A Novel cooked extruded lentils analog: physical and chemical properties

Mahmoud Abu-Ghoush · Sajid Alavi ·
Abdulaziz Al-Shathri

Revised: 26 April 2014 / Accepted: 14 July 2014 / Published online: 8 August 2014
© Association of Food Scientists & Technologists (India) 2014

Abstract Developing an extruded lentil analog is our aim. Lentil analog with six formulations were produced using a pilot-scale single (SS) and twin screw (TS) extruders. Texture analysis of lentil analogs prepared for consumption revealed that the products formulated with 60:40 and 70:30 soy: wheat ratios exhibited a significantly higher hardness, adhesiveness and lower springiness as compared to all other treatments. Differential Scanning Calorimeter (DSC) results indicated that all starches in dry blend are completely 100 % gelatinized by extrusion for all treatments at 100 °C. The maximum peak of viscosity for TS was formed after 5.58 min. from the run at 89.9 °C for the best treatment. However, this lentil analog product can provide a high quality lentil which can be used as a substitute for regular lentils.

Keywords Wheat · Soy · Lentil Analog · Extrusion · Texture

Introduction

Lentil are excellent sources of protein, carbohydrate, and dietary fiber (Khan et al. 1987; Sharma et al. 1989; Bahatty 1988; Achinewhu and Akah 2003). However, mature lentils seeds contain appreciable amounts of oligosaccharides of the

raffinose family. Also, raw legume seeds have antinutritional substances such as trypsin inhibitors and hemagglutinins (Hernandez- Infante et al. 1998) which must be inactivated before they can be safely consumed. Total lentils production has remained constant during the past two decades, whereas the population has increased remarkably during the same period. As a result of this, the per capita availability of food legumes has significantly declined and the cost has risen (Solanki et al. 1999). Also, nutritional and cooking quality characteristics of food legumes are very important from a consumer point of view. Looking for a product similar for lentils containing no raffinose family, antinutritional substance with much shorter cooking time will be highly appreciated.

Extrusion cooking is widely used to manufacture carbohydrate-based foods. Extrusion conditions will be controlled to obtain optimized product quality. Extrusion cooking is essentially a process in which moistened starchy or proteinaceous foods are worked into a viscous, plastic like dough and cooked before being forced through a die (Riaz 2000; Liu et al. 2011). Some results of cooking during the extrusion process are the gelatinization of starch, denaturation of protein, inactivation of many native enzymes causing food deterioration during storage, destruction of naturally occurring toxic substances, and diminishing of microbial counts in the final products (Colonna and Mercier 1983). Extrusion cooking and puffing of cereals is widely practiced (Onwulata et al. 1998). Extrudate structure is stabilized as the matrix transforms to a glassy state on cooling and drying. However, extrusion cooking produces a wide range of finished products from inexpensive raw materials with minimum processing time. Snacks are one of the fastest-growing segments of the food industry (İbanoğlu et al. 2006). Consumers are buying snacks in greater variety and quantity than ever, and extrusion technology can produce almost all of them (Onwulata et al. 2001; Saeleaw et al. 2012).

M. Abu-Ghoush (✉)
Clinical Nutrition and Dietetics Dept, The Hashemite University,
The Hashemite Kingdom of Jordan, Zarqa 13133, Jordan
e-mail: abulaith@hu.edu.jo

S. Alavi
Department of Grain Science and Industry, Kansas State University,
Manhattan, KS 66506, USA

A. Al-Shathri
Department of Food and Nutrition Sciences, King Faisal University,
The Kingdom Of Saudi Arabia, P.O.Box 420, Al-Ahsa 31982,
Saudi Arabia

