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ORIGINAL ARTICLE

Defatted flaxseed meal incorporated corn-rice flour blend based extruded product by response surface methodology

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Abstract Considering the evidence of flaxseed and its defatted flaxseed meal (DFM) for human health benefits, response surface methodology (RSM) based on three level four factor central composite rotatable design (CCRD) was employed for the development of DFM incorporated corn – rice flour blend based extruded snack. The effect of DFM fortification (7.5–20 %), moisture content of feed (14–20 %, wb), extruder barrel temperature (115–135 °C) and screw speed (300–330 RPM) on expansion ratio (ER), breaking strength (BS), overall acceptability (OAA) score and water solubility index (WSI) of extrudates were investigated using central composite rotatable design (CCRD). Significant regression models explained the effect of considered variables on all responses. DFM incorporation level was found to be most significant independent variable affecting on extrudates characteristics followed by extruder barrel temperature and then screw rpm. Feed moisture content did not affect extrudates characteristics. As DFM level increased (7.5 % to 20 %), ER and OAA value decreased. However, BS and WSI values were found to increase with increase in DFM level. Based on the defined criteria for numerical optimization, the combination for the production of DFM incorporated extruded snack with desired sensory attributes was achieved by incorporating 10 % DFM (replacing rice flour in flour blend) and by keeping 20 % moisture content, 312 screw rpm and 125 °C barrel temperature.

Keywords Defatted flaxseed meal · Dietary fiber · Extrusion · Protein · Response surface methodology

Introduction

Consumer's view on food previously as hunger satisfaction and providing basic nutrition has dramatically shifted in the last decade towards health protective (maintenance of well being) and preventive against health disorders. In this regard, functional foods have emerged as adjuvant especially in prevention and management of human diseases for maintaining optimum health state. Flaxseed (*Linum usitatissimum L.*) has been gaining popularity as functional food or ingredient due to owing high content of biologically active compounds, their health benefits and disease preventive properties (Ratnayake et al. 1992; Ranhotra et al. 1993; Cunnane et al. 1993; Arjmandi et al. 1998; Prasad 2001; Tolkachev and Zhuchenko 2004; Toure and Xueming 2010; Ganorkar and Jain 2013). Flaxseed is grown globally as oilseed or fiber (linen) crop. World annual production of flaxseed is 24 lacs tones (FAOSTAT 2012). Flaxseed production in India is estimated about 1.3 lacs tones (FAOSTAT 2012). Flaxseed is processed by pressing crushed seed or solvent extraction to extract the oil. Flaxseed oil is well established richest source of omega-3 fatty acid (Morris 2007; Canadian Grain Commission 2009) and therefore it is utilized in food products to enhance the nutritional value. The byproduct of flaxseed oil extraction process is defatted flaxseed meal (DFM). In 2006–2007, World flaxseed meal production was estimated at 1.4 million tons (Agriculture and Agri-Food Canada 2007). DFM contains high amount of dietary fiber, lignan and proteins (Madhusudhan et al. 2000; Mueller et al. 2010). All these compounds possess human health benefits (Hall et al. 2006). Moreover, DFM was reported to have protective ability for

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distal colon of mice from precancerous lesions (Gomides et al. 2013). DFM exhibited broad spectrum of bioactivities along with hypo-cholesterolemic and anti-atherosclerotic effect (Kasote et al. 2011; Prasad 2005). However, this large amount of DFM has not been optimally utilized in human food systems although flaxseed meal has been incorporated into livestock feeds as protein and fiber supplement (Bell and Keith 1993). The low value flaxseed meal that is underutilized in human food systems highlights the need for exploration into value added product especially functional foods for increased human health and economic benefits.

The Indian snacks market is estimated to be worth Rs. 150 billion with the organized segment accounting for half of the market share and is growing at a rate of 15–20 % (Rais et al. 2013). Extruded snack food products have given a new dimension in the convenience RTE snack foods and its market is growing worldwide. These products are relished by all age groups because of crispy texture and amenability for wide range of flavors (Brennan et al. 2013). Researchers also explored pulses and legumes in combination with cereal blend to increase the nutritional value (Chakraborty and Banerjee 2009, Seth and Rajamanickam 2012). Ahmed (1999) studied an extruded corn based flax snack and reported that increase of flaxseed flour decreased expansion ratio and increased bulk density. Processing and properties of extruded flaxseed corn puff was also reported by Wu et al. (2007). However, there is a dearth of literature on utilization of DFM in rice – corn flour blend extruded product. Therefore, the present investigation was undertaken to develop DFM incorporated extruded product.

Materials and methods

Raw materials

Rice flour, corn flour, common salt (Brand Tata) and black pepper powder (Brand Everest) were procured from local market of Anand, Gujarat (India) in ready to use form. Flaxseed was obtained from Department of Seed Science and Technology, C.S. Azad Agricultural University, Kanpur (India). Analytical grade chemicals and reagents of Qualigens and S.D. fine chemicals were used in the analysis.

Preparation of flour and blend for extruder feed

Cleaned flaxseed was roasted in Kenstar microwave oven (Model OM-34 ECR) at microwave power of 580 watt for 300 s (Ganorkar and Jain 2014a). The oil from roasted flaxseed was extracted using hand operated oil expeller (M/s Rajkumar Agro Engineers Co., Nagpur, India) to obtain defatted meal. DFM was ground to powder in domestic mixer (M/s Sumeet Mixer Model DXE plus) for 2 min and sieved through 40 mesh screen to obtain DFM flour. Chemical composition like moisture content, ash, crude protein, crude fat and crude fiber of DFM, rice and corn flour were carried out by standard methods (AOAC 2000). Carbohydrate content is estimated by difference method.

