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ORIGINAL ARTICLE

Effect of selected dehulled legume incorporation on functional and nutritional properties of protein enriched sorghum and wheat extrudates

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Abstract The effect of legume incorporation (5%, 10% and 15%) on functional and nutritional properties of sorghum and wheat extrudates was investigated. Sorghum extrudates incorporated with legumes showed lower water absorption index water solubility index and pasting properties viz., peak viscosity, minimum viscosity, breakdown viscosity, final viscosity and total set back and similar degree of gelatinization and nutritional profile. At 15% incorporation level, water absorption index and water solubility index found to be maximum while degree of gelatinization and all the pasting properties showed lowest values for both sorghum and wheat extrudates. Similarly nutritional profile observed to be significantly higher for 15% as compared to 10% and 15% incorporation levels. Incorporation of legumes at 15% could be effective in producing high energy dense food products having better functional and nutritional properties.

Keywords Extrudates · Gelatinization · Legumes · Protein · Sorghum · Wheat

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Introduction

Sorghum is grown in arid regions, and has a high agronomic potential even under adverse tropical conditions. However, antinutritional components limit its direct consumption as food and feed. Wheat, an important source of dietary fiber for cereal based food industry. Starch forms a major source of carbohydrates in human diet and has great economic importance. Many factors affect preference and acceptability of foods like intrinsic (appearance, taste, and flavour) and extrinsic (social and cultural) to food products (Deliza et al. 1996). Seeds of legume have high protein, dietary fiber, mineral compounds and vitamin B group (Martín-Cabrejas et al. 2004; Schneider 2002; Hughes 1991). Kahlon et al. (2005) ascribed low incidence of blood circulation diseases, relatively due to high consumption of legumes. Hence, lysine deficient and methionin rich cereals in combination with legumes will yield protein of high biological value.

Extrusion cooking is a high-temperature, short-time process in which moistened, expansive, starchy and/or proteinacious food materials are plasticized and cooked in a tube by a combination of moisture, pressure, temperature and mechanical shear, resulting in molecular transformation and chemical reactions (Castells et al. 2005). Smith and Singh (1996) reported it as one of the popular techniques for producing ready to eat snacks, having numerous processing conveniences over conventional processing method. Parallel to the increased applications, interest has grown in the physico-chemical, functional and nutritionally relevant effects of extrusion processing. It also significantly reduces antinutrients present in legumes (Abd El Hady and Habiba 2003; Alonso et al. 2000; Leontowicz et al. 1999; Marzo et al. 2002). Nutritional concern about extrusion cooking is reached at its highest level when extrusion is used specifically to produce nutritionally balanced or enriched foods, like weaning foods, dietetic foods, and meat replacers (Plahar et al. 2003). Also, extrusion technology causes substential viscosity reduction in cereal gruels and enhances its nutrient densities (De Muelenaere 1989; Anderson et al. 1969). Thus, extrusion technique allows to broaden the product range, and increasing the consumption of leguminous seeds product matrix. The objective of this study was to evaluate the changes in functional and nutritional properties of selected dehulled legumes incorporated sorghum and wheat extrudates.

Materials and methods

Raw materials

Different dehulled legumes (black gram, green gram, lentil, peas) and cereals (sorghum and wheat) were cleaned, graded and subjected to coarse grinding in plate mill to make grits (1.65–2.36 mm). Different legume grits were blended (0, 5, 10 and 15%) with sorghum and wheat grits, separately. For making extrudates, about 2 kg of blended materials of 14% (wb) were used.

Extrusion cooking condition

Extrusion cooking was performed using a heavy-duty low cost collet extruder (Food extrusion laboratory, CIPHET, India), driven by 10 hp AC motor. Feed rate was controlled with a 1 hp DC motor. The length to diameter (L/D) ratio of extruder was 5:1. The barrel was enrobed with cold/ tap water circulation to maintain the temperature. The screw speed (500 rev/min) was kept constant during extrusion cooking. The extruder barrel was fitted with 4.0 mm die nozzle. With the previous laboratory trails, extrudates were prepared keeping constant feed rate (25 kg/h) and feed moisture (14%, w.b.).

Sample preparation for analysis

The extrudates were ground (particle size <0.85 mm) and subjected to functional and nutritional analysis.

