Journal of Scientific & Industrial Research
Vol. 79, May 2020, pp. 430-436

Optimization of Extrusion Process for Development of Nutritious Snacks using Rice and Chickpea Flour

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Received 29 May 2019; revised 22 December 2019; accepted 20 March 2020

A systematic study was conducted to develop nutritionally superior extruded snacks from blend of high amylose rice and chickpea flour using a twin-screw extruder. The effect of barrel temperature 160°C–200°C, moisture content of feed 11%−15%, feed composition 95% rice : 5% chickpea to 35% rice : 65% chickpea and screw speed - 160 to 280 rpm on dependent variables i.e. specific mechanical energy (SME), water solubility and water absorption indices (WAI and WSI), bulk density (BD), expansion ratio (ER), breaking strength (BS), L*, a*, b* and overall acceptability was investigated by Central composite rotatable design (CCRD). The optimized condition obtained by numeric optimization were barrel temperature (186°C), feed moisture (12%), feed proportion (74% rice: 26% chickpea) and screw speed of 222 rpm.

Keywords: Amylose rice, Chickpea, CCRD, Screw speed, Barrel temperature, Moisture content

Introduction

Rice is mainly used for extrusion cooking due to its excellent expansion property, bland taste, attractive appearance and ease of digestion.[1] However, it is generally low in protein, certain amino acids, fiber and other micronutrients. Thus, it is feasible to blend rice with legumes for development of proteinaceous products. Numerous studies in past have reported blending of cereals with legumes for development of extruded products.[1,2] Chickpea contains high content of protein, readily available carbohydrates and profuse amount of fiber.[3] Blending chickpea with rice will not only improve the nutritional status of extrudates but could also affect the quality characteristics of snacks.[2] Thus, the aim of this study was to develop nutritionally superior snacks with better functional characteristics and sensory attributes through extrusion cooking.

Material and Methods

Raw material

High amylose rice (cv. Pusa Sugandh-3) and chickpea (var SKUAST-233) were obtained from Mountain Research Center for Field Crops (MRCFC), Khudwani, Anantnag, J&K, India. The paddy was milled in modern rice mill (ASR RM 209) at the Division of Food Science Technology, SKUAST-Kashmir, Shalimar, J&K. Polished rice and chickpea were ground separately in a lab mill to obtain flour. Experiments were carried out in a laboratory model extruder with twin-screw configuration (Basic Technology Pvt. Ltd., India). Flour samples were weighed in accurate proportions and moisture content of the blends were ascertained through pre-conditioning as per the experimental design. Extrudates were cut with a sharp knife at the exit end of the die and packaged after cooling for quality evaluation.

Statistical design and optimization

Fractional factorial, 5-level-4 factor rotatable design of Response Surface Methodology was employed to investigate the four selected independent variables i.e. rice: chickpea flour proportion, moisture content of feed, barrel temperature and screw speed. Polynomial quadratic (second order) equations were developed for each response and statistical significance was tested by ANOVA. Numerical optimization was done through Response Surface Methodology. The optimization criteria selected for optimization of extrusion cooking conditions was to maximize ER, SME, WAI, WSI and overall acceptability while BD and BS were minimized.

System response and products characteristics

SME, WAI and WSI were calculated as per the standard formulae[4]. Bulk density (BD) was measured

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as weight upon volume. ER was calculated using Vernier caliper (0.001mm accuracy) by dividing extrudate thickness with the diameter of die.[5] BS was measured by Texture Analyzer (Stable Micro System, TA-XT2i, USA). The colour measurement was done using Hunter Lab Colorimeter (A60-1010- 615 Model Colorimeter, Hunter Lab, Reston VA, USA). Sensory evaluation of samples was carried out by previously trained panelist for the attributes of colour, appearance, taste, and texture on a 5-point sensory scale (1 represented poor and 5 represented excellent). The overall acceptability of each sample was calculated as the average of sensory score for colour, taste, appearance and texture.

