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Effect of Fenugreek Seed Powder and Oat Flour Incorporation on Physical and Functional Properties of Extruded Product

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ABSTRACT

Experiments were conducted based on preliminary evaluation by varying the proportions of fenugreek seed powder (FSP) (1-5%) and oat flour (OF) (3-15%) using central composite rotatable design. Composite flour containing rice (%60), chickpea (%30) and corn flours (%10) was used as a base material in extrusion. Physical and functional properties like bulk density (BD), hardness (HD), lateral expansion (LE), water absorption index (WAI) and water solubility index (WSI) were significantly ($p<0.05$) affected by the proportions of FSP and OF. Increase in OF proportion resulted in an increase in BD, LE and WAI values, FSP proportion had a positive effect on LE, HD, WAI values and specific length. WSI was negatively affected by both FSP and OF. Storage studies of quality extruded product (2.28% FSP and 4.76% OF) showed lower moisture uptake at atmospheric storage conditions in comparison to the accelerated storage conditions. Shelf life of the extrudates packed in aluminium lined polyethylene packages was higher than that packed with high density polyethylene packages due to higher water vapour transmission rate of the later packaging material.

Keywords: Extrusion, Oat, Fenugreek, Functional properties, Storage

Çemen Unu ve Yulaf Unu İlavesinin Ekstrüde Ürünün Fiziksel ve Fonksiyonel Özelliklerine Depolama Sırasında Etkisi

ÖZ

Deneyler, merkezi bileşik döner bir tasarım kullanarak çemen unu (FSP) (% 1-5) ve yulaf unu (OF) (3-15%) oranlarını değiştirmek sureti ile ön denemelere göre yapılmıştır. Pirinç (60%), nohut (% 30) ve mısır (% 10) unlarından oluşan kompozit un, ekstrüzyonda ana malzeme olarak kullanılmıştır. FSP ve OF oranları, yığın yoğunluğu (BD), sertlik (HD), yanal genişleme (LE), su emme indeksi (WEG) ve suda çözünürlük indeksi (WSI) gibi fiziksel ve fonksiyonel özellikleri anlamlı ($p<0.05$) şekilde etkilemiştir. OF oranındaki artış, BD, LE ve WAI değerlerinde artışa neden olurken, FSP oranının LE, HD ve WAI değerleri ile özgül uzunluk üzerine olumlu etkisi olduğu görülmüştür. WSI değeri hem FSP ve hem de OF tarafından olumsuz şekilde etkilenmiştir. Ekstrüde edilmiş ürünün (%2.28 FSP ve %4.76 OF) depolama çalışmaları, hızlandırılmış depolama koşullarında karşılaştırıldığında atmosferik depolama koşullarında nem alımında düşüş olduğu görülmüştür. Alüminyum katmanlı polietilen paketlerde ambalajlanan ekstrüde ürünlerin raf ömrü, su buharı transmisyon oranı yüksekliğinden dolayı yüksek yoğunluklu polietilen ambalajlarda paketlenen ürünlerindekinden daha fazla olmuştur.

Anahtar Kelimeler: Ekstrüzyon, Yulaf, Çemen, Fonksiyonel özellikler, Depolama

INTRODUCTION

Extrusion technology has been commercially stable in food industry for a long time [1, 2]. As a high temperature short time process, (HTST) extrusion involves simultaneous thermal and pressure treatment along with mechanical, shearing, and completes cooking resulting in a ready to eat product. Use of extrusion process for producing snack foods is increasing at a fast rate because the process could improve the nutritional quality of carbohydrate-based products by diversification or fortification [3]. Extruded products are preferred by consumers because of crispiness and good swelling properties [4] and they are mainly prepared using rice, corn and pulse flour.

Oats are unique among the common cereal grains due to high lipid and protein content and also linoleic and oleic acids account for 45.0% and 30.4%, respectively, of the total lipid in unprocessed oats [5]. Oats have a high β-glucan having anti-atherogenic properties [6], enhance immune response to infection [7, 8], decrease peak insulin and glucose concentrations [9], and be responsible for lowering serum and plasma cholesterol levels [10, 11, 12].

