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ORIGINAL ARTICLE

Quality Attributes of Extruded Breakfast Cereal from Low Amylose Rice and Seeded Banana *(Musa Balbisiana*, ABB)

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Abstract

The low-amylose rice flour incorporated with seeded banana powder was extruded to prepare ready to eat breakfast cereals in a single-screw extruder. Response surface methodology using a central composite design was used to evaluate the effects of independent variables, namely seeded banana flour (66-234 g/kg), barrel temperature (86-154 ^{o}C) and feed moisture content (11-18 %, wb) at constant screw speed (350 rpm), on product responses of expansion, texture and bulk density. Multiple regression equations were obtained to describe the effects of each variable on product responses. Increase in barrel temperature and low feed moisture reduced the bulk density and breaking strength but increased expansion of extrudate. The compromised optimal conditions obtained by numerical integration for development of extrudates were: 13.5 g/100g seeded banana, 12.5% feed moisture and processing temperature of 140 ^{o}C. Extrudates made of low amylose rice flour incorporated with seeded banana were found to have considerable amount of Mg (13.25 mg) and K (21.7 mg).

Keywords: Extrusion, Feed moisture, Expansion, Seeded banana, Viscosity.

1. Introduction

Ready to eat breakfast cereals (RTEBC's) have brought a dramatic change to the cereal industry, the key being quality extruded products offered to consumers at comparatively lower price (Lin *et al.*, 2002; Yeh and Jaw, 1999). They can be sweet or savory, light or substantial, and many even are endowed with attributes such as 'healthy' and 'just for fun' (Desrumaux *et al.*, 1999). Despite increased use of extrusion cooking to manufacture products such as snacks, puffed products, breakfast cereals and fortified products, quality can vary considerably depending on extruder type, screw configuration, die profile, screw speed, barrel temperature, feed moisture and type of feed used. Advantages of extrusion cooking are extensively studied (Balasubramanian *et al.*, 2012a; Eastman *et al.*, 2001; Parker *et al.*, 2000; Camire *et al.*, 1990) signifying wide acceptability. During extrusion cooking raw materials undergo high shear, thus allowing partial starch hydrolysis (Colonna *et al.*, 1984). Many factors affect preference and acceptability of foods like intrinsic (appearance, taste, and flavour) and extrinsic (social and cultural) to food products (Deliza *et al.*, 1996).

Low amylose rice (*Oryza sativa*) that is native of Assam has been traditionally used for making various rice products. The low amylose content of the rice gives the desirable eating quality to the products. Seeded banana *(Musa balbisiana*, ABB) , locally called *bhimkol* has been found to be very rich in macro- and micronutrients and traditionally fed to the infants (Barthakur and Arnold, 1990) and the dried banana pulp is marketed as baby food. It has been reported that 100 g of fresh *bhimkol* pulp satisfies the RDA for K, Mn, Zn and Se of six month infants.

The effectiveness of response surface methodology in optimizing formulation and processing conditions in development of extruded product have been reported by different researchers (Altan *et al.*, 2008; Yagci and Gogus, 2008; Ding *et al.*, 2005). Thus keeping in view the commercial potential of *bhimkol* incorporated rice extrudates, the present study has been planned to optimize the process parameters to develop low-amylose rice extrudates incorporated with *bhimkol*.

2. Material and Methods

2.1 Preparation of Composite Flour

Low amylose rice and seeded banana hereafter, referred to as *bhimkol* were procured from local market. The rice was cleaned to remove foreign matter and ground in a hammer mill (ALFA Instruments, India) to get fine flour. *Bhimkol* was sliced into pieces and dried in the tray drier (Labotech, BD Instruments, India) at 55 °C for 10 h followed by grinding in a Pulverizer (FRITSCH, Germany) to get fine flour of 1mm size. Rice flour was blended with *bhimkol* flour and the composite flour (300g each) was extruded through single-screw extruder after proper mixing (conditioned with water for 24 h to achieve feed moisture level between 8 to 18%, wb).

