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Response surface analysis and process optimization of twin screw extrusion of apple pomace blended snacks

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ABSTRACT

Optimization of the extrusion process for apple pomace blended snacks was done using RSM. A blend of apple pomace, maize and soy flour was extruded at five levels of moisture content (12.6–19.4%), barrel temperature (116–184°C) and screw speed (232–568 rpm). The effects of these variables on product responses, viz. bulk density, expansion ration, colour, water absorption index, water solubility index, crispiness, sensory score of overall acceptance, and specific mechanical energy were determined and analyzed. Feed moisture had significant effect on all product responses, whereas screw speed and barrel temperature, both had significant effect on SME, ER and crispiness of the product. The response surface models fitted to all responses were highly significant, and had adequate precision more than 12 (>4 desirable), without having any lack of fit. Optimized extrusion parameters for preparation of quality snacks were 14% moisture, 130°C barrel temperature and 300 rpm screw speed.

Key words: Apple pomace, Extruded snack, RSM, Screw extrusion

The global scenario of food industry sales touched a level of $374 billion annually with the pace of 2% annual increase (Nielsen 2014). Similarly, global extruded snack food market reached a value of around US$ 50 Billion in 2016, growing at a CAGR of around 3% during 2009-2016 (IMARC 2017). The extruded snacks market in India also grew at a significant pace, and expected to grow at a CAGR of more than 11% during 2016-21 (MOFPI 2015). In 2015, mixed extruded snacks grabbed the largest market share among various snacks food. Combination of various ingredients makes the products in this category tastier, crispier and nutritious consequently the segment has increasing demand from every section of the society, especially from kids and younger generation.

Apple pomace, a by-product of juice making industry, is a rich source of many nutrients including carbohydrates, minerals and fibre. In India, total production of this by product was about 1 million tonnes per annum however only approximately 10000 tonnes of apple pomace was being utilized (Manimehalai 2007). The crude fibre content of apple pomace is approximately 14-30% of the dry weight. The composition of apple pomace with respect to its fibre content, viz. sugar, cellulose, hemicelluloses, pectin and roughage appears to have the best proposition for incorporation in the bakery and snacks industry for production of high fibre foods (Rohit and Dorcus 2014). Apple pomace, available in abundance at a very cheap or no cost for blending with corn extrudates, represents a potentially valuable source of fibre and associated polyphenols that may have applications as functional food ingredients and possible nutritional benefits.

Extrusion technology, high temperature-short duration processing has been increasingly used in the food industries for the development of new products such as cereal-based snacks including dietary fibre, baby foods and breakfast cereals (Sebio and Chang 2000). The combination of thermal energy generated by viscous dissipation during extrusion as well as shearing effect cooks the raw mixture quickly so that the properties of the materials are modified by physico-chemical changes of the biopolymers (Thymi *et al.* 2005). The characteristics of the extrudates blending with the functional ingredients for greater functionality and higher nutrition e.g., grains, fruits, and vegetable have been widely investigated in literatures (Camire *et al*. 2007, Singh *et al*. 2007, Altan *et al*. 2008a, Yağcı and Göğüş 2008, Anton *et al*. 2009, Céspedes *et al*. 2009, Chakraborty *et al*. 2010), but rarely about apple pomace yet.

Response surface methodology, a mathematical

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technique employed for developing and optimizing product/processes (Mayers and Montgomery 2002). It has been successfully applied in the product/process optimization studies such as baking parameters of chapatti (Yadav *et al*. 2008), corn extrudate fortified with yam (Hsiang-Wen Chiu *et al*. 2013), micronutrient fortified extruded Rice (Hussain *et al*. 2014). RSM provide, minimise the numbers of trials and multiple regression approach to achieve optimization (Seth 2012).

Therefore, this research was aimed to investigate the operational parameters of extruder and the effect of process variables on the characteristics of extrudates blended with apple pomace by using response surface methodology.

MATERIALS AND METHODS

Maize (*Zea mays*), Genome type DMRH-1308 was obtained from the ICAR-Indian Institute of Maize Research, New Delhi. Defatted soy flour (gluten free) was procured from local market, and apple pomace was obtained from HPMC, Parwanoo, Himachal Pradesh. The procured material was subjected to cleaning, grading followed by drying and stored in polyethylene bags. As per requirement of the experiment, clean and dry grain was milled in a laboratory scale hammer mill equipped with 60-mesh IS sieve. A 250 g sample of raw materials were obtained by mixing the ingredients in the proportions (maize:soy:apple pomace, 70:15:15).

