

Optimization of barrel temperature and kidney bean flour percentage based on various physical properties of extruded snacks

G. Agathian · A. D. Semwal · G. K. Sharma

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Abstract The aim of the experiment was to optimize barrel temperature (122 to 178 ± 0.5 °C) and red kidney bean flour percentage (KBF) (12 to 68 ± 0.5 %) based on physical properties of extrudates like flash off percentage, water absorption index (WAI), water solubility index (WSI), bulk density (BD), radial expansion ratio (RER) and overall acceptability (OAA) using single screw extruder. The study was carried out by central composite rotatable design (CCRD) using Response surface methodology (RSM) and moisture content of feed was kept as constant 16.0 ± 0.5 % throughout experiments. Mathematical models for various responses were found to fit significantly ($P < 0.05$) for prediction. Optimization of experimental conditions was carried out using numerical optimization technique and the optimum barrel temperature and kidney bean flour percentage were 120 °C (T_1) & 142.62 °C ($T_2 = T_3$) and 20 % respectively with desirability value of 0.909 . Experiments were carried out using predicted values and verified using *t*-test and coefficient of variation percentage. Extruded snack prepared with rice flour (80 %) and kidney bean flour (20 %) at optimized conditions was accepted by the taste panellists and above 20 % KB incorporation was found to decrease overall acceptability score.

Keywords Single screw extruder · Rice flour · Response surface methodology · Numerical optimization · Central composite rotatable design

Introduction

Due to several advantages like fast processing time, considerable saving in energy leading to lower price of the products, possible production of oil free puffed products etc., extrusion cooking is widely popular in the food industries. It has wide application in snack food market ranging from breakfast cereals, pasta and noodles, vermin celli, expanded crunchy snacks, etc., besides pet foods. It is well known that extrusion cooking is used to make products having better flavour, digestibility, storage life and safety.

Rice (*Oryza sativa* L.) is ranked first among cereal crops based on production in India and rice based snack foods are very popular in market. In recent years, the demand for snacks with improved nutritional and functional properties has increased. Several authors worked on improving nutritional profile of extruded cereals or starches have been reported (Perez-Navarrete et al. 2006; Liu et al. 2000; Onwulata et al. 2001; Rampersad et al. 2003; Bhattacharya and Prakash 1990). In the present experiment Red Kidney beans (*Phaseolus vulgaris* L.) was taken to improve nutritional profile of rice based extruded snack. Legumes are good sources of protein, dietary fibres, vitamins and minerals including trace elements (Tharanathan and Mahadevamma 2003; Morrow 1991). In addition, colored dry beans possess strong in vitro antioxidant activity (Beninger and Hosfield 2003; Madhujith and Shahidi 2005) which may explain the protective benefits of bean consumption on development of degenerative diseases. High in soluble fibre, protein and low in fat bean consumption has been inversely associated with reduced risk of coronary diseases and some types of cancer (Azevedo et al. 2003; Winham and Hutchins 2007).

Addition of high-fibre, high-protein alternate ingredients to starch has been demonstrated to significantly affect the texture, expansion and overall acceptability of extruded snacks

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(Liu et al. 2000; Veronica et al. 2006). Extrusion cooking increases macromolecular degradation of fibre, its solubility and changes its physiological effects (Lue et al. 1991). For the production of protein and mineral enriched snacks, rates of fortification seem to vary according to the nature of each material, so optimization of fortification percentage is one of the important variables to study.

Response surface methodology (RSM) is an efficient statistical tool for optimizing complex processes. The one of the advantage of RSM is minimum experimental trials needed to evaluate multiple parameters and their interactions (Irakoze Pierre Claver et al. 2010). Statistical design tools such as RSM are quite effective and most suitable in optimizing the ingredients levels in products as well as the process parameters (Prachi and Premavalli 2012; Vatsala et al. 2001; Jorge et al. 2012). RSM has been successfully applied for optimizing extrusion conditions in several food processes (Batistuti et al. 1991; Vargas-López et al. 1990). Quantitative data in an experimental design can be used to determine and simultaneously solve multivariate equations to optimize processes or products (Sefa-Dedeh et al. 2003). Also it has been successfully used for developing, improving and optimizing processes (Wang et al. 2007). Optimizing extrusion temperature and percentage ingredients for the production of kidney bean fortified rice snack foods has not been reported. So a study was carried out to optimize barrel temperature and kidney bean flour percentage based on various physical properties of extruded snacks.

Materials and methods

Preparation of raw materials Whole dry dark red kidney beans (*Phaseolus vulgaris* L.) and Bangara thina rice (*Oryza sativa* L.) harvested at Karnataka state, India was procured from local market. All reagents were of analytical grade procured from E Merck India Pvt. Ltd., Bangalore. The beans and rice were hand-sorted to remove unwanted materials, splits, wrinkled seeds, and any debris and stored at room temperature. For extrusion processing, beans were crushed using a Grinder and milled finely using ultra centrifuge mill (Model Retsch ZM 200) to pass through a 500 µm sieve and mixing of bean flour and rice flour was carried out using legacy countertop mixer (Hobart, Troy, US). The required moisture content of premix was achieved by adding purified water using plastic water sprayer one litter capacity with uniform stirring. Flour mixture were packed in polypropylene bag and stored overnight at 5 °C in order to achieve equilibrium in moisture.

