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ORIGINAL ARTICLE

Effect of chickpea and spinach on extrusion behavior of corn grit

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Abstract The present work was carried out to see the effect of blending of corn grit (CG) with varying levels of chickpea grit (CP 0–100%) and spinach leaf powder (SP 0–6%) on the characteristics [color, expansion, density, hardness, water absorption index, total phenolic content (TPC), antioxidant activity (AOA; as DPPH and ABTS free radical scavenging activities)] and sensory properties of extrudates. CP and SP were rich in proteins and minerals (Cu, Fe, Zn, Mg, Ca, K and Na). Their blending significantly influenced the physicochemical and antioxidant properties of CG extrudates. TPC and AOA of extrudates increased with the increased incorporation of CP and SP, though specific mechanical energy and extrudate expansion, generally, decreased while density and hardness increased. Sensory analysis revealed that CP and SP at incorporation levels of 25% and 4%, respectively could be blended with CG for making highly acceptable antioxidant-rich expanded snack.

Keywords Antioxidant · Color · Extrudates · Texture · Sensory

Introduction

Extrusion cooking is a HTST process in which a food material is subjected to heating, shearing and compression. Nowadays, a large variety of breakfast cereals and snack foods are manufactured using this technology. The raw materials commonly used for food extrusion are cereal grains which are high in starch (Singh and Smith 1997; Singh et al. 1998). Most commercially available extruded products employ corn grit (CG) as the main ingredient which is obtained after dry milling of corn (Shevkani et al. 2014). CG provides all the desirable features for the production of extruded products of high acceptability. However, corn extrudates are nutritionally poor due to lower contents of several essential nutrients, such as, proteins (essential amino acids), dietary fiber, minerals and polyphenols.

Legumes are considered as the second most important source of human food after cereals. Thy are good sources of high quality proteins (20–40%) especially when consumed in combination with cereals. Additionally, these are inexpensive source of other nutrients such as resistant starch, dietary fiber, vitamins, minerals and polyphenols (Singh et al. 2017). Chickpea is one of the most important legumes of Indian sub-continent. It is a good source of protein and carbohydrate while its protein quality is even better than other legumes such as pigeon pea, black gram and green gram (Kaur and Singh 2005; Tiwari and Singh 2012). It contains high amounts of protein, complex carbohydrates, dietary fiber, folate and essential minerals (Meng et al. 2010). At the same time, chickpea can be used to prepare snack products with desirable texture and expansion attributes, if proper processing conditions and ingredient composition is selected (Meng et al. 2010).

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The incorporation of vegetables to corn-based extruded products can also be considered an appropriate option for nutritional/functional improvement of snack due to the presence of high concentration of vitamins, minerals and fibers. Spinach is a green leafy vegetable which is well known for its high nutritional value. Spinach leafs are particularly high in total dietary fiber (15%) and essential minerals like K, Mg, Na, Ca, Cu and Fe (579, 81, 84, 98, 0.28 and 9.49 mg/100 g, respectively) (Singh et al. 2016a). They also contain biologically active phytochemicals, like carotene, phenolic acids, flavonoids and fatty acid derivative compounds (lipoic acid) which have been hypothesized to possess anti-carcinogenic, antimicrobial and antioxidant activity (Vázquez et al. 2013; Singh et al. 2016b).

Recently, there has been an increase in the interest for developing and evaluating nutritionally rich extruded snacks by blending cereals with fruits, vegetables, tubers, etc. with cereals (Chiu et al. 2013; Kaur et al. 2015; Singh et al. 2016c). India is amongst the main chickpea and spinach producing countries of the world. However, the combined effect of blending chickpea and spinach to CG for extrusion cooking has not been reported in the literature. Therefore, the present study was undertaken to produce extruded products of high consumer acceptability by blending corn, chickpea, and spinach and to investigate the effect of this blending on the extrusion parameters and quality attributes of CG extrudates.

Materials and methods

Materials

Corn grit (CG) and chickpea grit (CP) were kindly provided by Kulwant Nutrition, Batala, India. Fresh spinach leaves were purchased from the local market of Amritsar (India). These were carefully sorted to remove stems and roots. The leaves were washed thoroughly and blanched by immersing in boiling water for 1 min followed by in ice-cold water. Afterwards, the blanched leaves were dried in a cabinet drier at 50 °C for 24 h and ground to pass all through 60 mesh sieve (BSS). The dried spinach powder (SP) was then sealed in lock pouch and stored at − 20 °C till evaluation/use. Gallic acid, Folin-Ciocalteu reagent, 2,2-diphenyl-1-picrylhydrazyl (DPPH), 2,2′-azinobis-3-etheylbenzothiazoline-6-sulfonic acid (ABTS) and 6-hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic acid (Trolox) were purchased from Sigma-Aldrich Company Ltd. (St Louis, USA). Other chemicals used were of at least analytical grade.