Extrusion was performed on a co-rotating and intermeshing twin-screw extruder Model BC 21. The barrel diameter and its length to diameter ratio (L/D) were 2.5 cm and 16:1, respectively. The extruder had four barrel zones. Temperature of the first, second and third zone were maintained at 40, 70 and 100 ^{o}C, respectively, throughout the experiments, while the temperature at last zone (compression and die section) was varied according to the experimental design. The diameter of die opening was 3 mm. The extruder was thoroughly calibrated with respect to the combinations of feed rate and screw speed to be used. The feed rate was varied for optimum filling of the extruder barrel corresponding to the screw speed. The moisture content of feed was varied by injecting water (approximately 50^{o}C) into extruder with water pump. A variable speed die face cutter with four bladed knives was used to cut the extrudates.

Raw materials were equilibrated to room temperature and extruded as per the experimental design by mixing desired proportion of feed formulation. The blended formulation consisted of 70% maize, 15% defatted soy and 15% apple pomace, mixed thoroughly in a ribbon mixer. When the extruder reached a steady state, as indicated by nearly constant values for extruder torque and product temperature, samples were collected in steel trays and kept at ambient temperature for cooling. The extruded samples were sealed in polythene (HD) bags and stored at room temperature (25±4°C) till analysis.

A central composite rotatable design was employed to determine the extrusion conditions. The independent variables considered were feed moisture content (12.6-19.4%), barrel temperature (116–184^{o}C) and screw speed (232–568 rpm). The outline of experimental design with the actual and coded level (Table. 1) consisted of 20 experimental runs with eight factorial points, six axial points and six centre points. Dependent variables were bulk density (BD), expansion ratio (ER), water absorption index (WAI), water solubility index (WSI), colour, crispiness, overall acceptability and SME. Response Surface Methodology was used to investigate the effect of extrusion conditions on the product responses. Experiments were randomized in order to minimize the systematic bias in observed responses due to extraneous factors. The individual effect of each variable and the effect of interaction in coded levels of variables were determined.

Bulk density (g/cc) of extrudates was determined by a volumetric displacement procedure as described by Patil *et al.* (2007). The volume of the expanded sample was measured by using a 100-mL graduated cylinder by rapeseed displacement. The volume of 20 g randomized samples was measured for each test. The ratio of sample weight and the replaced volume in the cylinder was calculated as BD (w/v).

Expansion ratio was measured as the ratio of cross sectional area of the dried cylindrical extrudate to that of the die (Chakraborty *et al.* 2009). The diameter of the extrudate was the average of ten random measurements. This index described the degree of puffing undergone by the sample as it exits the extruder.

Water absorption index and Water solubility Index were determined according to the method developed for cereals (Anderson *et al.* 1969, Stojceska *et al.* 2008, Yagci and Gogus 2008). The ground extrudates were suspended in water at room temperature for 30 min, during this period gently stirred by vortex stirrer, and then centrifuged at 3000× g for 15 min. The supernatants were poured into an evaporating dish of known weight. The WAI was the weight of gel obtained after removal of the supernatant per unit weight of original dry solids. The WSI was the weight of dry solids in the supernatant expressed as a percentage of the original weight of sample.

$$\text{Water absorption index (g/g)} = \frac{\text{weight gain 6 gel (g)}}{\text{sample weight (g)}}$$

$$\text{Water solubility index (\%)} = \frac{\text{weight 6 dry solids in supernatant (g)}}{\text{sample weight (g)}} \times 100$$

The colour values of ground extrudates samples in terms of L, a^* and b^* were measured using HunterLab LabScan XE (NR-3000; 10°/D65). Color values were recorded as L= lightness (0=black, 100=white), a (–a=greenness, +a = redness), and b (–b=blueness, +b = yellowness). Total colour change was calculated as follows:

$$\text{Total colour change} = \sqrt{(L - L_0)^2 + (b - b_0)^2 + (a - a_0)^2}$$

where, the subscript ‘0’ indicates initial colour values of the raw material.

