Oryza Vol. 53 No.4, 2016 (428-436)

Quality characteristics of honey enriched brown rice flour extrudates

HP Bobade*[1], S Sharma[1], V Nanda[2] and B Singh[1]

[1]Punjab Agricultural University, Ludhiana, Punjab, India

[2]Sant Longowal Institute of Engineering and Technology, Longowal, Punjab, India

Corresponding author e-mail: hanu.chk@gmail.com

Accepted :19 January 2017 Published :03 February 2017

ABSTRACT

Research was undertaken to investigate the effect of brown rice flour along with honey on physico-chemical properties of extrudates at varying processing conditions. Brown rice flour and honey at different proportion (1.59-18.41%) were blended and extruded by co-rotating twin screw extruder at varying extrusion conditions viz., feed moisture (14-18%) and barrel temperature (120-180 °C) at constant screw speed (500 rpm). Effect of these independent factors on expansion ratio, bulk density (BD), water absorption index (WAI), water solubility index (WSI) and hardness as responses were studied. Central composite rotatable design was used to plan the experiments. Product responses were significantly ($p<0.05$) influenced by all the independent variables. Results indicated that expansion ratio was negatively affected by feed moisture, barrel temperature and honey proportion, whereas the bulk density and hardness were positively affected by these variables. Feed moisture had positive but barrel temperature and honey proportion had negative effect on water absorption index of extrudates. Consequence of feed moisture on water solubility index was negative, while that of barrel temperature and honey was positive. This study demonstrated the potential utilization of brown rice flour and honey in preparation of nutritionally high quality extruded products.

Key words: *Brown rice flour, honey, extrusion, expansion ratio, bulk density, hardness*

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 (Reid 1998; Huang *et al*. 2006; 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. Consumption of whole grain foods has shown a reduction in the risk of several diseases, such as cardiovascular diseases, obesity, diabetes and some types of cancers (Slavin 2004; Topping 2007). One of the most significant components in the whole-cereal grains that play a significant part in its health properties is dietary fiber and phenolics, which are mainly concentrated in the outer layers of the cereal grain (Slavin 2004). Production of whole grain foods is a complicated task for the food industry due to the mechanical negative effects of the bran on protein network formation and consequently on the sensory properties of the end product (Salmenkallio 2001). Accordingly, the most common forms of cereal composition are milled products, such as white wheat flour or white rice.

Rice (*Oryza sativa* L.) is the staple food for nearly two-thirds of the World's population (Wynn 2008). Various studies have been carried out on the enrichment of snacks with different ingredients, such as soy flour (Li *et al.* 2005; Nwabueze 2007), soy protein isolate (Lee and Brennand 2005; Verônica *et al*. 2006), tomato powder (Huang *et al*. 2006; Ibanoglu *et al.* 2006), vitamins (Athar *et al.* 2006), carrot and basil powder (Ibanoglu *et al*. 2006), among other ingredients. In this context, enrichment of brown rice flour extruded products with honey as functional ingredient will enhance the nutritional value of extruded products. Therefore, the present investigation was undertaken to study the effects of brown rice flour and honey on the physico-chemical characteristics of extrudates at varying feed moisture and barrel temperature.

MATERIALS AND METHODS

Raw Materials

Paddy (PR 118) was procured from Directorate of Seeds, Punjab Agricultural University (PAU), Ludhiana. Paddy was dehusked with the help of Satake Rice Mill, Japan and milled into the flour by Laboratory Torrento Mill so as to produce a flour of particle size smaller than 250µ (Lamberts *et al.* 2007). Commercial grade honey was obtained from the department of Processing and food engineering, PAU, Ludhiana.

Blend preparation

Brown rice flour and honey in different proportions as indicated in Table 2 were measured and placed in mixing bowl. The requisite quantity of water was sprinkled over the mix and contents were blended in the laboratory mixer at high speed for 2 min to ensure homogeneity of the feeding material before extrusion. The blended samples were passed through a 2 mm sieve to break the lumps, if any, formed during mixing process due to addition of moisture. The blended samples were then subsequently transferred to high density (0.97 g/cm^3) polyethylene bags and stored for 12 h at room temperature to equilibrate the moisture throughout the sample (Stojceska *et al.* 2009).