Extrusion conditions After sieving conditioned flour premix through 500 µm sieve, extrusion were carried out using a laboratory single screw extruder (Model: Brabender 20 DN,

make: Germany) with pressure and temperature sensor; three heating zones; screw with 4:1 compression ratio; a 6 mm diameter & 20 mm long die; and output capacity of up to 4 kg/h. Throughout the production, a screw speed was in the range of 105±5 rpm, with a screw diameter of 30 mm and barrel L/D of 14, feed rates of 53±2 rpm were maintained. Three temperature zones were indicated by T₁, T₂ & T₃ and T₂ & T₃ were equal in values for all experiments and represented as X₁, the value of T₁ was kept constant throughout experiments as 120 °C. T₃ is barrel temperature near to die and feed moisture content was maintained at 16.0±0.5 %.

Experimental design Statistical software design expert 7.0.0 (Stat-ease, Inc. Minneapolis, MN 55413) was used to design experiment as well as analyse the data without any blocks. Six responses taken in this study were flash off percentage, bulk density, radial expansion ratio, water solubility index, water absorption index and OAA of extruded KBF incorporated rice snack. A 13 complete full factorial CCRD was used with two independent variables: i) Temperature of 2nd & 3rd Zone together represented as X₁ (121.72 to 178.28 °C) and ii) Percentage Kidney bean X₂ (11.72–68.28 %) and the same is represented by Table 1. Each Independent variables investigated in this experiment had five levels which were -1.4142, -1, 0, +1 and +1.4142. Moisture content of feed, barrel Temperature of zone 1 (T₁), feeder rate and screw speed were maintained with fixed level.

Flash off % Flash off percentage is calculated by the difference in percentage of moisture content of feed and extruded products and expressed as percentage of steam flashed off from food material during extrusion cooking (Harper 1981).

Radial Expansion ratio The average diameters of 5 randomly selected extrudates were measured using a digital vernier calliper (Precise measure DMV01, Sudherson measuring & engineering pvt. Ltd., Delhi, India). Three random measurements were taken along each 12–15 cm strand. The ratio of the mean diameter of the extrudates to that of the die (6.0 mm) was calculated as the expansion ratio (Kumagai et al. 1987).

$$\text{RER} = \frac{\text{Diameter of Extruded Products}}{\text{Diameter of Die}}$$

Bulk density The extruded pieces with an approximate length of 0.5 cm were placed in a pre-weighed 100 ml graduated measuring cylinder. The graduated cylinder with the extruded pieces was tapped gently on a flat surface to a constant volume before determining sample weight. The bulk density was calculated as weight per unit volume. All measurements were done in triplicate and the results of bulk density are reported as g/cc (Harper 1981).

Table 1 Central composite rotatable design of independent variables in their coded and uncoded form with responses

Std order	Coded(Uncoded)		Flash off %	WAI (g/g)	RER (mm/mm)	BD (g/cc)	WSI (g/g)	OAA
	X ₁ (Barrel Temperature °C)	X ₂ (Kidney bean flour %)						
1	-1(130)	-1(20)	1.17	6.77	2.08	0.184	2.23	7.7
2	+1(170)	-1(20)	1.44	7.52	1.57	0.195	6.52	6.2
3	-1(130)	+1(60)	1.21	5.2	1.72	0.259	6.33	6.6
4	+1(170)	+1(60)	1.58	6.05	1.55	0.271	11.17	4.9
5	-1.414(121.72)	0(40)	1.11	6.12	1.87	0.234	3.6	6.7
6	+1.414(178.28)	0(40)	1.56	6.9	1.35	0.249	9.21	4
7	0(150)	-1.414(11.72)	1.28	7.63	2.1	0.145	3.46	8.4
8	0(150)	+1.414(68.28)	1.46	5.45	1.65	0.282	9.73	6.1
9	0(150)	0(40)	1.31	7.3	1.93	0.214	6.36	7
10	0(150)	0(40)	1.29	7.21	1.93	0.213	6.18	7.1
11	0(150)	0(40)	1.33	7.24	1.94	0.209	6.2	7.2
12	0(150)	0(40)	1.34	7.24	1.89	0.204	5.84	7.1
13	0(150)	0(40)	1.35	7.1	1.95	0.212	6.17	7.3

Where X₁=Barrel Temperature T₂=T₃, X₂=Red kidney bean flour percentage in feed, RER Radial Expansion Ratio (mm/mm), BD Bulk Density (g/cc), WAI Water absorption index (g/g), WSI Water solubility index (g/g) and OAA Overall acceptability (Nine point hedonic scale)

Water absorption index The water absorption index (WAI) determination was done according to the method of Kaur and Singh (2006). 20 g of ground extrudate was mixed in 20 ml of distilled water for 30 min at 30±1 °C followed by centrifugation at 1,000 X g for 15 min. Taking triplicate measurements per sample, WAI calculated as the increase in weight of the sediment (gel) formed after decanting the supernatant, as per the following formula.

$$WAI(g/g) = \frac{\text{Weight gain by gel (g)}}{\text{Dry weight of extrudate (g)}}$$

Water solubility index For water solubility index (WSI), the supernatant from the WAI determination was decanted in pre-weighed evaporation dish and dried to constant weight in the oven. The WSI was calculated using the following equation:

$$WSI\left(\frac{g}{g}\right) = \frac{[\text{Weight of dish(g)} + \text{dried supernatant(g)}] - [\text{Weight of dish(g)}]}{\text{Weight of dry sample(g)}}$$

Sensory evaluation of Extruded snacks ensory evaluation of spiced extruded Rice-bean snacks prepared as per RSM design was evaluated by semi-skilled panellist for overall acceptability using 9 point hedonic scale as per method of Larmond E (1977) rating of 9=liked extremely to 1=disliked extremely. Acceptability scores using the mean of the seven observations were recorded. Immediately after extrusion samples were dried in hot air oven at 60 °C for 2 h. Vanaspathi (15 g) was heated in a stainless steel vessel to 100 °C and fresh spice mix (9 g) was added to hot vanaspathi with continues mixing. The vessel was removed from the flame and dried

extruded samples (90 g) were added in the hot spice mix and stirred continuously to confirm uniform coating of the spices. The spice coated samples were served for sensory evaluation. Spice mix was prepared using citric acid, red chilli powder, Salt, sugar, black pepper, dried onion and garlic powder.