Analysis of raw materials

Color properties

Color properties of the raw materials (CG, CP and SP) were determined using Ultra Scan VIS Hunter Color Lab (Hunter Associate laboratory Inc., Reston VA, USA) following the method described elsewhere (Shevkani et al. 2015). Color was measured as L^*, a^* and b^* values, where L^* indicates the lightness (luminance), a^* indicates the degree of redness to greenness while b^* indicates blueness to yellowness.

Protein content, ash content, moisture content and mineral composition

Protein, ash and moisture content of CP, CG and SP were estimated using standard methods (AOAC 2000). Mineral composition of raw materials was determined using an Atomic Absorption Spectrometer (Agilent Technologies, USA). Exactly, 1 g of CG, CP and SP were heated for 6 h at 550 °C in a furnace. The resultant ash was dissolved in 1 N nitric acid (2.5 ml), filtered and analyzed for Cu, Fe, Mn, Zn, Mg, Ca, K and Na content. The instrument was calibrated with standard stock solutions of the respective minerals.

Total phenolic content and antioxidant activity

Extracts for total phenol content (TPC) and antioxidant analysis were prepared at 25 °C by mixing CP, CG, and SP (0.2 g) and 80% methanol (2 ml) for 2 h using an orbital shaker (200 rpm) and centrifugation at 7000 *g* for 10 min. Supernatants were collected while sediments were re-suspended with 80% methanol, shaken and centrifuged as mentioned above. The two supernatants/extracts were pooled and filtered through 0.45 µm syringe filters (Pal, USA) to remove any insoluble particles. All extracts were made in triplicate and analyzed immediately for TPC and antioxidant activity (AOA). TPC was determined following the method of Singleton et al. (1999) with slight modifications. Briefly, 100 µl of the extract was mixed with distilled water to dilute the same to 4.8 ml. Then, 300 µl Folin–Ciocalteau reagent was added and the mixture was allowed to incubate for 8 min. After the incubation period, 20% sodium carbonate solution (900 µl) was added with mixing. The solutions were, then, left for 30 min at 40 °C before their absorbance was noted at 765 nm using a UV/Vis spectrophotometer (Perkin-Elmer, USA). Gallic acid was used as a standard and the results were reported as mg GAE (gallic acid equivalents)/100 g. Total antioxidant activity was determined following ABTS and DPPH free radical scavenging tests. Exactly, 100 µl extract was reacted with 3.9 ml DPPH solution (6×10^{-5} mol/l). Absorbance at 515 nm was noted at 0 and 30 min after the reaction (Brand-Williams et al. 1995). ABTS free radicals were generated by reaction of 7 mM ABTS with 2.45 mM potassium persulfate in dark for 12 h. The working solution was made by diluting ABTS stock with 80% methanol to give absorbance of 0.7 ± 0.02 at 734 nm. Exactly 3 ml ABTS working solution and 100 µl extract were mixed, after which the absorbance was noted at 734 nm at 0 and 1 min (Ozgen et al. 2006). Calibration curve was constructed by plotting percentage inhibition against the concentration of Trolox in both assays and AOA was expressed as µM trolox/mg.

Extrusion cooking and extrudate properties

Calculated amounts of CG, CP and SP were mixed to get homogenous blends as shown in Table 1. Extrusion was performed on a co-rotating and intermeshing twin-screw extruder (BC 21, Clextral, Firminy, France) at constant moisture, temperature and screw speed of 16%, 150 °C and 500 rpm, respectively. The motor power rating of the extruder was 8.5 kW. Barrel diameter and its length to diameter ratio (L/D) were 25 mm and 16:1, respectively while the diameter of die opening was 6 mm. Feed was introduced into the extruder using a single screw volumetric feeder (DS and M, Modena, Italy). Extruder was equipped with a torque indicator, which showed percentage of torque in proportion to the current drawn by drive motor. The terminal section of the extruder was heated by an induction heating belt while the feeding section was cooled with running water. The extruder was fitted with as variable speed cutter to cut extrudates. The extrudates were collected when constant values of pressure, temperature and torque were obtained. They were allowed to cool to room temperature and then sealed in PET jars and stored under refrigeration till evaluated. Specific mechanical energy (SME), which indicates mechanical energy input was also calculated (Hu et al. 1993). Color properties of extrudates were determined by noting L^*, a^* and b^* values using the aforementioned colorimeter. Diameter was measured using a digital Vernier caliper from three different locations along the length of eight extrudates from each blend. Density of the extrudates was calculated by determining weight and volume of eight extrudates following the formula $\pi r^2 l$, where r is the radius while l is the length of the extrudates. The density was reported as g/cm^3. Water absorption index (WAI) was determined following the method of Anderson et al. (1969). TPC and antioxidant activity were determined using the methods described above. TPC and AOA (DPPH and ABTS) were determined as described in previous section (analysis of raw materials). A portion of the extrudates was fried at 170 °C in refined soybean oil for 4 min. The fried extrudates were evaluated for hardness (resistance to compression) using a texture analyzer (TA/XT2 plus, Stable Microsystems, Crawley, UK). Five randomly selected fried extrudates from each blend were subjected to compression (60%) with a probe

Table 1 Formulation of corn grit (CG), chickpea (CP) and spinach (SP) blends and specific mechanical energy (SME) of extrudates