DFM was fortified with the substitution of rice flour (Table 1) in rice – corn flour blend (3:1). The moisture content of each flour blend was estimated by Infra-red moisture analyzer (M/s Advance Research Equipment Co., New Delhi, India). The flour blend was hydrated to achieve required moisture content level (Table 1) by adding calculated amount of water to the feed. All the flour blends were mixed in ribbon type blender. Different prepared flour blends were then kept in polyethylene bags at 4 °C for 24 h to achieve uniform distribution of moisture.

Extrusion

DFM - rice – corn flour blends were extruded using laboratory scale 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 mm and 3.5 mm flight. Parameters i.e. Feeder rpm 31 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. The samples were packed in aluminum/linear low density polyethylene laminates after cooling and stored at cool and dry place.

Experimental design and statistical analysis

Response surface methodology (RSM) was used to generate the experimental designs, statistical and regression model with the help of Design Expert Software Version 8 (STAT-EASE Inc., Minneapolis, USA). The Central Composite Rotatable Design (CCRD) with a quadratic model (Box and Draper 1987) was employed. Four independent variables namely DFM (%), moisture Content (%), screw rpm and barrel temperature (°C) were chosen. Each independent variable had three levels which were −1, 0 and +1. On the basis of preliminary trials, the level of independent variables like DFM (7.5–20 %), moisture content (14–20 %), screw rpm (300–330) and barrel temperature (115-135 °C) were established. A total of 30 different combinations including six replicates of center point each signed the coded value (0) were chosen in random order according to a CCRD configuration for four factors divided in three blocks (Cochran and Cox 1957). The α-values in the design outside the ranges were selected for

Table 1 Central composite rotatable design with actual values employed and experimental 375 results for response variables of extruded DFM – corn – rice flour blend

Run	Independent Variables				Responses			
	DFM (%) ×1 (×1)	Moisture content (%) ×2 (×2)	Screw RPM ×3 (×3)	Barrel Temperature (°C) ×4 (×4)	ER	BS (kgf)	OAA	WSI
1	13.75 (0)	17 (0)	315 (0)	125(0)	2.93	1.678	7.2	14.83
2	13.75 (0)	17 (0)	285(−α)	125(0)	2.42	2.174	6.8	11.28
3	7.5 (−1)	20 (+1)	330(+1)	115(−1)	3.11	0.945	7.9	8.76
4	13.75 (0)	23 (+α)	315(0)	125(0)	2.85	1.765	7.1	9.54
5	20 (+1)	20 (+1)	300(−1)	135(+1)	2.13	2.087	5.2	14.67
6	13.75 (0)	11(−α)	315(0)	125(0)	2.72	1.765	6.8	7.89
7	20 (+1)	14(−1)	300(−1)	115(−1)	2.30	1.994	6.1	13.88
8	13.75 (0)	17(0)	315(0)	125(0)	2.80	1.96	7.1	8.12
9	20 (+1)	14(−1)	330(+1)	135(+1)	2.60	1.789	5.7	15.34
10	7.5 (−1)	20 (+1)	300(−1)	115(−1)	2.95	1.342	8.1	5.79
11	7.5 (−1)	20 (+1)	300(−1)	135(+1)	3.14	1.145	8.3	8.59
12	1.25 (−α)	17 (0)	315(0)	125(0)	3.26	0.873	8.5	1.67
13	13.75 (0)	17 (0)	315(0)	125(0)	2.78	1.765	7.9	13.56
14	13.75 (0)	17 (0)	345(+α)	125(0)	2.53	2.093	7.2	16.33
15	7.5 (−1)	14 (−1)	300(−1)	115(−1)	2.90	1.484	7.4	5.7
16	13.75 (0)	17 (0)	315(0)	125(0)	2.92	1.423	6.8	14.12
17	7.5 (−1)	14 (−1)	330(+1)	135(+1)	3.22	1.735	8.2	7.98
18	20 (+1)	20 (+1)	330(+1)	135(+1)	2.78	1.832	5.3	17.68
19	13.75 (0)	17 (0)	315(0)	105(−α)	2.10	2.959	5.1	9.76
20	7.5 (−1)	14 (−1)	300(−1)	135(+1)	3.05	1.789	8.2	7.59
21	7.5 (−1)	20 (+1)	330(+1)	135(+1)	2.94	1.865	7.9	8.93
22	26.25 (+α)	17 (0)	315(0)	125(0)	2.15	2.823	5.0	20.23
23	20 (+1)	20 (+1)	330(+1)	115(−1)	2.40	2.457	5.3	18.76
24	20 (+1)	14 (−1)	330(+1)	115(−1)	2.50	2.878	5.6	16.34
25	20 (+1)	20 (+1)	300(−1)	115(−1)	2.10	2.796	5.2	15.67
26	13.75 (0)	17 (0)	315(0)	125(0)	2.93	2.156	7.3	14.89
27	7.5 (−1)	14 (−1)	330(+1)	115(−1)	2.89	2.087	8	5.7
28	13.75 (0)	17 (0)	315(0)	125(0)	3.10	1.998	8.1	15.1
29	20 (+1)	14 (−1)	300(−1)	135(+1)	2.30	2.278	6.4	18
30	13.75 (0)	17 (0)	315(0)	145(+α)	2.40	2.211	6.6	16.9

rotability of the design (Thompson 1982). The experimental design in the coded (x) and actual (X) levels of variable is shown in Table 1.