Optimization and verification of model Optimization of barrel temperature and KBF percentage was carried out using numerical optimization technique. The desired goals for each factors and responses were chosen, different importance were assigned to each goal to adjust the shape of its particular desirability functions (Myers and Montgomery 2002). The goals are combined into an overall composite function called the desirability function D (x) which is defined as.

$$D(x) = (d_1 \times d_2 \times \dots \times d_n)^{1/n}$$

Where d₁, d₂, ... d_n responses and n was the total number of responses in the measure. The characteristics of goal may be altered by adjusting the weight or importance. In the test X₁, X₂ & Flash off% were kept in range while RER, WAI & OAA were maximized and WSI & BD were minimized. Verification of the model was carried out by one sample t-test and coefficient of variation % calculation to compare the experimental and predicted values of the responses.

Results and discussion

Responses under different combination of barrel temperature (X₁) and kidney bean flour percentage (X₂) as per

RSM in their coded and uncoded form are given in Table 1. Flash off %, WAI, RER, BD, WSI and OAA of extruded snacks at different combination of X_1 and X_2 ranged from 1.11 to 1.58 %, 5.2 to 7.63 g/g, 1.35 to 2.1 mm/mm, 0.132 to 0.285 g/cc, 2.23 to 11.17 g/g and 4 to 8.4 hedonic scales.

Both barrel temperature and KBF affects all responses significantly ($P < 0.05$). Interactive effect of Barrel temperature (X_1) and KBF (X_2) on Flash off % and RER was significant ($P < 0.05$). Square term X_2^2 in quadratic equation influence flash off %, WAI and WSI significantly ($P < 0.05$) when compared to X_1X_2 whose influence was insignificant. Square term X_1^2 shows significant effect on WAI, RER, BD and OAA. Increase in KBF percentage decreased OAA & RER and increased BD of product. R^2 can be defined as the ratio of the explained variation to the total variation was a measure of degree of fit (Myers and Montgomery 2002). The closer the R^2 value to unity, the better the empirical model fits the actual data.

As per ANOVA Table 2 the adjusted R^2 for responses were close to their predicted R^2 . The coefficient of variation (CV) explains the extent to which the data are dispersed (Snedecor and Cochran 1967). As a general rule, the coefficient of variation should not be greater than 5 % and smaller the value of CV means better reproducibility. In this study the coefficient of variation were less than 5 % for all responses (Table 3) a relatively lower value of the coefficient of variation indicating better precision and reliability of the experiment. The F-value for all responses model were greater than the tabulated F-value which indicating the adequacy of the models to predict different responses at different extrusion conditions. The quadratic regression model for the influence of KBF percentage (X_2) and

barrel temperature (X_1) on various responses in uncoded values were presented by the following equations.

$$\begin{aligned} \% \text{Flashoff} = & + 0.757 + (1.821e^{-003})X_1 - (0.0111)X_2 \\ & + (6.250e^{-005})X_1X_2 \\ & + (1.218e^{-005})X_1^2 - (5.594e^{-005})X_2^2 \end{aligned} \quad (1)$$

$$\begin{aligned} \text{WAI} = & - 16.787 + 0.306X_1 + 0.0272X_2 \\ & + (6.250e^{-005})X_1X_2 \\ & + (9.7e^{-004})X_1^2 - (9.34e^{-004})X_2^2 \end{aligned} \quad (2)$$

$$\begin{aligned} \text{RER} = & - 4.454 + 0.104X_1 - 0.032X_2 \\ & + (2.125e^{-004})X_1X_2 \\ & + (4.053e^{-004})X_1^2 - (7.406e^{-005})X_2^2 \end{aligned} \quad (3)$$

$$\begin{aligned} \text{BD} = & + 0.964 - 0.012X_1 + (1.763e^{-003})X_2 \\ & + (6.250e^{-007})X_1X_2 + (3.872e^{-005})X_1^2 \\ & + (3.719e^{-006})X_2^2 \end{aligned} \quad (4)$$

$$\begin{aligned} \text{WSI} = & - 3.186 - 0.015X_1 + (0.011)X_2 \\ & + (3.438e^{-004})X_1X_2 + (3.578e^{-004})X_1^2 \\ & + (5.953e^{-004})X_2^2 \end{aligned} \quad (5)$$

Table 2 Analysis of variance of the fitted model for different responses

Term	Flash off %	WAI(g/g)	RER(mm/mm)	BD(g/cc)	WSI(g/g)	OAA
Model	Quadratic	Quadratic	Quadratic	Quadratic	Quadratic	Quadratic
F-value (model)	107.81	112.55	75.37	84.95	319.56	113.15
P-value (model)	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Mean	1.34	6.748	1.81	0.217	6.384	6.64
SD	0.021	0.11	0.04	0.00648	0.22	0.17
CV %	1.55	1.7	2.19	2.94	3.41	2.52
R^2	0.9872	0.9877	0.9818	0.9828	0.9956	0.9878
Adjusted R^2	0.9780	0.9789	0.9687	0.9705	0.9925	0.9790
Predicted R^2	0.9633	0.9287	0.8895	0.8986	0.9794	0.9311
Lack of Fit (P-value)	0.7566	0.0956	0.0627	0.0850	0.2960	0.120