Physico-chemical analysis of final products

Proximate composition (moisture, protein, fiber, ash and fat content) was determined by standard AOAC[6] procedures and carbohydrate content was determined by difference procedure. Energy value was assessed with the help of adiabatic bomb colorimeter (C5000, Germany).

Statistical Analysis

Results are expressed as mean of three individual determinations and analysis was done using Completely Randomized Design (CRD) by SPSS (Statistical Package for Social Sciences) software.

Results and Discussion

ANOVA

Regression models obtained were highly significant ($p<0.001$) and coefficient of determination (R^2) was recorded in the range of 0.99–0.87. Predicted R^2 and adjusted R^2 for all the parameters were close to each other. Coefficient of variation, which suggests the accuracy of regression models ranged from 0.26–8.64%. Range of adequate precision (10.98–116.03) obtained for models was highly acceptable.

Effect of extrusion conditions on dependent parameters

Specific mechanical energy

Specific mechanical energy (SME) measures the work done by the motor per unit mass in the extrusion system.[7] The SME for rice-chickpea based snacks varied from 51–92 Wh/kg (Table 1).

$$SME = 75.50 - 19.42A - 2.25C - 4.79A^2 - 5.29B^2 \quad \ldots (1)$$

The regression Eq. (1) and Fig. 1b depicts that when the level of chickpea flour was increased in feed formulation (A), SME decreased. Similarly, with the increase in temperature (C) and moisture content (B), SME showed a decreasing trend. With the increase in chickpea flour level in the feed formulation, SME decreased because of high protein and fat content in chickpea flour as compared to rice flour which decreased the viscosity of feed matrix due to dilution of starch content and thus, reduced Specific mechanical energy.[3] Singh *et al.*[8] reported more or less similar findings when corn flour was replaced with buckwheat flour. High barrel temperature results in extrudates with low SME values as the dissipation of viscosity is minimized by enhanced starch gelatinization rate at high temperature which leads to reduced SME.[5] Water acts as a lubricant in the feed mix and requires less energy and thereby reduced SME. Results are in sound agreement with Hussain *et al.*[4] for lotus rhizome incorporated extrudates.

Expansion Ratio (ER)

Expansion ratio is important characteristic of extrudates and governs the consumer acceptability of puffed products.[3] The expansion ratio in the present study ranged from 2.36 to 4.34 (Table 1)

$$ER = 3.71 - 0.99A - 0.27B - 0.44A^2 \quad \ldots (2)$$

The fitted regression Eq. (2) and Fig. 1e illustrates that with the increase in feed moisture (B) and chickpea flour (A) level in feed formulation, the ER was decreased. Expansion of extrudates decreased when chickpea level in feed blend was increased possibly due to its dilution effect on proportion of the starch in blend in view of its more protein and fat percentage. High protein content affects distribution of polar water molecules as well as structural integrity which reduces the expansion of the snacks. Seth *et al.*[9] also reported similar findings for rice-corn flour based snacks supplemented with protein rich yam flour. Amylopectin structure is changed by high moisture percentage during extrusion which reduces the radical expansion.[4] Hegazy *et al.*[2] also reported same results in chickpea snacks.

Bulk Density

Bulk Density and expansion are inversely related.[3] Light extrudates are desirable from consumer point of view.[4] Bulk density of rice-chickpea based snacks ranged from 0.11 g/cm^3 to 0.28 g/cm^3 (Table 1).

Table 1 — Effect of processing conditions on system parameters and product characteristics of chickpea flour incorporated rice based extrudates