Fenugreek *(Trigonella foenum-graceum L.)* commonly known as '*methi*' in India. Fenugreek seed is pleasantly bitter in taste but it is a good source of many nutrients and has medicinal properties. It lowers the blood glucose [13] and cholesterol level [14]. Its seeds are rich in minerals, vitamin A (1040 IU), choline (1161µg), folic acid (84 µg) and dietary fiber [15]. Adding fenugreek fiber to refined flours helps to fortify with a balance of soluble and insoluble fiber. Flour fortified with 8–10% fenugreek fiber has been used to prepare bakery foods like pizza, bread, muffins, and cakes with acceptable sensory properties [16].

In view of the promising nutritional and health benefits of oat and fenugreek, a study was conducted to develop the acceptable snack products using extrusion technology, by using corn, rice and chickpea as the base material and to investigate the effect of their inclusion on the physical and functional properties and storage stability of extruded snack products and also determine its shelf life.

MATERIALS and METHODS

The ingredients used in the development of extruded products include: rice flour, corn flour, chickpea flour, oat flour and fenugreek seed powder. All the flours were purchased from local market Longowal (Sangrur, Punjab, India) and were cleaned to remove any foreign material, dirt, stones, and grits by passing through 60 BSS sieve for uniform particle size. Rice flour, chickpea flour, corn flour, oat flour and fenugreek seed powder so produced were stored in air tight polythene bags for further use.

Experimental Design and Data Analysis

Response surface methodology (RSM) was adopted in the design of experimental combinations. The central composite rotatable design for two independent variables of fenugreek seed powder and oat flour (FSP, 1, 2, 3, 4 and 5% and OF, 3, 6, 9, 12 and 15%) was performed as shown in Table 1. The levels of each variable were established according to literature data and preliminary trials. Composite flour (Rice flour: Chickpea flour: Corn flour: 60:30:10) as a base material was set according to the preliminary trails and literature data for suitable extrusion cooking. The outline of experimental design with the coded and actual levels is presented in Table 2. Dependent variables were product responses include lateral expansion, bulk density, water absorption index and water solubility index, specific length and texture. Response surface methodology was applied for experimental data analysis using a commercial statistical package, Design-Expert Version 6.0.10. RSM was used to optimize the level of FSP and OF for quality extruded product, the optimized product was then used to study the storage stability.

Extrusion Experiments

Extrusion was performed using a co-rotating twin-screw extruder (Basic Technology Pvt. Ltd., Kolkata, India). The main drive was provided with 7.5HP motor (400V, 3ph, and 50cycles). The output shaft of worm reduction gear was provided with a torque limiter coupling. The screw configuration (250 rpm) that was a standard design for processing cereals and flour-based products was used. Barrel length to diameter ratio (L/D) was 8:1. The barrel of the extruder received the feed from a co-rotating variable speed feeder. The barrel was provided with two electric band heaters and two water cooling jackets. A temperature sensor was fitted on the front die plate which was connected to temperature control placed on the panel board. The die plate of the die fixed by a screw nut tightened by a special wrench provided. The initial experimental temperature was reached within 30 min and samples were then poured into feed hopper and the feed rate was adjusted to 8 kg/h for easy and non-choking operation. The die diameter was selected at 4mm as recommended by the manufacturer for such product. The barrel zone temperatures were kept constant at 118°C throughout the experiments, moisture content of feed material was kept as 14% (wb) and screw speed was maintained at 250 rpm. Extrudates were cut with a sharp knife and left to cool at room temperature for about 20min.

Table 1. Coded and actual values of independent variables of extruded product

Independent variables	Code	Coded levels				
		(-á)-1.414	-1	0	1	(+á)-1.414
FSP (%)	A	1.586	2	3	4	4.414
OF (%)	B	4.758	6	9	12	13.242

Table 2. Experimental combinations in coded and actual levels of fenugreek seed powder and oat flour for production of extruded samples

Run	Coded levels		Actual levels	
	A	B	FSP %	OF %
1	+1	+1	4	12
2	+1	-1	4	6
3	-1	+1	2	12
4	-1	-1	2	6
5	+1.414	0	4.414	9
6	-1.414	0	1.586	9
7	0	+1.414	3	13.242
8	0	-1.414	3	4.756
9	0	0	3	9
10	0	0	3	9
11	0	0	3	9
12	0	0	3	9

Bulk Density

The bulk density (BD) (g/cm^3) was calculated by measuring the actual dimensions of the extrudate [19]. The diameter and length of the extrudate were measured using vernier caliper with least count of 0.1mm. The weight per unit length of extrudate was determined by weighing measured lengths (about 1cm) of extruded products. 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 value was reported.

$$BD = \frac{4\,m}{\pi D_e^2 l_e}$$

Where, m (g) is the mass of a length l_e of extrudate, D_e is diameter of the extrudate (cm), and l_e is the length (cm) per gram of the extrudate (cm/g).