RER Radial Expansion Ratio (mm/mm), BD Bulk Density (g/cc), WAI Water absorption index (g/g), WSI Water solubility index (g/g) and OAA Overall acceptability (Nine point hedonic scale)

Table 3 Constraints and criteria for optimization along with predicted & validated values

Constraints	Goal	Lower limit	Upper limit	Importance	Predicted	Validated values*	CV%
X ₁ (°C)	In range	130	170	3	142.62	–	–
X ₂ (%)	In range	20	60	2	20.00	–	–
Flash off %	In range	1.11	1.58	3	1.24	1.294±0.02	3.01
WAI(g/g)	Maximize	5.2	7.63	3	7.441	7.238±0.25	1.96
RER(mm/mm)	Maximize	1.35	2.1	4	2.10	1.964±0.05	4.73
BD(g/cc)	Minimize	0.145	0.282	4	0.168	0.178±0.01	4.09
WSI(g/g)	Minimize	2.23	11.17	3	3.469	3.369±0.23	2.07
OAA	Maximize	4	8.4	5	8.099	7.8±0.2**	2.66

Where X₁=Barrel Temperature T₂=T₃, X₂=Red kidney bean flour percentage in Feed, RER Radial Expansion Ratio (mm/mm), BD Bulk Density (g/cc), WAI Water absorption index (g/g), WSI Water solubility index (g/g) and OAA Overall acceptability (Nine point hedonic scale)

*Experiments were carried out in triplicate and ** Mean of seven observations

$$OAA = -34.988 + 0.623X_1$$

$$-0.0301X_2 - (1.25e^{-004})X_1X_2 - (2.206e^{-003})X_1^2 + (1.687e^{-004})X_2^2 \tag{6}$$

The positive sign in front of the terms indicates synergistic effect, while negative sign indicates antagonistic effect. All the above models did not showed a significant lack of fit ($P > 0.05$) and coefficient of determinants are higher than 0.95, the proposed models approximates the response surfaces and can be used suitably for prediction at any values of the parameters within experimental range.

Flash off percentage High temperature and moisture content of feed plays very important role in Flash off percentage value. When food material was forced through an extruder die, at high temperature water present in food matrix expands the starch content, producing a porous, sponge-like structure in the extruded product. The model F-value of 107.82 implies the model is significant. Surface and contour plot of flash off % versus barrel temperature (X₁) and KBF % (X₂) represented by Fig. 1. Flash off % of extruded snacks with different combination of temperature and KBF as per experimental design given in Table 1. Flash off % increased sharply with increasing barrel temperature and the maximum flash off % of 1.58 was observed by 60 % KB incorporated snack prepared at 170 °C. Due to depolymerisation and decomposition of starch and protein at high temperature 170 °C and 178.2 °C with flash off % of 1.58 and 1.56 %, samples showed low acceptability value.

Water absorption index WAI decreases significantly ($P < 0.05$) with increasing percentage of KBF. The highest water absorption index (WAI) of 7.63 was observed in 11.7 % KBF incorporated rice snack at 150 °C barrel temperature and lowest value of 5.2 at 60 % KBF (Table 1). A decrease of WAI with addition of KBF may be due to the

dilution of starch in rice KB blends (Jones et al. 2006). WAI has been generally attributed to the dispersion of starch in excess water and the dispersion is increased by the degree of starch damaged due to gelatinization and extrusion induced fragmentation that is molecular weight reduction of amylose and amylopectin molecules (Yagci and Gogus 2008). Temperature dependent increase in water absorption index related to gelatinization % of starch present in extruded samples in turn it affects water solubility index also (Dansby and Bovell-Benjamin 2003). But at high temperature and pressure in extrusion cooking gelatinized starch granules and protein molecules undergo depolymerisation which in turn affects WAI of extruded snacks. The significant decrease in WAI observed at 178.28 °C for 40 % KBF incorporated rice snack. The change in WAI with respect to X₁ and X₂ in the form of surface and contour plot represented by Fig. 2. Model for the effect of temperature X₁ and percentage kidney bean flour X₂ on WAI fits well for quadratic Eq. 2. The equation was statistically significant ($P < 0.05$) with $R^2 = 0.984$ which indicates good relationship of the model to the experimental data.

Radial expansion ratio The radial expansion ratio (RER) is one of the important characteristic of extruded snacks responsible for crispy and porous texture. Degree of expansion of extruded snacks is closely linked to the size, number and distribution of air cells within the material (Ruiz-Ruiz et al. 2008). RER results of extruded KBF fortified rice snack were shown in Table 1. Expansion ratio of extruded snacks decreases significantly with increasing percentage of KBF (Fig. 3). High fibre and protein content in KBF was responsible for low expansion ratio, fibre prevents air bubbles from expanding to their maximum size (Perez-Navarrete et al. 2006). Barrel temperature influence RER in a positive direction, maximum RER of 2.1 was shown by 11.72 % KBF incorporated snack prepared at 150 °C. But extruded snack prepared at high temperature 170 °C and above showed