The responses function (y) measured were expansion ratio (ER), breaking strength (BS), overall acceptability (OAA) and water solubility index (WSI) of extruded product. These values were related to the coded variables (xi, $i = 1, 2, 3$ and 4) by a second degree polynomial using the equation below.

$$y = b_0 + b_1x_1 + b_2x_2 + b_3x_3 + b_4x_4 + b_{12}x_1x_2 + b_{13}x_1x_3 + b_{14}x_1x_4b_{23}x_2x_3 + b_{24}x_3x_4 + b_{34}x_3x_4 + b_{11}x_1^2 + b_{22}x_2^2 + b_{33}x_3^2 + b_{44}x_4^2 \quad (1)$$

The coefficients of the polynomial were represented by b0 (Constant terms), b1, b2, b3 and b4 (linear effects), b11, b22 b33 and b44 (quadratic effects) and b12, b13, b14, b23, b24 and b34 (interaction effects). The analysis of variance (ANOVA) tables were generated and the effect of regression coefficients of individual linear, quadratic and interaction terms were determined. 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 included in the regression.

Table 2 Proximate composition of DFM, Rice flour and corn flour

Parameters	Defatted flaxseed meal (DFM)	Rice flour	Corn flour
Moisture content, (wb %)	6.14 ± 0.89	11.18 ± 0.73	9.76 ± 0.83
Ash, %	9.40 ± 0.93	0.08 ± 0.02	1.07 ± 0.08
Fat, %	2.10 ± 0.51	1.10 ± 0.29	1.73 ± 0.33
Protein, %	28.13 ± 0.82	6.18 ± 0.43	10.93 ± 0.62
Dietary fiber, %	29.0 ± 1.01	0.16 ± 0.06	1.29 ± 0.27
Carbohydrate, %	25.6	81.46	76.51
CG content (mg/100 g)	49 ± 1.69	-	-

Reported values are the mean values of three replicates

Extruded product characteristics

Expansion ratio (ER)

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

Breaking strength (BS)

It 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 (Ganorkar and Jain 2014b).

OAA score

It 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.

Water solubility index (WSI)

Extrudates samples were ground and sieved through 500 μm sieve. Distilled water (10 ml) was placed in a tare centrifuge tube and 0.5 g of extrudates was dispersed in the water. Precaution was taken to avoid lump formation and in order to facilitate homogenous dispersion. With intermittent shaking every 5 min, dispersion was allowed to stand for 30 min. The sample was centrifuged (M/s Remi) at 1800 × g for 15 min. The supernatant was decanted into a tare aluminum pan and dried at 105 °C until constant weight (Anderson et al. 1969; Yagci and Gogus 2008).

$$\mathrm{WSI}\,(\%) = \frac{\text{Weight of dry solids in supernatant} \times 100}{\text{Dry weight of extrudate}} \tag{2}$$

Results and discussion

Proximate composition of DFM (Table 2) revealed that DFM is good source of protein and fiber.

Model fitting

The effects of independent variables on response variables ER, BS, OAA and WSI 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 (Gan et al. 2007). The regression coefficients for each response variable

Table 3 Regression coefficient analysis

Parameter	Estimated regression coefficients			
	ER	BS (kgf)	OAA	WSI
Intercept	2.91	1.83	7.4	13.44
DFM level (b1)	−0.30*	0.40*	−1.09*	4.51*
Feed moisture (b2)	0.002	−0.065	−0.075	0.48
Screw RPM (b3)	0.074**	0.021	−0.008	0.82***
Temperature (b4)	0.067***	−0.123***	0.192***	0.936**
b12	−0.023	0.127	−0.2	−0.117
b13	0.083***	−0.066	−0.062	0.137
b14	0.0006	−0.176***	−0.05	−0.381
b23	0.015	−0.075	0.012	0.576
b24	−0.009	0.015	−0.075	−0.4
b34	0.016	−0.051	−0.062	−0.465
b11	−0.026	−0.025	−0.135	−0.598
b22	−0.005	−0.045	−0.085	−1.157
b33	−0.083**	0.046	0.072	0.114
b44	−0.139	0.159**	−0.360	−0.003
R^2 value	0.89	0.78	0.91	0.91
P- value for quadratic model	< 0.0001	0.0067	< 0.0001	< 0.0001
P- value for lack of fit	0.184	0.232	0.640	0.969
Mean	2.71	1.94	6.88	12.12
SD	0.16	0.34	0.46	1.89

*Significant at 0.01 level, **Significant at 0.05 level, ***Significant at 0.10 level