Lateral Expansion

The ratio of diameter of extrudate (D_e) and the diameter of die (D_d) was used to express the expansion of extrudate [18, 19]. Six lengths of extrudate (approximately 12cm) was selected at random during collection of each of the extruded samples, and allowed to cool to room temperature. The diameter of the extrudate was then measured, at 10 different positions along the length of each of the six samples by using a vernier caliper with least count 0.1 mm. Lateral expansion was calculated using the mean of the measured diameters:

$$LE = \frac{(D_e - D_d)}{D_d} \times 100$$

Water Absorption Index (WAI) and Water Solubility Index (WSI)

The WSI and WAI values were measured using a technique developed for cereals [22]. About 2.5 g of ground extrudate was suspended in 25 mL water at room temperature for 30min, with intermediate stirring, and then centrifuged at 4000 rpm for 15 min [23]. 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 formulae:

$$WAI\left(\frac{g}{g}\right) = \frac{\text{Weight gain by gel}}{\text{Dry weight of extrudate}}$$

Specific Length (SL)

The length of extrudate (l_e) and mass (m_e) were measured for 15 pieces of dried product from each treatment, and used to obtain the specific length [24]. The extrudate was cut by hand into pieces of about 5 cm in length. Each treatment was measured 15 times according to Karkle et al. [25].

Specific length (mm/g) $= l_e \;/\; m_e$

Hardness

Textural properties of the extrudate were determined by a crushing method using a TA-XT2 texture-analyzer equipped with a 50kg load cell. An extrudate 40mm long was compressed with a probe SMS–P/75–75mm diameter at a crosshead speed 5mm/s to 3mm/s of 90% of diameter of the extrudate. The compression generates a curve with the force over distance. The highest first peak value was recorded as this value indicated the first rupture of product at one point and this value of force was taken as a measurement for hardness [21].

Statistical Analysis of Responses

The responses (bulk density, lateral expansion, hardness, WAI, WSI and Specific length) for different experimental combinations were related to the coded variables (A, B) by a second order polynomial equation:

$$Y = \beta_0 + \beta_1 A + \beta_2 B + \beta_{11} A^2 + \beta_{22} B^2 + \beta_{12} A.B + \varepsilon$$

The coefficients of the polynomial were represented by β_0 (constant), β_1, β_2, (linear effects); β_{11}, β_{22} (quadratic effects), β_{12} (interaction effects); and ε (random error). Data were modelled by multiple regression analysis and the statistical significance of the terms was examined by analysis of variance for each response.

Storage Stability of Extruded Product

Optimized extruded product prepared were filled in aluminium foil laminated polyethylene (ALP) and high density polyethylene (HDPE) pouches (70×70 mm) and packets were closed by heat sealing taking care that minimum possible air space remained in packets. The sealed sample pouches were placed under accelerated and atmospheric storage condition. These conditions were 90±1% relative humidity using saturated solution of potassium nitrate and 38±1°C (accelerated storage) in incubator maintained thermostatically and 75±1% RH and 35±1°C (atmospheric storage). One packet was taken out from the desiccators at 14 days interval up to 56 days and analyzed for moisture content.

Determination of Shelf Life of Extruded Product

The shelf life was calculated using the following equation [25].

$$\int d\theta = \frac{Ws}{P * kA} \int_{Xi}^{Xc} \frac{dX}{RH - aw}$$

Where, ϴ shelf life (days), W_s = weight of the dry solids (g), P* = saturated vapour pressure of water at ambient temperature (P_a), k = permeability of the packaging material (kgm^{-2} day^{-1} Pa^{-1}), A = area of the package (m^2), RH = relative humidity of the environment in which the package is placed (%), a_w = water activity of the product, X_i = initial moisture content (%, db) and X_c = critical moisture content (%, db).