Experimental design and statistical analysis

Response surface methodology (RSM) which involves design of experiments, selection of levels of variables in experimental runs, fitting mathematical models and finally selecting variable levels by optimizing the response was employed. In the present study, central composite rotatable design was used to plan the experiments comprising three independent processing variables (feed moisture, barrel temperature and level of honey) at five different levels ($-\alpha$, -1, 0, +1, $+\alpha$). The response variables considered were expansion ratio, bulk density, water absorption index, water solubility index and hardness. The levels of each variable were established according to literature information and preliminary trials. The outline of the experimental design is presented in Table 1. In total, twenty experiments were conducted (Table 2), with six experiments at centre point to calculate the repeatability of the method. The experiments were conducted in a randomized order to minimize the effects of unexplained variability in the observed responses due to extraneous factors.

The experimental data obtained were analysed after fitting them into a second order polynomial model given below. A quadratic polynomial regression model was assumed for predicting individual responses (Wanasundara and Shahidi 1996). The model proposed for each response of Y was:

$$Y = B_0 + B_1X_1 + B_2X_2 + B_3X_3 + B_{12}X_1X_2 + B_{23}X_2X_3 + B_{13}X_1X_3 + B_{11}X_{12} + B_{22}X_{22} + B_{33}X_{32} \quad (1)$$

Where Y = the response, X_1= feed moisture, X_2 = barrel temperature, X_3 = honey proportion, B_0 = intercept, B_1, B_2, B_3 are linear, B_{12}, B_{23}, B_{13} are interactive and B_{11}, B_{22} and B_{33} are quadratic regression coefficient terms.

Coefficients of determination (R^2) were computed and adequacy of the model was tested by separating the residual sum of squares into pure error and lack of fit. For each response, response surface plots were produced from the fitted quadratic equations, by holding the variable with the least effect on the response equal to a constant value, and changing the other two variables.

Table 1. Coded levels for independent variables used in the experiment

Factor	Level					
		$-\alpha$	-1	0	+1	$+\alpha$
A: Feed moisture (%)	X1	11.95	14	17	20	22.05
B: Barrel Temperature (^{0}C)	X2	99.55	120	150	180	200.45
C: Honey proportion (%)	X3	1.59	5	10	15	18.41

^{a} = 1.682

Table 2. Influence of feed moisture, barrel temperature and honey proportion on properties of rice-honey extrudates

	Process variables			Product Responses				
Sl. No.	Feed Moisture (%)	Barrel Temperature (^{0}C)	Honey Proportion (%)	Expansion Ratio	Bulk density (g/cm^3)	Water absorption index(g/g)	Water solubility index (%)	Hardness (N)
1	14	120	5	4.48	0.1494	3.97	12.23	64.14
2	20	120	5	4.21	0.1719	4.49	10.53	66.27
3	14	180	5	4.04	0.1798	3.39	15.59	67.91
4	20	180	5	3.67	0.2149	3.78	13.91	71.83
5	14	120	15	3.39	0.2418	3.21	13.39	74.27
6	20	120	15	3.01	0.2589	3.69	13.03	79.06
7	14	180	15	3.27	0.2443	2.78	16.52	75.89
8	20	180	15	2.71	0.2662	3.36	15.94	82.34
9	11.95	150	10	3.82	0.2075	3.17	14.58	70.21
10	22.04	150	10	3.14	0.2498	4.18	12.73	77.32
11	17	99.54	10	3.72	0.2132	3.8	11.14	71.14
12	17	200.45	10	3.13	0.2498	3.09	16.93	77.73
13	17	150	1.59	5.15	0.0989	4.62	13.17	58.13
14	17	150	18.40	3.24	0.2382	3.35	15.91	76.07
15	17	150	10	4.76	0.1268	4.14	15.28	62.71
16	17	150	10	4.78	0.1259	4.13	15.38	62.93
17	17	150	10	4.75	0.1271	4.15	15.32	62.54
18	17	150	10	4.76	0.1267	4.14	15.19	62.77
19	17	150	10	4.75	0.1274	4.13	15.23	62.59
20	17	150	10	4.76	0.127	4.15	15.33	62.68

Extrusion

A twin screw co-rotating extruder (Clextral BC 21, Firminy France) was used with a barrel length of 400 mm and a screw diameter of 25 mm (L/D ratio of 16). The screw configuration was composed of mixing and conveying elements with reverse element in the last section of the barrel. The extruder was operated at a constant feed rate of 10 kg/h. The first three heating zones of the barrel were kept at a temperature of 40, 70 and 100^{0}C, respectively. Temperature of the forth zone was varied according to the experimental plan as given in Table 2. After extrusion, the extrudates were packed in high density (0.97 g/cm3) polyethylene package and subsequently analyzed for the quality characteristics.

