Quality characteristics, fatty acid profile and glycemic index of extrusion processed snacks enriched with the multicomponent mixture of cereals and legumes

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Abstract
Extrudate snacks were prepared from base material (rice and corn) and optimized combination of ingredients were analyzed for effects of extrusion cooking on physical, functional, fatty acid profile, total dietary fiber, structural properties, and glycemic index. Physical and functional properties differ significantly ($p \leq 0.05$). Increase in total dietary fiber content was observed by extrusion. Fatty acid profile did not show any significant variation. Snack prepared using base material had softer structure (10.02 N) than snack prepared using optimized combination (10.30 N). Total flavonoid content was reduced by extrusion cooking from 1003 to 802 μg(CE)/g. In pasting properties, higher value of cold viscosity was observed in extrudate snack (140 cP) than unextruded raw mixture (79 cP). In comparison to unextruded raw mixture the peak, final and setback viscosity of extrudate snacks was lower. These findings signify that extrusion is a cooking process. Glycemic index by in vitro analysis showed lower value of extrudate snacks made from optimized combination than extrudate snacks made from base material. Therefore, extrusion cooking and proper selection of ingredients can be successfully used for the production of extruded snacks with significant fatty acid retention, higher fiber content and low glycemic index.

KEYWORDS
dietary fiber, extrusion, fatty acid profile, glycemic index, morphology

1 INTRODUCTION

Extrusion cooking is a continuous process of mixing, kneading, cooking, and forming. It is a low cost, versatile, and very proficient technology in food technology. During the process of extrusion, the ingredients go through various chemical and structural alterations, such as gelatinization of starch, denaturation of protein, formation of complex between amylose and lipids, $\alpha$-linolenic acid retention, and degradation effects of vitamins, pigments, and others (Ilo & Berghofer, 1999; Imran & Anjum, 2014).

The world health and nutritional policies are presently promoting the increase in protein and dietary fiber content in foodstuffs, mainly in cereal-based products. Among the materials, the addition of protein and fiber rich legume was found to have good impact on starch-based extrudate products (Berrios, 2006). In contrast, incorporation of ingredients high in protein and fiber to starch has been confirmed to affect...
the properties such as expansion ratio, texture, and sensory properties of extrudate products (Liu et al., 2000; Veronica et al., 2006). In order to prepare nutritionally acceptable extrudate snacks, fortification to the cereal based products has to be varied according to the nature of each ingredient.

Fenugreek (Trigonella foenum-graecum) is one of the important spices, which is widely used as a flavoring agent in food and beverages, also in medicines (Bukhari et al., 2008; Wani & Kumar, 2018). It has rich flavonoids like quercetin, orientin, luteolin, vitexin, apigenin, and isovitexin (Shang et al., 1998), a lot of health benefits to these natural antioxidants (Kaviarasan et al., 2004). Lipid content (5.5%–7.5%) of the seed of fenugreek comprising mostly of 85% neutral lipids, 10% phospholipids, and 5% glycolipids. Fatty acid profile consisting of unsaturated fatty acids constituting mostly of 40% linoleic, followed by 25% linolenic, and 14% oleic acids (Baccou et al., 1978; Sulieeman et al., 2000).

Now a day’s oats (Avena sativa) have gained its interest in research and commercially, mainly because of its high nutritional profile (Peterson, 2001). Oats are brilliant sources of various dietary fiber constituents of (1 → 3), (1 → 4)-β-D-glucan arabinosylans and cellulose (Skendi et al., 2003). The neutral cell wall of polysaccharide β-glucan has excellent functional and nutritional characteristics. It attains maximum viscosities at minimum concentrations and is of particular significance in human nutrition (Malkki & Virtanen, 2001).

Peas belong to legumes that can be used in food industry for various food formulations. Field pea, such as most other legumes, has higher protein content, especially lysine. They have lesser quantity of methionine and cysteine. So the addition of legumes to cereal based product which are low in lysine and protein results in a development of protein enriched food (Hood-Niefer & Tyler, 2010).

Because the starch is the main constituent of extruded snacks and is responsible for production of quality snacks. However, the addition of fenugreek seed powder (FSP), oat flour (OF), and dried green pea flour (DGPF) can affect the physicochemical, mechanical, and structural properties. In our earlier study (Wani & Kumar, 2016a), a blend of FSP, fenugreek leaf powder (FLP), OF, and DGPF was optimized to quality extrudate snacks. The aim of the current work was to find out the influence of extrusion cooking on the physical, functional, structural, and nutritional characteristics of optimized extruded snacks.

2 | MATERIALS AND METHODS

The samples required were FSP, FLP, OF, DGPF, and base material of rice and corn flour (RF and CF). FLP was ground in a grinder to powder form. All the samples were stored for further evaluation.