Table 1 Formulations of the different lentil analog products

Ingredient	Treatment 1 *SW(50:50)M	Treatment 2 SW (50:50)G	Treatment 3 SW (50:50)L	Treatment 4 SW (50:50)	Treatment 5 SW (60:40)	Treatment 6 SW (70:30)
Soy flour (defatted)	49 %	49 %	49 %	49.44 %	59.44 %	69.44
Wheat flour	49 %	49 %	49 %	49.44 %	39.44 %	29.44
Salt	1 %	1 %	1 %	1 %	1 %	1 %
Monoglyceride	0.88 %	0	0	0	0	0
HPMC (hydroxyl propylmethylcellulose)	0	0.88 %	0	0	0	0
Lecithin	0	0	0.88 %	0	0	0
Vitamins	0.12 %	0.12 %	0.12 %	0.12 %	0.12 %	0.12 %

*50 %Soy + 50 %wheat and monoglyceride “SW(50:50)M”; 50 %Soy + 50 %wheat and methyl cellulose gum “SW (50:50)G”; 50 %Soy + 50 %wheat and lecithin “SW (50:50)L”; 50 %Soy + 50 %wheat “SW (50:50)”; 60 %Soy + 40 %wheat “SW (60:40)”; 70 %Soy + 30 %wheat “SW (70:30)”.

Wheat grains are low in protein content (7–14 %) and are deficient in certain amino acids such as lysine (Claughton and Pearce 1989). Legumes such as soy bean are higher in protein (18–24 %) and can be used to support the deficiency of certain amino acids in the wheat grains such as lysine (Potter 1986; Rababah et al. 2006).

There is no information regarding the utilization of wheat and soy flour and in lentil analog production by extrusion processing. The objectives of this article are to identify the extrusion parameters for producing lentil analog product by using extrusion technology, as well as to develop a value-added extruded product that is similar to lentils in physical and chemical properties. This study also aims to demonstrate a method for preparation of lentil analogs with short cooking/preparation times.

Materials and methods

Materials

Soft red winter whole wheat flour (Graham flour) was obtained from cereal food processor (Kansas city), and the defatted Soy flour obtained from (Honeysole, USA). The following

materials were generously donated by their respective company: Soy Lecithin (ADM, Decatur, IL); Methyl cellulose gum (Belcamp, MD); Bounus Blend multi-vitamins (Caravan ingredients, KS).

Formulations

Six different extruded treatments were formulated. The extruded product was based on Soy flour (as a good source of protein) with wheat flour. The amount of the protein, fat, fiber and ash in each formulation was approximated to be the same amount as the true lentil or higher. Different binders and emulsifiers were used to improve the quality and the physical properties of the final products. These binders were carbohydrate or protein polymers that function as emulsifiers, texturizers, and oil and water binding agents as can be shown in Table 1.

Extrusion processing for lentil analog food

A pilot-scale twin screw extruder (model TX-52, Wenger Manufacturing, Inc., Sabetha, KS) with screw of medium-shear screw profile (Fig. 1) and circular die opening of 0.125" with 18 holes, was used to process all materials.

Fig. 1 A pilot-scale twin screw extruder properties with screw of medium-shear screw profile

30/45 °C	110/110 °C	110/110 °C	110/111 °C	79/103 °C
----------	------------	------------	------------	-----------

Number	Desc
3	Full pitch of screw
1	Set(3) of forward kneading blocks
5	¾ pitch of screw
1	½ pitch of screw
1	Set (3) of forward kneading blocks
1	¾ pitch of core screw
6 head	

Table 2 Proximate analysis of the selected treatments* in addition to the control

Treatments	%Protein	% Fat	%Fiber	% Ash
T3	29.78 ^c ±0.03	0.74 ^a ±0.07	2.97 ^b ±0.03	2.56 ^b ±0.02
T5	32.68 ^b ±0.01	0.57 ^b ±0.02	2.76 ^b ±0.09	4.92 ^a ±0.01
T6	35.55 ^a ±0.2	0.51 ^b ±0.005	2.96 ^b ±0.03	4.97 ^a ±0.02
Lentil (control)	24.83 ^d ±0.25	0.51 ^b ±0.05	3.05 ^a ±0.02	2.56 ^b ±0.03

*T3: 50 %Soy + 50 %wheat and lecithin “SW (50:50)L”; T4: 50 %Soy + 50 %wheat “SW (50:50)”; T5: 60 %Soy + 40 %wheat “SW (60:40)”; T6: 70 %Soy + 30 %wheat “SW (70:30)”.