Physico-chemical properties

Expansion ratio

Five random pieces of extrudate were selected from each sample and diameter was measured using vernier caliper. Expansion ratio (ER) was then calculated as the ratio of diameter of extrudates divided by diameter of die (Kollengode *et al*. 1996). The average value is expressed as expansion ratio.

Bulk Density

Bulk density (BD) of extrudates was calculated by measuring the actual dimensions of the extrudates. Five random pieces of the extrudates were selected from each sample and its length (L) and diameter (d) were measured using vernier caliper, simultaneously mass (m) of the extrudate was also recorded using precision weighing balance. The Bulk density (g/cm^3) was calculated according to the method of Alvarez-Martinez *et al.* (1988) and average value is reported.

$$\text{Bulk Density (g/cm}^3\text{)} = \frac{4m}{\Pi d^2 L}$$

Water absorption and solubility indices

Water absorption index (WAI) and water solubility index (WSI) of extrudates were determined by a modification of method of Anderson *et al*. (1969). The extrudate samples were ground and sieved through 500µ sieve. 2.5 g sample was placed in the tared centrifuge tube and 30 ml distilled water at 25^{0}C was added. The tubes after closing were shaken to form dispersion and care was taken to avoid lumping in order to produce smooth dispersion. After standing for 30 min (with intermittent shaking every 10 min), the samples were centrifuged at 3000 rpm for 15 min. The supernatant was decanted into a tared aluminum pan and dried at 130 ± 1^{0}C in hot air oven until constant weight. The weight of the gel remaining in the centrifuge tube was noted. The results were expressed as the average of two measurements.

$$\mathrm{WAI}\left(\mathrm{g/g}\right)=\frac{\text{Dry grain of gel}}{\text{Dry weight of extrude}}$$

$$\mathrm{WSI}\left(\mathrm{g/g}\right)=\frac{\text{Weight of dry solids in supernatant}}{\text{Dry weight of extrude}}\mathrm{x}100$$

Hardness

Textural quality of the extruded snacks was examined by using a TA-XT2i Texture Analyzer (Stable Microsystems, Surrey, UK). The compression probe (50 mm dia, aluminium cylinder) was applied to measure the compression force required for samples breakage which indicates hardness. Hardness of extruded snacks was expressed in Newton (1N = 101.97 g force). Testing conditions were 1.0 mm/s pre-test speed, 2.0 mm/s test speed, 10.0 mm/s post test speed and 5 mm distance (Pardhi 2011).

RESULTS AND DISCUSSION

Model description

In this study, response surface methodology was used to model physico-chemical properties of extrudates prepared by enrichment of brown rice flour with varying proportions of honey at different moisture and temperature conditions of extrusion. A quadratic polynomial regression response surface model Eq. (1) was fitted to all the response parameters. The multiple regression equation representing the effect of processing variables on product responses is given by the second order model; the models explained the variability in the experimental data obtained. The data on values of physico-chemical properties of extrudates is given in Table 2. Table 3 shows, coefficient of equations obtained by fitting of experimental data. The regression models for expansion ratio, bulk density, water absorption index, water solubility index and hardness were highly significant ($P<0.05$) with a high correlation coefficient. None of the model showed significant lack of fit ($P>0.05$) indicating that all the second order polynomial models correlated well with the measured data. It is suggested that for good fit model, R^2 should be at least 80%. The results showed that the model for all the response variables was highly adequate because they have satisfactory levels of R^2 (more than 80%) and there is no significant lack of fit in all the response variables. The model having significant lack of fit is not a good indicator of the response and hence should not be used for prediction (Myers and Montgomery 2002). Thus, these models which had non-significant lack of fit could adequately be used as predictor models. Moreover, non-significant lack of fit in the models makes them as predictive models.

Table 3. Regression coefficients of the polynomial function and the coefficients of determination

Coeff-icient	Expan-sion ratio	BD	WAI	WSI	Hardness
B_0	4.76	0.13	4.14	15.29	62.69
B_1	-0.20[a]	0.012[a]	0.27[a]	-0.54[a]	2.14 [a]
B_2	-0.18[a]	0.011[a]	-0.24[a]	1.65[a]	1.85[a]
B_3	-0.53[a]	0.039[a]	-0.35[a]	0.82[a]	5.24[a]
B_{12}	-0.035	2.175x10^{-3}	-3.750 x10^{-3}	-0.025	0.43 [a]
B_{13}	-0.037[a]	-2.325 x10^{-3}[a]	0.019[a]	0.31[a]	0.65[a]
B_{23}	0.070[a]	-7.950 x10^{-3}[a]	0.066	-0.087[a]	-0.55[a]
B_{11}	-0.46[a]	0.036[a]	-0.18[a]	-0.60 [a]	3.99[a]
B_{22}	-0.48[a]	0.037[a]	-0.26[a]	-0.47 [a]	4.23[a]
B_{33}	-0.21[a]	0.015[a]	-0.074[a]	-0.29 [a]	1.64[a]
R^2	0.99	0.99	0.98	0.99	0.99

[a] significant at 5 % level; Bulk density (BD); water absorption index (WAI); Water solubility index (WSI).