Water absorption index and water solubility index

About 2.5 g of ground extrudates (20 mesh ASTM) were dispersed in 25 ml of distilled water, taking care to break up any lumps. After stirring for 30 min using magnetic stirrer, dispersions were rinsed in to tared 50 ml centrifuge tube was made up to 32.5 g and then centrifuged at 3000×*g* for 10 min. The supernatant was decanted for determination of solids and sediments (Singh and Smith 1997). Water absorption index (WAI) and water solubility index (WSI) were determined as follows.

$$\mathrm{WAI}(\%) = \frac{\text{weight of sediment}}{\text{weight of dry solids}} \times 100$$

$$\mathrm{WSI}(\%) = \frac{\text{weight of dissolved soilds in supernatant}}{\text{weight of dry solids}} \times 100$$

Degree of gelatinization

About 0.2 g of ground extrudate was dispersed in 100 ml distilled water and stirred for 5 min before being centrifuged for 25 min. Supernatant (1 ml) was diluted with water (10 ml) and of iodine solution (0.1 ml) was added. The absorbance at 600 nm was read using UV–VIS spectrophotometer against a reagent blank. Similar type slurry was prepared from (0.2 g) extrudate, (95 ml) water and (5 ml) 10 M KOH. It was stirred for 5 min and centrifuged for 25 min as before. Supernatant (1 ml) was then diluted with distilled water (10 ml). The absorbance was then read as before (Wotton and Bamunuarachchi 1978).

$$\text{Degree of gelatinization}(\%) = \frac{\text{Absorbance of fresh solution}}{\text{Absorbance of alkali solubilized solution}} \times 100$$

Rheological properties

Pasting properties of ground extrudate powders were determined using a Rapid Visco Analyser (RVA) Model 3-D (Newport Scientific Pvt. Ltd, Australia) with Thermocline software (3.0 version) by ICC (1995). Sample suspension was prepared by placing extrudate powder (3 g) in an aluminium canister containing (30 ml) distilled water. Following programmed heating and cooling cycle was used. Each sample was stirred (960 rpm, 10 s) while heated at 50 °C and then constant shear rate (160 rpm) was maintained for the rest of the process was performed. Temperature was held at 50 °C up to 1 min. Then, samples were heated (50–95 °C, 3 min 42 s) and held at 95 °C for 2 min 30 s. Subsequently, samples were cooled down (95–50 °C, 3 min 48 s) and then held at 50 °C for 2 min. A RVA plot of viscosity (cp) versus time (s) was used to determine peak viscosity (PV), minimum viscosity(MV), breakdown viscosity (BD) final viscosity (FV) and total set back (TSB). Each analysis was done in duplicate.

Nutritional evaluation

Fat, crude fiber and ash were determined by standard methods (AOAC 2000). Protein content was determined by

Micro Kjeldhal method. The ground extrudate (0.5 g) was digested in (10 ml) H_2SO_4 at 420 °C using copper sulphate and potassium sulphate catalyst mixture (3 g) until the solution becomes colourless i.e. nitrogenous compounds converts into ammonium sulphate. The ammonium sulphate formed was decomposed with an alkali (NaOH) and ammonia liberated is absorbed in excess of (25 ml) neutral boric acid solution and then titrated with standard acid (0.1 N HCl).

Statistical methods

Three replicate experiments were carried out. The analysis of variance test (ANOVA) and Duncan's multiple range test (DMRT) was carried out using Ag Res, version 7.01 (Pascal International Software solutions, USA)

Results and discussion

WAI and WSI

Figure 1 depicts the WAI and WSI of legumes incorporated sorghum and wheat extrudates. WAI of sorghum and wheat extrudates alone found to be 3,648 g/kg and 4,119 g/kg (Fig. 1 a&b). WAI of legume incorporated extrudates were ranged between 5,399–5,836 g/kg and 5,608–5,963 g/kg for sorghum and wheat, respectively. Among the selected legumes, pea showed a maximum WAI at different incorporation levels viz., 4,876 g/kg, 5,101 g/kg and 5,836 g/kg for sorghum and 5,684 g/kg, 5,775 g/kg and 5,963 g/kg for wheat extrudates. Similarly, an increase in WAI of wheat flour incorporated with 5–15% defatted soy flour was reported (Doxastakis et al. 2002; Indrani et al.