Blend	Corn grit (%)	Chickpea (%)	Spinach (%)	SME (kWh/kg)
1	100	0	0	106.8
2	75	25	0	109.1
3	50	50	0	102.4
4	25	75	0	97.9
5	0	100	0	82.3
6	100	0	2	115.7
7	75	25	2	106.8
8	50	50	2	97.9
9	25	75	2	91.2
10	0	100	2	64.5
11	100	0	4	104.6
12	75	25	4	100.2
13	50	50	4	106.8
14	25	75	4	62.3
15	0	100	4	44.5
16	100	0	6	102.4
17	75	25	6	95.7
19	50	50	6	97.9
20	25	75	6	86.6
21	0	100	6	80.1

(P/75) at a pre and post-test speeds of 1 mm/s. The maximum force required for the compression of one extrudates was expressed as extrudates hardness. Sensory analysis of fried extrudates was done by a group of 12 trained and semi-trained personnel, including faculty members, research fellows and post graduate students of Department of Food Science and Technology, Guru Nanak Dev University, Amritsar, India. They evaluated extrudates for color, texture, mouth feel, taste and overall acceptability on a 9-point hedonic scale (from 1 = extremely dislike to 9 = extremely like).

Statistical analysis

The data reported is mean of triplicate observations (except if mentioned above), respectively. The data was subjected to Analysis of Variance (ANOVA) using Minitab Statistical Software (MINITAB, State College, PA, USA). The data was also analyzed for Principal Component Analysis in order to see the overall relationships between various properties of extrudates.

Results and discussion

Physiochemical properties

Color values (*L**, *a** and *b**) of CG, CP and SP are given in Table 2. *L** value, indicating luminescence or lightness was the highest for CP (78.0), followed by CG (76.1), and SP (52.9). CG and CP showed positive values of *a** (13.0 and 7.5, respectively) and *b** (38.3 and 29.9, respectively) whereas SP showed negative *a** (− 7.5) and positive *b** (15.0). The *a** values is an indicator of red to green color whereas *b** values is an indicator of blue to yellow color. The results indicated that CG and CP were yellowish-red likely due to carotenoids whereas SP was green owing to chlorophylls. *L**, *a** and *b** value of 86.38–93.47, 1.03–1.95 and 12.96–22.83, respectively for different corn grits and flours and 28.4, − 6.2 and 10.3, respectively for fresh homogenized spinach have been reported earlier by Shevkani et al. (2014) and Singh et al. (2016a), respectively.

CG, CP and SP showed protein content of 7.9, 23.1 and 32.0%, respectively and ash content of 1.0, 2.7 and 11.2%, respectively (Table 2). Higher ash content in foods is related to the presence of higher amount of inorganic matter including minerals. The protein and ash content in the range of 20.6–26.7% and 2.72–2.91%, respectively for chickpea flour against 4.58–14.22% and 0.13–4.81%, respectively for corn grits have been reported earlier (Kaur and Singh 2005; Shevkani et al. 2014). Minerals have a crucial role in several metabolic processes and functioning of the vital organs. These are classified as major minerals (Na, Ca, K and Mg) and trace minerals (Zn, Cu, Fe, F, Cr, Se and Mo). Cu, Fe, Zn, Mg, Ca, K and Na were present in higher amounts in SP and CP than CG. Corn grit contained 0.39 ppm Cu, 0.135 ppm Fe, 0.713 ppm Mn, 0.476 ppm Zn, 20.9 ppm Mg, 24.0 ppm Ca, 62.2 ppm K and 22.2 ppm Na against 0.243, 0.403, 0.768, 0.583, 63.6, 161.0, 218.7 and 80.0 ppm, respectively in CP, and 0.180, 0.970 0.152, 0.859 93.4, 163.0 281.1 and 34.3 ppm, respectively in SP. The results indicated that SP and CP were nutritionally superior to CG, thus, may be used for protein and mineral enrichment of CG extrudates.

Table 2 Physical and chemical properties of corn grit, chickpea grit and spinach powder

Component	Corn grit	Chickpea grit	Spinach powder
*L**	76.1 ± 0.26b	78.0 ± 0.24c	52.9 ± 0.59a
*a**	13.0 ± 0.16c	7.5 ± 0.09b	− 7.5 ± 0.21a
*b**	38.3 ± 0.24c	29.9 ± 0.09b	15.0 ± 0.42a
Protein content (%)	7.9 ± 0.4a	23.1 ± 0.5b	32.0 ± 0.7c
Ash content (%)	1.0 ± 0.05a	2.7 ± 0.2b	11.2 ± 0.4c
Cu (mg/kg)	0.039 ± 0.05a	0.243 ± 0.01c	0.180 ± 0.04b
Fe (mg/kg)	0.135 ± 0.09a	0.403 ± 0.08b	0.970 ± 0.06c
Mn (mg/kg)	0.713 ± 0.08b	0.768 ± 0.05b	0.152 ± 0.07a
Zn (mg/kg)	0.476 ± 0.07a	0.583 ± 0.08b	0.859 ± 0.11c
Mg (mg/kg)	20.9 ± 1.1a	63.6 ± 4.3b	93.4 ± 3.9c
Ca (mg/kg)	24.0 ± 0.97a	161.0 ± 5.8b	163.0 ± 2.5c
K (mg/kg)	66.2 ± 3.8a	218.7 ± 8.6b	281.1 ± 9.2c
Na (mg/kg)	22.2 ± 1.4a	80.0 ± 2.2c	34.3 ± 1.3b