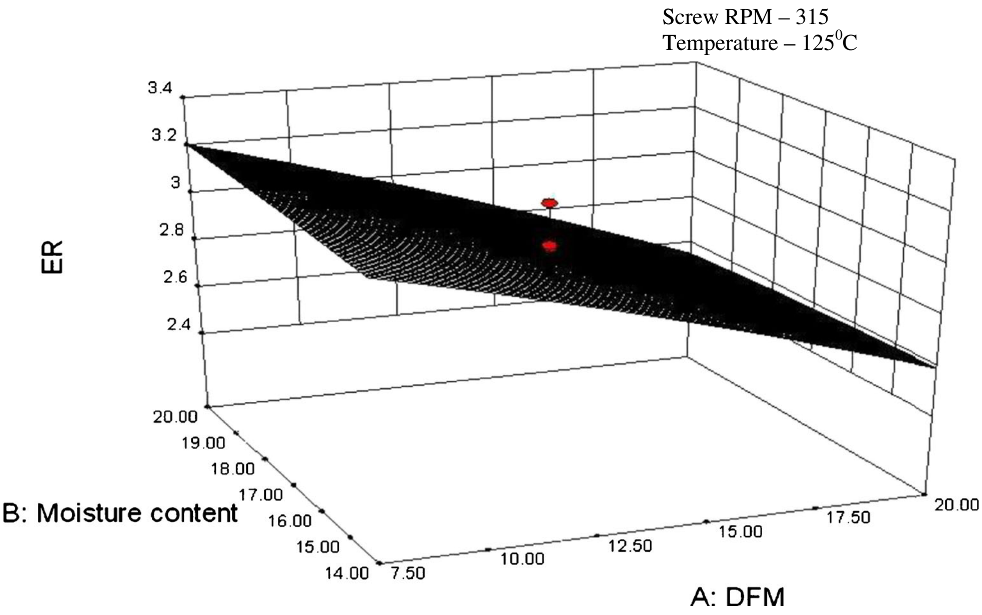


Fig. 1 Response surface plot for expansion ratio as a function of defatted flaxseed incorporation and moisture content at a screw RPM of 315 and Barrel Temperature of 125 °C

are given in Table 3. Models for all response variables were adequate. 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.

Expansion ratio (*ER*)

Expansion is important characteristic of extruded product and describes the degree of puffing undergone by the sample as it exits the extruder. (Asare et al. 2012; Seth and Rajamanickam 2012). The ER of extruded product varied between 2.1 to 3.26 (Table 1). The data presented in the Table 3 showed that the ER was negatively related to linear effects of defatted flaxseed meal incorporation level ($p < 0.01$) and quadratic effect of screw rpm ($p < 0.05$). However, ER was positively related to linear effect of screw rpm ($p < 0.05$), barrel temperature ($p < 0.10$) and interaction effect between defatted flaxseed meal and screw rpm ($p < 0.10$). The multiple regression models for predicting ER showed R^2 value of 0.89. The

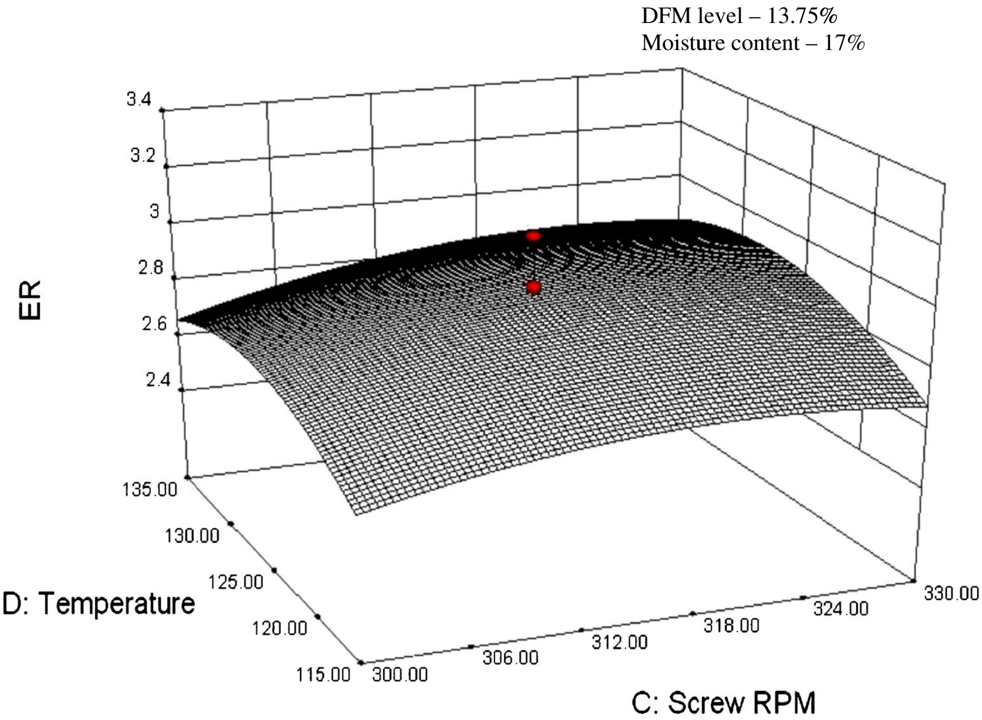
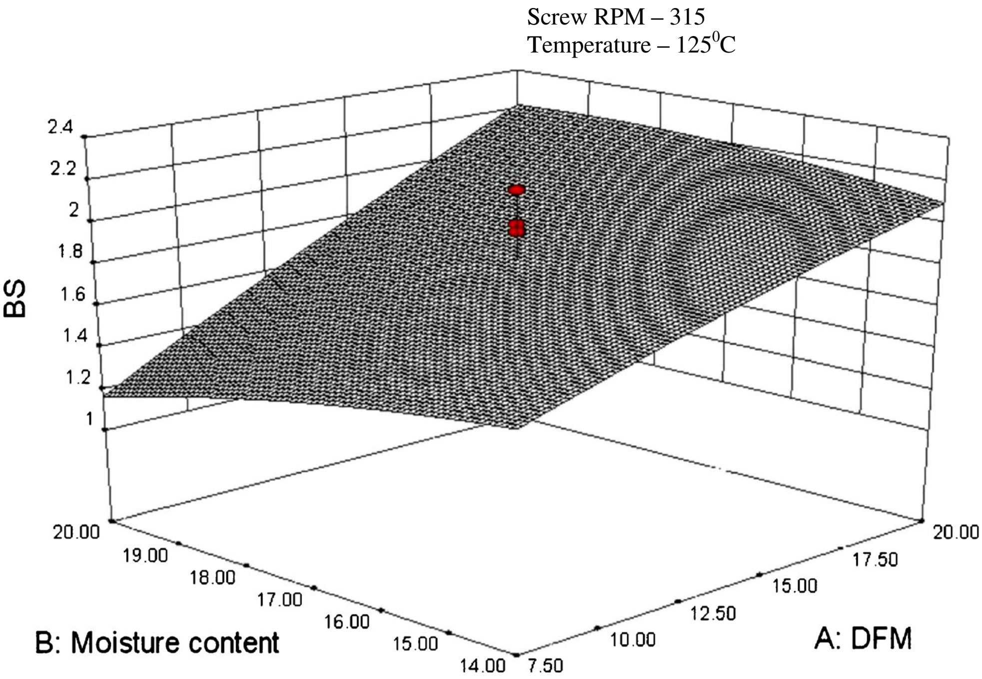