Run	RF: CF (A)	FM (%) (B)	BT (°C)	SS (rpm) (D)	SME (Wh/kg)	WAI (g/g)	WSI (%)	ER	BS (N)	BD (g/cm^3)	OAA	L*	a*	b*
1	35	13	180	220	74	4.82	12.79	3.87	47.15	0.18	4.3	76.17	3.41	24.82
2	20	14	170	250	82	5.38	11.75	3.62	55.11	0.14	4.3	79.28	3.21	21.52
3	50	12	170	250	65	4.78	16.43	2.92	73.38	0.22	2.7	73.02	3.93	26.63
4	35	13	180	220	74	4.88	12.78	4.11	42.38	0.17	4.27	76.32	3.39	21.61
5	20	14	190	250	79	5.35	11.75	3.88	33.7	0.14	4.19	78.19	3.19	23.82
6	50	14	170	250	60	4.63	16.35	2.85	78.42	0.27	2.8	72.31	4.1	26.87
7	50	12	190	190	62	4.75	16.41	3.11	68.45	0.21	2.66	70.49	3.94	27.51
8	35	11	180	220	71	4.8	13	3.89	41.45	0.17	2.65	77.21	3.95	23.93
9	50	12	190	250	59	4.75	16.46	3.08	65.35	0.19	3.1	72.39	3.98	26.68
10	20	12	170	250	83	5.37	11.73	3.86	38.59	0.11	3.4	80.76	3.11	19.92
11	35	13	180	160	70	5	13.4	3.51	48.42	0.19	3.25	75.92	3.37	24.98
12	35	13	200	220	73	4.9	13.05	3.89	44.16	0.16	4.5	75.11	3.29	25.12
13	20	12	190	190	79	5.04	11.72	4.16	35.85	0.14	3.32	79.48	3.17	21.23
14	50	12	170	190	63	4.87	16.38	2.94	69.14	0.21	2.52	72.12	3.96	27.93
15	20	12	190	250	78	5.26	11.73	4.1	25.7	0.13	3.8	80.17	3.18	19.97
16	35	13	180	220	77	4.83	12.96	3.77	50.15	0.16	4.27	76.21	3.32	24.82
17	35	13	180	220	78	4.81	12.74	3.72	49.15	0.17	4.28	76.42	3.36	24.82
18	20	14	170	190	83	5.43	11.72	3.84	42.84	0.16	3.17	81.05	3.21	21.52
19	5	13	180	220	92	5.95	11.35	4.34	26.23	0.12	4.4	82.28	4.13	19.48
20	35	13	180	220	76	4.82	12.77	2.98	46.14	0.18	4.29	76.08	3.37	24.82
21	35	13	180	220	74	4.83	12.78	3.83	47.15	0.15	4.3	76.12	3.51	24.82
22	50	14	170	190	62	4.84	16.34	2.68	70.51	0.28	2.35	71.57	3.97	27.13
23	20	14	190	190	78	5.41	11.72	3.65	42.81	0.14	3.97	78.74	3.28	21.92
24	50	14	190	250	60	4.71	16.41	2.81	62.3	0.21	2.92	71.42	4.1	26.97
25	35	13	180	280	75	4.93	13.44	3.74	44.2	0.15	4.04	76.92	3.31	24.27
26	35	15	180	220	71	4.92	13	3.25	55.42	0.17	2.87	74.92	3.43	24.92
27	35	13	160	220	75	4.97	13.03	3.21	59.53	0.19	3.74	78.23	3.31	24.13
28	20	12	170	190	82	5.3	11.73	4.04	28.75	0.14	3	81.47	3.19	20.18
29	65	13	180	220	51	4.74	21.17	2.36	81.56	0.27	2.32	66.21	6.01	30.5
30	50	14	190	190	62	4.82	16.37	2.83	69.34	0.255	2.39	69.95	4.2	27.92

RF:CF = Rice flour: chickpea flour; FM = Feed moisture; BT = Barrel temperature; SS = Screw speed; SME = Specific Mechanical Energy; WAI = Water absorption index; WSI = water solubility index; ER = Expansion ratio; BS = Breaking strength; BD = Bulk Density; OAA = Overall acceptability

