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## FOOD SCIENCE & TECHNOLOGY | RESEARCH ARTICLE

# Physical and functional characteristics of extrudates prepared from fenugreek and oats

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**Abstract:** This study was conducted to investigate the effect of fenugreek seed powder (FSP) and oat flour (OF) on the physical and functional properties of extruded snack product such as bulk density (BD), hardness (HD), lateral expansion (LE), water absorption index (WAI) and water solubility index (WSI) using response surface methodology. All the properties were found to be significantly ( $p < 0.05$ ) affected by proportion of FSP and OF. Results indicated that with the increase in the FSP content, an increase in the values of BD, HD, WAI and WSI was noticed, whereas negative effect of FSP on LE was observed. Results showed negative effect of OF on HD and WSI and an increased effect on BD, LE and WAI of the extruded product. Numerical optimization results showed that a mixture of 2% FSP and 6% OF had higher preference levels for parameters of physical and functional characteristics and could be extruded to produce acceptable quality extrudates.

**Subjects:** Food Chemistry; Food Engineering; Food Science & Technology

**Keywords:** extrusion; physical and functional properties; oat; fenugreek

### 1. Introduction

Extruded snacks and breakfast cereals produced by extrusion technology have become an important part of our daily diet. There is an increasing demand to develop extruded foods enriched with dietary fibre because of the health effects of fibre on cardiovascular, diabetes and the immune systems (Anderson et al., 2009). Fenugreek (*Trigonella foenum-graecum*) is an annual herb found in different parts of the world. Studies have shown various physiological health benefits such as anti-cancer, antifertility, antidiabetic, antiparasitic, lactation stimulant and hypocholesterolaemic effects

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### PUBLIC INTEREST STATEMENT

Fenugreek is having good-quality protein and dietary fibres, possess lot of physiological health benefits like hypocholesterolemic and hypoglycemic effects. Oats are most nutritious cereals, possessing excellent lipid profile and high amounts of soluble fibre. Therefore, extrusion cooking of these ingredients is of advantage because extrusion cooking is the most widely used process. So the development and consumption of extruded snack products having health and nutritious benefits would help increase the health status of the population. Also, the effect on the properties of extruded snack products will be determined.

**Table 1. Values of independent variables at two levels of the 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

(Al-Habori, Al-Aghbari, & Al-Mamary, 1998; Karim, Sohail, Munir, & satar, 2011). Fenugreek possesses higher amounts of dietary fibre than cereals and legumes, thus making it an interesting raw material for the development of fibre-rich extruded product. Fenugreek has been used to develop bakery (Hooda & Jood, 2005) and extruded products (Wani, Solanke, & Kumar, 2015). Extruded snack product enriched with fenugreek possessing higher antioxidant activity has been developed (Wani & Kumar, 2015a).

Oats are generally considered as a minor cereal crop when considered in terms of areas or grain produced annually. Oat is a nutritionally rich cereal possessing high concentrations of soluble fibre and crowded nutrients. Oats are good sources of functional ingredients like  $\beta$ -glucan, having health benefits (Wani et al., 2014) such as hypocholesterolemia and hypoglycemic effects (Behall, Scholfield, & Hallfrisch, 1997; Jenkins, Jenkins, Zdravkovic, Würsch, & Vuksan, 2002). Oats have been used in a number of products like ready-to-eat snacks (Wani et al., 2015), bread and breakfast cereals (Decker, Rose, & Stewart, 2014). Therefore, using fenugreek and oat flour (OF) as a functional ingredient in extruded food products to improve the nutritional quality and provide beneficial health effects is a good idea.

Applying extrusion technology for the production of fibre-rich extruded product is challenging because of the high fibre content leading to lower expansion, harder, higher density and less crispy texture (Wani & Kumar, 2015b). In the present study, extruded snack products were produced using fenugreek seed powder (FSP) and OF and the extrudates were evaluated for physical and functional characteristics.