Table 1 Effect of extrusion conditions on dependent variables

Actual and coded values			Product responses							
Feed moisture (%)	Temp. (ºC)	Screw speed (rpm)	BD (g/cc)	ER	WAI (g/g)	WSI (%)	Colour	Crispi-ness	Sensory score	SME (Wh/kg)
14 (-1.00)	130 (-1.00)	300 (-1.00)	0.0688	2.208	3.702	32.542	33.704	16.000	9.5	62.762
18 (1.00)	130 (-1.00)	300 (-1.00)	0.1630	2.128	3.467	24.129	29.600	8.000	6.1	110.161
14 (-1.00)	170 (1.00)	300 (-1.00)	0.0964	1.782	3.492	31.143	38.924	16.571	7.8	94.780
18 (1.00)	170 (1.00)	300 (-1.00)	0.1764	1.723	3.570	25.450	35.670	5.667	6.5	104.325
14 (-1.00)	130 (-1.00)	500 (1.00)	0.0811	2.331	3.327	32.746	38.170	18.000	8.6	69.237
18 (1.00)	130 (-1.00)	500 (1.00)	0.1588	2.133	3.542	15.943	37.732	13.400	6.7	106.829
14 (-1.00)	170 (1.00)	500 (1.00)	0.0897	1.839	3.171	34.333	30.874	13.333	7.7	72.689
18 (1.00)	170 (1.00)	500 (1.00)	0.1264	1.782	3.680	21.132	33.453	5.333	6.5	64.097
12.64 (-1.68)	150 (0.00)	400 (0.00)	0.0920	2.110	3.734	33.639	39.414	13.719	7.7	72.109
19.36 (1.68)	150 (0.00)	400 (0.00)	0.1946	1.892	3.912	21.854	35.540	1.667	6.2	105.938
16 (0.00)	116.36 (-1.68)	400 (0.00)	0.1308	2.553	3.404	23.739	32.835	18.667	6.6	85.580
16 (0.00)	183.64 (1.68)	400 (0.00)	0.1360	1.924	3.431	23.876	31.707	9.509	6.3	62.459
16 (0.00)	150 (0.00)	231.80 (-1.68)	0.0792	1.619	3.150	30.613	33.414	14.667	9.0	106.223
16 (0.00)	150 (0.00)	568.20 (1.68)	0.0840	1.730	2.918	31.388	35.693	18.760	8.5	80.121
16 (0.00)	150 (0.00)	400 (0.00)	0.0824	1.821	3.490	25.900	31.630	18.125	8.8	81.457
16 (0.00)	150 (0.00)	400 (0.00)	0.0960	1.838	3.644	23.543	32.169	16.000	7.7	75.225
16 (0.00)	150 (0.00)	400 (0.00)	0.0956	1.861	3.615	22.432	32.688	17.000	7.2	74.335
16 (0.00)	150 (0.00)	400 (0.00)	0.0984	1.851	3.686	27.645	30.868	18.224	7.6	74.780
16 (0.00)	150 (0.00)	400 (0.00)	0.0928	1.814	3.715	24.442	31.880	18.333	8.2	77.006
16 (0.00)	150 (0.00)	400 (0.00)	0.0908	1.801	3.574	26.132	32.581	17.666	8.1	68.993

Crispness of the extrudates were measured using texture analyzer supplied with "Texture Expert" software, fitted with 5 kg load. Force-deformation data were obtained using 2 mm diameter test probe. Tests were conducted using compression mode and the probe was allowed to penetrate the product for a distance of 3 mm. The test settings included test speed of 0.5 mm/s, and strain of 90%. Force time curve was recorded and analyzed by the inbuilt software program which indicates the peak force and also counts the number of major peaks obtained during the test and expressed in terms of Crispiness (Subir *et al.* 2011). Ten randomly collected samples were measured for each extrusion condition and mean of the observations was recorded for reporting.

Sensory evaluation was conducted by using a nine point hedonic scale (Armbrister and Sester 1994, Xiong *et al.* 2002). A semi-trained panelist consisting of 30 members selected from the CIPHET, Ludhiana and IARI, New Delhi of age group varying from 21 to 55 years. The attributes evaluated for the extruded snack were appearance and colour, texture, odour, flavour and taste and over all acceptability.