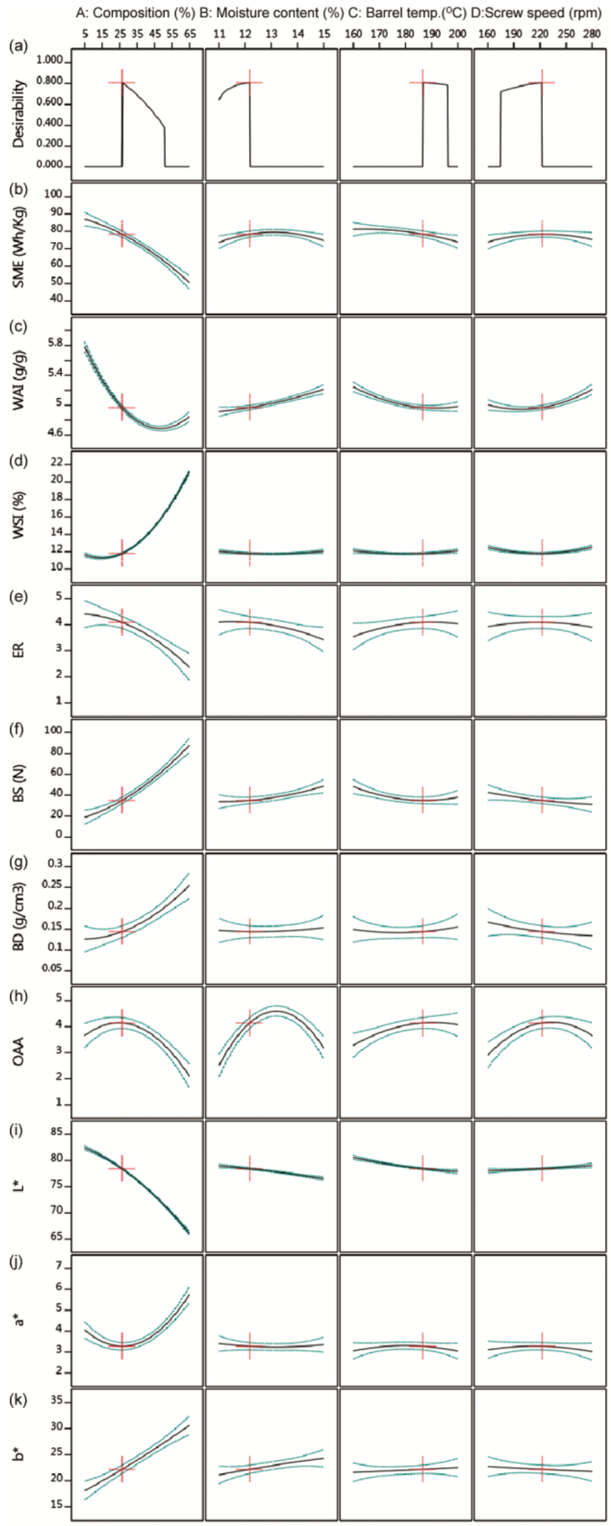
$$BD = 0.168 + 0.087A + 0.02B - 0.014C - 0.017D + 0.03A^2 \quad \dots (3)$$

The regression Eq. (3) and Fig. 1g depicts that when feed moisture content (B) and chickpea flour (A) level in feed formulation increased, BD also recorded an increase whereas when barrel temperature (C) and screw speed (D) increased, BD was found to decrease.

At higher chickpea flour level dense extrudates were obtained. This may be ascribed to higher protein content of chickpea which rupture the melt cell walls and thus, prevents the expansion of air bubble during extrusion.[3] High feed moisture content limits the elasticity of dough through plasticization of melt, thereby reducing SME and expansion which consequently increases the density of the extrudates.[8] High screw speed produces high friction which leads to protein denaturation and starch degradation that may be the possible reason for development of low density extrudates at high screw speed.[5] Decrease in BD of extrudates with increase in barrel temperatures can be justified by the fact that extrudates lose moisture as super-heated steam under higher temperature conditions and become puffier with low BD.[10] Hussain *et al.*[4] reported similar results for snacks developed for snacks stem incorporated rice based extrudates.