The percentage of samples used for the preparation of extruded product using optimized mixture of previously optimized experiments (OF 22%, DGPF 9%, FSP 2%, and FLP 0.70%) and remaining amount was base material (RF 80% and CF 20%) (Wani & Kumar, 2016a), and another extruded product was prepared using only base material (RF 80% and CF 20%). Extrusion cooking was performed by twin-screw extruder. The feed moisture content, barrel temperatures, and screw speed used in this study were 12%, 110°C, and 200 rpm (Wani & Kumar, 2016b). The physical and functional properties examined included as lateral expansion (LE), bulk density, hardness, water absorption index, water solubility index, and color. The nutritional properties, such as fatty acid profile, dietary fiber, and glycemic index, were examined to determine their suitability as healthy snacks.

2.1 | Quality analysis of extruded product

LE was calculated by following formula as stated by Meng et al. (2010).

\[ \text{Lateral expansion} = \left( \frac{\text{diameter of extrudate} - \text{diameter of die opening}}{\text{diameter of die opening}} \right) \times 100. \] (1)

**Bulk density of the extrudate samples was calculated by following formula:**

\[ \text{Bulk density} = \frac{4m}{\pi d^2 L} \] (2)

**Instrumental hardness:** About 10-cm-long sample was crushed with a 3-point bend ring (probe), which was adjusted at 3-mm target distance and trigger force of 5 kg loaded by 50-kg load cell (Altan et al., 2008).

The Hunter lab colorimeter were used to analyze the color of an extruded sample and the L*, a*, and b* values were noted. Standard white reference tile was used for calibration.

2.2 | Total flavonoid content

Total flavonoid content (TFC) was found by a slight modification to the Dowd technique as implemented by Arvouet-Grand et al. (1994). A total of 5 ml of AlCl₃ (2%) in methanol was added with equal amount of extract (1 mg/ml). After every 10 min, the absorption of sample was noted at 415 nm. Blank sample is composed of 10 ml (5-ml extract solution and 5 ml of methanol) without AlCl₃. Standard curve with catechin was used to find out the TFC.

2.3 | Morphology

Microscope (LEICA EZ4 HD) was used to find out the morphology of extruded snacks. Sharp blade were used to obtain a cross sectional area of sample. Using 20X magnifications, extrudate was photographed under microscope. Images showed the results of sample (Wani & Kumar, 2019).


2.4 | Pasting properties

This property was determined using inbuilt extrusion standard of RVA by Rapid Visco Analyser (RVA, Perten). About 3.5 g of ground extrudate per 25 ml of distilled water was mixed. The sample mixture was equilibrated at 25°C for 2 min, heated at the rate of 6°C/min to 95°C, then held at 95°C for 3 min, later on cooled to 25°C at the rate of 6°C/min, and finally, held at 25°C for 5 min. A total of 20.0 min took place for this process (Wani & Kumar, 2016c).

2.5 | Dietary fiber

Enzymatic–gravimetric method was used to determine the dietary fiber using AOAC 985.29 method (AOAC, 2000).

2.6 | Fatty acid profile

Total, saturated, and unsaturated fatty acid was determined using hydrolytic extraction gas chromatographic method, according to the procedure described by AOAC official method 996.06 (AOAC, 2002).

2.7 | Glycemic index

Glycemic index of raw mixture and extruded snacks was determined by the method formulated by International Diabetic Institute, Melbourne, Australia, by rapid in vitro procedure. This method involves homogenization of a predetermined quantity of a sample based on a standard amount of available starch. The available glucose was determined by hexokinase enzymatic spectrophotometer method. This method was designed to approximate the conditions in the human body in regard to carbohydrate digestion and absorption according to Livesy (2003) and IDI (2006).

2.8 | Statistical analysis

Experimental data were analyzed using one-way analysis of variance (ANOVA) using Statistica 7 (statistical soft, TUSA, USA). The means were separated for comparison by Duncan’s Multiple Range Test (DMRT), and the statistical significance was defined as p ≤ 0.05. Data were expressed as the mean value ± standard deviation. The data reported in all of the tables are the averages of triplicate observations.

3 | RESULTS AND DISCUSSION

The results of physical properties of extruded snack product are presented in Table 1. Physical properties of extrudate snacks prepared from (base material) RF and CF and optimized mixture of components differ significantly (p ≤ 0.05). LE was found to be lower in extrudates produced from optimized raw mixture than the extrudates produced from base material. Lower expansion may be due to the effects of fiber and protein content of the ingredient such as fenugreek, oats, and dried green pea. Similar results were also reported by several authors (Wani & Kumar, 2016a, 2016d; Shirani & Ganesharanee, 2009). The decreased effect of high fiber content on expansion may be attributed to the competition with starch for the excess water found in the surrounding medium. Similar findings were reported by Larrea et al. (2005) in high fiber extrude biscuits.

