RESEARCH PAPER
FOOD SCIENCE
RESEARCH JOURNAL
e ISSN-2230-9403 ■ Visit us : *www.researchjournal.co.in*
Volume 8 | Issue 1 | April, 2017 | 14-20
DOI : 10.15740/HAS/FSRJ/8.1/14-20

Utilization of whole grain cereal flours and honey in preparation of extruded products

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This paper explores the possibility of utilizing the whole grain cereal flours along with honey in preparation of quality extruded products. Flours of whole wheat, brown rice, whole maize in single and in combination (3:4:3) were mixed with 10 per cent honey and extrusion was carried out at various optimized feed moisture and temperature levels to produce extruded snacks, breakfast cereals and porridge. The extruded products were evaluated for different quality characteristics including anti-oxidant activity and total phenolics content. The various products did not show significant variations in quality attributes, however, cereals had marked influence in determining the quality of these extruded products. Extruded products prepared from cereal flours in combination resulted in better physical properties followed by extruded products prepared from maize flour. With respect to the phenolics content and antioxidant activity, extruded products prepared from maize flour showed better results than extruded products prepared from other cereal flours. The whole wheat flour showed its least suitability in preparation of extruded products.

Key Words : Extruded products, Whole grain cereal flour, Honey, Antioxidant activity, Total phenolic content

How to cite this article : Bobade, Hanuman and Sharma, Savita (2017). Utilization of whole grain cereal flours and honey in preparation of extruded products. *Food Sci. Res. J.,* **8**(1): 14-20, **DOI : 10.15740/HAS/FSRJ/8.1/14-20**.

INTRODUCTION

Extruded foods such as snacks and breakfast cereals have become part of the dietary habits of a great part of the population. They can be prepared with ingredients or components that give them specific functional properties (Huang *et al.*, 2006 and Ibanoglu *et al.*, 2006). Notably, starch rich ingredients like refined cereal flour is the obvious choice for extrusion as it results in products with optimum physical properties (expansion, density, crispiness, water absorption and solubility index) and hence, more likely acceptable by consumers. Contrarily, extruded products prepared from such an ingredient as refined cereal flour lacks nutritional value owing to presence of only starchy endosperm in refined cereal flours which is devoid of bran and germ fractions, most nutritious components of cereal grains.

The past two decades have seen a rapid increase in consumer demand for healthy foods, which has prompted recent research to find methods for production of healthy and functional foods. The usage of whole grain cereal instead of milled cereals is one such trend for production of healthy and functional foods. Hence, utilization of whole grain cereal flours in preparation of extruded foods will be prolific. However, though the whole grain cereal flours are nutritionally rich in fibres, vitamins, minerals and several phytochemicals (Fardet, 2010), foods prepared from such flours have poor physical properties and sensory appeal.

A new trend is to market the sweetened cereals as

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snacks. However, many studies (Brown *et al.*, 2009 and Moreira, 2013) indicated that the high intakes of sucrose have been associated with increased risk of coronary heart diseases, obesity, type 2 diabetes and other dietary implications. In this regard, honey could prove good alternative to the common sugars in preparation of sweetened extruded products. In the present work, attempt is made to prepare extruded products from whole grain cereal (wheat, rice and maize) flours in combination with honey at previously optimized processing conditions and evaluate the quality characteristics of these extruded products in lieu possible utilization of these ingredients in quality extruded products as convenience food.

METHODOLOGY

Wheat (var. HD 2967), paddy (var. PR 121), maize (var. PMH 1) was supplied by Directorate Seeds, Punjab Agricultural University, Ludhiana, Punjab, India. Brown rice was obtained by dehulling the paddy in laboratory dehuller (Satake, Japan). Grains after cleaning were grinded in Torrento Flour Mill (Tech Electric Enterprise, Ahmedabad, India) to obtain the whole grain flours (250µ). Honey (sunflower cultivar) was supplied by Department of Entomology, Punjab Agricultural University, Ludhiana, India.