Expansion Ratio

Expansion ratio of honey enriched brown rice extrudates was ranged between 2.71-5.15 (Table 2). It is evident from the Table 3 that all independent variables, namely, feed moisture, barrel temperature and honey proportion have negative effect on the expansion ratio. The effect of honey proportion is most noticeable among all the independent factors suggesting that honey predominantly suppresses the expansion of extrudates. Interactive effect of moisture and honey proportion and that of temperature and honey also had significant ($P<0.05$) but negative effect on the expansion ratio. The significant interaction term means that a change in honey proportion can affect the influence of moisture and temperature on expansion ratio. Similarly, quadratic effect of all independent variables had significant and negative effect on expansion ratio. However, Fig.1 clearly indicated that at low level of moisture and temperature, the value of expansion ratio was increasing slightly up to certain moisture and temperature but beyond which expansion ratio again decreased. Further, it is apparent from the Fig. 2 that the trend, however, was not observed with honey proportion.

Expansion ratio of the extrudates, in fact, increased up to certain moisture and temperature values after which it fell drastically. Increasing feed moisture from 14 to 17 per cent and temperature from 120-150^{0}C caused an increase in expansion ratio values for most compositions. This resultant behavior observed in this study is in agreement with results of Falcone and Philips (1988) who found that increasing moisture content from 13-18 per cent increased expansion of sorghum extrudates but further increase caused a decrease in expansion. The decrease in the value of expansion ration for higher temperatures (>150^{0}C) may probably due to the greater fragmentation of starch. Similar effect of temperature on expansion of extrudates was observed by Mendonca *et al*. (2000) who reported decrease in porosity of extrudates at higher extruder temperature (150^{0}C) which can be attributed to increased dextrinization and weakening of structure. The higher feed moisture, on the other hand, probably reduced barrel temperature resulting in lower flashing of moisture and finally in a reduced expansion ratio. Similar effect of moisture and temperature on expansion of rice extrudates were observed by Hagenimana *et al*. (2006).

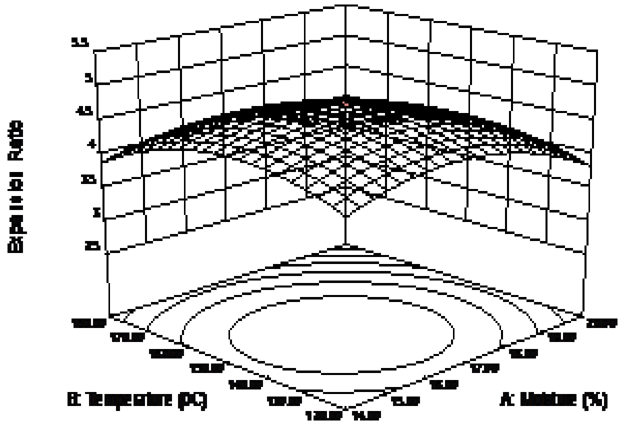

Fig.1. Effect of moisture and temperature on expansion ratio of extrudates

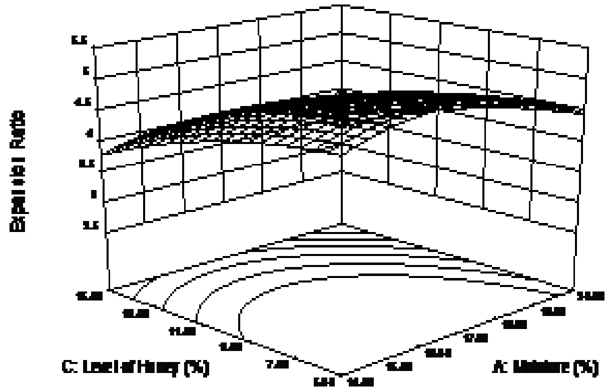

Fig. 2. Effect of moisture and honey level on expansion ratio of extrudates

The effect of processing conditions on expansion ratio showed inverse behavior as in bulk density. This seems to be consistent result. Many researchers (Raysas-Duarte *et al.* 1998; Suknark *et al.* 1997) found that expansion ratio is inversely related with the bulk density of extrudates.