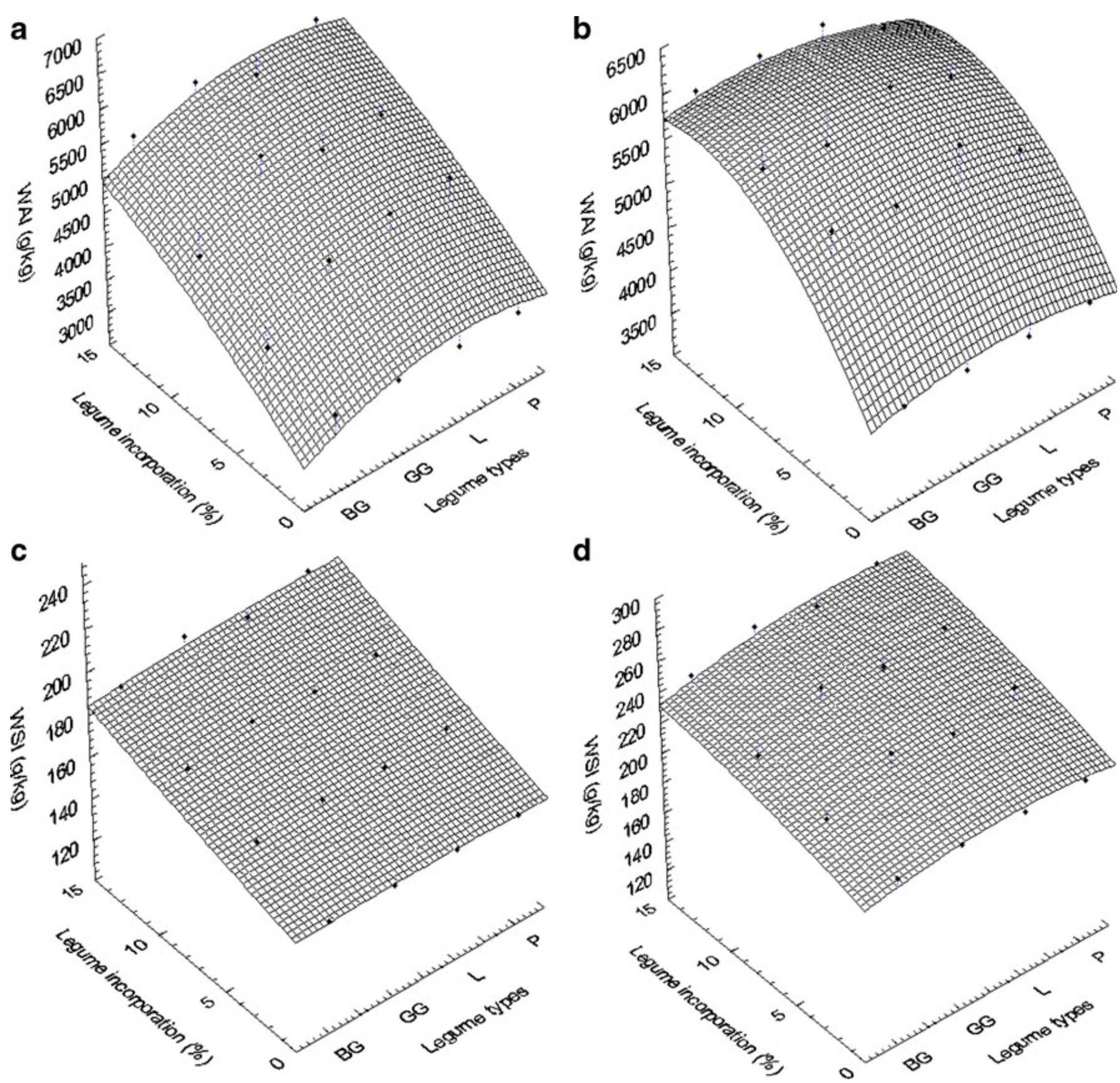


Fig. 1 Response surface plot for WAI (**a** and **b**) and WSI (**c** and **d**) for sorghum and wheat extrudates

1997). WSI of extrudates was found to be 153 g/kg and 209 g/kg for sorghum and wheat alone, respectively. The legumes incorporation showed a little increase in WSI up to 198 g/kg and 259 g/kg for sorghum and wheat (Fig. 1 c&d). The 15% legume incorporation showed maximum WSI 186 g/kg, 195 g/kg, 190 g/kg and 198 g/kg for sorghum and 241 g/kg, 254 g/kg, 249 g/kg and 259 g/kg for wheat extrudates, respectively. The extrudates with legume incorporated protein increases the water solubility of extrudates. Badrie and Mellowes (1992) reported increase in WSI for extruded cereal flakes incorporated with peanut flour and 4% soy flour/oil with cassava flour.