RESULTS and DISCUSSION

Table 3 shows the proximate composition of FSP and OF samples. A significant difference (P≤0.05) was observed in moisture, ash, protein content and total carbohydrate of FSP and OF, while a non significant difference was observed only in the crude fat content.

Table 3. Proximate composition of FSP and OF

Composition (%)	FSP	OF
Moisture	7.38 ±0.51^b	8.59 ±0.33^a
Ash	3.72 ±0.13^a	1.77±0.11^b
Crude protein	27.75±1.30^a	13.91±0.99^b
Crude fat	6.42±0.46^a	6.35±0.51^a
Crude fiber	16.09±0.32^a	2.61±1.04^b
Total carbohydrate	46.01±0.84^b	75.34±0.70^a

Values are means ± SD of 3 replications. Means figures in a row followed by different superscripts indicate that they are significant (p ≤ 0.05) different with each other determined by Duncan's tests.

Bulk Density

Bulk density is an important physical property of the extruded products. The bulk density, which considers expansion in all direction, ranged from 0.061 to 0.086 g/cm^3 (Table 4). Regression model fitted to experimental results of bulk density showed that the Model was significant. The "Lack of Fit F-value" 3.24 was insignificant, means good for the model to fit. The model was selected for representing the variation of bulk density (BD).

BD =+0.083 -0.0010*A +0.00047* B -0.0079* A^2 -0.0076 * B^2 +0.0018*A* B

Where A and B are the coded variable for FSP and OF respectively. In linear term, FSP (A) had negative linear effect on bulk density, whereas OF had positive linear effect on bulk density. Quadratic effect of both the FSP (A^2) and OF (B^2) had shown negative significant (P<0.05) effect on the bulk density. From the response surface plot (Figure 1a) it was observed that with the increase in FSP there was increases in bulk density at first later it decreased and with increase in OF content there was an increase in bulk density up to the level of 9%, there after the bulk density of the extruded product decreased down on further addition of OF. Our findings are similar to those reported for maize grits extrudates (0.09–0.32 g/cm^3 [27]. Increase in bulk density with increase in level of OF may be due to the increasing fiber content. This was because the fiber particles tended to break the cell walls before the gas bubbles had expanded to their full potential [28]. Similar effect of fiber has been found for extrusion of corn meal and sugar beet fiber, yellow corn with wheat and oat fiber, corn meal with soy fiber, salt and sugar, jatoba flour and cassava starch blends and corn starch with pectin and wheat fiber [28-32].

Lateral Expansion

Expansion is the most important physical property of the extruded product. Lateral expansion with other factors contributes to the appearance of the product. In this experiment the measured expansion of the extrudate from FSP and OF blend varied from 185 to 201 (Table 4). ANOVA results of lateral expansion fitted to experimental data of lateral expansion were significant. The model was selected for representing the variation of lateral expansion (LE):

LE = +188.75 +3.16*A +0.70* B +3.34* A^2 +4.84* B^2 +0.13*A*B

Where A and B are the coded variable for FSP and OF respectively. Both FSP and OF had positive linear effect on lateral expansion, the effect of incorporation of FSP 1 “2 increase in the content of both. Similar results were observed by Shirani and Ganesharanee [23]. Expansion of extrudates increased (P<0.05) with the incorporation of chickpea flour, with the highest expansion ratio determined in the extruded products made from 70:30 chickpea: rice mixture.

Table 4. Effect of independent variables of FSP and OF on the physical and functional properties of extruded product