Before extrusion runs, the extruder was calibrated to ensure selected feed rate and water injection rates were accurate. With the screw speed fixed at 314–318 rpm, the treatments blends were each extruded at in-barrel moisture content (MC) of 21 and 24 % (wet basis). The barrel temperature profile is also shown in Fig. 1. The lentil analog product was cut immediately after exiting the extruder die with a face-mounted rotary cutter turning at 1,940 rpm. Extruder conditions were allowed to stabilize for approximately 10 min before samples and process data were collected for 3–5 min for each treatment. Extrudates were subsequently dried at 180 °C with a double pass dryer/cooler (series 4,800, Wenger) adjusted for 15 min retention time (7.5 min each for the top and bottom belts). Cooling was accomplished at room temperature, with a 5-min retention time on the cooling belt.

Proximate analysis

The moisture, protein, fat, fiber and ash content of samples were determined at the Analytical Services Laboratory of Kansas State University according to the AACC (1999). The Water Hydration Capacity (WHC) was performed according to the AACC official standard method 56–35 (2008).

Color

The lightness of lentil analog extrudates was measured in triplicate using a Chroma Meter (Minolta CR-300, Minolta Corporation, Ramsey, NJ, USA) with a standard calibration plate CR-A44 with values of L^* = 93.2, a^* = 0.3139, and b^* = 0.3204. L^* is the lightness of the flour with values from zero for black to 100 for white, negative value of a^* shows greenness, where as positive value of a^* indicates redness. Positive value of b^* shows yellowness of the extrudates and negative value indicated blueness. The values were recorded and ten replicates were averaged.

Lentil analog texture

The lentil analog was cooked before doing the texture analysis test. While boiling, seventy gram of lentil analog was added to 125 ml boiling water with stirring for 3 min. After cooking, the sample was hold and covered for 5 min. at room temp. until the water was absorbed. Also, the commercial lentil (control) was prepared before doing the texture and sensory analysis test using the same procedure followed with the analog, except the amount of water added was 3 times the

Fig. 2 Comparison of water hydration capacity (%WHC) of lentil analog samples prepared under different treatments. Means with different superscripts indicate significant differences among all treatments, ($p < 0.05$). S: Soy, W: wheat, ratio soy to wheat e.g. 50:50, M: monoglyceride, G: methyl cellulose gum, L: lecithin

Fig. 3 Comparison of color-values of lentil analog samples prepared under different treatments. Means with different superscripts indicate significant differences among all treatments, ($p < 0.05$). S: Soy, W: wheat, ratio soy to wheat e.g. 50:50, M: monoglyceride, G: methyl cellulose gum, L: lecithin

amount of lentil and the boiling was done for 15 min. according to preliminary study.

Texture of cooked lentil analog was determined with TA-XT2 Texture Analyzer (Texture Technologies Scarsdale, NY) by using the texture profile analysis (TPA) test. The procedure that was followed according to the standard procedure for Texture analyzer procedures. The 20 g of cooked lentil analog product were added at the center of the probe and were tested with a 2.54 cm-diameter cylinder probe. This procedure was performed on three samples per treatment per evaluation day, thus producing 12 measurements per treatment. The hardness, adhesiveness, cohesiveness, Springiness, gumminess, and chewiness of each measurement were recorded. Measurements on the texture analyzer used the following setting: test mode T P A, pre-test speed 5 mm/s, test speed 1.00 mm/s, post-test speed 10 mm/

s, distance 50 %, trigger auto at 20 g, acquisition rate 200 pps, units force (gram) and Distance (% strain).