Water solubility Index

Water solubility of extrudates is regarded as a desirable trait because of ease in digestion.[11] WSI of extrudates varied from 11.35% to 21.17% (Table 1).



a) Desirability function response surface plots

b) Effect of independent variables on specific mechanical energy (SME) of extrudates.

c) Effect of independent variables on water absorption index (WAI) of extrudates.

d) Effect of independent variables on Water solubility Index (WSI) of extrudates.

e) Effect of independent variables on Expansion ratio (ER) of extrudates.

f) Effect of independent variables on Breaking Strength (BS) of extrudates.

g) Effect of independent variables on Bulk Density (BD) of extrudates.

(h) Effect of independent variables on Overall acceptability of extrudates.

(i) Effect of independent variables on luminosity (L*) value of extrudates.

(j) Effect of independent variables on redness (a*) value of extrudates.

(k) Effect of independent variables on yellowness (b*) value of extrudates.

Fig. 1 — Predictive plots depicting desirability function and effects of independent variables on system and product responses of extrudates

$$WSI = 12.80 + 4.75A + 3.54A^2 + 0.32C^2 + 0.70D^2 \quad \ldots(4)$$

The regression Eq. (4) and Fig. 1d indicates that WSI increased with the increase in all the independent variables except feed moisture (B). Solubility of extrudates increased when the proportion of chickpea flour in blend formulation was increased which could be due to high protein content of chickpea flour. Estrada-Giron *et al.*[12] reported almost same results for corn and bean blend extrudates. Increase in WSI with increase in screw speed could be due to higher SME as more shear leads to disruption of starch granules and consequently increases their water solubility. Gelatinization of starch is increased at high temperature which increases its solubility and consequently WSI of extrudates.[4] Singh *et al.*[8] also documented similar trend in corn-buckwheat snacks.

Water absorption Index

WAI measures the volume occupied by the starch granule after swelling in excess water[13] and was found in the range of 4.63–5.95 g/g (Table 1).

$$WAI = 4.83 - 0.56A + 0.05B - 0.05C - 0.03D - 0.18AB + 0.08AC - 0.14AD + 0.13BC - 0.15BD + 0.08CD + 0.52A^2 - 0.11C^2 - 0.14D^2 \quad \ldots(5)$$

The fitted regression Eq. (5) and Fig. 1c shows that as the moisture content (B) of the blend was increased, WAI increased while WAI was found to decrease when barrel temperature (C), screw speed (D) and chickpea flour (A) level in feed blend was increased. The decreasing effect of chickpea flour on

WAI might be probably because of decrease in starch content of blend which might have further reduced the extent of starch gelatinization and WAI of snacks.[8] Reduced degradation of starch in presence of high moisture content could be the possible reasons for enhanced WAI at higher levels of moisture content.[10] High temperature favours starch gelatinization which increased the solubility and reduced WAI of extrudates.[5] Low screw speed causes minimum damage to starch polymers thereby increasing the binding of water with available hydrophilic groups which increased the WAI of extrudates.[4] The results are in accordance with the findings of Singh *et al.*[8] for buckwheat incorporated wheat-based crackers.

Breaking strength (BS)

Breaking strength (BS) is an important parameter which depicts the hardness of snacks.[14] The BS values in this study varied from 21.7 N to 81.56 N (Table 1).

$$BS = 47.02 + 30.35A + 6.48B - 7.00C - 10.33AB - 15.91CD + 9.30A^2 - 7.25C^2 \quad \dots (6)$$

The fitted regression Eq. (6) and Fig. 1f demonstrates that when barrel temperature (C) was decreased, BS increased. However, as the feed moisture (B) and chickpea level (A) in feed formulation increased, BS of snacks increased as well. High chickpea flour in the feed resulted in harder extrudates due to increase in protein and fiber content which might have imparted structural integrity to extrudate by promoting protein-fibre interaction. Shevkani *et al.*[3] also reported similar results for chickpea and spinach incorporated snacks. When moisture content of feed material was increased, hardness of extrudates was also found to increase. Water acts as a plasticizer to the starch-based material which reduces the mechanical energy dissipation in the extruder and thus the product becomes dense due to compressed bubble growth. Hardness of extrudates was found to be low at high temperature. Increase in barrel temperature would decrease melt viscosity, which favours bubble growth and produces low density products with small and thin cells.[5] The results are in accordance with the findings of Hegazy *et al.*[2] for chickpea-based snacks.