Degree of gelatinization

The degree of gelatinization of legumes incorporated sorghum and wheat extrudates are illustrated in Fig. 2. Degree of gelatinization for sorghum and wheat extrudates alone found to be 301 g/kg and 336 g/kg (Fig. 2 a&b). The legumes incorporated sorghum and wheat extrudates showed a decrease in degree of gelatinization; the least obtained were 237 g/kg and 257 g/kg, respectively. Similarly, Ho and Izzo (1992) reported that the addition of protein with cereals increased the heat resistance capacity, hardness and stickiness of gel with the influence of temperatures. Among the legumes, black gram showed higher degree of gelatinization for sorghum (275 g/kg, 265 g/kg and 257 g/kg) and wheat (295 g/kg, 264 g/kg and 247 g/kg) at different incorporation levels. This data is corroborated with the decrease in degree of gelatinization attributed to variation in fat content of legumes (Madeka and Kokini 1992).

Pasting properties

The pasting properties of legumes incorporated sorghum and wheat extrudates are shown in Table 1. Incorporation of legumes with cereals resulted in decline of pasting characteristics viz., PV, MV, BD, FV, and TSB. It was reported that during extrusion cooking of cereals with different ingredients, starch-fat (Li and Lee 1996) and starch-protein (Symons and Brennan 2004; Ding and Wang 2004) complex formation will occur significantly. The PV found to be 356 cp, 358 cp, 365 cp and 367 cp for sorghum and 621 cp, 651 cp, 639 cp and 577cp for wheat incorporated at 5% levels of black gram, green gram, lentil and peas, respectively. Jiamping et al. (2008) also reported that there was a significant decreasing trend for fiber fractions from barley incorporated wheat starch as compared to its control starch. Thus, PV continued to decrease up to 287 cp and 530 cp for sorghum and wheat extrudates at maximum of 15% incorporation level. Taylor et al. (1997) reported to have higher peak viscosity and total setback for Porridge made of sorghum cooked in boiled water. MV does not show any variation for sorghum (202–214 cp) and wheat extrudates (257–279 cp). At 5% incorporation level, BD for sorghum extrudate was comparatively lower (106 cp, 92 cp, 87 cp and 74 cp) as compared to wheat extrudate (323 cp, 290 cp, 323 cp and 268 cp) for black gram, green gram, lentil and peas incorporation, respectively. The pea incorporation at 15% showed a maximum decrease of BD and found in the range 74 cp and 268 cp for sorghum and wheat, respectively. Similarly Lin et al. (1997) reported that protein inhibits retrogradation and hydrogen bond formation requiring more energy during cooling i.e. BD. FV for sorghum extrudates

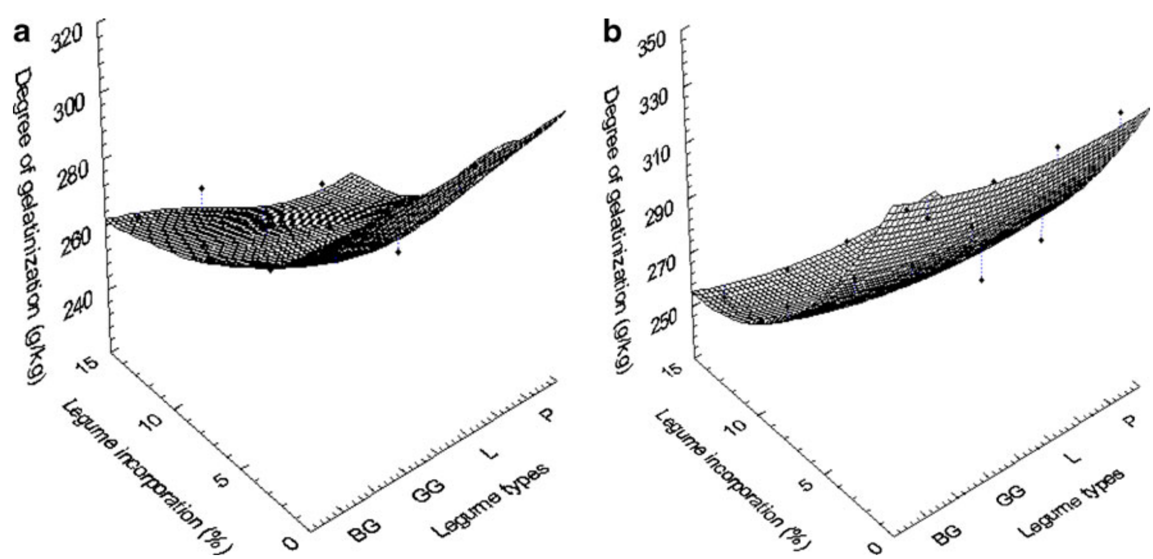


Fig. 2 Response surface plot for degree of gelatinization (**a** and **b**) for sorghum and wheat extrudates