Specific mechanical energy was calculated from rated screw speed, motor power rating (8.5 kW), actual screw speed, % motor torque and mass flow rate (kg/h) using the following formula (Pansawat *et al.* 2008)

$$\text{SME}\left(\frac{\text{Wh}}{\text{kg}}\right) = \frac{\text{Actual screw speed (rpm)}}{\text{Rated screw speed (rpm)}} \times \frac{\%\text{ motor torque}}{100} \times \frac{\text{motor power rating}}{\text{mass flow rate}\left(\frac{\text{kg}}{\text{h}}\right)} \times 1000$$

Responses obtained as a result of the proposed experimental design were subjected to regression analysis in order to assess the effects of feed moisture content, barrel temperature and screw speed. Second-order polynomial regression models were established for the dependent variables to fit experimental data for each response using statistical software Design-Expert 7.0.0 (Stat-Ease Inc., Minneapolis, MN).

$$y = b_0 + \sum_{i=0}^{3} b_i x_i + \sum_{i=0}^{3} b_{ii} x_i^2 + \sum_{i=0}^{3}\sum_{j=0}^{3} b_{ij} x_i x_j$$

where x_i (i = 1, 2, 3) are independent variables (feed moisture, barrel temperature and screw speed) respectively, and b_o, b_i, b_{ii} and b_{ij} are coefficient for intercept, linear, quadratic and interactive effects, respectively. Data were analyzed by multiple regression analysis and statistical significance of the terms was examined by analysis of variance (ANOVA) for each response. The adequacy of regression model was checked by correlation coefficients. The lack of fit test was used to judge the adequacy of model fit. To aid visualization of variation in responses with respect to processing variables, series of three-dimensional response surfaces plots were drawn.

RESULTS AND DISCUSSION

The effects of extrusion conditions on the product and process responses (Table 1), ANOVA and regression coefficients (Tables 2 and 3) for all the responses were significant (P<0.001). Models for all parameters were significant with a high coefficient of determination (R_2 > 0.85). All the parameters were significantly affected by feed moisture, barrel temperature and screw speed. Furthermore, coefficient of variation being lower than 10 % suggests the reasonable accuracy of the experiments and reproducibility of the models. Non significant lack-of-fit (P<0.05) indicated that the models correlated well with the measured data. Adequate precision (signal to noise ratio) greater than 4 is desirable. All the parameters showed high adequate precision (Table 2). Hence, proposed models can approximate the response surfaces and used suitably for prediction at any values of the parameters within experimental range.

Effect of process parameters on bulk density (BD)

The bulk density of the snack varied between 0.069 and 0.195 g/cm^3 (Table 1). The multiple regression model for predicting the bulk density could explain 97.83% of the observed variations (Table 2). The bulk density was significantly affected by the feed moisture at linear and quadratic level (P<0.05). The interactive terms of feed moisture-screw speed and barrel temperature-screw speed are significantly affecting bulk density of extrudates (P<0.05). The BD increased significantly with the increase in feed moisture content (Table 3, Fig 1). The high dependence of BD and expansion on feed moisture would reflect its influence on elasticity characteristics of the starch-based material. Increased feed moisture content during extrusion may reduce the elasticity of the dough through plasticization of the melt, resulting in reduced gelatinization, decreasing the expansion and increasing the BD of extrudate (Mercier and Feillet 1975). An increase in feed moisture increased the BD of rice flour-based extrudates (Hagenimana *et al.* 2006).

Effect of process parameters on expansion ratio (ER)

The expansion ratio varied from 1.619 to 2.553 for all the experimental runs (Table 1). The coefficient estimates of expansion ratio model (Table 3) showed that the levels of feed moisture and barrel temperature had highly significant (P < 0.01) negative effects in linear terms explained by parabolic curve (Fig 2). This might be due to high starch-protein interactions and formation of intermolecular disulphide bonds in the protein upon heat treatment that restricts the swelling of extrudate, thus exhibited low expansion ratio (Mahasukhonthachat *et al.* 2010). The significant (P< 0.01) negative effect of screw speed on BD and positive effect on ER could be attributed to the structural breakdown under increased shear environment. Increasing screw speed tends to increase the shearing effect, this causes protein and