Extrusion :

Extrusion of honey-cereals was performed at 16 per cent feed moisture, 150^{0}C extrusion temperature, 500 rpm screw speed and 10 per cent honey level in the feed. These processing condition were already optimized. Extrusion was carried out with the help of twin screw co-rotating intermeshing extruder (BC 21, Clextral, Firminy, France) having a screw length of 400 mm and diameter 25 mm. Four kinds of extruded snacks were produced, whole wheat flour-honey, brown rice flour-honey, maize flour-honey and cereals in combination (in 3:4:3 proportion).

Experimental design :

Four different blends *viz.*, whole wheat flour-honey, brown rice flour-honey, maize flour-honey and cereals in combination-honey were used to prepare three products *viz.*, extruded snacks, breakfast cereals and porridge. Extrusion processing parameters were earlier optimized by response surface methodology and are given in Table A. These extruded products were evaluated for expansion ratio, bulk density, water absorption and solubility indices, total phenolic content, antioxidant activity, colour, hardness and organoleptic characteristics.

Measurement of product characteristics :

Expansion ratio :

The ratio of diameter of extrudate and the diameter of die (6 mm) was used to express the expansion of extrudate.

Bulk density :

The bulk density (g/cc) of extruded products was measured by using 100 ml graduate cylinder by rapeseed displacement. The volume of 20 g Randomize sample was measured for each test. The ratio of sample weight and the replaced volume in cylinder was calculated as density.

Water absorption and water solubility index :

Water absorption and water solubility indices of the snacks were determined using the method outlined by Anderson *et al.* (1969).

Total phenolic content (TPC) :

Total phenolic contents in the extracts were estimated using Folin-Ciocalteu reagent (Sharma *et al.*, 2012).

DPPH radical scavenging activity assay :

Antioxidant activity (AOA) was measured using a modified version of the method described by Brand-Williams *et al.* (1995).

Colour :

Colour of extruded snacks was measured by using Minolta Spectrophotometer in the hunter lab colour mode.

Table A : Optimized extrusion processing conditions for product responses

Cereals	Feed moisture (%)	Barrel temperature (^{0}C)	Honey level (%)
Wheat	16.49	152.93	11.18
Brown rice	16.40	150.28	11.39
Maize	15.86	158.33	12.27
Cereals in combination	15.81	156.00	10.66

The colour of extruded products was expressed in L* (Lightness), a* (redness) and b* (yellowness) values.

Hardness :

Textural quality of the extruded snacks was examined by using a TA-XT2i Texture Analyzer (Stable Microsystems, Surrey, UK). The compression probe (75 mm dia, aluminium cylinder) was applied to measure the compression force required for samples breakage which indicates hardness.

Statistical analysis :

The analysis of variance was performed with the help of Statistical Package for the Social Sciences (SPSS, [PASW version 18.0] Inc., USA). Tukey's test ($p<0.05$) was used to detect differences among treatment means. Moreover, Pearson's correlation co-efficient value was determined (significance level $p<0.05$).

OBSERVATIONS AND ASSESSMENT

The results obtained from the present investigation as well as relevant discussion have been summarized under following heads :

Expansion ratio and bulk density :

The expansion ratio of extruded snacks did not vary considerably than expansion ratio of breakfast cereals. However, cereals differed in their ability to undergo puffing during extrusion. The least expansion ratio was observed in wheat extruded products followed by brown rice based extruded products. Wheat, brown rice and maize combined in 3:4:3 ratio exhibited highest degree of puffing followed by extruded products prepared from maize (Table 1). These results thus indicate that the die shape of extruder do not play decisive role in determining the expansion ratio of extrudates. Type of cereal used in extrusion had huge impact on expansion ratio of extrudates. This could be due to large differences in physico-chemical properties, mainly starch and fibre content of cereals as observed by Zhang *et al.* (2014). The least expansion in wheat extruded products could be attributed to its high protein content. Zhang *et al.* (2014) observed that increase in protein content hinder the puffing quality of extruded products. Protein decreases shear within the extruder, and reduces the amount of moisture flashed off, thus expansion is decreased. Starch in wheat is embedded in the protein matrix. In this regard, wheat being high in gluten content may restrict the gelatinization of starch. Further, protein, unlike starch, could form strong viscoelastic mass that do not puff across the die opening when exposed to pressure differential.