Table 1 Pasting properties of different dehulled legumes incorporated sorghum and wheat extrudates

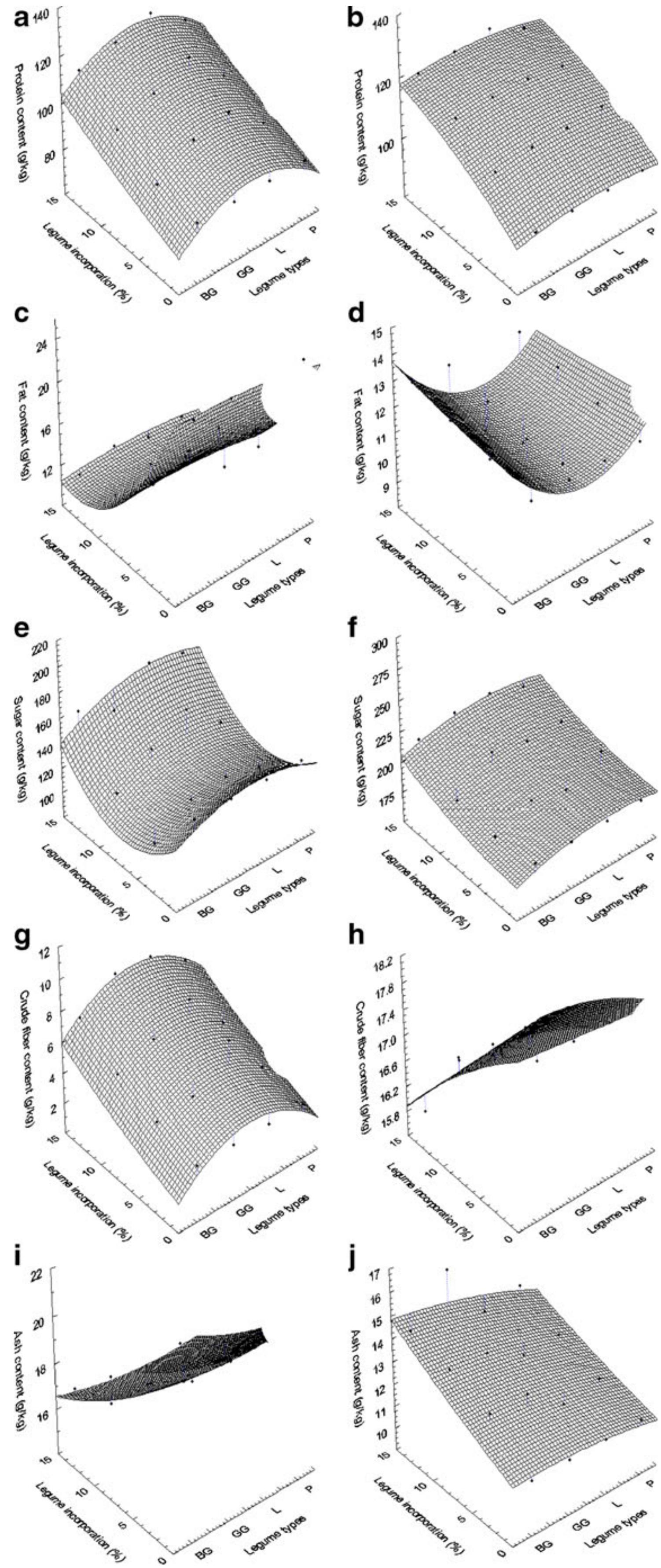
Cereal	Legume: Types	Legume: Incorporation levels (%)	Peak (cP)	Minimum viscosity (cP)	Break down (cP)	Final viscosity (cP)	Total Setback (cP)
Sorghum	BG	0	455^{h}	226^{j}	229^{m}	281^{h}	55^{k}
		5	356^{l}	217^{l}	139^{q}	267^{l}	50^{l}
		10	343^{l}	218^{k}	125^{s}	271^{l}	53^{k}
		15	320^{l}	214^{m}	106^{t}	259^{l}	45^{m}
	GG	0	455^{h}	226^{j}	229^{m}	281^{h}	55^{k}
		5	358^{i}	215^{m}	143^{p}	256^{j}	41^{n}
		10	310^{m}	206^{p}	104^{t}	244^{l}	38^{o}
		15	298^{n}	202^{q}	92^{u}	242^{m}	36^{q}
	Lentil	0	455^{h}	226^{j}	229^{m}	281^{h}	55^{k}
		5	365^{i}	214^{m}	151^{o}	259^{j}	45^{m}
		10	342^{j}	209^{n}	133^{r}	247^{k}	38^{p}
		15	295^{n}	208^{o}	87^{v}	244^{l}	36^{q}
	Peas	0	455^{h}	226^{j}	229^{m}	281^{h}	55^{k}
		5	367^{l}	210^{n}	157^{n}	250^{j}	40^{n}
		10	328^{k}	205^{p}	123^{s}	240^{n}	35^{q}
		15	287^{o}	213^{m}	74^{w}	237^{o}	34^{q}
Wheat	BG	0	656^{a}	255^{h}	401^{a}	505^{g}	250^{i}
		5	621^{b}	258^{t}	363^{e}	525^{e}	267^{e}
		10	612^{b}	263^{e}	349^{t}	524^{e}	261^{g}
		15	582^{e}	259^{t}	323^{g}	514^{t}	255^{h}
	GG	0	656^{a}	255^{h}	401^{a}	505^{g}	250^{i}
		5	651^{b}	260^{f}	391^{b}	511^{f}	251^{i}
		10	587^{d}	265^{d}	322^{h}	580^{b}	315^{d}
		15	568^{t}	278^{b}	290^{k}	540^{d}	262^{t}
	Lentil	0	656^{a}	255^{h}	401^{a}	505^{g}	250^{i}
		5	639^{a}	273^{c}	366^{d}	597^{a}	324^{b}
		10	617^{b}	248^{i}	369^{c}	565^{c}	317^{c}
		15	602^{c}	279^{a}	323^{g}	522^{c}	243^{j}
	Peas	0	656^{a}	255^{h}	401^{a}	505^{g}	250^{i}
		5	577^{t}	277^{b}	300^{j}	609^{a}	332^{a}
		10	574^{t}	257^{g}	317^{l}	520^{e}	263^{t}
		15	530^{g}	262^{e}	268^{l}	507^{g}	245^{j}