Bulk density

Bulk density has been linked with the expansion ratio in describing the degree of puffing in extrudates (Asare *et al*. 2004). Bulk density of extrudates was varied from 0.0989 to 0.2662 g/cm^3. Regression coefficients of bulk density given in Table 3 indicated that feed moisture, barrel temperature and honey proportion had significant ($P<0.05$) positive effect on bulk density, an exact opposite trend observed in case of expansion ratio. The similar effect of feed moisture and barrel temperature had been observed by Liu *et al.* (2011) in preparation of texturized rice produce by improved extrusion cooking technology. Moreover, interactively, feed moisture and honey proportion; temperature and honey proportion exerted significant and positive effect on the bulk density.

The effect of component variables on the bulk density of extrudates is presented in Table 2. The bulk density was found to be most dependent on honey proportion in comparison to feed moisture and barrel temperature. Higher honey proportion along with high moisture and high temperature resulted higher bulk density in the studied experimental range. However, lowest value of bulk density was observed at least honey proportion and at intermediate moisture and temperature. Though, the bulk density of extrudates increased with, in general, increasing the levels of all independent variables, the increment is more profound up to certain level of moisture (17%) and temperature (150^{0}C), exactly opposite behavior observed with expansion ratio (Fig. 3). The same effect of moisture on bulk density has been reported by Stojceska *et al.* (2009) in ready-to-eat snacks made from food by-products. Honey, however, as seen from Fig. 4 principally increased the bulk density of extrudate over entire range of proportion (1.59-18.41%). The quadratic effects of all independent variables also had significant positive effect on the bulk density of extrudates.

Increased feed moisture content during extrusion cooking would change the amylopectin molecular structure of the material reducing the melt elasticity thus decreasing the expansion ratio but increasing the bulk density of extrudate (Ding *et al*. 2005). On the contrary, though other researchers (Ding *et al.* 2005; Liu *et al.* 2011) reported decrease in bulk density of extrudates with increasing barrel temperature, exact opposite result is found in this study. This uncharacteristic behavior may be due to increased level of fibre and sugar (from honey) in the feed material.

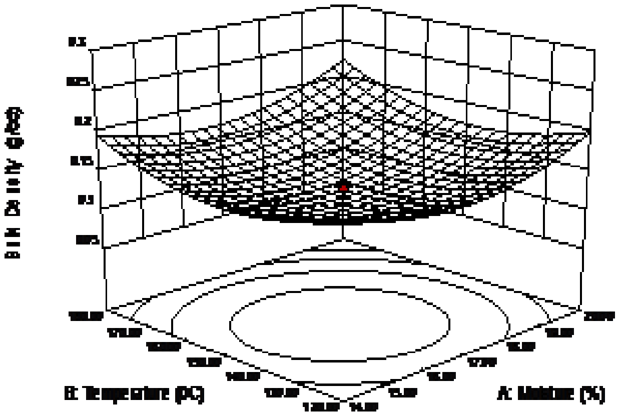

Fig. 3. Effect of moisture and temperature on bulk density of extrudates

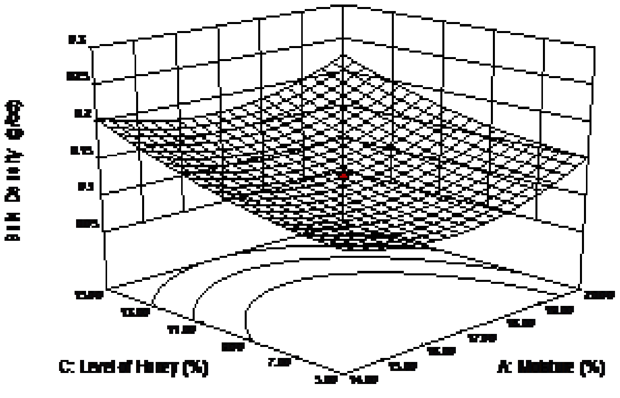

Fig. 4. Effect of moisture and honey level on bulk density of extrudates

The observed bulk density of extrudate was slightly higher than those reported by Charunuch *et al.* (2003) in rice extrudate. This could be due to increased amount of fibre and protein in brown rice flour used in this study. The non-starchy polysaccharides in fibre may bind water more tightly during extrusion than do protein and starch. This binding finally may inhibit the water loss at the die and thus reduce expansion and so probably increased bulk density (Camire and King 1991). Sarkar *et al.* (2011) also found increase in bulk density of rice flour extrudates with additional level of fibre.