S. No	FSP (%)	OF (%)	B.D. (g/cm^3)	L.E. (%)	Hardness (N)	WAI (g/g)	WSI (%)	S.L (mm/g)	E.R.
1	2.00	6.00	0.0614	190.5	7.68	1.14	4.12	78.5	0.081
2	1.59	9.00	0.0711	194	7.51	1.12	4.2	72.2	0.088
3	2.00	12.00	0.0614	192	7.067	1.29	4.3	70.1	0.088
4	4.41	9.00	0.0659	199.5	7.46	1.24	4.1	75.9	0.088
5	3.00	9.00	0.0825	189	9.86	2.54	4.45	89.6	0.078
6	3.00	9.00	0.0787	189	9.27	2.66	4.43	89.5	0.079
7	3.00	13.24	0.0737	200.9	6.35	1.40	4.01	76.5	0.082
8	3.00	4.76	0.0646	199	7.92	1.20	4.3	74.7	0.075
9	4.00	12.00	0.0644	201	7.06	1.11	4.1	78.2	0.078
10	4.00	6.00	0.0653	199	7.94	1.10	4.15	75.5	0.084
11	3.00	9.00	0.0829	188.5	9.47	2.68	4.43	89.5	0.08
12	3.00	9.00	0.0862	188.5	9.59	2.06	4.43	89.5	0.082

Table 5. Result of regression analysis of different responses of extrudate

	DF	BD	LE	HD	WAI	WSI	SL	ER
		F value						
Model	5	6.73*	12.50*	59.48*	18.42*	7.61*	74.11*	9.73*
A	1	0.47	18.37*	0.096	0.0069	1.94	8.31*	1.49
B	1	0.089	0.91	35.76*	0.50	1.57	0.77	4.36
A^2	1	20.25*	16.46*	131.28*	59.92*	19.80*	227.21*	27.43*
B^2	1	18.63*	34.54	181.12*	49.74*	19.10*	182.96*	1.08
AB	1	0.67	0.014	0.37*	0.097	2.12	19.18*	10.83*
Lack of fit	3	3.24	103.33*	0.6491	0.13	123.39*	1283.45*	2.06

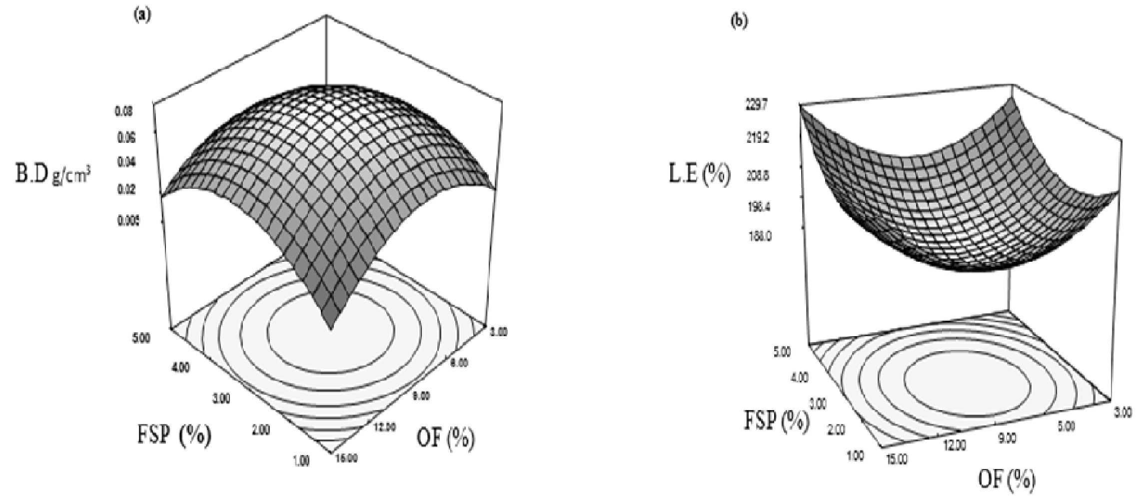

Figure 1. Response plot for (a) bulk density and (b) lateral expansion as a function of FSP and OF.

Water Absorption Index (WAI)

WAI measures the amount of water absorbed by starch that can be used as an index of gelatinization and it is generally agreed that barrel temperature and feed moisture exert greatest effect on the extrudate by promoting gelatinization [33]. However starch is the main responsible ingredient for the water absorption, the increase in starch content will increase WAI. In this experiment the WAI ranged from 1.10 to 2.68 (Table 4).