Differential scanning calorimeter (DSC)

A differential scanning calorimeter (DSC) (model Q100, TA Instruments, New Castle, DE) was used to determine the degree of starch gelatinization in the lentil analog produced by twin screw extruder using the method described by Alavi et al. (2002). About 10 mg of ground lentil analog samples were each placed in stainless steel pans with at least 30 mg of distilled water. This dilution ensured the sample moisture content $>65\%$, which is required for complete gelatinization of starch granules. The pans were then hermetically sealed using rubber rings and equilibrated at room temperature for 4 h before scanning from $10\text{ }^{\circ}\text{C}$ to $120\text{ }^{\circ}\text{C}$

Fig. 4 Comparison of Hardness, Adhesiveness, Gumminess, and Chewiness of lentil analog samples and the control (Massor) prepared under different treatments. Means with different superscripts indicate significant differences among all treatments, ($p < 0.05$). S: Soy, W: wheat, ratio soy to wheat e.g. 50:50, M: monoglyceride, G: methyl cellulose gum, L: lecithin

Fig. 5 Comparison of Cohesiveness, and Springiness of lentil analog samples and the control (Massor) prepared under different treatments. Means with different superscripts indicate significant differences among all treatments, ($p < 0.05$). S: Soy, W: wheat, ratio soy to wheat e.g. 50:50, M: monoglyceride, G: methyl cellulose gum, L: lecithin

in the DSC at a heating rate of 10 °C/min. Onset temperature (T_o , °C), peak temperature (T_p , °C), and gelatinization enthalpy (ΔH , J/g) were recorded for each run. Degree of gelatinization (DG) was calculated as shown below.

$$\%DG = \frac{\Delta H_0 - \Delta H_1}{\Delta H} \times 100(\%)$$

where ΔH_0 = gelatinization enthalpy of the native product starch and ΔH_1 = gelatinization enthalpy of the lentil analog sample. In this study, Degree of starch gelatinization was determined by comparing ΔH for an extruded products for the three test samples closest to the control (T3, T5, T6, and the control as can be seen in Table 2) which were selected according to the best pre sensory evaluation in addition to its raw blends.

Fig. 6 Thermal energy absorption curves by differential scanning calorimetry. T3: 50 %Soy + 50 %wheat and lecithin “SW (50:50)L”; T5: 60 %Soy + 40 %wheat “SW (60:40)”; T6: 70 %Soy + 30 %wheat “SW (70:30)”

Viscoamylograph

The visco/amylograph is used to measure the viscosity changes of starch during pasting, shear thinning and setback periods. The most important property of starch is its ability to swell and to yield a viscous paste when a water suspension of the granules is heated above the gelatinization temp. The BRABENDER® Amylograph was used in determining the gelatinization maximum viscosity for both treatments T5 and T6 in addition to its raw blends to study the changes that happen to the starch after being exposed to single screw and twin screw extruders.

Statistical analysis

Three replications and three sub-samples per replication were performed on six different treatments in addition to the control. Treatments were compared for their physical and sensory characteristics following a one-way complete randomized design. The analysis of variance and means comparison were

Fig. 7 Comparison of water hydration capacity (%WHC) of lentil analog samples prepared under different treatments by using Single Screw extruder (SS) and Twin Screw extruder (TS). Means with different superscripts indicate significant differences among all treatments, ($p < 0.05$). T5: 60 %Soy + 40 %wheat “SW (60:40)”; T6: 70 %Soy + 30 %wheat “SW (70:30)”

conducted by the general linear model (Proc GLM) and Anova (Proc ANOVA) procedures with Statistical Analysis System software (version 8.2, SAS Institute, Inc., Cary, NC). Comparisons among treatments were analyzed by Tukey’s Studentized Range (HSD), with a significance level at $P < 0.05$.