Water absorption index

Water absorption index (WAI) has been generally attributed to the dispersion of starch in excess water, and the dispersion is increased by the degree of starch damage due to gelatinization and extrusion induced fragmentation, that is, molecular weight reduction of amylose and amylopectin molecules (Raysas-Duarte *et al.* 1998).

The minimum value (2.78) of WAI was recorded at the highest temperature (180^{0}C), honey proportion (15%) and lowest moisture (14%), while the maximum value (4.62) of WAI was recorded at the lowest honey proportion and intermediate feed moisture (17%), barrel temperature (150^{0}C). Mercier and Feillet (1975) reported that WAI increases along with the increase in temperature, after which it decreases, probably due to increased dextrinization. The regression coefficients presented in Table 3 signify that the linear effect of all independent variables on water absorption index is significant ($P<0.05$). Feed moisture had positive effect, while barrel temperature and honey proportion had negative effect on the water absorption index of extrudates. Though quadratic effect of all independent variables was significant, the interactive effect of only moisture and honey together was significant.

Water solubility index

The values of water solubility index (WSI) of extrudates were ranged in between 10.53 and 16.93 per cent. The highest value of WSI was observed at 17 per cent feed moisture, 200.45^{0}C barrel temperature and 10 per cent honey proportion in the feed. The linear effect of moisture on water solubility index was significantly ($P<0.05$) negative suggesting that feed moisture suppressed the water solubility of extrudates, whereas barrel temperature and honey proportion had positive significant linear effect on the WSI. Effect of barrel temperature on WSI was most profound. Hagenimana *et al.* (2006) reported that the higher moisture content and lower temperature lead to the lowest value of WSI.

Generally, solubility increases with increased moisture content and temperature. However, at high temperature, moisture may flash off and thus resulting in increase in the amount of degraded starch granules forming more water soluble dextrins and other products. Colonna *et al.* (1989) observed that WSI is related to the presence of soluble molecules that have been attributed to dextrinization. The interactive action of feed moisture-honey proportion and barrel temperature-honey proportion had significant effect on the water solubility index. The quadratic effect of all three independent variables significantly influenced the water solubility index. These findings are in agreement with those reported by Hagenimana *et al*. (2006).

Hardness

Product hardness is the average force required for a probe to penetrate the extrudates. Hardness of brown rice based extrudates varied between 58.13 and 82.34 N (Table 2). Lowest value of hardness was observed at minimum honey proportion (1.59%) and intermediate feed moisture (17%) and barrel temperature at 150^{0}C, whereas the highest hardness was found at the highest values of independent variables. Feed moisture, barrel temperature and honey proportion had significant ($P<0.05$) positive effect on the hardness of extrudates. Increasing the values of these independent variables increased the hardness of extrudates. Increased moisture and honey proportion in feed lead to decreased expansion and dense extrudate as consequence of which the hardness of extrudate also increased. Similar results were reported by Liu *et al.* (2000). Higher values of hardness were associated with high BD and low ER. Furthermore, interactive effect of moisture-temperature and moisture-honey proportion (Fig. 5) also positively influenced the hardness while interactive effect of temperature and moisture (Fig. 6) negatively affected the hardness of extrudates suggesting that at constant honey level, increasing the feed moisture and barrel temperature could reduce the hardness of extrudates. The quadratic effect of all independent variable was found significantly ($P<0.05$) positive on the hardness of extrudates.