## 2. Materials and methods

The raw materials used in the production of ready-to-eat snack foods consisted of rice, chickpea, corn, FSP and OF which were bought from the local market Sangrur, Punjab, India. Flours were cleaned by sieving to remove any foreign material, dirt, stone and flour grits, by passing through 60-BSS sieve. After cleaning, the flours were placed in an airtight polythene bag until further use and kept in room condition for further use.

### 2.1. Experimental design

The response surface methodology was applied using a central composite rotatable design in the experimental design. All the experimental analyses of extruded product were carried out in triplicates. Table 1 shows independent variables selected for the experiments. The variables including FSP and OF and their levels were chosen using preliminary trials and literature survey. Composite flour (rice flour:chickpea flour:corn flour = 60:30:10) as a base material was used according to the preliminary trials. Response variables were bulk density (BD), lateral expansion (LE), hardness (HD), water absorption index (WAI) and water solubility index (WSI). Experiment was conducted to study the effect of FSP (1–5%) and OF (3, 6, 9, 12 and 15%) on the physical and functional properties. The moisture content of feed was adjusted to 18%.

Extrusion cooking was carried out using co-rotating twin-screw extruder (Basic Technology Pvt. Ltd. Kolkata, India) with the barrel length:diameter ratio as 8:1. The extruder was fixed with a die nozzle of 4-mm diameter and was run for 30 min in order to reach the desired temperature of 118°C. The screw speed was maintained at 250 rpm. Samples were then poured in to feed hopper and the feed rate was adjusted to 8 kg/h for easy and non-choking operation. Extrudates were cut with a

sharp knife and left to cool at room temperature for about 20 min. The samples were then packed in polythene bags and stored in desiccators until further analysis.

### 2.2. Bulk density

The BD ( $\text{g}/\text{cm}^3$ ) was evaluated by measuring the actual dimensions of the extrudate (Thymi, Krokida, Pappa, & Maroulis, 2005). The BD was calculated using the following formula, assuming a cylindrical shape of extrudate. Ten pieces of the extrudate were randomly selected and average value was reported.

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

where  $m$  (g) is the mass of a length  $L$  of extrudate,  $d$  is diameter of the extrudate (cm) and  $L$  is the length (cm) per gram of the extrudate (cm/g).

### 2.3. Lateral expansion

LE was determined according to the method of Ainsworth, Ibanoglu, Plunkett, and Ozer (2006). About ten lengths of extrudates were selected. The diameter of the extrudate was then measured using a vernier caliper at different positions. LE was then calculated using the mean of the measured diameters in mm:

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

### 2.4. Hardness

Texture analyzer (TA-XT2 texture-analyzer) was used to determine the HD of extrudate. Extrudates of 40-mm length were compressed with a probe SMS-P/75–75-mm diameter at a crosshead speed of 5–3 mm/s. The compression generates a curve with the force over distance (Newton). The highest first peak value was recorded as this value indicated the first rupture of snack at one point and this value of force was taken as a measurement for HD (Stojceska, Ainsworth, Plunkett, İbanoğlu, & İbanoğlu, 2008).

### 2.5. WSI and WAI

The WSI and WAI were determined with a slight modification to the method of Anderson, Conway, and Peplinski (1970) as modified by Wani and Kumar (2015b). Ground extruded sample (2.5 g) was dispersed in 25-g distilled water, followed by stirring for half hour using a vortex. The whole mixture was then rinsed into centrifuge tubes and more distilled water was added in order to make the volume up to 32.5 g. This was then followed by centrifugation at 4,000 rpm for 15 min. WAI and WSI were then calculated using following Equations (3) and (4), respectively.

$$\text{WAI (g/g)} = \frac{\text{Weight of sediment}}{\text{Dry weight of extrudate}} \quad (3)$$

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

## 3. Results and discussion

In the present study, the effect of the raw materials such as FSP and OF on the extruded snacks was examined. Response surface methodology was used for the optimization of variables for the production of quality extruded product based on FSP and OF. The general chemical composition of OF and FSP is: carbohydrate of 66.77 and 47.64%, crude fibre of 2.61 and 7.09%, protein of 13.91 and 27.75%, ash 1.77 and 3.72% and fat content of 6.35 and 6.42% (Wani & Kumar, 2015c). Table 2 showed the chemical composition of all raw ingredients used in this study.