Results and discussion

Moisture content and water hydration capacity

There were insignificant differences in the moisture content among all the treatments. The moisture content of all the treatments ranged between 9.3 and 10.0 %. This similarity in the moisture composition is primarily due to the similarity in the degree of water added to the system as well as due to the similarity in the main ingredients (wheat and soy flour) and the processing conditions. This similarity in the processing conditions did not change the moisture content among different treatments significantly (Liu et al. 2011). Also, the addition of the different additives such as the monoglycerides, methylcellulose, and lecithin at 0.88 % level did not affect significantly the moisture content in these treatments.

The ability of the lentil analog products to absorb water under certain conditions can be determined by the water hydration capacity (WHC). As can be shown in Fig. 2, the Lentil (control) had significantly the lowest WHC compare to all other treatments. Also, there were insignificant

Fig. 8 Comparison of Hardness, Adhesiveness, Gumminess, and Chewiness of lentil analog samples prepared under different treatments by using Single Screw extruder (SS) and Twin Screw extruder (TS).

Means with different superscripts indicate significant differences among all treatments, ($p < 0.05$). T5: 60 %Soy + 40 %wheat “SW (60:40)”; T6: 70 %Soy + 30 %wheat “SW (70:30)”

Fig. 9 Comparison of Cohesiveness, and Springiness of lentil analog samples prepared under different treatments by using Single Screw extruder (SS) and Twin Screw extruder (TS). Means with different

superscripts indicate significant differences among all treatments, ($p < 0.05$). T5: 60 %Soy + 40 %wheat “SW (60:40)”; T6: 70 %Soy + 30 %wheat “SW (70:30)”

differences at ($p < 0.05$) in the WHC among T1-T4 while there was a significant difference between these treatments and the other treatments T5, T6, and the Lentil. This variation could be due to the variation in the original composition between the Lentil and the other treatments as can be seen in Table 2. Therefore, it is expected that this variation in will have affect on all the physical, chemical properties of the of the extruded products (Gajula et al. 2009).

Color

All the treatments were statistically the same for lightness, *L*, *a* and *b* values ($p < 0.05$) as can be shown in Fig. 3. This was expected because all of treatments were formed from the same type of the ingredients that might influence the color attributes and the variations in the composition did not make any significant differences in the color values. Also, as mentioned earlier this similarity processing conditions did not change the color values among different treatments significantly.

Texture

Texture was affected by using different formulations and different additives in lentil analog productions. Hardness data showed that the Lentil (control) exhibited the highest value with statistically different ($p < 0.05$) compared to all other treatments (Fig. 4). This is expected due to the variation in the original composition between the Lentil and the other treatments which decreased the Lentil WHC. Also, it was found that the treatments containing higher amount of soy flour had significantly higher hardness values compared to all other treatments (Shogren et al. 2006; Singh et al. 2004), whereas the addition of the different additives such as the monoglycerides, and methylcellulose at 0.88 % level increased significantly the hardness values except for lecithin. This could be due to the variation in the effect of these additives on the lentil analog composition and its physical properties.

Gumminess, and chewiness data showed that the Lentil (control) had the highest value with statistically different ($p < 0.05$) compared to all other treatments (Fig. 4). This is

expected since both of these physical parameters are related to the hardness values (Gumminess = cohesiveness*hardness, chewiness = gumminess*springiness).

It was found that the treatments containing higher amount of soy flour (60:40 and 70:30) were significantly higher in adhesiveness compared to all other treatments (Fig. 4). The Lentil (control) had the lowest adhesiveness value with statistically different ($p<0.05$) compared to all other treatments (Fig. 4). This could be due to the variation in the functionality of the different components in each formulation. However, there were no significant differences in the adhesiveness property among the treatments which include different emulsifiers (monoglycerides, methylcellulose, and lecithin) in their formulations (Fig. 4).

There were no significant differences in the cohesiveness property among all treatments (Fig. 5). The Lentil and the other treatments that contain different additives (except for lecithin) exhibited a significantly higher springiness compared to the formula that contains soy: wheat flour (50:50).