Table 2 Analysis of variance for the fit of experimental data to response surface model

	Sum of squares							
Regression	BD	ER	WAI	WSI	Colour	Crispiness	OAA	SME
Adequate precision	25.728	49.971	18.863	12.172	20.290	25.207	8.653	16.722
R square	0.9783	0.9929	0.9451	0.9124	0.9708	0.9803	0.8521	0.9633
Adjusted R square	0.9588	0.9866	0.8956	0.8335	0.9445	0.9626	0.7190	0.9303
CV %	6.61	1.39	2.15	7.57	1.99	7.16	7.15	5.20
Lack of fit	0.182^{ns}	0.275^{ns}	0.633^{ns}	0.408^{ns}	0.493^{ns}	0.357^{ns}	0.563^{ns}	0.407^{ns}

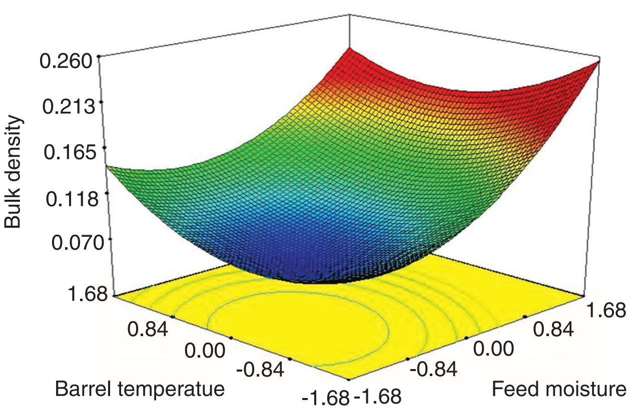

Fig 1 Effect of feed moisture and barrel temperature on bulk density of extruded snacks

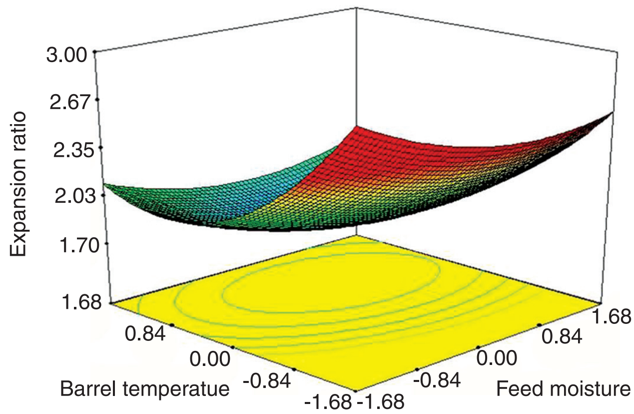

Fig 2 Effect of feed moisture and barrel temperature on expansion ratio of extruded snacks

Table 3 Regression coefficients for fitted models

Parameter	Regression coefficients							
	BD	ER	WAI	WSI	Colour	Crispiness	OAA	SME
Constant	0.0927**	1.831**	3.618**	25.03**	31.98**	17.58**	7.93**	75.31**
A. Moisture	0.0338**	-0.056**	0.064*	-4.68**	-0.86**	-3.79**	-0.76**	10.31**
B. Temperature	0.0019	-0.200**	-0.006	0.51	-0.16	-2.19**	-0.21	-3.81**
C. Screw speed	-0.0029	0.032**	-0.066**	-0.57	0.45*	0.79*	-0.09	-7.55**
A^2	0.0177**	0.625**	0.089**	0.86	1.91**	-3.6**	-0.33**	4.77**
B^2	0.0142**	0.147**	-0.55*	-0.53	0.07	-1.34**	-0.51**	-0.59
C^2	-0.0041	-0.053**	-0.191**	2.02**	0.88**	-0.40	0.31	6.24**
AB	-0.0069	0.020	0.076*	0.79	0.48	-0.79*	0.35	-10.50**
AC	-0.0075*	-0.015	0.110*	-1.99*	1.19**	0.79*	0.20	-3.49*
BC	-0.0081*	-0.001	0.011	0.86	-2.86**	-1.37**	0.03	-8.18**

*Significant at P<0.05, **Significant at P<0.01. BD, Bulk density; ER, expansion ratio; WAI, water absorption index; WSI, water solubility index; OAA, overall acceptability; SME, specific mechanical energy.

starch molecules to be stretched farther apart, weakening bonds and resulting in a puffer product (Filli *et al.* 2012). The effect of FM and SS were found to be dependent on each other (Table 3). Similar results were reported earlier for different types of the extruded products (Meng *et al.* 2010, Asare *et al.* 2012, Filli *et al.* 2012).