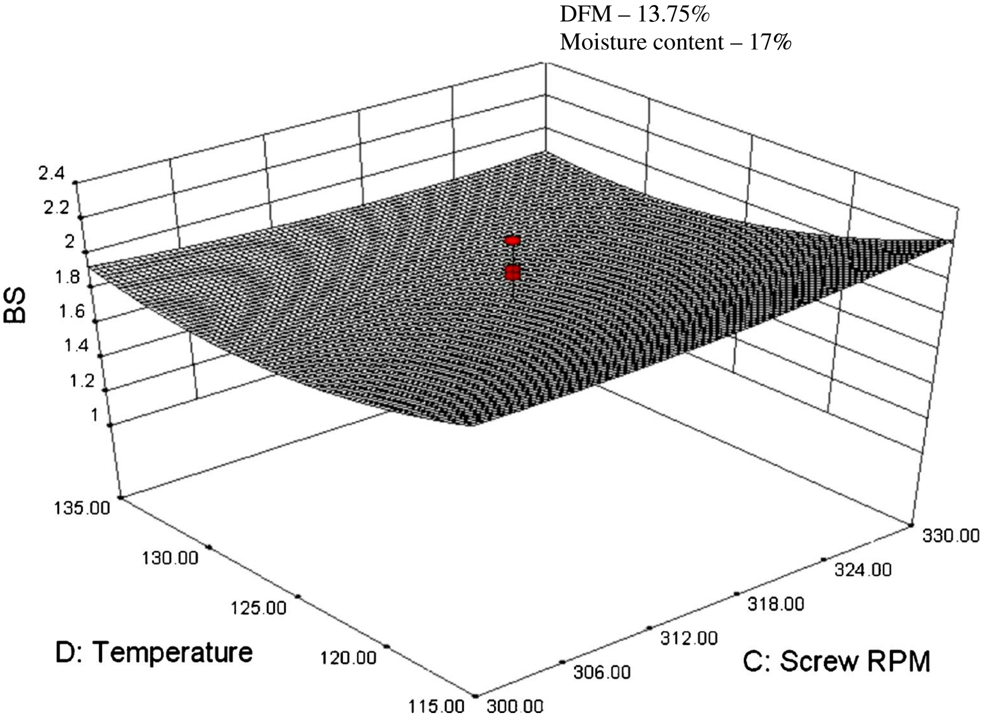
Fig. 2 Response surface plot for expansion ratio as function of screw RPM and Barrel Temperature at DFM incorporation level of 13.75 % and moisture content of 17 %

Fig. 3 Response surface plot for breaking strength as a function of defatted flaxseed incorporation and moisture content at a screw RPM of 315 and Barrel Temperature of 125 °C



response surface plot for ER (Fig. 1) showed the expansion of the extrudates decreased with increasing DFM incorporation level. Expansion phenomena are basically dependent on the viscous and elastic properties of melted dough (Launay and Lisch 1983). The enormous decrease of ER with increasing DFM could be explained by the negative effect of DFM content, which affects the extent of starch gelatinization, specific mechanical energy and rheological properties of the melted material in the extruder. High amount of dietary fiber and protein content of DFM (Table 2) affected the starch gelatinization. Non starch polysaccharides in the fiber 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 (Ganorkar and Jain 2014b). Moreover, proteins influence expansion through their ability to affect water distribution in the matrix and through their macromolecular

Fig. 4 Response surface plot for breaking strength as function of screw RPM and Barrel Temperature at DFM incorporation level of 13.75 % and moisture content of 17 %