Bulk density of extrudates produced from base material and optimized raw mixture were found to be 0.21 and 0.26 g/cm³, respectively. Increased bulk density in case of extrudates produced from optimized raw mixture might be due to higher protein and fiber amount of ingredients. High protein content may interact with water and other components by hydrophilic interactions, polar interactions, and hydrogen bonding, which results in the increase in weight and similarly increased bulk density (Wani & Kumar, 2016a). However, fiber tends to break the cell walls prior to the expansion of bubbles (Lue et al., 1991).

Hardness of extrudates prepared from base material and optimized mixture was 10.02 and 10.30 N, respectively. Higher hardness in case of extrudates prepared from optimized raw mixture as compared to extrudates prepared from base material may be attributed to the lesser expansion of products. Hardness is inversely proportional to the expansion as observed from study (Wani & Kumar, 2016a, 2016b). Similarly, harder products were found with the addition of extruded orange pulp higher in fiber content (Larrea et al., 2005).

Color is an essential attribute that has direct relation with the acceptability of final product and is one of the essential properties of snack products. The color values, that is, L, a, and b, were found to be significantly different among both the extruded sample (Table 1). It can be revealed from the table that the “L-” and “b-” values of
optimized extruded snack were lower than the extrudate prepared from base material. On the other hand, the “a” value of optimized extrudate was higher as compared to the extrudate made from base material. This significant difference among the sample might be due to the different ingredients mixture.

Overall acceptability of both the extrudates on an average was found to be 8 and 8.3 scored according to the nine point hedonic scale. A nonsignificant difference was observed between the two products. Overall acceptability was good for the optimized extruded snack product for the further analysis.

3.1 | TFC

TFC has attracted their attention by their enormous beneficial effects on the health of human. Majority among them have antioxidant properties. Extrusion cooking reduces the TFC value as shown in the Table 3. This reduction might be attributed to the damage caused by heat because the TFC is sensitive to high temperature (Sharma & Gujral, 2011; Xu & Chang, 2008). Our findings are supported by Huang et al. (2006) and Im et al. (2003) for sweet potato and buckwheat, respectively, upon heat processing.

3.2 | Morphology

Morphology of an extrudate snacks was observed through cross sectional structure and was analyzed by observing the distribution of air cell size (Figure 1). Analysis of air cell size of extrudate snacks was performed using microscope (Leica EZ4 HD, stereo microscope, UK). Microscope was adjusted for clear visibility. The photograph obtained was analyzed for two structural parameters, one among them is “air cell size” and another one is the “number of cells.” The size of air cells varies between the samples as was observed from the images. The extruded sample prepared using base material (i.e., rice and corn) had larger and thinner air cells, whereas the optimized extrudate had smaller and thick air cells. The difference in the sample was only noticed in cell size of extrudate snacks between the samples.

3.3 | Pasting properties

Extrusion cooking had a remarkable effect on the constituents of the sample such as starch. How much a product has been cooked can measured by again cooking the product in RVA and checking the original degree of change in starch.

When the raw material is processed by thermal and mechanical inputs, it will result into the reduction of peak and setback viscosities. The initial (cold) viscosities will increase by means of a pre-gelatinization effect and then ultimately reduces through granule rupture and dextrinization, as the degree of cook increases. Therefore, the RVA can be used to measure degree of cooking.

A higher value of final, peak, and setback viscosities indicates a lower degree of cook. Because the value of final, raw, setback viscosities of extruded sample as shown in Table 2 is lower than unextruded raw mixture; therefore, it can be concluded that the extruded sample was a cooked product. Raw peak, final, hold, and setback viscosity values of unextruded product were higher than the extruded product, whereas cold peak and breakdown was higher in case of extruded product. Raw peak, which is the highest viscosity, reached during heating cycle also called peak viscosity (Wani & Kumar, 2016c). Raw peak viscosities of unextruded and extruded samples are 1196 and 625 cP, respectively. Hold viscosities of unextruded and extrudate product varied between 1197 and 489 cP. Final viscosity can be observed during cooling cycle. The final and setback viscosity of unextruded and extruded product was 3890 and 617 and 2693 and 128, respectively.

In this study, extruded product showed lower value in pasting properties as compared to unextruded raw mixture, except cold and hold viscosities. The lower pasting properties of extruded products could be because of lower amount of available starch content for cooking during RVA processing, as the starch might be retrograded during extrusion process.

3.4 | Total dietary fiber

The results of total dietary fiber (TDF) of the raw and extrudate snack product are presented in Table 3. Extrusion cooking increases the TDF content. TDF of raw mixture and its extruded product was
found to be 7.09% and 7.71%. Increase in TDF was the result of an increase in soluble dietary fiber (SDF) (Vasanthan et al., 2002). Extrusion might lead to the formation of resistant starch and enzyme-resistant indigestible glucans formed by transglycosidation (Singh et al., 2007).