with different legumes at 5% incorporation level found to have lower values 267 cp, 256 cp, 259 cp and 250 cp for black gram, green gram, lentil and peas, respectively. In case of wheat extrudates at 5% legume incorporation showed a marginally higher value of FV. However, at 15% incorporation the sorghum (259 cp, 242 cp, 246 cp and 237 cp) and wheat (514 cp, 540 cp, 522 cp and 507 cp) extrudates showed the lower FV. Among the legumes incorporation of pea at 15% showed the lowest FV for sorghum (237 cp) and wheat (507 cp) extrudates, respectively. TSB at 5% incorporation level for sorghum with different legumes found to be lower (50 cp, 41 cp, 45 cp and 40 cp) as compared to wheat (267 cp, 251 cp, 324 cp and 332 cp) for black gram, green gram, lentil and peas incorporation, respectively.

Effect on nutritional quality

The nutritional properties of legumes incorporated sorghum and wheat extrudates are reported in Fig. 3. Extrusion cooking caused significant reduction in nutritional value and legume incorporation showed countable changes in the extrudates. Protein content of extrudates are in range of 86.3–119.6 g/kg and 97.5–121.8 g/kg for sorghum and wheat extrudates (Fig. 3 a&b). Incorporation of legumes resulted a slight increase in protein content. At 15% incorporation level, the protein content of sorghum extrudates showed 110 g/kg, 115 g/kg, 120 g/kg and 109 g/kg and wheat extrudates showed 118 g/kg, 120 g/kg, 122 g/kg and 117 g/kg for black gram, green gram and lentil