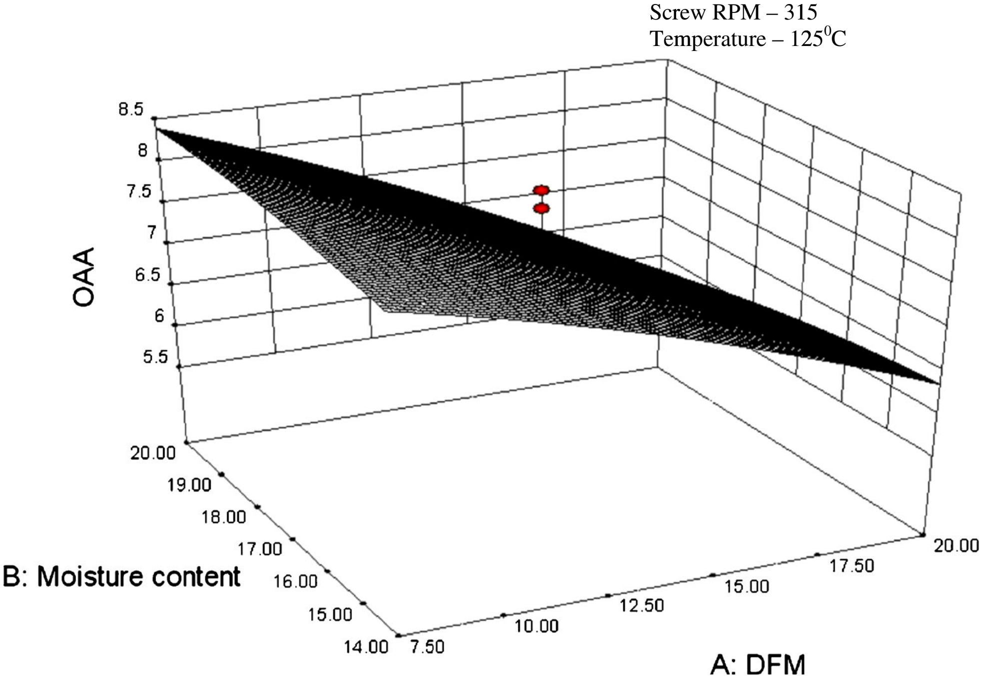


Fig. 5 Response surface plot for overall acceptability as function of DFM level and moisture content at screw RPM of 315 and Barrel Temperature of 125 °C

structure and confirmation which affects the extensional properties of the extruded melts (Moraru and Kokini 2003). Due to starch protein interactions and formation of intermolecular disulfide bonds in the protein upon heat treatment that renders the swelling of extrudates, thus exhibited low expansion ratio (Mahasukhonthachat et al. 2010; Seth and Rajamanickam 2012). These findings are well in line with the results reported by Pai et al. (2009). Response surface plot for ER (Fig. 2) inferred that as screw rpm increased, ER increased. Screw speed positively affects the shear stress in the extruder (Ilo et al. 1999). Increase in the shear stress creates increased shear environment which may increase the extent of starch gelatinization process and so it gave more expansion Barrel temperature was found to be positively related with ER. Temperature determines the vapor pressure of the moisture and thus degree of puffing. High temperature lowered the viscosity of the dough mass in the extruder ((Yagci and Gogus 2008). It facilitates the starch gelatinization at optimum, strengthening of

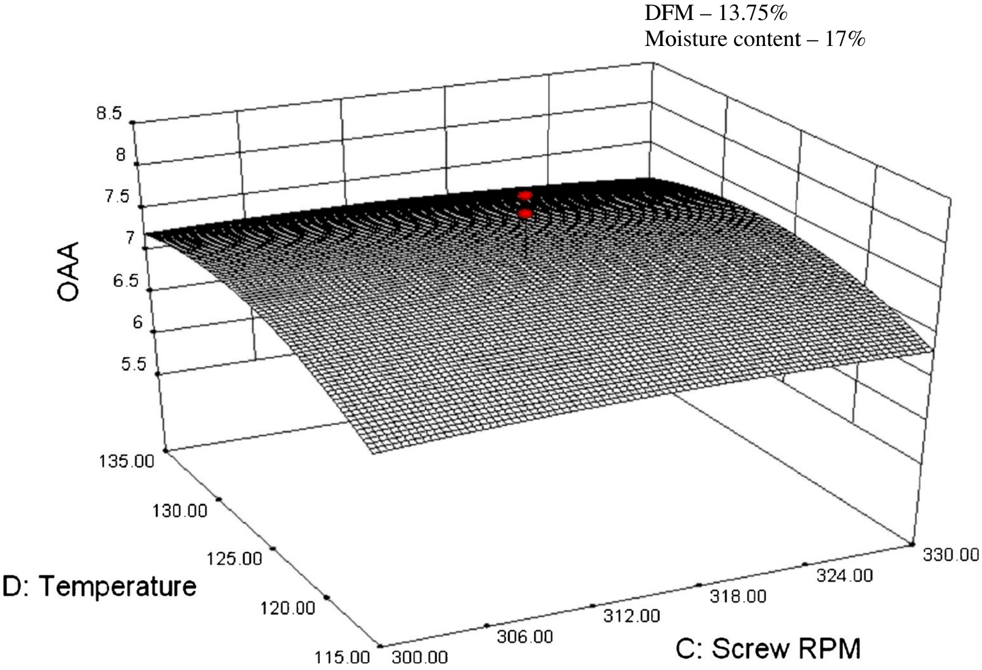


Fig. 6 Response surface plot for overall acceptability as function of Screw RPM and barrel temperature at DFM level of 13.75 % and moisture content of 17 %

structure and consequently increased ER (Seth et al. 2013). Kpodo and Plahar (1990) and Sobukola et al. (2012) reported similar results for yam based extruded product.