Values are mean ± SD

Values with the same letter in a row did not differ significantly ($P > 0.05$)

Extrudate characteristics

Color properties

The color values of extrudates are shown in Table 3. In comparison to the grits, the extrudates were less reddish and greenish (showed lower *a** and *b** values) suggesting thermal breakdown of pigments during extrusion cooking (Singh et al. 2016c). *L** value indicating lightness/darkness ranged from 65.6 to 80.4 (Table 3). The extrudates made from CG–CP blends showed higher lightness while the incorporation of SP decreased the same. The highest *L** value (80.4) was observed for the extrudates made from CG–CP blend (25:75). The extrudates made from CG and CG–CP blends showed positive *a** values while that from CG–CP–SP blends showed negative *a** values (Table 3). This could be due to the incorporation of SP which resulted extrudates with greenish ting. The lowest *a** was observed for extrudates from CG, CP and SP blends in ratio of 0:100:6, respectively. All the extrudates showed positive *b** values varying between 21.8 and 30.9, indicating the presence of yellowness. Two-way ANOVA showed significant effect of CP and SP on color parameters (*L**, *a** and *b**) of the extrudates wherein SP had greater effect than CP (Table 4).

Specific mechanical energy

The extrudates made from CG alone showed high SME which generally decreased (except extrudates from 75CG:25CP:0SP blend) with the incorporation of CP and SP depending on the level of incorporation (Table 1; Fig. 1). ANOVA also revealed a significant effect of both CP and SP on SME; however, the effect of CP was higher as compared to SP (Table 4). CG extrudates showed a SME of 106.8 kWh/kg whereas that from CG–CP–SP blends showed SME between 62.3 and 109.1 kWh/kg. SME is an indicator of the amount of mechanical energy used per unit mass during extrusion. It plays an important role in starch conversion by rupturing semi-crystalline structures, contributing to starch granule rupture (Carvalho et al. 2010) and is mainly controlled by melt viscosity, particularly when the extruder is operating at a constant screw speed (Zhang and Hoseney 1998). Therefore, the decrease in SME with incorporation of CP and SP could be due to the higher protein content of CP and SP than CG, which concomitantly decreased starch content in the feed resulting in low melt viscosity and SME. The decrease in SME with incorporation of CP may also be attributed to increase in fat content as CP has higher fact content than CG. Earlier, Thakur et al. (2017) observed a negative correlation of SME with fat content. They indicated that the presence of higher lipids caused lubrication of extruder barrel, resulting into reduction in SME. Additionally, the decrease in SME with increasing levels of SP (above 4%) might also be due to high content of fibers which increased viscosity by binding water and decreasing its availability for starch in the system (Singh and Muthukumarappan 2017). Decrease in SME with the incorporation of beetroot flour in CG has been reported earlier by Singh et al. (2016b).

Diameter and density

Expansion and diameter are important extrudate characteristics, influencing acceptance of the puffed products by customers. These parameters describe the degree of puffing during extrusion and affect textural characteristics of extruded products (Gujska and Khan 1991). The extrudates made from different CG–CP–SP blends showed diameter in the range of 7.8–15.4 mm. The extrudates made from CG alone and CG–SP blends showed higher diameter (14.4–15.4 mm) while CP and SP in combination decreased diameter depending on the level of incorporation (Table 3). Two-way ANOVA also revealed that extrudate diameter was significantly affected with both CP and SP, wherein CP had greater effect than SP (Table 4). The expansion in the extruded-puffed products is mainly attributed to the bubbles which grow due to flash evaporation of moisture as the melt leaves the extruder die, where high pressure of the superheated steam overcomes the mechanical resistance in the melt (Moraru and Kokini 2003; Arhaliass et al. 2009). Diameter and expansion of cereal extrudates depends on the degree of starch gelatinisation/dextrinization (Chinnaswamy and Hanna 1988) which is influenced positively by SME during extrusion. The higher SME led to higher degree of dextrinization as mechanical energy favored gelatinization by promoting rupture of intermolecular hydrogen bonds (Gropper et al. 2002). PCA revealed a positive relation of diameter with SME (as their curves run close to each other on the loading plot) while negative with CP and SP incorporation level (as their curves lied in opposite directions) (Fig. 1). Therefore, low diameter of CG–CP–SP blend extrudates may be attributable to low SME as a result of the increased content of proteins and fibers in feed/melt which might have made the starch more resistant to gelatinize by making water unavailable and providing the starch granules a greater thermal stability. Increase in cooking (pasting) temperature of rice flour in the presence of higher amounts of cowpea proteins has been reported earlier (Shevkani et al. 2015). Seth et al. (2015) reported decrease in expansion of rice corn flour extrudates with the incorporation of yam flour with higher protein content.