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FLASH OFF %



X1 = A: Temperature (degree C)
X2 = B: KBF %

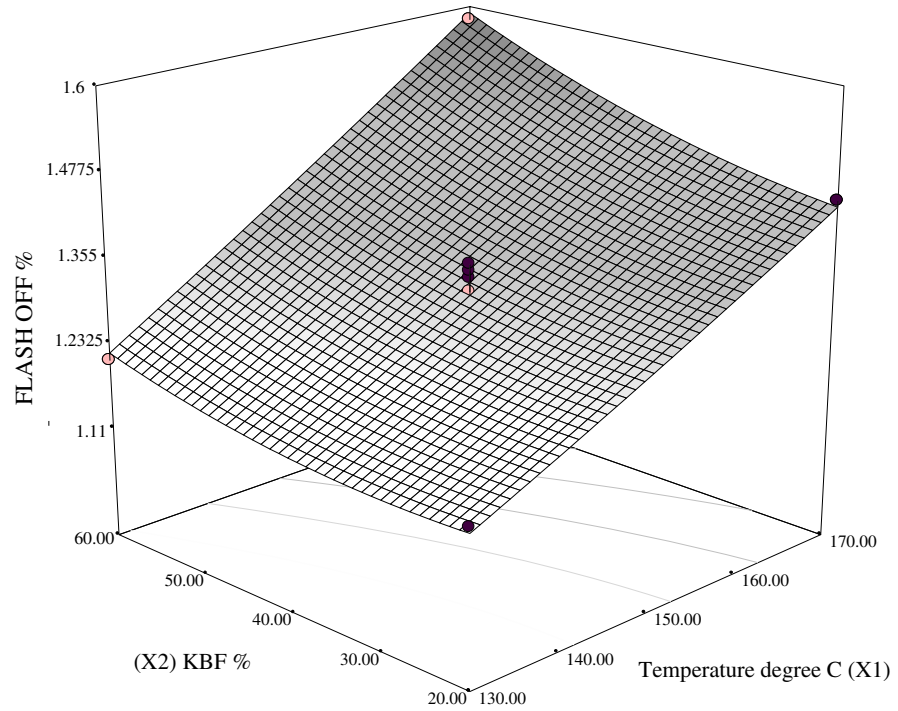


Fig. 1 Effect of barrel temperature X_1 and kidney bean percentage X_2 on Flash off %

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WAI (g/g)



X1 = A: Temperature (degree C)
X2 = B: KBF %

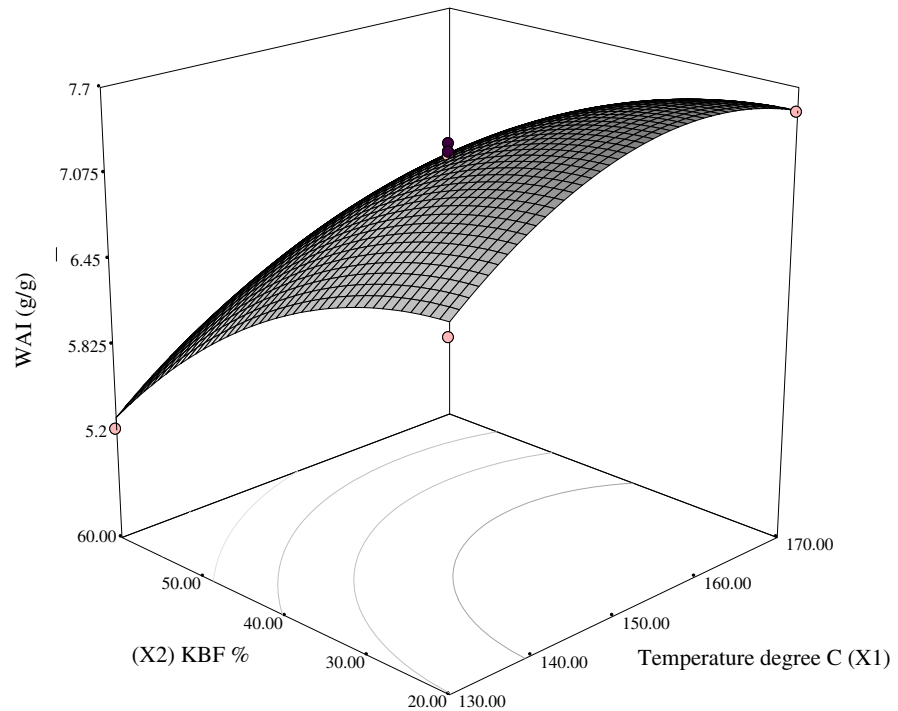


Fig. 2 Effect of barrel temperature X_1 and kidney bean percentage X_2 on WAI

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RER (mm/mm)

2.1

X1 = A: Temperature (degree C)