The regression analysis results for WAI are shown in Table 5. Regression model fitted to experimental results of WAI showed that model was significant. The "Lack-of-Fit F-value" 0.13 was not significant ($P > 0.05$) relative to pure error. Non significant lack of fit was good for the model to fit. The model was selected for representing the variation of WAI of the product:

$$W.A.I. = +2.49 - 0.0065^{*} A + 0.055^{*} B - 0.67^{*} A^2 - 0.61^{*} B^2 - 0.034^{*} A^{*} B$$

Data from Table 5 indicated that WAI of extrudate gave significant model ($P<0.05$). There was a positive linear effect of FSP (A) and OF (B). Quadratic terms of FSP (A^2) and OF (B^2) had shown significant negative effect (P<0.001) on water absorption index of extruded product. Response surface plot (Figure 2a) showed the effect of FSP and OF on WAI. It may be observed that WAI decreases due to the dilution of starch in extruded product as FSP content increases.

Water Solubility Index (WSI)

WSI is used as an indicator of degradation of molecular components. It measures the amount of soluble polysaccharide released from the starch component after extrusion. In this experiment the WSI ranged from 4.01 to 4.45% (Table 4). Table 5 showed the regression analysis for WSI. Regression model fitted to experimental results of WSI showed that Model F-value of 7.61 was significant. The model was selected for representing the variation of WSI:

$$W.S.I. = +4.44 -0.039^* A -0.035^* B -0.14^* A^2 -0.14^* B^2 -0.057^*A^*B$$

Where A and B are the coded variable for FSP and OF respectively. Table 5 above indicated that WSI of FSP and OF extrudate gave significant model (P<0.05). In linear term, FSP (A) and OF (B) were found to have negative effect. There was significant (P<0.05) negative quadratic effect of both the variables on WSI of extruded product. Response surface plot (Figure 2b) show the effect of FSP and OF on WSI of the product. With addition of both FSP and OF content there was a decrease in WSI of extruded product. Similarly, lower (P<0.05) WSI values were found for the extruded products with fenugreek polysaccharide compared to those for the chickpea–rice blend [23]. Similarly, the presence of apple pomace caused less solubilization of matrix components during extrusion, with decreased WSI as pomace level increased [25].

Specific Length

Specific length depends on amount of starch present in raw material. Specific length was calculated by dividing the average length (mm) of extrudate by its weight (g) [24]. In this study specific length ranges from 70.10 to 89.60 mm/g (Table 4). From the regression analysis it came to conclusion that model was significant. The model was selected for representing the variation of specific length (SL):

$$SL = +89.53 +1.29^* A -0.39^* B -7.55^* A^2 -6.77^* B^2 +2.78^*A^*B$$

In linear term, FSP (A) were found to have significant (P<0.05) positive effect on specific length of extruded product. Quadratic terms of FSP (A^2) and OF (B^2) had shown to have negative significant (P<0.0001) effect on SL. The interaction effect of both FSP and OF was significantly (P<0.05) positive. Figure 3a showed the effect of FSP and OF on SL of the product. With the increase in FSP content, significant (P<0.05) increase in the SL was observed, whereas with the increase in OF content of the extruded product a decrease in SL of the extruded product was observed.

Hardness

The hardness of the extrudate was determined by determining the force required to break the extrudate. Hardness is the textural property of the extruded product. It is the measurement of how easily the product could be broken in mouth. Higher the force received to break the product means higher hardness of the product. In this experiment hardness of the extrudate varied from 6.35 to 9.86 N (Table 4). The model was selected for representing the variation of hardness (HD):

$$Hardness = +9.55 +0.024^* A -0.47^* B -1.00^* A^2 -1.17^* B^2 -0.067^*A^*B$$

ANOVA from Table 5 indicates that regression model for hardness of FSP and OF supplement was significant (P<0.05). It was observed that FSP (A) had a positive linear effect on hardness of extruded product, whereas OF (B) were found to have significant (P<0.05) negative linear effect on hardness of the extrudate. Quadratic effect of both FSP (A^2) and OF (B^2) was found to be negatively significant (P≤0.0001). Figure 3b below showed the effect of FSP and OF on hardness. There was an increase in the hardness of product with the increase in the content of FSP at lower levels of OF, which decreases with the increase in the content of later and vice versa. Similar result found by Shirani and Ganesharanee [23] by inclusion of fenugreek significantly (P<0.05) increased the hardness of the extruded products compared to the control.