The difference in expansion ratio of brown rice and maize extruded could be explained on the basis of amylose-amylopectin content and lipid content. Fat also provides

Table 1 : Physical and functional properties of whole grain cereals-honey extruded products

Product	Wheat	Brown rice	Maize	#Cereals in combination
Expansion ratio				
Extruded snacks	2.11 ± 0.07^{qc}	2.19 ± 0.05^{qc}	2.54 ± 0.10^{qb}	2.72 ± 0.09^{qa}
Breakfast cereal	2.08 ± 0.10^{qc}	2.17 ± 0.12^{qc}	2.55 ± 0.15^{qb}	2.74 ± 0.19^{qa}
Porridge	2.18 ± 0.12^{pc}	2.27 ± 0.09^{pc}	2.68 ± 0.13^{pb}	2.85 ± 0.15^{pa}
Bulk density (g/cc)				
Extruded snacks	0.262 ± 0.009^{pa}	0.128 ± 0.007^{pb}	0.113 ± 0.005^{pb}	0.092 ± 0.010^{pc}
Breakfast cereal	0.265 ± 0.015^{pa}	0.13 ± 0.011^{pb}	0.115 ± 0.011^{pbc}	0.094 ± 0.013^{pc}
Porridge	0.266 ± 0.012^{pa}	0.133 ± 0.014^{pb}	0.111 ± 0.015^{pbc}	0.095 ± 0.014^{pc}
Water absorption index (g/g)				
Extruded snacks	4.83 ± 0.15^{pab}	4.17 ± 0.19^{pc}	4.55 ± 0.21^{pbc}	5.34 ± 0.23^{pa}
Breakfast cereal	4.86 ± 0.18^{pab}	4.19 ± 0.25^{pc}	4.51 ± 0.24^{pbc}	5.38 ± 0.31^{pa}
Porridge	4.88 ± 0.14^{pab}	4.14 ± 0.29^{pc}	4.56 ± 0.30^{pbc}	5.35 ± 0.28^{pa}
Water solubility index (%)				
Extruded snacks	22.03 ± 0.83^{pa}	22.91 ± 0.92^{pa}	22.75 ± 0.98^{pa}	23.66 ± 0.77^{pa}
Breakfast cereal	22.08 ± 0.72^{pa}	22.87 ± 0.81^{pa}	22.71 ± 0.91^{pa}	23.72 ± 0.65^{pa}
Porridge	22.05 ± 0.77^{pa}	22.93 ± 0.95^{pa}	22.78 ± 0.94^{pa}	23.69 ± 0.62^{pa}

Means followed by different superscript letters (p-q) within a column differ significantly.
Means followed by different superscript letters (a-d)within a row differ significantly.
Wheat:Brown rice:Maize::3:4:3

a lubricant function for extrusion cooking and may reduce the grinding effect within raw materials, thereby lowering expansion. More importantly, due to the ability of amylose to bind lipids, extrusion cooking results in the formation of amylose-lipid complexes, thus increasing bulk density and creating a more compact macrostructure (De Pilli *et al.,* 2011). The less proportion of amylose in maize may have augmented the expansion ratio of maize based extruded products over extruded products prepared from brown rice. It was interesting to note that the extruded products prepared from cereals in combination portrayed highest expansion ratio. This could be due to the effective interaction between the various components of wheat, brown rice and maize. Similar results have been reported by Zhang *et al.* (2014).

The bulk density values of extruded snacks, breakfast cereal and porridge did not vary significantly within a cereal. However, the bulk density of the extruded products prepared from different cereal grains varied significantly ($p<0.05$). The highest bulk density was observed for the extruded products prepared from wheat while the lowest bulk density was found in combined cereal grain based extruded products. The bulk density of the extruded products is the function of expansion ratio. High bulk density values result from compact structure of objects which are less puffy whereas highly expanded and puffed product occupy more volume and posses less weight and hence, expansion ratio is inversely related to the bulk density (Ilo *et al.,* 1996). This study also revealed that the products having high expansion ratio displayed less bulk density. Similar to expansion ratio, the variation in bulk density of the extruded products could be attributed to compositional differences in wheat, rice and maize grains.