X2 = B: KBF %

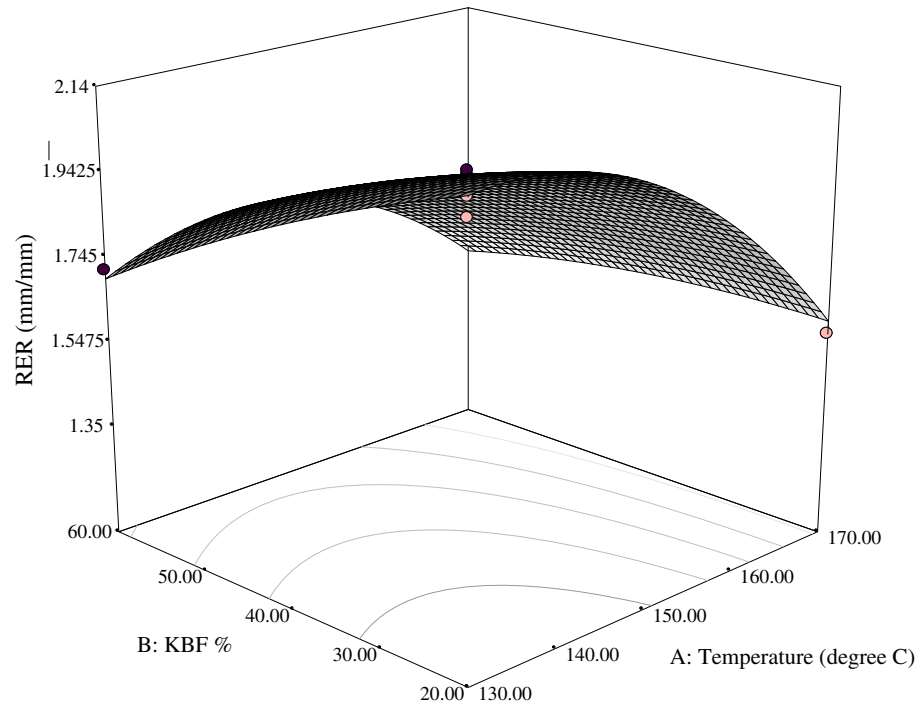


Fig. 3 Effect of barrel temperature X_1 and kidney bean percentage X_2 on RER

decreased value of RER, this may be due to partial degradation of starch granules and proteins at such a high temperature (Gutkoski and El-Dash 1999; Yang et al. 2008).

The RER for this model ranges from 1.350 to 2.10 and the final 2nd order quadratic Eq. 3 in terms of actual factors was statistically significant ($P < 0.05$) with $R^2 = 0.982$ which indicated good adjustment of the model with experimental data. The model F -value of 75.37 implies the model is significant. The predicted R^2 value 0.8898 is in reasonable agreement with the adjusted R^2 value of 0.969.

Bulk density Bulk density (BD) of extruded products was inversely proportional to RER and higher the value of BD means lower would be RER and vice versa. The bulk density of 20 % KBF incorporated snack increases from 0.184 to 0.195 with increase in temperature from 130–170 °C; the same trend was observed for 40 % and 60 % KBF incorporated rice snacks. At high temperature 170 °C and 178.28 °C very high rate of evaporation of moisture, depolymerization and degradation of starch leads to increase in bulk density value in comparison to low temperature. As per Table 1, KBF percentage affects BD more significantly when compared to barrel temperature; the same was represented by Fig. 4. The Eq. 4 is statistically significant and $R^2 = 0.9828$ which

indicates good adjustment of the model with experimental data. As addition of fibre and protein to rice flour through KBF in preparation of extruded rice snacks decreases expansion and increases bulk density. Bulk density ranges from 0.13 to 0.285 g/cc, the lowest value corresponds to the sample having 11.27 % KBF prepared at 150 °C and the highest value corresponds to sample having 68.28 % KBF prepared at 150 °C.

Water solubility index The water solubility index (WSI) is a parameter that indicates the total degradation undergone by starch granules; it is the integration of the effects of gelatinization, dextrinisation and the consequent solubilisation of starch (Gutkoski and El-Dash 1999). Also WSI is often used as an indicator of degradation of molecular components (Yang et al. 2008), which measures the degree of starch conversion during extrusion and the amount of soluble polysaccharides released from the starch component after extrusion process. In the present study, the increase in WSI with increasing percentage of kidney bean and temperature was well correlated by the plot as Fig. 5. The lowest value of WSI 2.23 shown by 20 % KBF at 130 °C and highest value of 11.17 % by 60 % KBF at 170 °C clearly supports the above statement. It has been established that proteins are the most reactant components in foods and easily undergoes

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BD (g/cc)

0.282

X1 = A: Temperature (degree C)