Extrudate density is inversely related to expansion. Extrudates made from CG–CP–SP blends showed density

Table 3 Physicochemical properties of extrudates from different corn grit (CG), chickpea grit (CP) and spinach (SP) blends

CG:CP:SP	*L**	*a**	*b**	Diameter (mm)	Density (g/cm^3)	Water absorption capacity (g/g)	Hardness (N)	Total phenolic content (mg GAE/100 g)	DPPH inhibition (µM trolox/mg)	ABTS inhibition (µM trolox/mg)
100:0:0	76.4 ± 2.7 g	2.5 ± 0.1n	27.8 ± 1.3e	14.9 ± 0.5 g	0.17 ± 0.02a	4.5 ± 0.1ef	94.6 ± 4a	41.1 ± 0.6a	1.1 ± 0.1a	1.8 ± 0.2 a
75:25:0	78.2 ± 0.4 h	1.9 ± 0.1 m	25.6 ± 0.2d	13.3 ± 0.2e	0.27 ± 0.04b	4.7 ± 0.2f	99.5 ± 2b	44.4 ± 0.7b	1.2 ± 0.2a	2.1 ± 0.1b
50:50:0	79.6 ± 0.3i	0.9 ± 0.1 k	22.7 ± 0.6b	10.5 ± 0.4d	0.44 ± 0.02d	3.0 ± 0.2b	112.3 ± 5c	51.0 ± 0.8e	1.5 ± 0.1b	2.2 ± 0.1b
25:75:0	80.4 ± 0.3i	1.3 ± 02 l	23.6 ± 0.6c	9.5 ± 0.3c	0.76 ± 0.01f	2.6 ± 0.1a	193.3 ± 2e	55.4 ± 0.9 g	1.8 ± 0.3bc	2.6 ± 0.0c
0:100:0	78.1 ± 0.1 h	0.7 ± 0.1 k	21.8 ± 0.1a	8.5 ± 0.2b	0.87 ± 0.04 g	3.3 ± 0.0c	209.6 ± 8f	60.4 ± 1.2gh	2.1 ± 0.1 cd	2.9 ± 0.3c
100:0:2	71.2 ± 0.0d	− 0.8 ± 0.0j	28.7 ± 0.1f	15.4 ± 0.3 g	0.15 ± 0.01a	4.7 ± 0.2f	102.5 ± 9bc	46.7 ± 0.7c	1.2 ± 0.1a	1.9 ± 0.0a
75:25:2	72.9 ± 0.1e	− 1.0 ± 0.0i	27.5 ± 0.1e	13.1 ± 0.4e	0.24 ± 0.05b	4.7 ± 0.2f	129.5 ± 13d	49.3 ± 1.0d	1.3 ± 0.3ab	2.2 ± 0.1b
50:50:2	73.9 ± 0.4f	− 2.9 ± 0.2 g	29.8 ± 0.2gh	9.9 ± 0.5 cd	0.61 ± 0.04e	4.1 ± 0.1e	231.6 ± 9 g	53.0 ± 0.6f	1.5 ± 0.2b	2.3 ± 0.1b
25:75:2	74.2 ± 0.7f	− 3.8 ± 0.6f	29.6 ± 0.2 g	8.5 ± 0.2b	0.82 ± 0.07 fg	3.8 ± 0.0d	245.6 ± 11gh	56.7 ± 0.8 g	1.9 ± 0.0c	2.7 ± 0.0c
0:100:2	74.7 ± 0.2f	− 4.9 ± 0.1e	29.4 ± 1.0 g	8.3 ± 0.4 ab	0.86 ± 0.02 g	3.8 ± 0.3d	336.3 ± 6j	62.2 ± 0.8 h	2.1 ± 0.2 cd	3.1 ± 0.2d
100:0:4	71.1 ± 0.2d	− 6.6 ± 0.0b	30.5 ± 0.4 h	14.6 ± 0.5 g	0.17 ± 0.04a	4.9 ± 0.1 g	110.5 ± 7c	47.9 ± 0.7 cd	1.2 ± 0.1a	1.9 ± 0.1a
75:25:4	67.3 ± 0.9b	− 2.3 ± 0.1 h	28.2 ± 0.4f	11.5 ± 0.3e	0.36 ± 0.04c	2.9 ± 0.3ab	128.2 ± 4d	53.6 ± 0.7f	1.3 ± 0.4ab	2.3 ± 0.2b
50:50:4	67.8 ± 1.5b	− 3.6 ± 0.2f	29.3 ± 0.5 g	9.6 ± 0.5c	0.60 ± 0.03e	4.1 ± 0.1e	182.4 ± 9e	57.1 ± 1.1 g	1.6 ± 0.2b	2.4 ± 0.1bc
25:75:4	70.2 ± 0.1c	− 5.4 ± 0.1d	30.9 ± 0.2 h	8.6 ± 0.3b	0.82 ± 0.03 fg	3.8 ± 0.4d	269.3 ± 2 h	61.3 ± 0.5 h	1.9 ± 0.1c	2.8 ± 0.1c
0:100:4	71.1 ± 0.2d	− 6.6 ± 0.1b	30.5 ± 0.2 h	8.0 ± 0.2a	0.88 ± 0.01 g	3.2 ± 0.1bc	341.6 ± 1j	66.0 ± 0.7i	2.2 ± 0.1d	3.2 ± 0.0d
100:0:6	66.0 ± 0.2a	− 1.3 ± 0.0i	25.2 ± 0.6d	14.4 ± 0.2 g	0.18 ± 0.01a	4.3 ± 0.1e	124.6 ± 14d	49.3 ± 0.8d	1.2 ± 0.1a	2.0 ± 0.3ab
75:25:6	65.6 ± 0.1a	− 3.1 ± 0.1f	28.2 ± 0.4f	11.7 ± 0.5e	0.37 ± 0.02c	4.3 ± 0.2e	118.4 ± 2 cd	56.2 ± 0.6 g	1.4 ± 0.1ab	2.2 ± 0.1b
50:50:6	67.3 ± 0.2b	− 4.4 ± 0.3e	29.9 ± 0.7gh	8.7 ± 0.4b	0.76 ± 0.04f	3.8 ± 0.1d	220.5 ± 1f	59.3 ± 0.5 h	1.7 ± 0.2bc	2.4 ± 0.2bc
25:75:6	67.1 ± 1.0b	− 6.2 ± 0.2c	30.1 ± 0.3 g	8.4 ± 0.3ab	0.89 ± 0.07 g	3.0 ± 0.3b	282.6 ± 6i	67.2 ± 0.6i	2.0 ± 0.1 cd	2.8 ± 0.1c
0:100:6	65.8 ± 0.2a	− 7.9 ± 0.0a	29.8 ± 0.2 g	7.8 ± 0.5a	0.96 ± 0.06 h	4.0 ± 0.1de	342.7 ± 3j	69.9 ± 0.9j	2.2 ± 0.2d	3.2 ± 0.4d