Water absorption index :

It depends on the availability of hydrophilic groups, which bind water molecules and on the gel-forming capacity of macromolecules (Sompong *et al.,* 2011). For a particular cereal, the water absorption index of extruded snacks, breakfast cereals and porridge showed non-significant ($p>0.05$) changes and very small variation was found in water absorption index of extruded products, themselves. However, the type of cereal used for preparation of these products showed statistically significant ($p<0.05$) variation. The highest value of water absorption index was found in the extruded products prepared from cereals used in combination followed by wheat while the lowest value was observed for brown rice.

Water absorption index is the indication of amount of hydrophilic polymers present in the sample as such polymers has capability to absorb and hold the water. Greater the polymers, more is the water absorption index. The low water absorption index of brown rice based extruded products could be due to more exposure and degradation of starch during extrusion and owing to scarcity of proteins. While the high water absorption index of extruded products prepared from combined cereals and wheat based extruded products may be due to high content of fibres and proteins which themselves has high water absorption capacity and secondly they may shield the exposure and degradation of starch during extrusion cooking. Presence of amylopectin also helps in increased water absorption index (Tester and Morrison, 1990) which is evident from the maize based extruded products against water absorption index of brown rice based extruded products. This finding differs from those of Altan *et al.* (2009) that showed that raw material properties had no effect on WAI. The results are, however, in agreement

Table 2 : Bioactive composition of whole grain cereals-honey extruded products

Product	Wheat	Brown rice	Maize	#Cereals in combination
Total phenolics content (mg $GAE/100g)				
Extruded snacks	97.11 ± 0.55^{pc}	66.84 ± 0.42^{pd}	145.24 ± 0.69^{pa}	101.85 ± 0.45^{pb}
Breakfast cereal	96.89 ± 0.52^{pc}	66.54 ± 0.48^{pd}	144.68 ± 0.75^{pa}	101.94 ± 0.50^{pb}
Porridge	97.51 ± 0.61^{pc}	66.97 ± 0.53^{pd}	145.72 ± 0.81^{pa}	102.05 ± 0.54^{pb}
Antioxidant activity (%RSA*)				
Extruded snacks	35.51 ± 0.38^{pb}	27.74 ± 0.27^{pd}	40.18 ± 0.35^{pa}	30.14 ± 0.31^{pc}
Breakfast cereal	35.62 ± 0.35^{pb}	28.12 ± 0.32^{pd}	40.92 ± 0.40^{pa}	30.87 ± 0.37^{pc}
Porridge	35.59 ± 0.47^{pb}	28.05 ± 0.39^{pd}	40.58 ± 0.44^{pa}	30.96 ± 0.45^{pc}

Means followed by different superscript letters (p-q) within a column differ significantly.
Means followed by different superscript letters (a-d)within a row differ significantly.
Wheat:Brown rice:Maize::3:4:3 $Gallic acid equivalent *Radical scavenging activity

with those reported by Carvalho *et al.* (2010) who reported significant effect of raw material properties on water absorption index of extrudates.

Water solubility index :

The water solubility index of extruded products did not show appreciable variations. The water solubility index of extruded products prepared from wheat, brown rice, maize and cereals in combination ranged from 22.03 to 26.75 per cent. Average highest value of water solubility index was observed in extruded products prepared from cereals in combination and lowest water solubility was observed in extruded products prepared from wheat.

Water solubility can be used as an index of gelatinization. More the starch conversion during extrusion, higher will be the water solubility index. Rice, being high in amylose and low in protein and fibre, could show high water solubility due to higher rate of starch conversion during extrusion (Dogan and Karwe, 2003). Contrary to rice, wheat had high fibre as well as protein content which could hamper the starch conversion during extrusion cooking and hence, show low water solubility index. Moreover, proteins and fibres have adverse effect on water solubility index. The lower WSI value of wheat and barley extrudates may be connected with their high content of starch, insoluble proteins and dietary fibre (Zhang *et al.*, 2014).