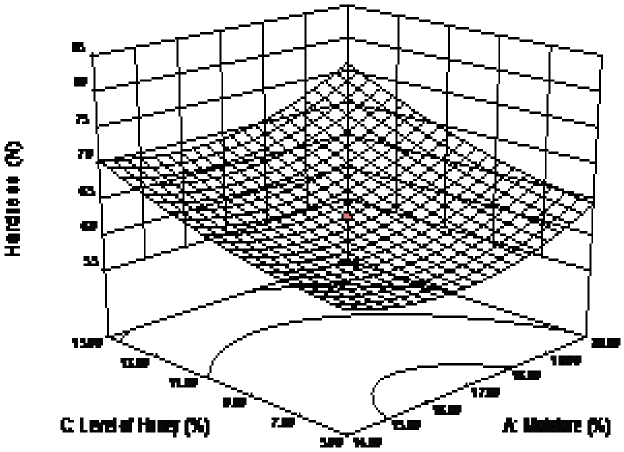

Fig. 5. Effect of moisture and honey level on hardness of extrudates

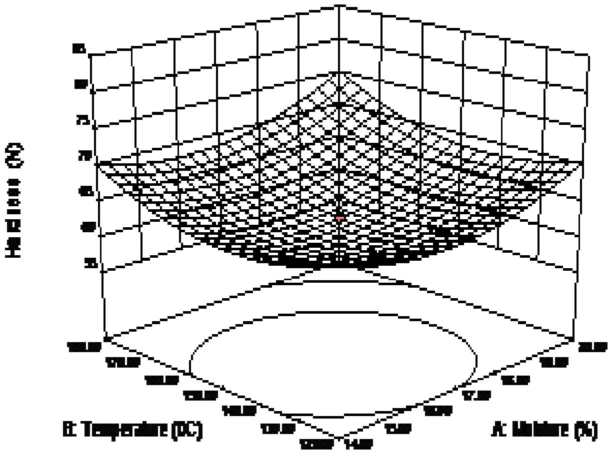

Fig. 6. Effect of moisture and temperature on hardness of extrudates

It is apparent from Table 3 that the hardness of extrudates was negatively correlated with the expansion ratio. Similar trend between hardness and expansion ratio have been reported by many workers (Jin *et al*. 1995; Rinaldi *et al*. 2000; Choudhury and Gautam 2003).

Honey addition in brown rice flour at varying proportion had marked effect on the physico-chemical properties of extrudates. Honey, as observed, was responsible to lower the expansion ratio, water absorption index and increased bulk density, water solubility index and hardness of the extrudates. The positive effect with respect to elevation of quality of extrudates was observed only with water solubility index otherwise, its addition lowered other quality parameters. Feed moisture had negative effect on expansion ratio, WSI and positive effect on bulk density, WAI and hardness of extrudates. This suggests that too much moisture in feed also hampers the quality of extrudates. Similarly, effect of barrel temperature on expansion ratio and WAI was negative whereas on bulk density, WSI and hardness it exercised a positive effect. Extrusion processing conditions, 14 per cent moisture; 1500C barrel temperature and 10 per cent honey in feed resulted in overall high quality of extrudates. Good quality extrudates could be resulted with brown rice flour and honey with aforesaid extrusion processing conditions. However, it will be prime and uphill task to analyze the extrudates in terms of their nutritional quality specifically nutrient retention, loss of anti-nutritional factors and production of hydroxymethyl furfural in honey-brown rice flour extrudates.

REFERENCES

Alvarez-Martinez L, Kondury KP and Harper JM 1988. A general model of expansion of extruded products. J. Food Sci. 53: 609-615

Anderson RA, Conway HF, Pfeifer VF and Griffin EL 1969. Roll and extrusion cooking of grain sorghum grits. Cereal Sci. Today 14: 4-12

Asare, EK, Sefa-Dedeh S, Sakyi-Dawson E and Afoakwa EO 2004. Application of response surface methodology for studying the product characteristics of extruded rice-cowpea-groundnut blends. Int. J. Food Sci. Nutr. 55: 431-439

Athar N, Hardacre A, Taylor G, Clark S, Harding R and McLaughlin J 2006. Vitamin retention in extruded food products. J. Food Compos. Anal. 19: 379-383

Camire ME and King CC 1991. Protein and fiber supplementation effects on extruded cornmeal snack quality. J. Food Sci. 56: 760-763

Charunuch C, Boonyasirikool P and Tiengpook C 2003. Physical properties of direct expansion extruded snack in utilization from Thai brown rice. Kasetsart J. (Nat. Sci.) 37: 368-378

Choudhury GS and Gautam A 2003. Hydrolyzed fish muscle as a modifier of rice flour extrudate characteristics. J. Food Sci. 68: 1713-21

Colonna P, Tayeb J and Mercier C 1989. Extrusion cooking of starch and starchy products. In: Mercier C, Linko P and Harper JM (eds). Extrusion cooking. St Paul: AACC, pp. 247-319

Ding QB, Ainsworth P, Tucker G and Marson H 2005. The effect of extrusion conditions on the physicochemical properties and sensory characteristics of rice-based expanded snacks. J. Food Eng. 66: 283-289

Falcone RG and Phillips RD 1988. Effects of feed composition, feed moisture and barrel temperature on physical and rheological properties of snack like products prepared from cowpea and sorghum flour by extrusion. J. Food Sci. 53: 1464-1469

Hagenimana A, Ding X and Fang T 2006. Evaluation of rice flour modified by extrusion cooking. J. Cereal Sci. 43: 38-46

Huang RC, Peng J, Lu FJ, Lui WB and Lin J 2006. The study of optimum operating conditions of extruded snack food with tomato powder. J. Food Process Eng. 29: 1-21