Optimization

A numerical multi-response optimization technique using RSM was applied [35] to determine the optimum combination of FSP and OF. The assumptions were to develop a product which would have minimum bulk density, maximum lateral expansion, minimum WAI, minimum WSI, minimum hardness, maximum specific length. Therefore, among responses, these parameters were attempted to show multi response optimization constraints. Under these criteria, the optimum formulations for development of FSP and OF extruded snack are 2.28% fenugreek seed powder and 4.76% oat flour.

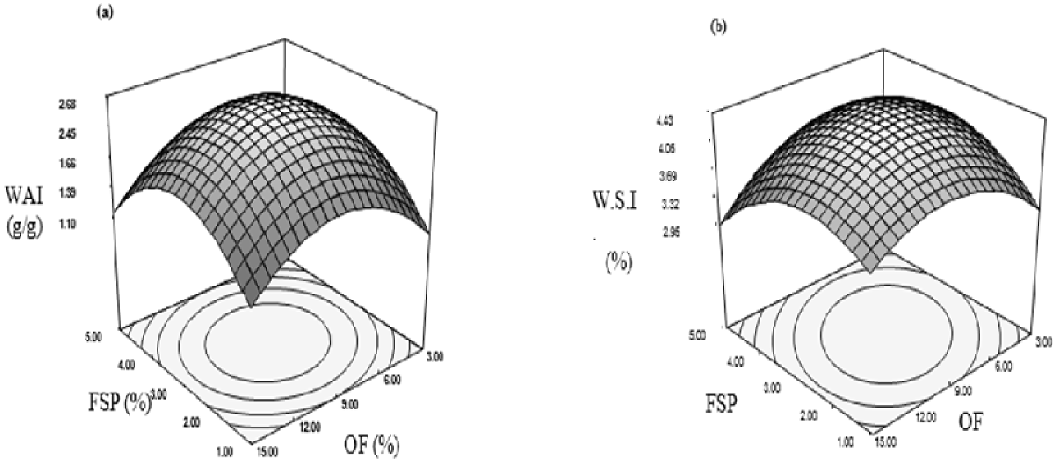

Figure 2. Response plot for (a) WAI and (b) WSI as a function of FSP and OF.

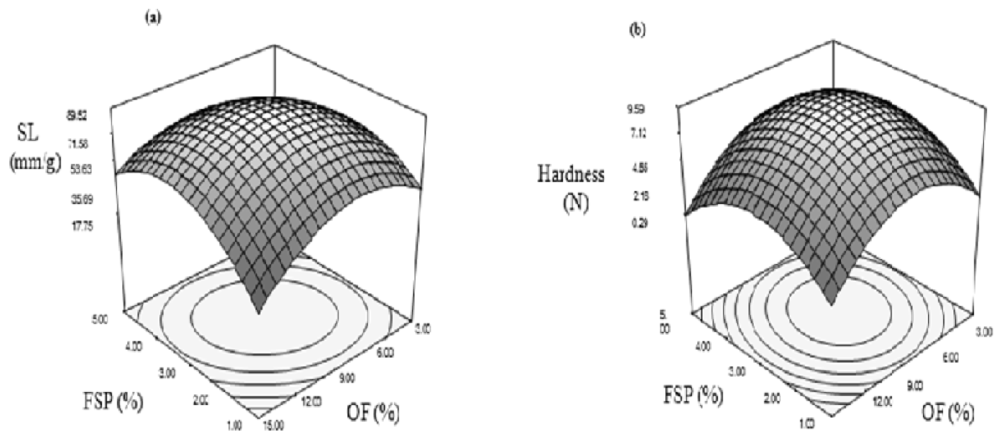

Figure 3. Response plot for (a) SL and (b) hardness as a function of FSP and OF.

Storage Studies of Extruded Product

Optimized formulation was used to develop an extruded snack products and the same sample was used for storage study. The sample was filled in aluminium-laminated polyethylene (ALP) and high density polyethylene (HDPE) pouches. The pouches were then carefully heat-sealed containing 5 g extruded sample and were stored under accelerated storage conditions (38±1°C and 90±1% RH) and atmospheric conditions (35±1°C and 75±1% RH). The samples were analyzed at regular intervals for the change in moisture content.