Total phenolic content and antioxidant activity :

Total phenolic content and antioxidant activity of honey incorporated extruded products prepared wheat, brown rice, maize and cereals in combination is reflected in the Table 2. Total phenolic content and antioxidant activity did not differ significantly ($p>0.05$) within the products, however, the cereal type used for preparation of these extruded products has statistically significant effect ($p<0.05$) on total phenolic content and antioxidant activity. The highest total phenolic contents (144.68-145.72 mg/100 g) and antioxidant activity (40.18-40.92 % RSA) is observed in the extruded products prepared from maize and honey. Minimum total phenolic content and antioxidant activity was exhibited by extruded products prepared from brown rice and honey.

The variation in total phenolic content and antioxidant activity in extruded products prepared from various cereal grains may be due to varying initial level of bioactive compounds in cereal grains. Adom and Liu (2002) reported that the various cereal grains differ significantly in total phenolic content and antioxidant activity. However, the decrease in total phenolic contents and antioxidant activity of whole grain cereals-honey extrudates could be due to loss attributed to the heat labile nature of these compounds as indicated by Han and Koh (2011).

The correlation co-efficient of 0.91 demonstrates that there exist is strong correlation between total phenolic content and antioxidant activity of extruded products. The

Table 3 : Colour characteristics and hardness of whole grain cereals-honey extruded products

Product	Wheat	Brown rice	Maize	Cereals in combination
L* value				
Extruded snacks	62.15 ± 1.15^{pc}	71.05 ± 0.60^{pqa}	67.45 ± 0.85^{pqb}	66.90 ± 1.25^{pb}
Breakfast cereal	61.85 ± 1.25^{pb}	69.75 ± 0.55^{qa}	68.95 ± 0.70^{qa}	67.75 ± 1.15^{pa}
Porridge	63.25 ± 1.05^{pc}	71.45 ± 0.40^{pa}	66.80 ± 0.90^{pb}	65.85 ± 1.00^{pb}
a* value				
Extruded snacks	3.20 ± 0.10^{pb}	2.65 ± 0.05^{pc}	4.55 ± 0.15^{pa}	3.25 ± 0.10^{pb}
Breakfast cereal	3.30 ± 0.15^{pbc}	2.95 ± 0.05^{pc}	4.50 ± 0.20^{pa}	3.45 ± 0.10^{pb}
Porridge	3.15 ± 0.15^{pb}	2.60 ± 0.10^{pc}	4.65 ± 0.10^{pa}	3.20 ± 0.15^{pb}
b* value				
Extruded snacks	18.35 ± 0.30^{pb}	17.25 ± 0.85^{pb}	24.45 ± 0.50^{pa}	18.15 ± 0.25^{pb}
Breakfast cereal	17.95 ± 0.25^{pb}	17.10 ± 1.05^{pb}	23.85 ± 0.65^{pa}	18.05 ± 0.20^{pb}
Porridge	18.25 ± 0.45^{pb}	17.40 ± 0.75^{pb}	24.50 ± 0.45^{pa}	18.35 ± 0.45^{pb}
Hardness (N)				
Extruded snacks	59.11 ± 2.08^{pa}	51.69 ± 2.15^{pb}	51.50 ± 2.37^{pb}	44.85 ± 1.92^{pc}
Breakfast cereal	60.38 ± 2.32^{pa}	54.29 ± 2.24^{pb}	53.41 ± 2.54^{pbc}	47.72 ± 2.19^{pc}
Porridge	58.03 ± 2.74^{pa}	49.75 ± 2.93^{pb}	50.08 ± 2.87^{pb}	43.15 ± 2.79^{pb}

Means followed by different superscript letters (p-q) within a column differ significantly.
Means followed by different superscript letters (a-d) within a row differ significantly.

linear correlation between total phenolic content and antioxidant activity signifies that the phenolic compounds present in extruded products have strong *in vitro* antioxidant activity. However, it is worth to note that the antioxidant activity may not have been attributed to the presence of phenolic compounds only but also some browning compounds formed during extrusion cooking which have capability to act as antioxidant. The same observations have been noted by Yilmaz and Toledo (2005).