Effect of process parameters on WAI and WSI

Water absorption index and water solubility index, are the two important measures related to the degree of starch conversion or damage as a result of extrusion processing (Normell *et al.* 2009). WAI measures the amount of water absorbed by starch and can be used as an index of starch gelatinization, while WSI indicates degradation of starch molecules (Sibel and Fahrettin 2008). WAI values for the extrudates ranged between 2.918 and 3.912 g/g, and for WSI it ranged between 15.94 and 34.33% (Table 1). The regression model had a coefficient of determination (R^2) and adjusted R^2 value of 0.9451 and 0.895 for WAI, and 0.9124 and 0.8335 for WSI respectively (Table 2). The statistical analysis demonstrated that linear terms of feed moisture and screw speed had a significant effect on the WAI and WSI (Table 3). It is generally agreed that feed moisture exerts the greatest effect on the extrudate by promoting gelatinization (Ding *et al.* 2005). At high moisture content, the viscosity of the starch would be low, which allows extensive internal mixing and uniform heating that would account for enhanced starch gelatinization while diminishing starch degradation (Miranda *et al.* 2011). Further, low moisture conditions results in greater shear degradation of starch during extrusion (Anastase *et al.* 2006). Therefore, WAI increased and WSI decreased with increase in feed moisture (Fig 3, 4). Similar effects were reported earlier for sorghum soy blend extrudate (Arun *et al.* 2015) and rice based extrudates (Ding *et al.* 2005). The significant (P<0.05) negative effect of screw speed on WAI suggests that higher screw speed degraded starch into smaller fragments, which are more soluble in water. The effect of screw speed on molecular degradation and gelatinization of starch is in agreement with van den Einde *et al.* (2004) and Normell *et al.* (2009).