Breaking strength (BS)

BS indicating texture of extruded product varied between 0.873 to 2.959 kgf (Table 1). The data presented in Table 3 revealed that BS was positively significantly related to the linear effect of DFM incorporation level (p < and quadratic effect of barrel temperature ($p < 0.05$). Moreover, it is negatively related to the linear effect of barrel temperature ($p < 0.10$) and interaction effect between DFM incorporation level and barrel temperature. The multiple regression model for predicting BS showed R^2 value of 0.78 (Table 3). The response surface plot (Fig. 3) inferred that an increase in DFM incorporation from 7.5 % to 20 %, BS increased. This might be due to high fiber and protein content of DFM (Table 2) which reduces the expansion. Fiber in DFM might have imparted structural integrity to the extrudates due to protein fiber interaction, as a result higher values of BS. Seth et al. (2013) reported similar results for yam-rice-corn extrudates. Product became less porous perhaps due to aggregation of protein molecules. Protein has an adverse effect on texture of extruded snack foods because of the surge in temperature of the product as it moves through and leaves the extruder. This surge is usually far above the temperature of the product if the corn meal alone is extruded (Faubion and Hoseney 1982). Addition of protein to starch-rich flours produces the usual "protein-type" extrudates that are harder and expand less (Veronica et al. 2006). 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. Fiber of DFM Ilo et al. (1999) reported similar results for rice and amaranth blend extrusion. Increasing amaranth content caused an enormous decrease in expansion an increase in the breaking strength. It is observed from Fig. 4 that increases in the barrel temperature caused decrease in BS. Higher temperature favored starch gelatinization, consequently increased ER. A more expanded product would take less force to shear and hence had a lower BS and vice versa. Many researchers (Sebio and Chang 2000; Kumar et al. 2010; Seth et al. 2013) reported similar findings of temperature on hardness. Moreover, breaking strength of extrudates could be related to the extrudates microstructure. Generally, product cell wall thickness appears to correspond well with product texture; thicker the cell walls, the higher the shear force (Jin et al. 1995).

Overall acceptability (OAA)

OAA scoring is subjective evaluation (sensory evaluation) for confirming the product acceptability by the consumer. The data pertaining to effect of various variables on OAA was presented in Table 1. From Table 3, OAA is negatively related to the linear effect of DFM incorporation level at 0.01 % significance level. It was positively related to the linear effect of barrel temperature ($p < 0.10$). It is observed from Fig. 5 that there was significant decrease in OAA score as DFM level increased. Expansion and porosity are the dominant quality attributes taken into consideration while development of extruded products. Increasing the incorporation level of DFM reduced ER and hardened

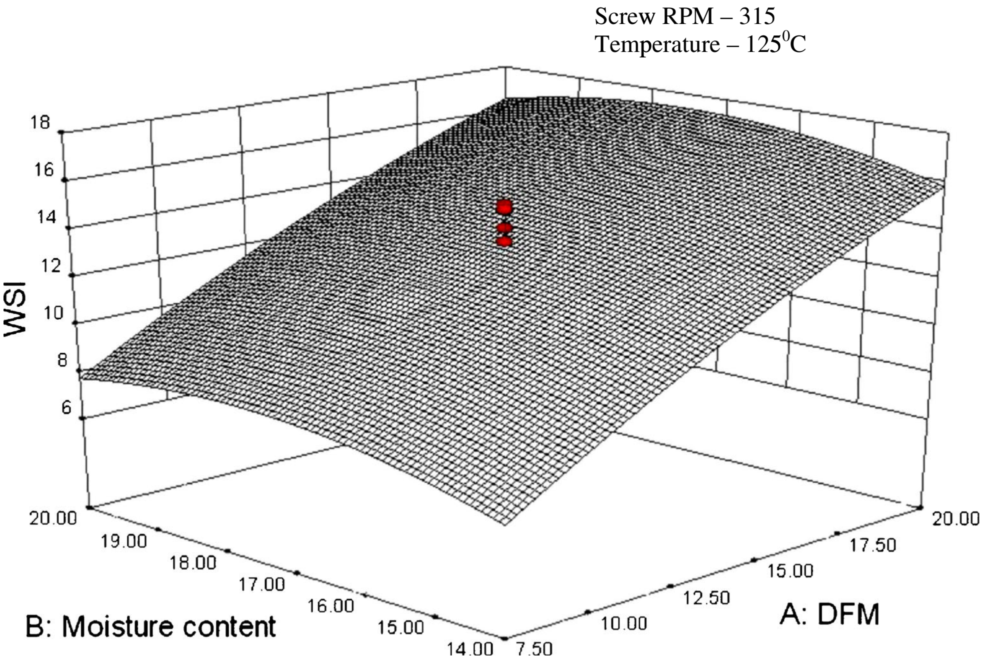


Fig. 7 Response surface plot for water solubility index as function of DFM level and moisture content at screw RPM of 315 and Barrel Temperature of 125 °C

the product (already discussed in previous sections) and consequently lowered OAA score. Secondary reason is the nutty flavor of flaxseed which increased at it higher DFM incorporation. Ganorkar and Jain (2014b) reported similar results for development of roasted flaxseed flour incorporated extruded product. Increase in the barrel temperature also increased OAA score (Fig. 6) due to increase in ER at elevated temperature.