2.2 Extrusion Cooking

Extrusion cooking was performed in a single screw extruder (G. L. Extrusion Systems Pvt. Ltd., India), driven by a 5 HP Induction motor. The feed and cutter were controlled with 1HP AC motor, separately. The composite flour was fed into the extruder with a pre-calibrated feeding screw and temperature was controlled by means of water circulation system. Steady state condition was assumed to have been reached when there were no visible drifts in product temperature.

Extrudates were produced at constant screw seed (350 rpm) and allowed to pass through 2 mm circular die and cut with a constant cutter speed (600 rpm). Extrudates were collected, cooled to room temperature under natural convection conditions and stored in LDPE bags for further analysis.

2.3 Experimental Design and Statistical Analysis

Response Surface Methodology (RSM) was applied to the experimental data using the package, Design expert version 7.1.1, (STATE-EASE Inc, Minneapolis, USA, Trial version). The same software was used for generation of response surface plots, surface perimposition of counter plots and optimization of process variables (Altan *et al.*, 2008a; Yagci and Gogus 2008; Ding *et al.*, 2005; Dhingra and Paul 2005). The results were means of three replicates. A three variable (five level of each variable) central composite design was employed (Montgomery 2001; Yagci and Gogus, 2008). The parameters and their levels were chosen based on literature available on rice based extrudates (Yagci and Gogus, 2008; Ding *et al.*, 2005; Upadhyaya, 2008). The independent variables included *bhimkol* powder (BP), feed moisture content (FMC) and barrel temperature (BT) as shown in Table 1. Response variables of sectional expansion index (SEI), bulk density (BD), breaking strength (BS), viscosity and colour values were determined. The five levels of the process variables were coded as -1.68, -1, 0, 1, 1.68 (Montgomery, 2001) and the design in coded (x) form is given in Table 2. Desirability, a mathematical method was used for selecting the optimum process values. In a study with several responses and factors, all goals get combined into desirability function and the numerical optimization finds a point that maximizes the desirability function.

Table 1: Experimental design for extrusion experiment with coded and actual variable levels

Run	Coded x_1^a	x_2^b	x_3^c	Un coded X_1^a	X_2^b	X_3^c
1	1	-1	1	200	10	140
2	0	0	0	150	13	120
3	0	-1.68	0	150	8	120
4	1.68	0	0	234	13	120
5	0	0	1.68	150	13	154
6	0	0	0	150	13	120
7	0	0	0	150	13	120
8	-1	-1	-1	100	10	100
9	1	1	-1	200	16	100
10	1	1	1	200	16	140
11	0	1.68	0	150	18	120
12	-1	1	1	100	16	140
13	-1	1		100	16	100
14	1	-1	-1	200	10	100
15	0	0	0	150	13	120
16	-1.68	0	0	66	13	120
17	-1	-1	1	100	10	140
18	0	0	0	150	13	120
19	0	0	-1.68	150	13	86
20	0	0	0	150	13	120

[a] *x_1 and X_1, concentration of bhimkol powder { g/kg};*
[b]*x_2 and X_2, feed moisture content {%}*
[c] *x_3 and X_3, extrusion temperature (°C)*

2.4 Evaluation of Sectional Expansion Index (SEI) of Extrudates

Expansion of extrudate was measured in terms of diameter, at three points on each piece, of the extruded product to the die diameter by using a vernier caliper (Ding *et al.*, 2005; 2006) to measure the average thickness of the extrudates. Measurements were taken on ten randomly selected pieces of extrudates.

$$\text{Expansion Index} = \frac{\text{Diameter of extrudate}}{\text{Diameter of die}}$$

$$\text{Sectional Expansion Index} = \left(\frac{\text{Diameter of extrudate}}{\text{Diameter of die}}\right)^2$$