Ibanoglu S, Ainsworth P, Ozer EA and Plunkett A 2006. Physical and sensory evaluation of a nutritionally balanced gluten-free extruded snack. J. Food Eng. 75: 469-472

Jin Z, Heish F and Huff HE 1995. Effect of soy fiber, salt, sugar and screw speed on physical properties and microstructure of corn meal extrudates. J. Cereal Sci. 22: 185-194

Kollengode AN, Sokhey AS and Hanna MA 1996. Physical and molecular properties of re-extruded starches as affected by extruder screw configuration. J. Food Sci. 61: 596-99

Lamberts L, Els DB, Greet EV, Wim SV, Veerle D, Walter DM and Jan AD 2007. Effect of milling on colour and nutritional properties of rice. Food Chem. 100: 1496-1503

Lee KA and Brennand CP 2005. Physico-chemical, textural and sensory properties of a fried cookie system containing soy protein isolate. Int. J. Food Sci. Tech. 40: 501-508

Li SQ, Zhang HQ, Jin ZT and Hseih F 2005. Textural modification of soy bean/corn extrudates as affected by moisture content, screw speed and soy bean concentration. Int. J. Food Sci. Tech. 40:731-741

Liu C, Zhang Y, Liu W, Wan J, Wang W, Wu L, Zuo N, Zhou Y and Yin Z 2011. Preparation, physicochemical and texture properties of texturized rice produce by Improved Extrusion Cooking Technology. J. CerealSci. 54: 473-480

Liu Y, Hsieh F, Heymann H and Huff HE 2000. Effect of process conditions on the physical and sensory properties of extruded oat-corn puff. J. Food Sci. 65: 1253-59

Mendonca S, Grossmann MVE and Verhe R 2000. Corn bran as a fibre source in expanded snacks. Lebensm-Wiss u-Technol. 33: 2-8

Mercier C and Feillet P 1975. Modification of carbohydrate component by extrusion cooking of cereal product. Cereal Chem. 52: 283-297

Myers RH and Montgomery DC 2002. Response Surface Methodology: Process and Product Optimization Using Designed Experiment (2nd ed). John Wiley and Sons. Inc

Nwabueze TU 2007. Effect of process variables on trypsin inhibitor activity (TIA), phytic acid and tannin content of extruded African breadfruit-corn-soy mixtures: a response surface analysis. Lebensm Wiss u-Technol. 40: 21-29

Pardhi SD 2011. Development of extruded product from brown rice. M.Sc. Thesis, Punjab Agricultural University, Ludhiana, India

Raysas-Duarte P, Majewska K and Doetkott C 1998. Effect of extrusion process parameters on the quality of buckwheat flour mixes. Cereal Chem. 75: 338-345

Reid R 1998. Hot and fruity: the future for snack flavours. Food Reviews, 25: 15-21

Rinaldi VEA, Ng PKW and Bennink MR 2000. Effect of extrusion on dietary fiber and isoflavone contents of wheat extrudates enriched with wet okara. Cereal Chem., 77: 237-240

Salmenkallio-Marttila M, Katina K and Autio K 2001. Effects of bran fermentation on quality and microstructure of high-fiber wheat bread. Cereal Chem. 78: 429-435

Sarkar P, Setia N and Choudhury GS 2011. Extrusion processing of cactus pear. Advance J. Food Sci.Tech. 3: 102-110.

Slavin J 2004. Whole grains and human health. Nutr. Res. Rev. 17: 99-110

Stojceska V, Anisworth P, Plunkett A and Ibanoglu S 2009. The effect of extrusion cooking using different water feed rates on the quality of ready-to-eat snacks made from food by-products. Food Chem. 114: 226-232

Suknark K, Philips RD and Chinnan MS 1997. Physical properties of directly expanded extrudates formulated from partially defatted peanut flour and different types of starch. Food Res. Int. 30: 575-583

Topping DJ 2007. Cereal complex carbohydrates and their contribution to human health. Cereal Sci. 46: 220-229

Verônica AO, Olusola OO and Adebowale EA 2006. Qualities of extruded puffed snacks from maize/soybean mixture. J. Food Process Eng. 29:149-161

Wanasundara PKJPD and Shahidi F 1996. Optimization of hexametaphosphate-assisted extraction of flaxseed protein using response surface methodology. J. Food Sci. 61: 604-607

Wynn T 2008. Rice Farming: How the Economic Crisis Affects the Rice Industry. Presented at the Rice Producers Forum, USRPA, Houston, TX, USA, 20 August 2008; Available online: http://www.ricefarming.com/home/2009_JanProducersForum.html (accessed on 21 April 2014)