Colour characteristics and hardness :

Variable trend in colour values of extruded products prepared from various cereal grains was manifested. Table 3 reveal that the highest L* value was seen in extruded products prepared from brown rice while the minimum L* value was observed for extruded products prepared from wheat.

L* value of extruded products varied significantly for different types of cereal except that the L* value of extruded products prepared from maize and cereals used in combination was found at par. This could be due the dominancy of pigmented maize in relatively mild colour of wheat and brown rice. Further, low L* value and relatively dark colour of wheat based extruded products could be due to high fibre and protein content of wheat. Peressini *et al.* (2015) found that high fibre foods are associated with the dark colour. On the other side, comparatively low fibre and protein content as well as protein uncovered starch in endosperm may be responsible for the lightness (high L* value) of brown rice based extruded products.

The results of this study indicated that though a* and b* values do not differ significantly ($p>0.05$) within the products, whole grain cereals have significant impact on the a* and b* values of extruded products (extruded snacks, breakfast cereals and porridge). Extruded products prepared from maize displayed highest a* and b* values (redness and yellowness, respectively) while lowest a* and b* values were observed for extruded products prepared from wheat. The higher redness and yellowness in maize extruded products could be due greater pigmentation found in maize. On the other hand, brown rice based extruded products showed lower a* and b* values owing to more whitish colour of brown rice. Bhattacharya *et al.* (1997) also found the same results for the colour characteristics of rice-green gram blend. The results of this study indicate that the colour differences in various whole grain cereal extruded products are manifested by the initial colour of the feed. The similar observations have been recorded by Peressini *et al* (2015) with respect to colour characteristics of snacks.

Type of cereal used in preparation of extruded products had statistically significant ($p<0.05$) effect on the hardness. However, the hardness of brown rice based extruded products and maize extruded products was at par. The hardness of wheat, brown rice, maize and cereals in combination for extruded products lied in the range of 58.03-60.38, 49.75-54.29, 50.08-53.41 and 43.15-47.72N. This indicated the variation in hardness of extruded products prepared from particular cereal was not substantial.

Hardness of the extruded products is influenced by the expansion properties and bulk density. High expansion ratio and low bulk density results in lower hardness of the extruded products (Meng *et al.*, 2010). The less dense product requires less force to break it down. The air cells and voids present in lighter products make it crisp and crunchy and hence, have low hardness values. It could easily be observed from the Table 2 that the hardness of extruded products is directly associated with the expansion ration and bulk density described earlier.

Conclusion :

All the cereals showed their optimal suitability with respect to utilization as whole grain in preparation of various extruded products. Amongst all cereals, maize demonstrated better results which produced nutritional and acceptable extruded snacks high in total phenolic contents, antioxidant activity and better physical properties. However, best quality extruded products were obtained when cereals flours were used in combination. Amongst the extruded products, snacks was found to be most acceptable than other products. The results of this study indicated that in lieu of production of nutritionally rich extruded products by utilization of whole grain cereals, these cereals should be used in combination.

LITERATURE CITED

Adom, K.K. and Liu, R.H. (2002). Antioxidant activity of grains. *J. Agric. Food Chem.,* **50** : 6182-6187.

Anderson, R.A., Conway, H.F. and Griffin, E.L. (1969). Gelatinization of corn grits by roll and extrusion cooking.

J. Cereal Sci., **14** : 4-12.

Altan, A., McCarthy, K.L. and Maskan, M. (2009). Effects of screw configuration and raw material on some properties of barley extrudates. *J. Food Engg.,* **92**: 377-382.

Bhattacharya, S., Sivakumar, V. and Chakraborty, D. (1997). Changes in CIELab colour parameters due to extrusion of rice-greengram blend: a response surface approach. *J. Food Engg.,* **32** : 125-131.