Fig. 3 Response surface plot for protein (**a**, **b**), fat (**c**, **d**), sugar (**e**, **f**), crude fiber (**g**, **h**) and ash (**i**, **j**) for sorghum and wheat extrudates



incorporations, respectively. The fat content of extrudate was lower or remains unchanged (Fig. 3 c&d). There was seen comparatively lower fat content (10.1–11.1 g/kg) for sorghum at 15% incorporation level. Among the legume incorporated lentil showed a lesser value (9.3 g/kg) for wheat extrudates, at 15% incorporation level and was justified by its inherent lower fat content in raw lentil. Similarly, 54% decrease of lipid content during extrusion was reported in chickpea (Cardoso-Santiago and Arêas 2001) and faba bean (Prakrati et al. 2000). This trend of declaine to partial decomposition and volatilization of lipid components was also attributed (Smith and Singh 1996). Total sugar content was ranged between 146–170 g/kg and 188.9–219.4 g/kg for legumes incorporated sorghum and wheat extrudates (Fig. 3 e & f). There is a decrease in the carbohydrate content of extrudate with its corresponding raw materials during extrusion are in accordance with other reports (Mercier and Feillet 1975; Andersson et al. 1981; Fornal et al. 1985; Schwizer and Reimann 1986). The total sugar content did not change significantly. However, maximum was observed for lentil incorporated sorghum and wheat extrudates (170 g/kg and 219 g/kg) at 15% incorporation level. Crude fiber content of extrudates incorporated with legumes was equivalent to sorghum and wheat extrudates alone (Fig. 3g&h). The fiber content of sorghum extrudates were in the range of 3.67–8.67 g/kg. But wheat extrudates have not shown any significant changes in crude fiber (1.62 g/kg to 1.73 g/kg). These results are corroborated with the studies on the dietary fiber content of untreated and twin screw extruded wheat flour and whole wheat meal samples. Ash content of legumes incorporated extrudate were not changed much (Fig. 3 i&j). The ash content showed a decreasing trend and ranged between (20.8–16.1 g/kg) at 15% incorporation level for sorghum. Similar results of 10% reduction in ash content in chickpea extrudates was reported (Cardoso-Santiago and Arêas 2001). Ash content of wheat extrudates incorporated with legumes remains almost same were in the range of 11.5–15.9 g/kg. Marzo et al. (2002) reported less influence of extrusion cooking in ash content.

Conclusion

Incorporation of legumes with sorghum and wheat improved the nutritional characteristics and caused remarkable changes in WAI, WSI and pasting characteristics. The extrudates incorporated with legumes showed higher water absorption index and water solubility index with better pasting properties and decreasing trend for degree of gelatinization. Thus, legumes incorporation shows a promising trend for protein rich extrudates production and could be effective in producing high energy dense food products based on sorghum and wheat.

References

Abd El Hady EA, Habiba RA (2003) Effect of soaking and extrusion conditions on antinutrients and protein digestibility of legume seeds. Lebensm Wiss Technol 36:285–293

Alonso R, Aguirre A, Marzo F (2000) Effects of extrusion and traditional processing methods on antinutrients and in vitro digestibility of protein and starch in faba and kidney beans. Food Chem 68:159–165

Anderson RA, Conway HF, Pfeifer VF, Griffin EJ (1969) Roll and extrusion cooking of grain sorghum grits. Cereal Sci Today 14:372–376

Andersson Y, Hedlund B, Jonsson L, Svennsson S (1981) Extrusion cooking of a high-fiber cereal product with crispbread character. Cereal Chem 58:370–374

AOAC (2000) Official methods of analysis, 17th edn. Association of Official Analytical Chemists, Washington

Badrie N, Mellowes WA (1992) Soyabean flour/oil and wheat bran effects on characteristics of cassava (*Manihot esculenta Crantz*) flour extrudates. J Food Sci 57:108–111

Cardoso-Santiago RA, Arêas JAG (2001) Nutritional evaluation of snacks obtained from chickpea and bovine lung blends. Food Chem 74:35–40

Castells M, Marin S, Sanchis V, Ramos AJ (2005) Fate of mycotoxins in cereals during extrusion cooking: a review. Food Addit Contam 22:150–157

Deliza R, Macfie H, Hedderley D (1996) Information affects consumer assessment of sweet and bitter solutions. J Food Sci 61:1080–1083

De Muelenaere HJH (1989) Extrusion: a first and third world tool. In: Technology and the Consumer, Vol 1. Proceedings of the SAAFoST Tenth Biennial Congress and a Cereal Science Symposium. Natal Tecknikon Printers, Durban, South Africa, pp 22–42

Ding WP, Wang YH (2004) Comparative studies on the retrogradation of rice flour system and rice starch system. J Zhengzhou In Technol 25:16–19

Doxastakis G, Zafiriadis I, Irakil M, Marlani H, Tananaki C (2002) Lupin, soya and triticale addition to wheat flour doughs and their effect on rheological properties. Food Chem 77:219–227