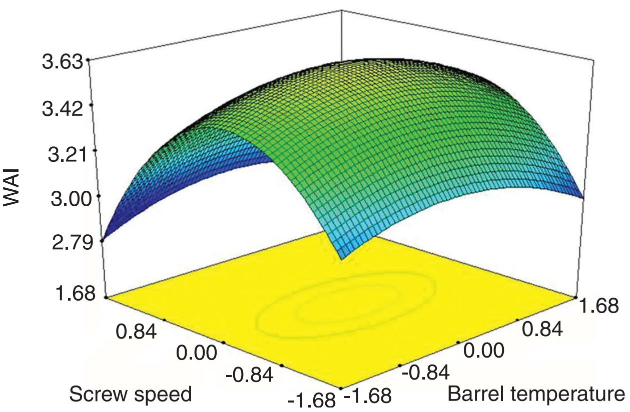

Fig 3 Effect of barrel temperature and screw speed on WAI of extruded snacks

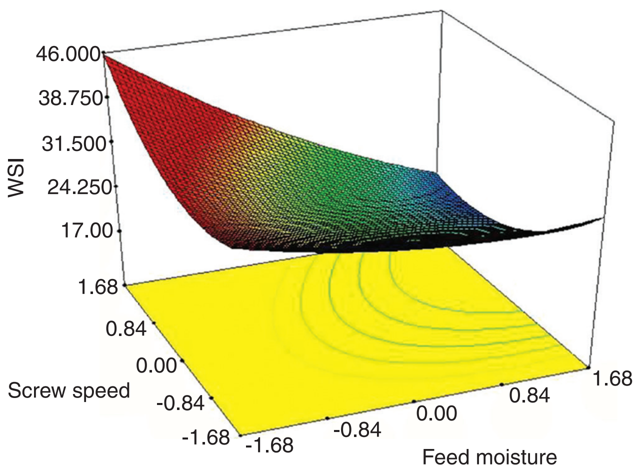

Fig 4 Effect of feed moisture and screw speed on WSI of extruded snacks

Effect of process parameters on colour

The colour of the extruded snack food varied between 29.60 to 34.41% (Table 1). The regression model for predicting the colour could explain 97.08% of the observed variations (Table 2). The colour was found to be significantly affected by the amount of feed moisture and screw speed at linear and quadratic levels (P<0.01) (Table 3). The higher colour values were found at lower feed moisture levels and at higher screw speed. Changes in the yellowness during extrusion cooking of blend was induced by the effects of two different reactions: non-enzymatic browning and pigment destruction (Ilo and Berghofer 1999), where the caratenoids might have been damaged by thermal treatment and some browning might have made up the colour loss. This could be due to high fibre content of apple pomace that may affect the starch gelatinisation upon extrusion.

Effect of process parameters on crispiness

The crispiness of the snack varied between 1.67 and 18.76 (Table 1). The multiple regression model for predicting the crispiness could explain 98.03% of the observed variations (Table 2). It was observed that the crispiness was significantly affected by the feed moisture and barrel temperature at linear and quadratic levels (P<0.01). The interactive terms of feed moisture-barrel temperature and feed moisture-screw speed are significantly affecting crispiness of extrudates (P<0.05), whereas interaction of barrel temperature-screw speed was highly significant over crispiness (P<0.01). The degree of expansion affects density, fragility, and softness of the extruded products (Chang *et al.* 1998). Crispiness decreased with increase in feed moisture and barrel temperature. This is in agreement with the degree of cooking, as indicated by ER in this study. Increasing feed moisture and barrel temperature decreased the degree of starch gelatinization and, as a result, pore wall became thicker and hard and heavy product was obtained (Adrian *et al.* 2008). This result corroborated with those of Liu *et al.* (2000), Li *et al.* (2005) and Normell *et al.* (2009). Increase in screw speed increased crispiness (Table 3); this may be attributed to the relative increase in the amount of ER due to compression of the extruded material at higher screw speed.

Effect of process parameters on sensory evaluation

Sensory evaluation of the developed snack food was carried out on a nine point hedonic scale to find its suitability on the basis of overall acceptability (OAA). OAA values for the extrudates ranged between 6.1 and 9.5 (Table 1). The response surface plots (Fig 5) and ANOVA for the model of OAA (Table 2) revealed that the coefficient of determination (R^2) and adjusted R^2 were 0.8521 and 0.7190 respectively. The regression coefficients of OAA model shows that feed moisture had highly significant negative effect on OAA (Table 3), which might be due to higher bulk density and lower expansion of extrudates at higher feed moisture levels. The barrel temperature had significant effect on sensory scores of overall acceptability (P<0.01) at quadratic level, due to darker appearance of the extrudates at higher barrel temperatures.

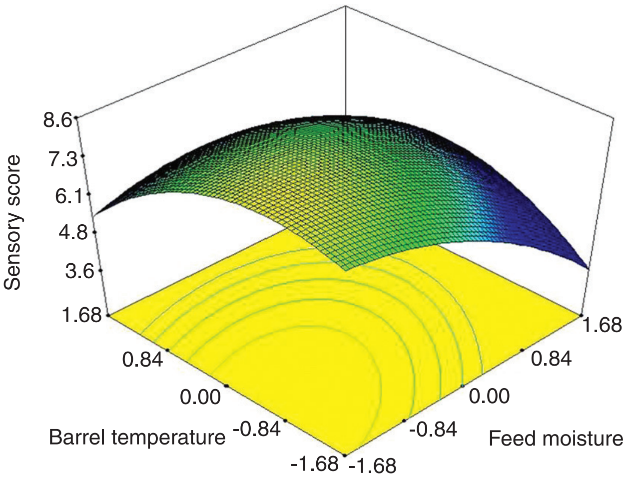

Fig 5 Effect of feed moisture and barrel temperature on sensory score of overall acceptability of extruded snacks.