### 3.5 Fatty acid profile

The results of the fatty acid composition of unextruded sample and its extruded snack product were shown in Table 3. Saturated fatty acid composition of unextruded sample and its extruded snack product were found to be 0.63 and 0.65, respectively. On the other hand, monounsaturated fatty acid was found to be 1.96 and 1.94 for raw mixture and its extruded snack, respectively. The polyunsaturated fatty acid of raw mixture and extruded snack product were found to be 1.47 and 1.43, respectively. The results revealed that extrusion cooking has nonsignificant decreases in monounsaturated and polyunsaturated fatty acid of the sample. Availability of literature is limited about the influence of extrusion cooking on fatty acids retention. Similar result was found by Guzman et al. (1992) before and after extrusion for the fatty acid content of corn meal.

The composition of different fatty acids such as, palmitic, oleic, stearic, linoleic, and α-linolenic acids found in unextruded raw mixture and its extruded product were shown in Table 3. It was observed from the results that fatty acid composition was not affected by extrusion.

### 3.6 Glycemic index

The extruded product prepared using base material and optimized mixture was analyzed for glycemic index. Glycemic index of extruded products prepared using base material and optimized mixture was 73 ± 3 and 47 ± 1.2, respectively. The presence of fenugreek, oats, and dried green pea in the extrudate prepared using optimized mixture decreases (p ≤ 0.05) the level of glycemic index lower than 55 that is reflected as the highest level for the products with low glycemic index. Ability of fenugreek, oats, and green pea to lower the glycemic index levels in extrudates in comparison to extrudates of base material (corn and rice) by in vitro analysis was clear in this work. It is the greater amount of TDF content in fenugreek and small amount of starch in pea in comparison to RF and CF of base material that might be responsible for low glycemic index levels in the extruded product prepared using optimized mixture of fenugreek, oats, and DGPF. Similarly, Shirani and Ganesharane (2009) found the low glycemic index value in extrudates produced from fenugreek polysaccharide.

### 4 CONCLUSION

The results of this work demonstrated that the extrusion cooking has influence on physical and functional properties, TFC, and dietary fiber content. There was a nonsignificant change in fatty acid profile of extrudates than raw mixture. Softer texture of extrudates prepared with base material was observed as compared to extrudates prepared with optimized texture. Results indicated that extrusion is a cooking process as it cooks the raw mixture into the final extruded snack product, as shown by increase in cold viscosity and decrease in peak and setback viscosity. It can be concluded that extrusion processed snacks can be fruitfully used for the preparation of extruded snacks with considerable retention of fatty acids, high fiber content, and low glycemic index.

### CONFLICT OF INTEREST

No conflict of interest was declared by the authors.

### AUTHOR CONTRIBUTIONS

All the authors have equally contributed in the preparation, writing, conceptualization, supervision, review, and edit of the manuscript.

| Parameter | Unextruded raw mixture | Extruded product |
|-----------|------------------------|------------------|
| Saturated fatty acid (%) | 0.63 ± 0.1 | 0.65 ± 0.1 |
| Monounsaturated fatty acid (%) | 1.96a ± 0.2 | 1.94a ± 0.1 |
| Polyunsaturated fatty acid (%) | 1.47a ± 0.0 | 1.43a ± 0.0 |
| Palmitic acid (%) | 0.54a ± 0.0 | 0.52a ± 0.0 |
| Stearic acid (%) | 0.09a ± 0.0 | 0.10a ± 0.0 |
| Oleic acid (%) | 1.96 ± 0.2 | 1.95 ± 0.1 |
| Linoleic acid (%) | 1.43 ± 0.1 | 1.42 ± 0.2 |
| Linolenic acid (%) | 0.04a ± 0.0 | 0.05a ± 0.0 |
| Total dietary fiber (%) | 7.09 ± 0.5 | 7.71 ± 0.7 |
| Total flavonoid content µg (CE)/g | 1003a ± 13 | 802b ± 9 |

Note: Means sharing the same letter in column are not significantly different from each other (p ≤ 0.05; DMRT).

Abbreviation: CE = Catechin equivalent.
ETHICS STATEMENT

I hereby declare that this manuscript has not been published elsewhere. There is no conflict of interest, and all co-authors met the criteria for authorship. The study does not require any ethical approval. If any error is subsequently found in the manuscript, I will inform the journal.

DATA AVAILABILITY STATEMENT

The data used during the current study are available from the corresponding author upon reasonable request.

FUNDING INFORMATION

The study was self-funded.

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How to cite this article: Wani SA, Ganie NA, Kumar P. Quality characteristics, fatty acid profile and glycemic index of extrusion processed snacks enriched with the multicomponent mixture of cereals and legumes. *Legume Science*. 2021;3:e76. https://doi.org/10.1002/leg3.76