Values are mean ± SD

Values with the same letter in a column did not differ significantly ($P > 0.05$)

Table 4 *F* values obtained from two-way analysis of variance (ANOVA) of the properties of extrudates prepared from corn grit (CG), chickpea grit (CP) and spinach (SP) blends

Parameter	Chickpea	Spinach	Interaction
Mean diameter	2065**	94.2**	10**
Density	1980**	74.6**	13.8**
*L**	12.65**	649.05**	8.24**
*a**	3125**	16,150**	697.2**
*b**	8.88**	391.4**	48.2**
WAI	239.21**	73.6**	74.47**
Hardness	2,210,255**	468,055**	5683**
TPC	1015**	445**	8.9**
DPPH inhibition	764.6**	34.1**	NS
ABTS inhibition	1025**	33.1**	2.82*

WAI water absorption index, *WSI* water solubility index, *TPC* total phenolic content, *SME* specific mechanical energy, *NS* non-significant

$*P < 0.05$; $**P < 0.005$

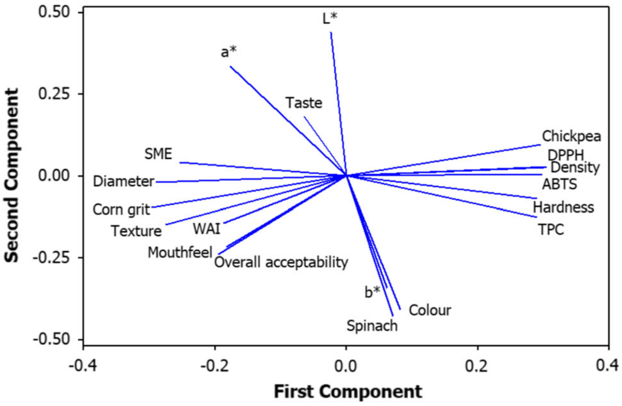


Fig. 1 Principal component analysis loading plot highlighting the overview of properties of corn grit, chickpea grit and spinach extrudates

in the range of 0.15–0.96 g/cm^3 (Table 3). The extrudates made from CG alone and CG–SP blends were less dense (0.15–0.18 g/cm^3) than those made from CG–CP–SP blends (0.24–0.96 g/cm^3). This may be due to the presence of high amount of starch that gelatinized leading to the increase in the volume of the extrudates. CP and SP in combination increased density depending on the level of incorporation (Fig. 1; Table 4). Incorporation of CP had much greater effect than SP (Table 4), suggesting that higher amount of proteins in melt ruptured cell walls, hence the air bubbles were prevented from expanding during the extrusion process thus resulted in dense extrudates. The presence of high amounts of proteins and fibers have been reported to increases density of starch-based extruded products (Onwulata et al. 2001; Moraru and Kokini 2003; Veronica et al. 2006).