Instrumental Colour

Colour is a vital attribute of extrudates which governs the consumer acceptability.[1] Luminosity of thirty different extrudates varied from 66.21 to 82.28 (Table 1) while redness and yellowness ranged from 3.11 to 6.01 and 19.48 to 30.5 (Table 1) respectively

$$L^* = 76.22 - 8.17A - 0.99B - 1.42C + 0.38D + 0.46AB + 1.84AD - 0.72BD + 1.09CD - 2.02A^2 + 0.15D^2 \quad \dots (7)$$

$$a^* = 3.39 + 0.86A + 1.57A^2 \quad \dots (8)$$

$$b^* = 24.29 + 5.80A \quad \dots (9)$$

The fitted regression Eq. (7) and Fig. 1i indicates that L* value was found to decrease when chickpea flour incorporation was increased in formulation (A) and also when moisture content (B) of feed mix and barrel temperature (C) increased. In contrast, it was found that with the increase in screw speed (D), L* value increased. The regression Eqs 8 & 9 for a* and b* (Figs 1j and k) demonstrates that out of different independent variables, only feed proportion recorded a significant positive effect on a* and b*. a* and b* values were found to increase as the level of chickpea in feed blend was increased. Due to anthocyanin pigments present in chickpea, the higher incorporation of chickpea flour resulted in dull coloured extrudates. The other reason behind decreased luminosity and increased redness and yellowness of extrudates with the increase in chickpea flour could be its high protein content which might have favoured maillard reaction[3] and lead to formation of brown pigments during extrusion cooking. Increase in feed moisture caused the luminosity of extrudates to decrease due to formation of compact air cells which enhances the light absorption and consequently darken the extrudates.

Reduced luminosity (L* value) recorded at higher barrel temperature could be attributed to maillards reaction and caramelization of sugars occurring during extrusion cooking. At the same time, higher the screw speed, lesser will be the retention time of the dough inside the extruder, which reduces the severity of maillard reaction and caramelization and thus, increase the L* value of the extrudates. Shevkani *et al.*[3] reported same findings when rice flour was replaced with chickpea flour and spinach powder for development of extrudates.

Overall Acceptability

The overall acceptability (OAA) of developed extrudates ranged from 2.32 to 4.50 (Table 1)

$$OAA = 4.29 - 0.98A + 0.30C + 0.45D - 0.15AB - 1.13A^2 - 1.73B^2 \quad \dots (10)$$

The fitted regression Eq. (10) and Fig. 1h shows that with the increment in barrel temperature (C) as well as in screw speed (D), overall acceptability of snacks increased while increase in chickpea flour level in feed formulation and feed moisture content decreased their overall acceptability. Due to high protein content of chickpea, the density and hardness of extrudates is increased which limits the expansion of extrudates. Further, chickpea flour incorporation imparts dull colour and bitter taste to extrudates.[3] Shevkani *et al.*[3] also reported that overall acceptability of extrudates decreased when chickpea flour incorporation was increased beyond 50%. Low moisture content favours the expansion and reduces the density of extrudates which enhances the overall acceptability of snacks. At higher barrel temperature, extrudates were found more acceptable. High barrel temperature favours various biochemical reactions such as maillards reaction[15], caramelization of sugars, starch gelatinization and protein denaturation which enhances the flavour as well as colour of the extrudates and thus makes them more palatable. Higher screw speed provides more porosity to the extrudates[16] which possibly enhanced the overall acceptability of snacks.