**Table 2. Chemical composition of raw material**

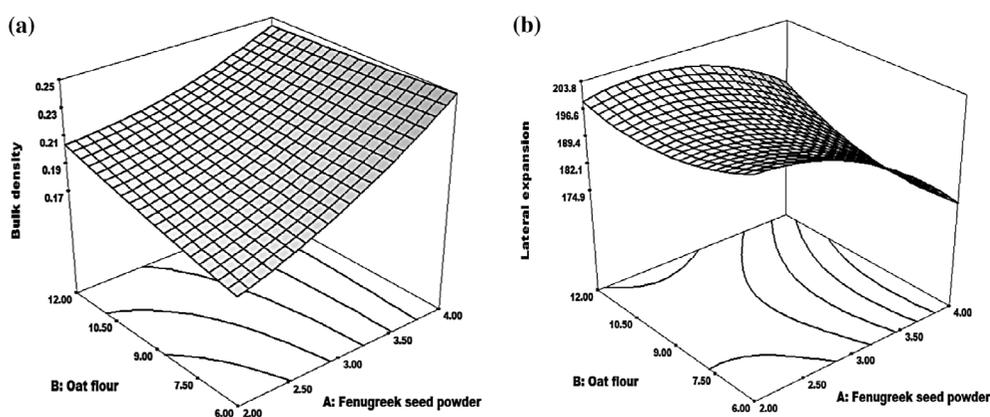
Parameters	FSF	OF	Corn flour	Chickpea flour
Moisture (%)	7.38	8.59	11.57	8.40
Ash (%)	3.72	1.77	1.43	2.79
Crude protein (%)	27.75	13.91	8.86	24.61
Crude fat (%)	6.42	6.35	4.32	4.64
Crude fibre (%)	7.09	2.61	2.00	1.75
Total carbohydrate (%)	47.64	66.77	73.82	57.78

Note: Wani and Kumar (2014, 2015a, 2015c).

**Table 3. Effect of FSP and OF on physical properties of extruded product for 18% moisture content**

S. No.	A	B	FSP	OF	BD	LE	Hardness	WAI	WSI
1	+1	+1	2	6	0.17	201	20.37	1.25	2.6
2	+1	-1	4	6	0.25	170.5	25.18	2.55	3.8
3	-1	+1	2	12	0.19	200	22.02	3.2	3
4	-1	-1	4	12	0.23	185.5	25.8	3.57	2.6
5	+1.41	0	1.58	9	0.18	194.5	19.16	2.32	2.6
6	-1.414	0	4.41	9	0.26	169.2	25.45	3.59	2.6
7	0	+1.414	3	4.75	0.19	205	25.35	1.16	3.8
8	0	-1.414	3	13.2	0.23	203	23.54	3.18	2.6
9	0	0	3	9	0.20	190	26.01	2.58	2.6
10	0	0	3	9	0.21	190	27.35	2.4	2.7
11	0	0	3	9	0.21	195	25.92	2.23	2.6
12	0	0	3	9	0.20	194.5	26.23	2.24	2.8
13	0	0	3	9	0.19	197	26	2.2	2.9

**Figure 1. Response plot for BD and LE as a function of FSP and OF.**



### 3.1. Effect of process variables on product BD

BD is one of the important physical properties of the extruded snacks. Density is an important characteristic as far as packaging requirement is considered. In the present study, BD was found to be in the range of 0.17–0.26 g/cm<sup>3</sup> (Table 3).