Table 6. ANOVA for effect of storage days and packaging material on the moisture content of extruded products at accelerated and atmospheric storage conditions

Source of variation	DF	Accelerated storage F_{cal}	Atmospheric storage F_{cal}
Storage days (SD)	8	34.76	78.93
Packaging material (PM)	1	3.23	0.28
SD×PM	8	1.24	0.14

The change in moisture content of the extruded samples kept under accelerated and atmospheric storage conditions for 56 days are shown in Figure 4. There was a gradual increase in the moisture content of the sample in both the packages. ANOVA data (Table 6) indicated that type of packaging material and storage time significantly ($P<0.01$) affects the moisture gain by extruded product. The increase in moisture content of extruded sample contained in the package of HDPE and ALP may be due to the migration of water vapour from the storage environment into the packaging material. The moisture uptake depends upon water vapour permeability of packaging film which was higher for HDPE than that of ALP pouches. It can also be observed from Figure 4 that moisture uptake was at slower rate at atmospheric storage conditions as compared to the accelerated storage conditions. This can be is due to higher temperature and relative humidity 38±1°C and 90±1% during accelerated storage conditions.

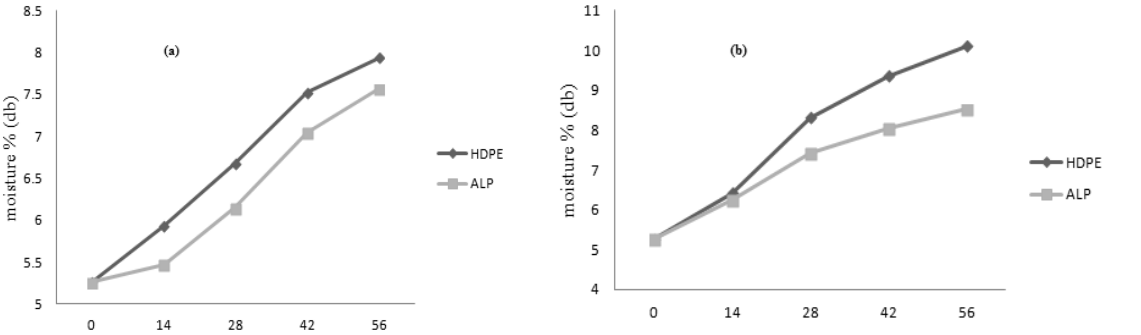

Figure 4. Variation in moisture content of extruded product in HDPE and ALP pouches during (a) atmospheric storage conditions (35±1ºC and 75±1% RH) (b) accelerated storage (38±1ºC and 90±1% RH)

Shelf Life of Extruded Product

Initial moisture content of extruded product was 5.263% (db) for extruded products. The final moisture content was decided on the basis of moisture absorbed by extruded product. This moisture content was considered as the critical moisture content. The area of both pouches HDPE and ALP was 0.0098 m^2 (i.e. 2 × 0.07 × 0.07). Water vapour permeability, K (Kg. m^{-2}.day^{-1}.pa^{-1}) of the packaging material was computed for HDPE and ALP pouches were 2.43 × 10^{-6} and 1.04 × 10^{-6} kg.m^{-2}.day^{-1}.pa^{-1} respectively. Shelf life $Θ_s$ of the samples kept under different storage conditions were found to be as 50 days and 74 days for products kept under HDPE and ALP under atmospheric conditions, whereas the shelf life of products kept under HDPE and ALP under accelerated storage conditions were found to be 37 and 56 days. Higher shelf life of the extruded product in atmospheric conditions may be due to the lower temperature and relative humidity during storage period. It can also be observed that shelf life of the extruded product packed in ALP was higher than in case of HDPE which may be correlated to the higher WVTR of the HDPE pouches.

CONCLUSIONS

Product responses were affected by both FSP and OF. The results showed that varying levels of FSP and OF could be incorporated into an extruded snack product depending upon the desire texture of final product. On the basis of evaluation made using numerical optimization method, a blend of 2.28% FSP and 4.76% OF was used to produce an extruded product with better LE, SL, and less hardness. Upon storage, moisture uptake was at slower rate during atmospheric storage conditions as compared to the accelerated storage conditions. The Shelf life of extruded product was high in the atmospheric storage condition than in the accelerated storage conditions.

Conflict of interest: None.

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