Degree of pregelatinization

Gelatinization temperature of T3, T5, T6 raw blends, and the control were observed at 71.68, 73.77, 73.94 and 74.85 °C,

respectively. Peak was not found from extrudate samples in the range from 60 to 80 °C in which gelatinization temperature of T3, T5, T6, are present and there were no significant differences among the treatments. It was concluded that all starch in dry blend are completely gelatinized by extrusion, and its %DG (Degree of Gelatinization) is 100 % for all treatments as can be seen in the endotherms which were observed on all DSC thermograms for all extrudates at approximately 100 °C (Fig. 6). This indicated gelatinization of starch granules and molecular breakdown during extrusion (Liu et al. 2011; Gajula et al. 2009). It has been known that as starch is heated in the presence of water, granules maximum swell leading to % DG which will not happen in the presence of uncooked starch granules (Brennan and Samyue 2004; Lee and Inglett 2006).

Comparison of lentil analog prepared from single and twin screw extruder

The physical properties of the lentil analog (T5, T6) were compared by using two types of extruders (single screw and

Fig. 10 An image of the lentil analog as a raw and cooked final product

twin screw). These physical properties are water hydration capacity (WHC), texture properties and viscosity of the different treatments.

As can be shown in Fig. 7, the T5 and T6 treatments which were produced by using the SS (Single Screw) extruder had significantly the highest WHC compared to that by using TS (Twin Screw) extruder. This variation could be due to the effect of different processing conditions on the starch composition of the granules (Liu et al. 2011; Alavi et al. 2002).

Hardness, adhesiveness, Gumminess, and Chewiness data showed that the T5, and T6 (TS) exhibited the highest value with statistically different ($p < 0.05$) compared to all T5 and T6 (SS) treatments (Fig. 8). This variation could be due to the effect of different processing conditions on the starch composition of the granules as mentioned earlier.

There were no significant differences in the cohesiveness property among all treatments (Fig. 9). The T5 and T6 (SS) exhibited a significantly higher springiness compared to the T5 and T6 (TS).

The Maximum peaks of viscosity were not found for the extrudate samples of T5 and T6 by using SS extruder while there were maximum peaks of viscosity by using TS. The maximum peak of viscosity was formed after 5.58 min. from the run at 89.9 °C for T5 while it was formed after 6.4 min. from the run at 96.1 °C. It can be concluded that there was a significant effect of SS processing conditions on the starch granules and composition compared to the TS processing conditions as can be determined from the peaks of viscosity for T5 and T6.

An image of the lentil analog product as raw and cooked can be seen in Fig. 10. This will help in getting more information about this product.

Conclusions

A novel extruded lentil analog product was produced which can provide a high-protein diet, and rich in essential vitamin and minerals. This product can be supplied to the general population in countries of South Asia and the Middle-East as a substitute for regular lentils. Texture profile analysis of lentil analogs prepared for consumption revealed that the Lentil (control) exhibited a significantly higher hardness and lowest adhesiveness as compared to all other extruded treatments. The DSC results indicated that all starch in dry blend are completely gelatinized by extrusion. Also, it was found that there was a significant effect of SS processing conditions on the starch granules and composition compared to the TS processing conditions as can be determined from the peaks of viscosity for T5 (Soy: wheat, 40:60) and T6 (Soy: wheat, 70:30).

Acknowledgments Sincere thanks to the Jordanian-American Commission for Educational Exchange (The Binational Fulbright Commission) for their supporting this work to increase mutual understanding between the people of the United States and people of Jordan. The authors thank Eric Maichel, Operations Manager, KSU Extrusion Center, for conducting all extrusion runs. We also thank Kaleb Beyer (Wenger Mfg.).