Table 2: The regression models for process variables

Response	Model[a]	R^2
SEI	$12.74 - 1.49\, x_2 + 1.18\, x_3 - 0.53 x_2^2$	0.945
BD	$0.18 + 0.022\, x_2 - 0.028\, x_3 + 9.572 \times 10^{-3}\, x_2^2 + 8.758 \times 10^{-3}\, x_3^2$	0.877
BS	$0.88 + 0.25\, x_2 - 0.20\, x_3 + 0.066\, x_2^2 - 0.11\, x_2.x_3$	0.96
PV	$677.46 + 40.72\, x_1 + 77.61\, x_2 - 85.36\, x_3$	0.818
FV	$122.20 – 1.84\, x_1 + 10.86\, x_2 – 2.75\, x_3 + 3.24\, x_2^2$	0.876
Hunter *L*	$55.22 - 2.36\, x_1 + 2.45\, x_2 – 1.59\, x_3 – 1.47\, x_1^2$	0.773
Hunter ΔE	$7.98 + 0.42\, x_1 – 2.46\, x_2 + 1.63\, x_3 + 2.22\, x_1^2$	0.758

[a]*Significance by F-test (P≤0.05)*

x_1 concentration of bhimkol power { g/kg}; x_2 feed moisture content {%}; x_3 extrusion temperature (^oC)

2.5 Evaluation of Bulk Density (BD) of Extrudates

Bulk density of extrudates was determined using glass-bead displacement method using a graduated cylinder (100 ml). The cylinder was tapped soundly 20 times. The weight of each sample was weighed on an electronic balance. The bulk density (g/cm^3) was calculated by dividing the weight of the extrudates by the volume displaced. Ten measurements were taken for each treatment (Bhatnagar and Hanna, 1995).

2.6 Evaluation of Breaking Strength (BS) of Extrudates

Texture evaluation of the extrudates was performed with texture analyzer (TA-HD-plus, Stable Micro Systems, UK). Breaking strength of extrudates was determined as the maximum force offered by extrudates during compression and three point cutter test, respectively (Onwulata *et al.,* 2001).

$$\text{Breaking Strength (N/mm}^2\text{)} = \frac{\text{Peak breaking force}}{\text{Cross sectional area}}$$

2.7 Evaluation of Colour Values

The colour values of low-amylose rice extrudates incorporated with *bhimkol* in terms of *L*, *a*, *b* values was measured using colour measurement spectrophotometer (Hunter Lab, Ultra-scan VIS).

2.8 Rheological Properties

Pasting properties of extrudate powders were determined using a Rapid Visco Analyser (RVA) Model 2-D (Newport Scientific Instrument) with Thermocline software (3.0 version) by ICC Standard Method No. 162 (1995). Briefly sample suspension was prepared by placing extrudate powder (3.5g) in an aluminum canister containing 25g distilled water. A programmed heating and cooling cycle was used. Each sample was stirred at 960 rpm for 10 s while heating at 50ºC, and then constant shear rate (160 rpm) was maintained for the rest of the process. Temperature was held at 50ºC up to 1 min. Then the samples were heated (50-95ºC, 3 min 42 s) and held at 95ºC for 2 min 30 s. Subsequently samples were cooled down (95-50ºC, 3 min 48 s) and then held at 50ºC for 2 min. An RVA plot of viscosity (cp) versus time (s) was used to determine peak viscosity (PV) and final viscosity (FV).

2.9 Water Absorption Index (WAI) and Water Solubility Index (WSI)

WAI and WSI were determined using the Anderson *et al.* (1969) procedure. Each flour (2.5 g) was suspended in 30ml of distilled water in a tared 60ml centrifuge tube. The slurry was stirred with a glass rod for 1min at room temperature and centrifuged at 3000 xg for 10min. The supernatant was poured carefully into a tared evaporating dish. WAI was calculated from the weight of the remaining gel and expressed as g gel per kg (dry sample). WSI, expressed as g solids per kg original solids, was calculated from the weight of dry solids recovered by evaporating the supernatant overnight at 110°C.