Brand-Williams, W., Cuvelier, M.E. and Berset, C. (1995). Use of a free radical method to evaluate antioxidant activity. *LWT-Food Sci. Technol.,* **28** : 245-251.

Brown, I.J., Tzoulaki, I., Candeias, V. and Elliott, P. (2009). Salt intakes around the world: Implications for public health. *Internat. J. Epidemiol.,* **38**: 791-813.

Carvalho, C.W.P., Takeiti, C.Y., Onwulata, C.I. and Pordesimo, L.O. (2010). Relative effect of particle size on the physical properties of corn meal extrudates: Effect of particle size on the extrusion of corn meal. *J. Food Engg.,* **98**:103-109.

De Pilli, T., Derossi, A., Talja, R.A., Jouppila, K. and Severini, C. (2011). Study of starch-lipid complexes in model system and real food produced using extrusion-cooking technology. *Inn. Food Sci. Emer. Technol.,* **12** : 610-616.

Dogan, H. and Karwe, M.V. (2003). Physicochemical properties of quinoa extrudates. *Food Sci. Technol. Internat.,* **9** : 101-114.

Fardet, A. (2010). New hypotheses for the health-protective mechanisms of whole-grain cereals: what is beyond fibre? *Nutr. Res. Rev.,* **23** : 65-134

Han, H.M. and Koh, B.K. (2011). Antioxidant activity of hard wheat flour, dough and bread prepared using various processes with the addition of different phenolic acids. *J. Sci. Food Agric.,* **91**:604-608.

Huang, R.C., Peng, J., Lu, F.J., Lui, W.B. and Lin, J. (2006). The study of optimum operating conditions of extruded snack food with tomato powder. *J. Food Process. Engg.,* **29**:1-21.

Ibanoglu, S., Ainsworth, P., Ozer, E. A. and Plunkett, A. (2006). Physical and sensory evaluation of a nutritionally balanced gluten–free extruded snack. *J. Food Engg.,* **75**: 469-472.

Ilo, S., Tomschik, U., Berghofer, E. and Mundigler, N. (1996). The effect of extrusion operating conditions on the apparent viscosity and the properties of extrudates in twin-screw extrusion cooking of maize grits. *LWT-Food Sci. Technol.,* **29**:593-598.

Meng, X., Threinen, D., Hansen, M. and Driedger, D. (2010). Effects of extrusion conditions on system parameters and physical properties of a chickpea flour-based snack. *Food Res. Internat.,* **43**: 650-658.

Moreira, P.I. (2013). High-sugar diets, type 2 diabetes and Alzheimer's disease. *Curr. Opin. Clinc. Nutr. Metab. Care,* **16**: 440-45.

Peressini, D., Foschia, M., Tubaro, F. and Sensidoni, A. (2015). Impact of soluble dietary fibre on the characteristics of extruded snacks. *Food Hydrocolloids,* **43**:73-81.

Sharma, P., Gujral, H.S. and Singh, B. (2012). Antioxidant activity of barley as affected by extrusion cooking. *Food Chem.,* **131**:1406-1413.

Sompong, R., Siebenhandl-Ehn, S., Berghofer, E. and Schoenlechner, R. (2011). Extrusion cooking properties of white and coloured rice varieties with different amylose content. *Starch/Starke,* **63**:55-63.

Tester, R.F. and Morrison, W.R. (1990). Swelling and gelatinization of cereal starches.I. Effects of amylopectin, amylose, and lipids. *Cereal Chem.,* **67** : 551-557.

Yilmaz, Y. and Toledo, R. (2005). Antioxidant activity of water-soluble Maillard reaction products. *Food Chem.,* **93**: 273-278.

Zhang, C., Zhang, H., Wang, L. and Qian, H. (2014). Physical functional and sensory characteristics of cereal extrudates. *Internat. J. Food Prop.,* **17** : 1921-1933.

Received : *16.01.2017;* **Revised:** *09.02.2017;* **Accepted :** *19.02.2017*