Water solubility index (*WSI*)

WSI is used as an indicator of degradation of molecular components (Kirby et al. 1988). It measures the degree of starch conversion during extrusion which is amount of soluble polysaccharide released from the starch component after extrusion (Yagci and Gogus 2008). The values of WSI of extrudates as function of independent variables are shown in Table 1. WSI ranged from 5.7 to 20.23 %. Regression analysis of extruded product (Table 3) revealed that WSI was positively related to the linear effect of DFM incorporation level ($p < 0.01$), screw rpm ($p < 0.10$) and barrel temperature ($p < 0.05$). The multiple regression models for predicting WSI showed R^2 value of 0.91. WSI increased as a function of DFM content, screw speed and barrel temperature (Figs. 7 and 8). Increased WSI in extruded products can be related to the lower molecular weight components, which can be separated quite easily from each other when the processing conditions are more severe (Collona et al. 1989). DFM is high in fiber and protein content. The fiber molecules disrupt continuous structure of the melt in the extruder hindering elastic deformation during extrusion (Moraru and Kokini 2003; Yagci and Gogus 2008). Increase in screw speed imparted higher shear to extrusion melt, consequently affected degradation of starch during extrusion. Higher barrel temperature causes weakening and degradation of starch molecules. Therefore, higher values of WSI may be due to disintegration of starch granules and low molecular weight compounds from extrudates melt during extrusion process, this caused an increase in soluble material.

Optimization

Numerical optimization of all independent variables using Design Expert (Version 8) STAT EASE software was carried out. All the levels of independent variables were kept in range except DFM. It was kept at target level of 10 % as the approach was to incorporate maximum DFM without affecting extrudates responses negatively. 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 WSI were kept minimum. The actual process variables for the best combination of the responses (Desirability – 0.836) were 10 % DFM incorporation with rice flour, 20 % moisture content (wb) of extruder feed, 311.52 screw rpm and 125.39 °C barrel temperature. The response function were calculated from the final polynomial and the response at this optimized combination were Expansion Ratio of 3.08, BS of 1.4 kgf, OAA score of 7.95 and WSI of 9.63. Screw rpm of 312 and barrel temperature of 125 °C rounded off for the actual run.

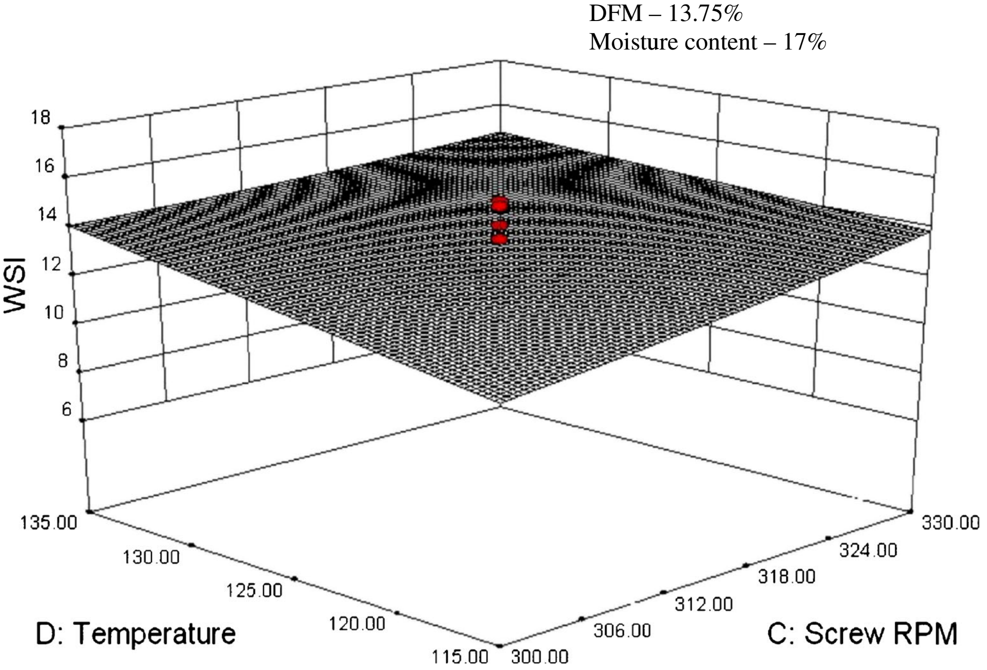


Fig. 8 Response surface plot for water solubility index as function of Screw RPM and temperature at DFM of 13.75 % and moisture content of 17 %

Conclusion

Evaluation of developed extruded product on the basis of attributes like ER, BS, OAA and WSI showed that there were strong relationship between ER and the levels of DFM, screw speed and barrel temperature. DFM level significantly negatively correlated with ER and OAA of extrudates while significantly increased BS and WSI. Moisture content did not significantly affect on the responses. Interaction effects of moisture content with screw speed and barrel temperature were significantly correlated with ER and BS respectively during the investigation. 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 for maximum acceptability of extruded product were found to be 10 % DFM incorporation with rice flour, 20 % moisture content (wb) of extruder feed, 312 screw rpm and 126 °C barrel temperature. Value addition of low value DFM through successful incorporation in cereal flours blend to achieve functionality in extruded snack food will definitely open up opportunities to food industries.

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