Optimization

The optimum extrusion processing conditions for development of chickpea incorporated rice based snacks were selected from various optimal solutions provided by the software and the solution with highest desirability value (0.80) (Fig. 1a) was selected. The optimum processing conditions were feed proportion (74% high amylose rice flour and 26% chickpea flour), barrel temperature (186 °C), screw speed (222 rpm) and feed moisture content (12%). The predicted values of Expansion ratio, Breaking Strength, Water absorption index, Water solubility index, Bulk density, Specific mechanical energy, L*, a*, b* and overall acceptability were 4.09, 34.92 N, 4.97 g/g, 11.82%, 0.144 g/cm^3, 78.34 Wh/kg, 78.42, 3.27, 22.22, and 4.12 respectively. After applying optimized conditions, the actual values obtained for ER, BD, BS, WAI, WSI, SME, L*, a*, b* and OAA were 4.19, 0.148 g/cm^3, 33.67 N, 4.86 g/g, 11.70%, 76.35 Wh/kg, 75.87, 3.22, 21.47 and 4.03. The values predicted by software for different parameters and the values obtained while evaluating the optimized product were in sound agreement with each other with a difference of lower than 3.57.

Proximate composition of raw material (rice flour and chickpea flour) and optimized product

The proximate analysis of the optimized product as well as rice and chickpea flour are depicted in Table 2. The snacks had significantly lower moisture content (2.13%) than both the flour samples. The contents of fiber, ash, protein, carbohydrate as well as calorific value increased significantly ($p<0.05$) whereas fat content decreased in extrudates relative to rice flour. Replacement of rice flour with chickpea flour upto 26% in developed snacks could be ascribed the reason behind increase in protein content of snacks. In addition, extrusion slightly enhances protein content by improving its digestibility due to protein denaturation. Significant reduction in fat content of extrudates with respect to rice flour could be ascribed to formation of lipid complexes with starch and protein.[16] Further, incorporation of chickpea flour increased the fibre content of snacks compared to rice flour due to its high fibre content. The increase in ash content of snacks over rice flour can be attributed to incorporation of chickpea flour (26%) as well as the enhanced bioavailability of minerals during extrusion by inactivation of anti-nutritional factors. Since the carbohydrate content was determined by difference method, therefore increase in carbohydrate content of snacks in relation to rice

Table 2 — Proximate composition of optimized product and raw material

Samples	Moisture (%)	Crude Protein (%)	Crude Fat (%)	Carbohydrate (%)	Ash (%)	Crude Fiber (%)	Calorific Value (Kcal/100g)
Rice Flour (RF)	$10.36^a \pm 0.17$	$8.69^a \pm 0.12$	$0.76^a \pm 0.09$	$79.00^a \pm 0.05$	$0.48^a \pm 0.02$	$0.71^a \pm 0.02$	$357.64^a \pm 2.53$
Chickpea Flour (CF)	$9.06^b \pm 0.04$	$20.27^b \pm 0.05$	$3.92^b \pm 0.03$	$57.37^b \pm 0.07$	$5.81^b \pm 0.23$	$3.57^b \pm 0.20$	$345.84^b \pm 2.06$
Optimized Extruded Snacks (74:26 RF: CF)	$2.13^c \pm 0.12$	$8.91^c \pm 0.05$	$0.63^c \pm 0.11$	$85.78^c \pm 0.16$	$1.32^c \pm 0.14$	$0.93^c \pm 0.54$	$384.43^c \pm 1.47$
C.D ($p<0.05$)	0.049	0.062	0.055	2.32	0.065	0.074	8.42
SE(d)	0.02	0.01	0.01	0.65	0.01	0.02	2.38

Values with different superscripts are statistically ($p<0.05$) different. C.D. Critical difference; SE(d): Standard error of the differences.

flour might be because of reduction in moisture content and higher protein content of snacks. Similar results have been reported by Singh *et al.*[8] for corn-buckwheat based extrudates.

Conclusions

Extrusion processing conditions i.e. chickpea incorporation, moisture content of blend, extrusion temperature and screw speed significantly affected the extruder system parameter and quality attributes of snacks. Out of the different selected independent variables, feed formulation had a dominant effect on dependent variables. The optimum extrusion processing conditions predicted for development of rice-chickpea based snacks using response surface methodology were 186°C barrel temperature, 222 rpm screw speed and a feed formulation of 26:74% chickpea:rice flour and 12% feed moisture.

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