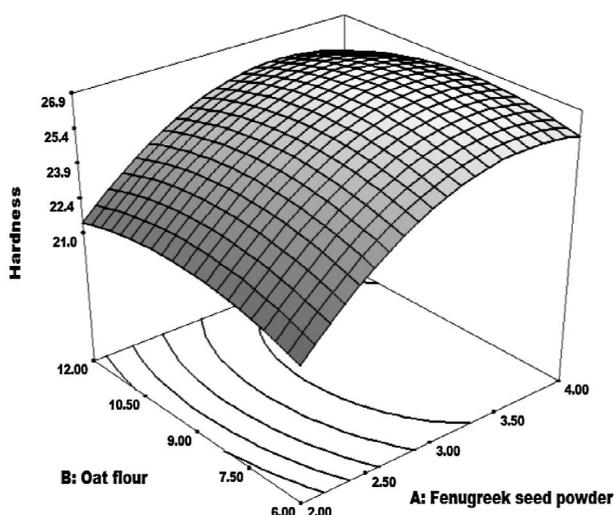
Response surface plot for BD as function of FSP and OF is given in Figure 1(a). Increase in the values of FSP and OF increases the BD. Regression analysis showed a significant ( $p \leq 0.05$ ) positive effect

**Table 4. Regression analysis report calculated on coded levels where all are independent variables**

Factor	BD	LE	HD	WAI	WSI
Intercept	0.2	193.3	26.302	2.33	2.7
FSP (A)	0.029*	-10.09*	2.18*	0.43*	0.1
OF (B)	0.007	1.396	-0.03	0.72*	-0.31213*
A <sup>2</sup>	0.008	-6.64*	-2*	0.33*	-0.025
B <sup>2</sup>	0.0082	4.43	-0.93*	-0.06	0.275*
AB	0.0082	4	-0.25	-0.2325*	-0.4*
R <sup>2</sup>	0.91	0.92	0.94	0.98	0.87

\*Level of significance at  $p \leq 0.05$ .

**Figure 2. Response plot for HD as a function of FSP and OF.**



of FSP and also a positive effect of OF on the BD (Table 4). The increased effect on BD may be due to the higher fibre and protein contents of both FSP and OF. As Lue and Huff (1991) have found fibre molecules are likely to fracture the cell walls as soon as the bubbles of gas swell. Increase in the value of BD was also observed by Wani et al. (2015) for extruded product prepared from fenugreek and oat. Other researchers (Chang, Silva, Gutkoski, Sebio, & Da Silva, 1998; Jin, Hsieh, & Huff, 1994; Yanniotis, Petraki, & Soumpasi, 2007) have also found the similar results for extruded products rich in fibre.

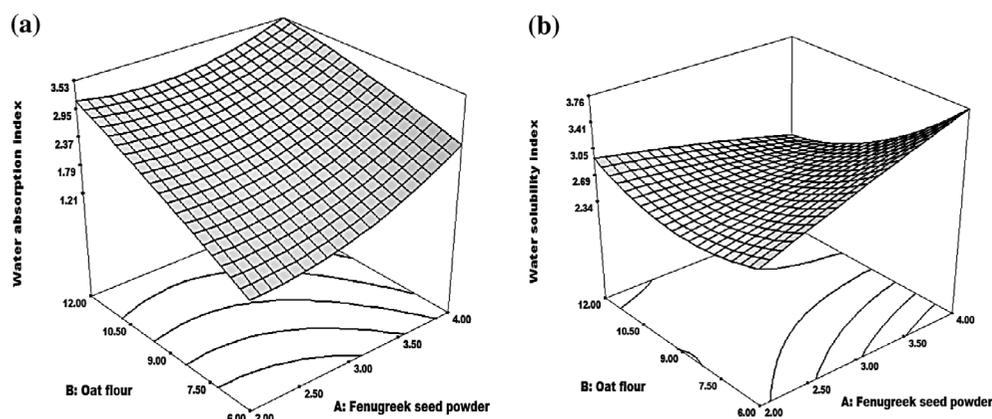
### 3.2. Effect of process variables on product LE

In this experiment, the expansion of the extrudate from FSP and OF mixture varied from 169.2 to 205% (Table 3). It was observed from Table 4 that FSP had a negative ( $p \leq 0.05$ ) effect on LE, whereas OF had a positive effect on this parameter. Figure 1(b) also showed the significant decreased effect of FSP on LE as compared to OF. Altan, McCarthy, and Maskan (2008) and Wani and Kumar (2015b) also observed a similar effect. The decreased effect of FSP may be due to higher protein and fibre contents because proteins affect the spreading of water in the medium and because of the structure that affects the extensional properties of the extruded melts (Moraru & Kokini, 2003). Also, the modification of viscoelastic properties due to the competition for the water availability between the fibre and starch resulted in a delay in starch gelatinization, therefore leading to lower expansion in the products (Onwulata, Konstance, Smith, & Holsinger, 1998).