Effect of process parameters on SME

The calculated SME ranged from 62.46 to 110.16 Wh/kg (Table 1). An ANOVA was conducted to assess the significant effects of the independent variables on responses and which of the responses were significantly affected by the varying processing conditions. The coefficient of variation (CV), which indicates the relative dispersion of the experimental points from the predictions of the model, was found to be 5.20% for SME (Table 2). A reasonably good coefficient of determination R^2 (0.9633) and adjusted R^2 (0.9303) showed that the model developed for SME appeared to be adequate. All process variables had significant effects on SME ($P < 0.01$) (Table 3). The positive coefficient of the linear terms of feed moisture indicated that SME increases with increase of moisture, while negative coefficients for other linear terms indicated that SME decreases with increase in barrel temperature and screw speed. Any variable affecting the viscosity of the food melts in the extruder would

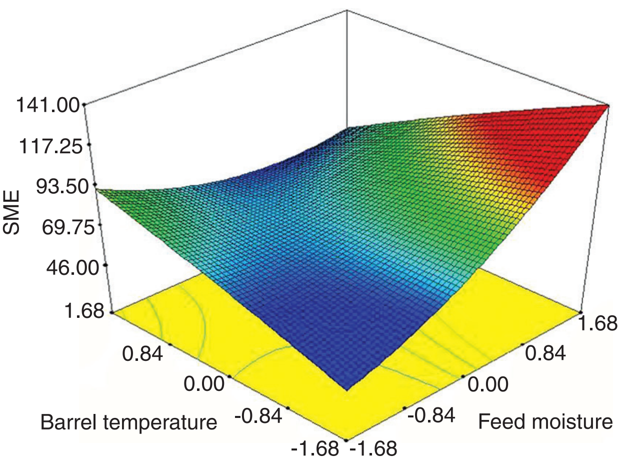

Fig 6 Effect of feed moisture and barrel temperature on SME of extruded snacks.

Table 4 Actual and predicted response through response surface models

Values	Bulk density	Expansion ratio	WAI	WSI	Colour	Crispiness	Sensory	SME
Predicted	0.082	2.319	3.669	30.332	35.494	17.867	8.404	62.475
Actual	0.082	2.316	3.667	30.337	35.497	17.863	8.403	62.459
Variation %	0.250	0.116	0.062	0.016	0.010	0.025	0.004	0.025

correspondingly affect SME (Akdogan 1996). Elevating the barrel temperature caused a decline in the melt viscosity, consequently, decreasing the SME (Fig 6).

Optimisation and validation

Numerical optimisation of process variables was carried out for the preparation of extruded snack. Design Experts program (version 7.0.0) of the STAT-EASE software was used for simultaneous optimisation of the responses. Desired goals were assigned for all the parameters for obtaining the numerical optimum values for the responses. All the levels of feed moisture, barrel temperature, and screw speed were kept in range. The response parameters like bulk density and SME were kept minimum, and all other responses were kept maximum respectively. The optimum values obtained for feed moisture, barrel temperature and screw speed were 14%, 130ºC and 400 (rpm), respectively (Desirability 0.790). The corresponding optimum values of BD, ER, WAI, WSI, colour, crispiness, OAA and SME were 0.082 gD cm^3, 2.32, 3.76 g/g, 30.34%, 35.50%, 17.86, 8.4 and 62.46 Wh/kg respectively. The variation of predicted response values was within 0.3% of the actual values (Table 4).

RSM revealed the significant effect of all three important extrusion parameters (feed moisture, barrel temperature and screw speed) on physical properties of twin-screw extruded apple pomace blended snacks. Within the experimental range, feed moisture was the most important factor affecting the physical properties of the extrudate. The effect of feed moisture on most of the properties of the extrudate was found to be linear. The extrusion parameter had significant quadratic effect on expansion ratio, and WAI; the interactive effect of feed moisture and screw speed were found significant on BD, WAI, WSI, colour, crispiness and SME. However the interactive effect of barrel temperature and screw speed had significant effect on BD, colour, crispiness and SME. The BD, WAI and SME increased with the increase in moisture and decreased with the increase in screw speed; while ER, colour and crispiness increased with the increase in screw speed and decreased with the increase in moisture. The SME decreased with the increase in screw speed and barrel temperature, whereas it increased with the increase in feed moisture.

Some disagreements were found between the results of the present study and the published results, which could be due to the different configurations of the extruder, the experimental range and feed composition. The optimum values for feed moisture, barrel temperature and screw speed were observed as 14%, 130ºC and 300 rpm respectively. It can be thus concluded that apple pomace could be used as a blend to prepare nutritious and highly acceptable snacks.

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