interaction effect with moisture content only found to be significantly related. The proposed models found to be statistically valid and can be suitably used to predict responses at values lying in experimental range. The optimum conditions of 15 % RFF fortification with rice flour, 16 % moisture content (wb) of extruder feed, 120 °C extruder barrel temperature and 330 RPM of screw speed were found to be suitable for maximum ER and OAA score with minimum BS and BD. It was demonstrated that flaxseed could be effectively utilized to produce nutritionally enriched rice – corn flour based extruded product by properly selecting extrusion conditions.

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