X2 = B: KBF %

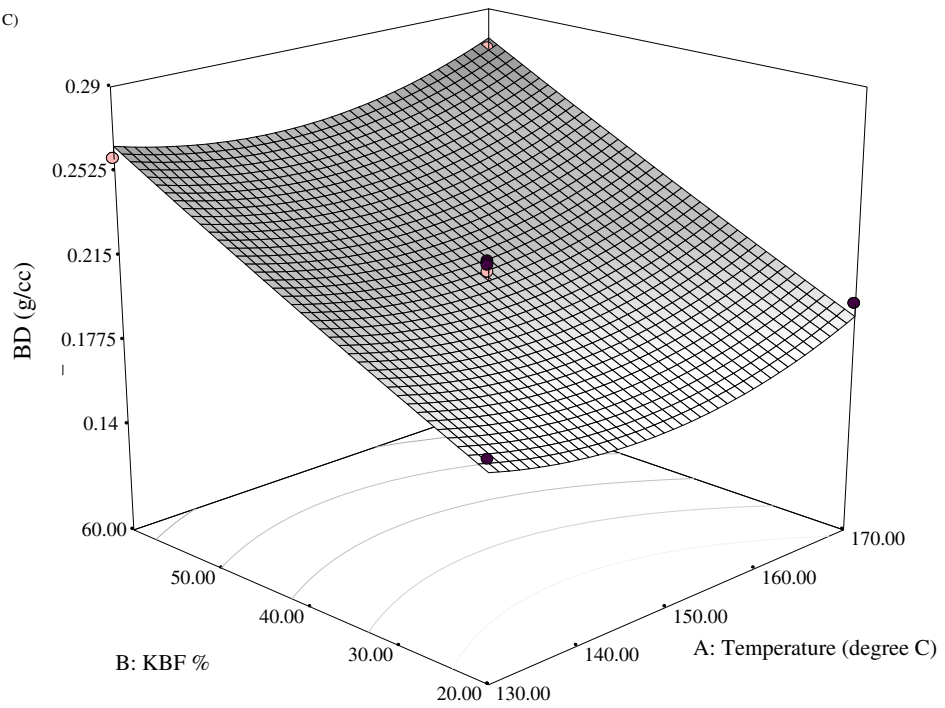


Fig. 4 Effect of barrel temperature X_1 and kidney bean percentage X_2 on BD

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WSI (g/g)

11.17

X1 = A: Temperature (degree C)

X2 = B: KBF %

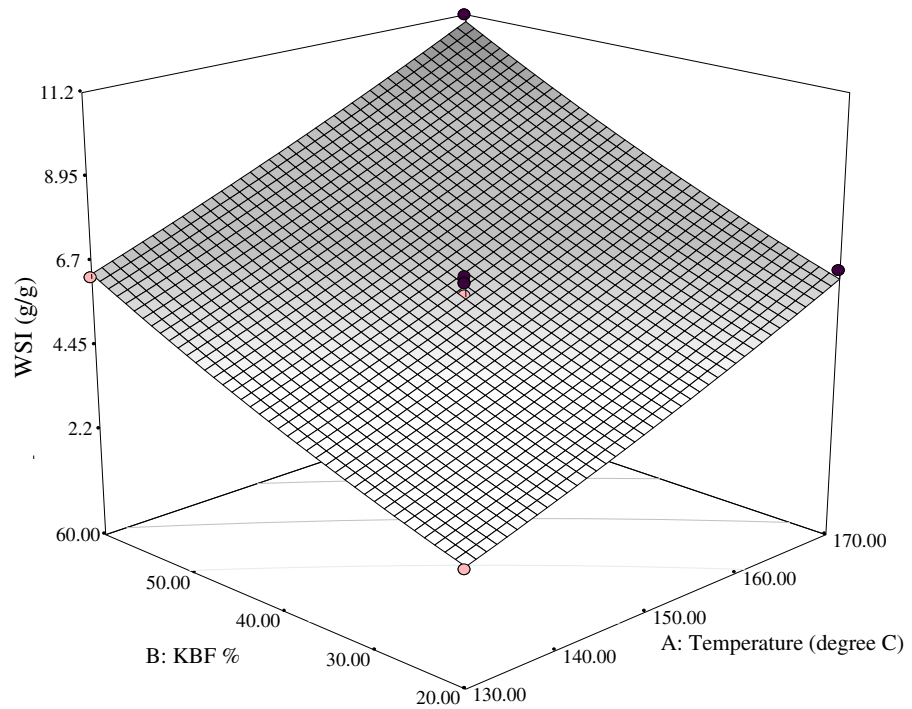


Fig. 5 Effect of barrel temperature X_1 and kidney bean percentage X_2 on WSI

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OAA (hedonic scale)



X1 = A: Temperature (degree C)
X2 = B: KBF %

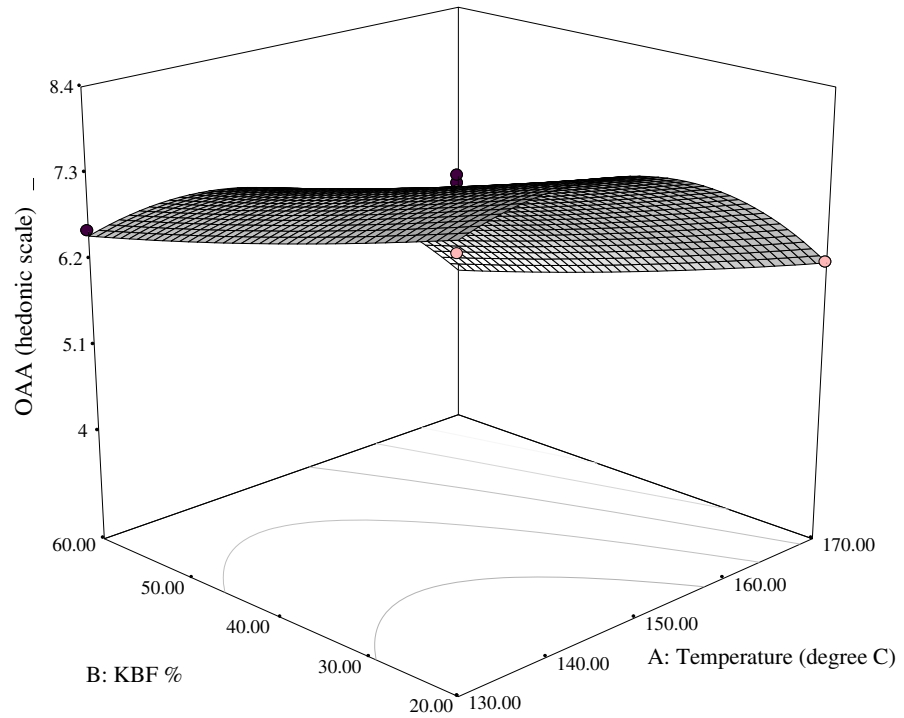


Fig. 6 Effect of barrel temperature X_1 and kidney bean percentage X_2 on OAA

degradation with respect to temperature (Pomeranz 1970; Wolf and Cowan 1971). This can be one of the

reasons for the increase in WSI value with respect to KBF quantity in extruded snacks. In addition to the