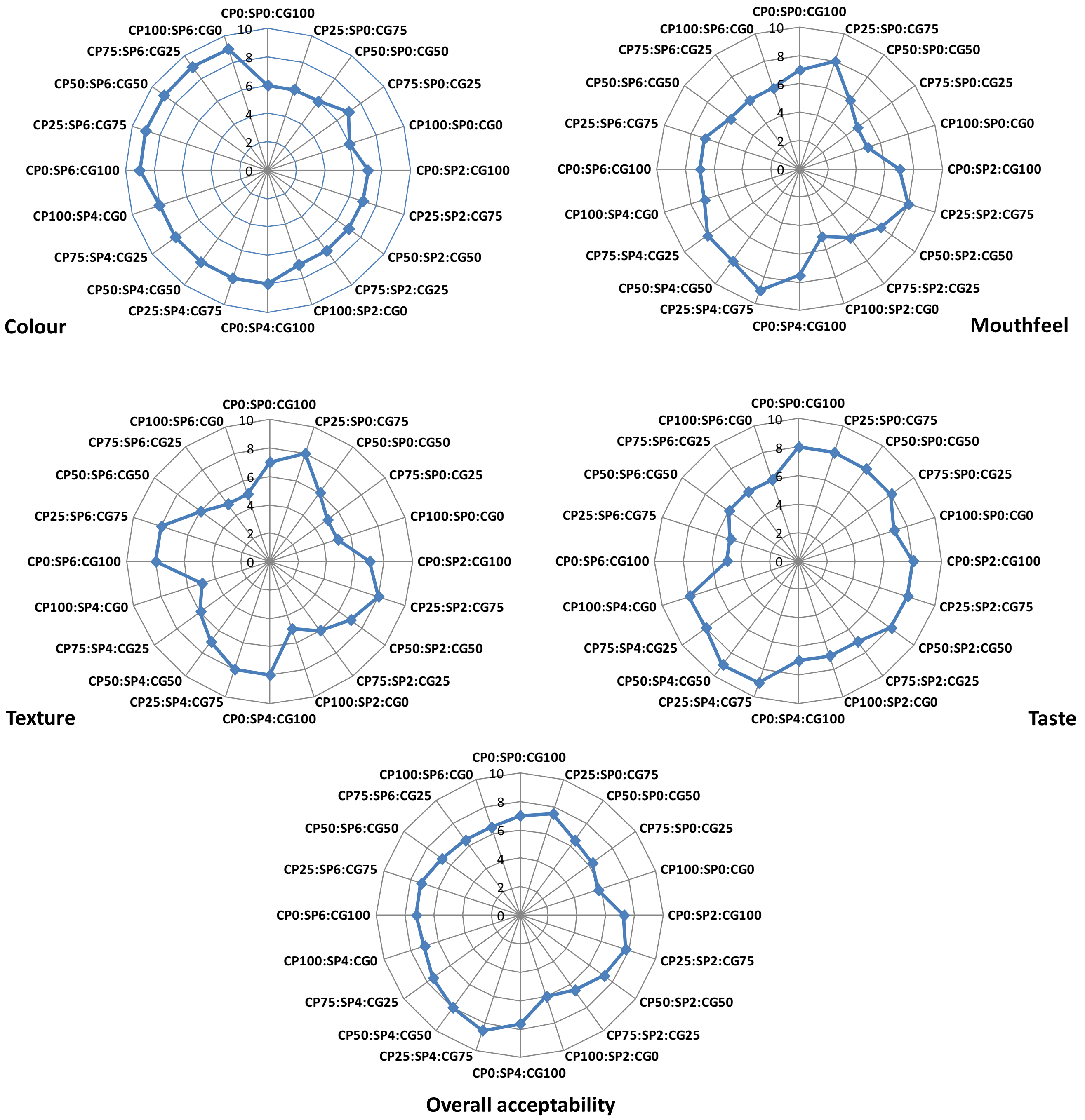
Water absorption index

WAI is a measure of physical and chemical changes in starch which take place during extrusion of starch-rich raw materials. The extrudates made from different CG–CP–SP blends showed WAI in the range of 2.6–4.9 g/g. The extrudates made from CG showed WAI of 4.5 g/g which, in general, decreased with the increased incorporation of CP and SP (except for extrudates from CG–CP–SP blends in ratios of 75:25:0, 100:0:2, 75:25:2, and 100:0:4 which differed insignificantly for WAI. As WAI primarily indicate the degree of starch gelatinization during extrusion cooking (Singha et al. 2018), the decrease in WAI may be attributed partly to the concomitant reduction in the starch content with increase incorporation of CG and SP. However, PCA (Fig. 1) as well as ANOVA revealed that CG incorporation had greater effect than SP (Fig. 1 and Table 4). This suggested that the presence of higher amounts of proteins in the melt (due to greater incorporation of CG) might have promoted the formation of inter- and intra-molecular protein bonds with amylose and amylopectin which led to reduced WAI (Fernandez-Gutierrez et al. 2004). Higher gelatinization temperatures (as determined by higher pasting temperatures) have been reported for corn grit, flours and starch with higher protein content and rice flours in the presence of greater amounts of pulse proteins (Singh et al. 2014; Shevkani et al. 2014).