### 3.3. Effect of process variables on product HD

The HD of the extrudate was determined by measuring the force required to break the extrudate (Singh & Smith, 1997). In the current study, HD of the extrudate varied from 19.16 to 27.35 N (Table 3).

**Figure 3. Response surface plot for (a) WAI and (b) WSI of extruded product as a function of FSP and OF.**



From the regression analysis (Table 4), it was observed that FSP showed a significant ( $p \leq 0.05$ ) positive effect on the HD and OF showed a negative effect on HD of extrudate. The reason can be that a lower expansion of snacks can lead to increased HD, as high contents of protein and fibre in FSP lead to lower LE (Wani et al., 2015). Similar observation was found by Shirani and Ganesharane (2009) and Wani et al. (2015). They observed increased HD with increase in FSP. Figure 2 shows the HD of extrudate as a function of FSP and OF.

### 3.4. Effect of process variables on product WAI

WAI measures the amount of water absorbed by the polysaccharide released from the starch component after extrusion. In this experiment, the WAI ranged from 1.16 to 3.39 g/g (Table 3). Table 4 shows the coefficients of the model and other statistical attributes of WAI. Regression model fitted well with the experimental results. WAI showed a significant ( $p \leq 0.05$ ) positive effect with both the variables. From the response surface plot (Figure 3(a)), it was observed that increase in FSP and OF increases significantly ( $p \leq 0.05$ ) the value of WAI of extruded snack product. Increased value of WAI with FSP and OF could be due to the high water absorption capacity of the fibre present in fenugreek and oats as water absorption is a characteristic feature of flours enriched with fibre. Our findings were in agreement with the results of Chaplin (2003) and Wani et al. (2015). It was found that fibre bonds with water molecules through various types of interactions like hydrophobic, hydrogen bonding and polar interactions.

### 3.5. Effect of process variables on product WSI

WSI of the extrudate snack was found to be in the range of 2.6–3.8% (Table 3). From the report of regression coefficient for WSI, it was noticed that WSI of the extruded snack product showed a negative ( $p \leq 0.05$ ) effect with OF. Response surface plot (Figure 3(b)) showed that WSI of the extruded snack product increases with increase in the value of FSP. Shirani and Ganesharane (2009) observed significant ( $p < 0.05$ ) increase in WSI values of the extruded products prepared from fenugreek and fenugreek polysaccharide compared to those prepared from the chickpea–rice blend.

### 3.6. Optimization

A numerical multi-response optimization technique was applied (Park, Rhee, Kim, & Rhee, 1993) to determine the optimum combination of FSP and OF. The assumptions were to develop a product which would have minimum BD, maximum LE, WAI and WSI in the range and minimum HD. The responses were predicted by the Design Expert-6 software for these optimum process conditions. The result showed that a mixture of 2% FSP and 6% OF could be used for the development of quality extrudate with a desirability of 0.91. The optimum extruded snacks obtained in this way possess the estimated physical and functional characteristics as provided above. 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.

#### 4. Conclusion

It was observed that the product properties were affected by the supplementation of different proportions of FSP and OF. It can be concluded from the result that varying levels of FSP and OF could be used for the development of an extruded product depending on the desired properties of the final product. A mixture of 2% FSP and 6% OF extruded at 118°C, 250 rpm and moisture input of 18% had higher desirability for the parameters of BD, LE, texture (HD), WAI and WSI. The conclusion of this study is that there is a possibility of developing value-added products from FSP and OF by extrusion processing.

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#### Competing Interests

The authors declare no competing interests.

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