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Desirability



X1 = A: Temperature (degree C)
X2 = B: KBF %

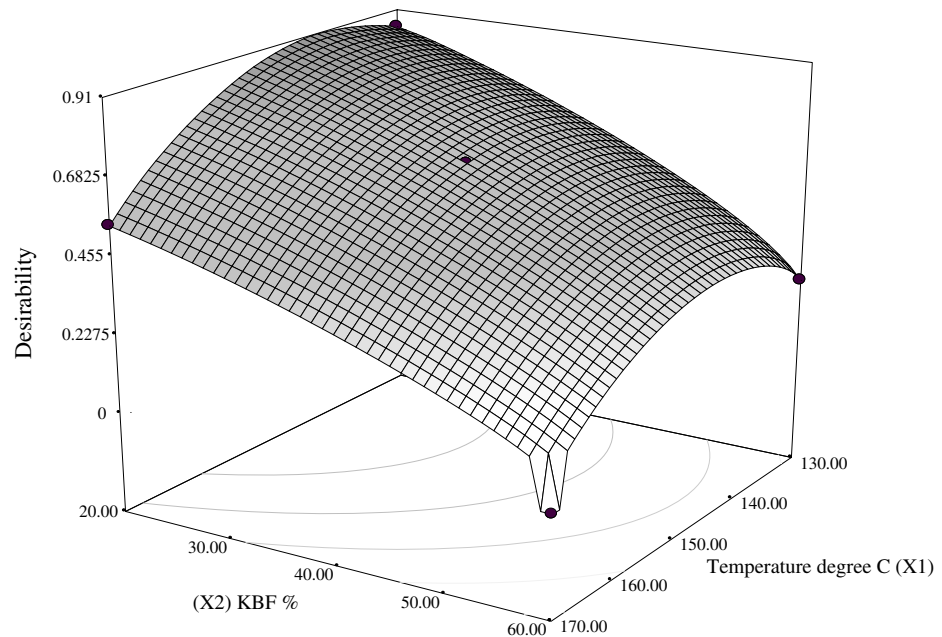


Fig. 7 Effect of barrel temperature X_1 and kidney bean percentage X_2 on desirability

above comparatively high amylose content in kidney bean flour affects WSI significantly.

Sensory properties Sensory score of the products developed at various barrel temperatures and percentage kidney bean flour is shown in Table 1. Both barrel temperature and percentage kidney bean flour affects the overall acceptability score of snacks. At 150 °C, the extruded snack prepared shows more acceptability than lower and higher temperatures. At low temperature, snack with higher BD and lower RER was produced and at high temperature 178 °C, product starts charring and shows very low acceptability score. OAA score decreases with increasing KBF percentage, extruded snack prepared with 11.73 % KBF showed OAA score of 8.4 and snack prepared with 68 % KBF showed 6.1 hedonic points. Sensory score of the product can be correlated to BD, RER, WAI and WSI of extruded snack. Extruded snack with lower BD & WSI and high value of RER and WAI were more preferable for consumption. The recommended model for OAA with respect to barrel temperature and percentage kidney bean flour is given by the second order quadratic Eq. 6. The R^2 value of 0.9878 and F value of 113.12 clearly indicates the model equation fits well with the experimental data. Figure 6 shows how temperature and KBF affects OAA of snacks.

Optimization of process parameters and Verification of models The desired goal for the present experiment was optimising KBF % (X_2) and barrel temperature (X_1) based on physical properties of extruded snacks. Table 3 shows software generated optimum conditions of independent variables with the predicted and experimentally arrived values of responses for desired goal. In optimization process more importance were given to BD, RER and OAA of products. Out of three solution generated using numerical optimization technique based on the above conditions, solution no.1 having the maximum desirability value of 0.909 observed at 20 % KB flour and 142.62 °C was selected as the optimum condition for extrusion of KBF incorporated rice snack. The desirability graph (Fig. 7) clearly indicates that both KBF and barrel temperature affects Desirability.

Extrusion of KBF incorporated rice snack was conducted at the optimum process condition obtained by numerical optimization technique and the quality attributes of the resulting product was determined. Extruded snacks prepared showed better RER, BD and OAA values of 1.964, 0.178 and 7.8 respectively. The experimentally arrived values and values predicted by the equations of the model were tested using t-test and there was no significant difference recorded between the actual and predicted values ($P < 0.05$). Closeness between the experimental and predicted values of responses further verified by calculating percentage coefficient of variation

and values were less than 5 % indicated the suitability of the corresponding models to predict responses.

Conclusions

Designed experiments were carried out using RSM for the extrusion of KBF fortified rice flour using a single screw extruder. The second order quadratic equation developed were found to have $R^2 > 0.95$, Lack of fit > 0.05 , and $P < 0.0001$ which indicates good fitness of model for prediction purpose. The optimum barrel temperature and KBF percentage determined using RSM and numerical optimization technique was 120 °C, 142.62 °C ($T_1, T_2 = T_3$) and 20 % respectively. Both barrel temperature and KBF affects all responses significantly ($P < 0.05$). Increase in KBF percentage decreased OAA & RER and increased BD of product. The variation of physical properties of extruded snack studied in the present experiment was very useful for optimization of (X_2) KBF % and (X_1) barrel temperature.

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