Total phenolic content and antioxidant activity

TPC of CP–SP–CG blend extrudates is shown in Table 3. The extrudates showed TPC in the range of 41.1–69.9 mgGAE/100 g. The extrudates prepared with CG alone showed the lowest TPC (41.1 mgGAE/100 g), which increased progressively with increase incorporation of CP and SP (44.4–69.9 mgGAE/100 g). The extrudates made with 100% CP and 6% SP blend showed the highest TPC. This might be due to higher TPC in legumes and spinach than corn (Bunea et al. 2008; Singh et al. 2017). Analysis of variance and PCA also revealed that TPC of extrudates increased significantly with both CP and SP, wherein CP had greater effect than SP (Table 4; Fig. 1). Vegetables as well as pulse grains are generally rich in polyphenolic constituents which have several health benefits such as disease prevention and nutrient bioavailability improvements owing to their antioxidant activities (Welch and Graham 2004; Singh et al. 2017). Singh et al. (2015) also reported that incorporation of jambolan fruit pulp improved TPC of rice muffins.

DPPH and ABTS inhibition significantly increased with increase in level of CP and SP in CG extrudates (Table 3). This showed an increase in antioxidant activity of CG extrudates in the presence of higher amounts of CP and SP.



Colour

Mouthfeel

Texture

Taste

Overall acceptability

Fig. 2 Sensory properties of extrudates from different corn grit (CG), chickpea grit (CP) and spinach (SP) blends

ANOVA as well as PCA also revealed a significant effect of both CP and SP on the DPPH as well as ABTS inhibition (Table 4; Fig. 1). Antioxidant property is an important feature considered for improving the nutritional quality of food, as antioxidants may play roles in reducing the risks of degenerative diseases and oxidative damage associated with it (Singh et al. 2017). The increase in antioxidant activity (DPPH and ABTS inhibition activity) may be attributed to the presence of higher TPC in the extrudates with SP and CP. Phenolic compounds in foods, because of their *o*-dihydroxyl group in the aromatic ring, can quench singlet oxygen and act as radical terminators (Vulic et al. 2014). PCA supported the relationship as TPC related positively with ABTS and DPPH inhibition activity on the PCA loading plot (Fig. 1).

Hardness

The extrudates prepared from different CG–CP–SP blends differed significantly for hardness (Table 3). The extrudates from CG alone showed the lowest hardness, while the incorporation of both CP and SP increased the same (Table 3). ANOVA also revealed significant effect of CP, SP and their interaction on extrudate hardness (Table 4). PCA also revealed a positive relation of extrudate hardness with incorporation level of CP and SP wherein the relationship was stronger with CP (Fig. 1). In addition, PCA also revealed a positive relation between extrudate hardness and density suggesting that the addition of greater amounts of CP and SP in blends increased the levels of compounds other than starch that induced lubricating effect on the melt and limited starch gelatinization, which in turn prevented expansion of air bubbles by rupturing cell walls and led to harder extrudates (Ainsworth et al. 2007; Singh et al. 2016c). In addition, the fiber and proteins of CP and SP might have also contributed to increased hardness by imparting structural integrity due to protein–fiber interaction (Chiu et al. 2013). Seth et al. (2015) also reported increase in hardness of rice-corn extrudates with the incorporation of yam flour having higher protein and crude fiber content. A correlation of expansion and cell structure of extrudates with hardness has been reported earlier by Ding et al. (2005).

Sensory properties

The effect of CP and SP incorporation on color, mouthfeel, taste and overall acceptability of extrudates is depicted in Fig. 2. The overall acceptability, color, mouthfeel, texture and taste scores of the extrudates ranged from 6.3–8.5, 5.7–8.3, 4.9–8.7, 4.8–8.1 to 5.3–8.7, respectively. The extrudates prepared with CP $> 50\%$ had hard texture and scored ≤ 6 for sensory texture. SP incorporation, on the other hand, had marginal effect on sensory texture but it significantly improved color of extrudates by imparting desirable greenish color. The incorporation of SP (up to 4% incorporation levels) also improved taste of extrudates, while further incorporation made them to taste slightly bitter. CP incorporation also had an improving effect on taste of extrudates but the incorporation of higher amounts ($> 50\%$) resulted in harder extrudates which led to lower sensory scores. Overall, extrudates made with 75% CG, 25% CP and 4% SP scored the highest for texture, taste and overall acceptability indicating that the most acceptable extrudates could be prepared from CG–CP–SP in the ratio of 75:25:4.

Conclusion

The study revealed the potential of CP and SP in increasing nutritional density of extruded snacks. The addition of CP and SP increased TPC and antioxidant activity of extrudates suggesting possible utilization of CP and SP in the production of functional expanded snack foods. The replacement of CG with 25% CP and 4% SP resulted in the most acceptable extrudates while the incorporation of greater amounts of CP and SP resulted less expanded, dense and harder products. The results also highlighted that SP also have potential to replace the synthetic colorants in snacks.

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