Fornal L, Smietana Z, Soral Smietaana M, Fornal J, Szpendowiski J (1985) Products extruded from buckwheat flour and its mixtures with milk proteins. II. Chemical characteristics and physico-chemical properties of proteins and starch of products extruded from buckwheat flour and its mixture with milk proteins. Acta Aliment Pol 11:397–411

Ho CT, Izzo MT (1992) Lipid-protein and lipid-carbohydrate interactions during extrusion. In: Kokini JL, Ho CT, Karwe MV (eds) Food Extrusion Science and Technology. Marcel Dekker, New York, pp 415–426

Hughes JS (1991) Potential contribution of dry bean dietary fiber to health. Food Technol 45:122–125

ICC Standard Method No. 162 (1995)

Indrani D, Savithri GD, Venkateswara RG (1997) Effect of defatted soy flour on the quality of buns. J Food Sci Technol 34:440–442

Jiamping S, Caiyun H, Shaoying Z (2008) Effect of protein on the rheological properties of rice flour. J Food Process Preserv 32:987–1001

Kahlon TS, Smith GE, Shao Q (2005) In vitro binding of bile acids by kidney bean (*Phaseolus vulgaris*), black bean (*Vigna mungo*), bengal gram (*Cicer arietinum*) and moth bean (*Phaseolus aconitifoli*ns). Food Chem 90:241–246

Leontowicz H, Leontowicz M, Kostyra H, Gralak MA, Kulasek GW (1999) The influence of extrusion or boiling on trypsin inhibitor and lectin activity in leguminous seeds and protein digestibility in rats. Pol J Food Nutr Sci 8(49):77–87

Li M, Lee TC (1996) Effect of cysteine on the functional properties and micro structures of wheat flour extrudates. J Agric Food Chem 44:1871–1880

Lin S, Hseih F, Huff HE (1997) Effect of lipids and processing conditions on degree of starch gelatinization of extruded dry pet food. Lebensm Wiss Technol 30:754–761

Madeka H, Kokini JL (1992) Effect of addition of zein and gliadin on the rheological properties of amylopectin starch with low-to-intermediate moisture. Cereal Chem 69:489–494

Martín-Cabrejas MA, Sanfiz B, Vidal A, Mollá E, Esteban R, López-Andréu FJ (2004) Effect of fermentation and autoclaving on dietary fiber fractions and antinutritional factors of brans (*Phaseolus vulgaris* L.). J Agric Food Chem 52:261–266

Marzo F, Alonso R, Urdaneta E, Arricibata FJ, Ibáñez F (2002) Nutritional quality of extruded kidney bean (*Phaseolus vulgaris* L. var. Pinto) and its effects on growth and skeletal muscle nitrogen fractions in rats. J Anim Sci 80:875–879

Mercier C, Feillet P (1975) Modification of carbohydrate components by extrusion-cooking of cereal products. Cereal Chem 52:283–297

Plahar WA, Onuma Okezie B, Gyato CK (2003) Development of a high protein weaning food by extrusion cooking using peanuts, maize and soybeans. Plant Food Hum Nutr 58:1–12

Prakrati R, Ameeta K, Kushwah HS (2000) Effect of extrusion cooking variables on biochemical composition of faba bean (*Vicia faba* L.). J Food Sci Technol—India 37:373–379

Schneider AVC (2002) Overview of the market and consumption of pulses in Europe. Br J Nutr 88(3):S243–S250

Schwizer TF, Reimann S (1986) Influence of drum-drying and twin-screw extrusion cooking on wheat carbohydrates. I. A comparison between wheat starch and flours of different extraction. J Cereal Sci 4:193–203

Singh N, Smith AC (1997) A comparison of wheat starch, wheat and oat in extrusion cooking process. J Food Eng 34:15–32

Smith AC, Singh N (1996) New applications of extrusion cooking technology. Indian Food Industry 15:14–23

Symons LJ, Brennan CS (2004) The effect of Barley β-glucan fiber fractions on starch gelatinization and pasting characteristics. J Food Sci 69:257–260

Taylor John RN, Dewar J, Taylor J, Ascheraden RF (1997) Factors affecting porridge making quality of South African Sorghums. J Sci Food Agric 73:464–470

Wotton M, Bamunuarachchi A (1978) Water binding capacity of commercial produced native and modified starches. Starch/Starke 33:159–161