References

- Achinewhu SC, Akah GN (2003) Chemical, functional and sensory properties of processed African yam beans (*Sphenostylis stenocarpa*) and cowpeas (*Vigna unguiculata*). *Plant Foods Hum Nutr* 58:1–6
- Alavi SH, Chen K, Rizvi SH (2002) Rheological characteristics of intermediate moisture blends of pregelatinized and raw wheat starch. *J Agric Food Chem* 50:6740–6745
- American Association of Cereal Chemists (AACC) (1999) Approved methods of the AACC (44–19. St. Paul, MN)
- American Association of Cereal Chemists (AACC) (2008) Approved methods of the AACC (56–35. St. Paul, MN)
- Bahatty RS (1988) Composition and quality of lentil (*Lens culinaris* Medik.): a review. *Can Inst Food Sci Technol* 21: 144–160
- Brennan CS, Samyue E (2004) Evaluation of starch degradation and textural characteristics of dietary fiber enriched biscuits. *Int J Food Prop* 7(3):647–657
- Cloughton SM, Pearce R (1989) Protein enrichment of sugar-snap cookies with sun flower protein isolate. *J Food Sci* 54:354
- Colonna P, Mercier C (1983) Macromolecular modifications of manioc starch components by extrusion-cooking with and without lipids. *Carbohydr Polym* 3:87–108
- Gajula H, Liu S, Alavi S, Herald T, Madl R, Bean SR, Tilley M (2009) Pre-cooked fiber-enriched wheat flour obtained by extrusion: rheological and functional properties. *Int J Food Prop* 12(1):27–44
- Hernandez- Infante M, Sousa V, Montalvo I, Tena E (1998) Impact of microwave heating on hemagglutinins, trypsin inhibitors and protein quality of selected legume seeds. *Plant Foods Hum Nutr* 52:199–208
- İbanoglu S, Ainsworth P, Özer EA, Plunkett A (2006) Physical and sensory evaluation of a nutritionally balanced gluten-free extruded snack. *J Food Eng* 75:469–472
- Khan MA, Rana IA, Ullah I, Jaffery S (1987) Physico-chemical characters and nutrient composition of some improved lines of lentils grown in Pakistan. *J Food Compos Anal* 1:65–70
- Lee S, Inglett GE (2006) Rheological and physical evaluation of jet-cooked oat bran in low calorie cookies. *J Food Sci Technol* 41:553–559
- Liu S, Alavi S, Abughoush M (2011) Extruded Moringa leaf-oat flour snacks: physical, nutritional, and sensory properties. *Int J Food Prop* 14(4):854–869
- Onwulata CI, Konstance RP, Smith PW, Holsinger VH (1998) Physical properties of extruded products as affected by cheese whey. *J Food Sci* 63:814–818
- Onwulata CI, Konstance RP, Smith PW, Holsinger VH (2001) Co-extrusion of dietary fiber and milk proteins in expanded corn products. *LWT Food Sci Technol* 34:424–429
- Potter NN (1986) Food science, 4th edn. Van Nostrand Reinhold, Inc., NY
- Rababah T, Al-Mahasneh M, Ereifej K (2006) Effect of chickpea, broad bean, or isolated soy protein addition on the physicochemical and sensory properties of biscuits. *J Food Saf Sens Nutr Qual Food* 71: 438–442

- Riaz MN (2000) Extruders in food applications book. Technomic Publishing
- Saeleaw M, Dürschmid K, Schleining G (2012) The effect of extrusion conditions on mechanical-sound and sensory evaluation of rye expanded snack. *J Food Eng* 110:532–540
- Sharma AK, SinghB SAK, Bakshi AK, Verma MM (1989) Variation and association amongst lentil cooking characteristics. *LENS Newsletter* 16:29–32
- Shogren RL, Hareland GA, Wu YV (2006) Sensory evaluation and composition of spaghetti fortified with soy flour. *J Food Sci Saf Sens Nutr Qual Food* 71:428–432
- Singh S, Raina CS, Bawa AS, Saxena DC (2004) Sweet potato-based pasta product: optimization of ingredient levels using response surface methodology. *Int J Food Sci Technol* 39:191–200
- Solanki IS, Kapoor AC, Singh U (1999) Nutritional parameters and yield evaluation of newly developed genotypes of lentil (*Lens culinaris Medik.*). *Plant Foods Hum Nutr* 54:79–87