2.10 Nutritional Evaluation

Energy value was estimated in a bomb calorimeter (Model LECO AC-350, LECO Corp.) and protein content was determined by Micro Kjeldhal method. Moisture, fat, crude fiber and ash were determined by standard methods (AOAC, 2000). Carbohydrates were determined by difference. Magnesium and potassium content were determined using flam-mode in an Atomic Absorption Spectrophotometer (Model 3600, Thermofisher).

2.11 Sensory Evaluation

Sensory attributes such as color, hand feel, flavour, surface finish, taste, crispiness, mouth feel and over all acceptability of extrudates were evaluated by a trained panel of 10 members. A 9-point hedonic scale reading (1-4 dislike extremely to slightly, 5-neither like nor dislike, 6-9 like to slightly extremely) was used. The samples were prepared by conditioning the extrudates at 105°C for 3 min in hot air oven for sensory evaluation.

3. Results and Discussion

Variable of responses (SEI, BD, BS, PV, FV and Hunter –*L*, ΔE) of extrudates with independent variables *bhimkol* powder (BP), feed moisture content (FMC) and barrel temperature (BT) are shown in Table 3. A complete second order model was tested for its adequacy to decide the variation of responses with independent variables. To aid visualization of variation in responses with respect to processing variables, series of three dimensional response surfaces (Fig 1 to 4) were drawn using design expert software (Statease 7.1.1).

$$y = b_o + b_1 x_1 + b_2 x_2 + b_3 x_3 + b_4 x_4 + b_{11} x_1^2 + b_{22} x_2^2 + b_{33} x_3^2 + b_{44} x_4^2 + b_1 b_2 x_1 x_2 + b_1 b_3 x_1 x_3 + b_1 b_4 x_1 x_4 + b_2 b_3 x_2 x_3 + b_2 b_4 x_2 x_4 + b_3 b_4 x_3 x_4 + \varepsilon$$

3.1 Effect of Extrusion Cooking on Sectional Expansion Index (SEI) of Extrudates

ANOVA for the model of SEI as fitted shows significance ($P<0.05$) and the lack of fit is non-significant ($P>0.05$). The response surface regression model on SEI yielded excellent fits with coefficient of determination ($R^2 = 0.945$) for *bhimkol* incorporated rice extrudates. Temperature has a significant positive linear effect ($p<0.01$) whereas it's non-significant quadratic effect ($p>0.05$) was negative. Feed moisture has significant negative linear and quadratic effect on SEI of *bhimkol* incorporated rice extrudates. SEI of *bhimkol* incorporated rice extrudates varied between 9.18 and 15.42 based on the level of extrusion variables. Guha and Ali (2006) reported better SEI for extrusion cooking of low amylose rice at 120 °C. Chinnaswamy and Hanna (1998) also reported better expansion index for corn starch extrudates in the temperature range 110 to 140 °C. The response surface (Fig 1) shows that temperature and feed moisture content had a dominant effect on SEI whereas level of *bhimkol* incorporation seemed to have a minimum effect. Altan (2008b) had reported significant effect of barrel temperature on SEI of barley flour extrudates. SEI increased rapidly with the increase in BT which may be due to higher degree of superheating of water in the extruder encountering bubble formation and expansion of the melt (Ding *et al.,* 2006). Significant decrease in SEI has been observed with the increase in FMC. According to Ding *et al.* (2005; 2006) decrease in expansion may occur due to reduction of elasticity of dough through plasticization of melt. The increase in FMC reduces the friction between the feed material, screw and barrel and also has a negative effect on the starch gelatinization and consequently reduces product expansion (Liu *et al.*, 2000).

3.2 Effect of Extrusion Cooking on Bulk Density (BD) of Extrudates

Bulk density of *bhimkol* incorporated rice extrudates ranged from 0.13 to 0.27. SEI is not

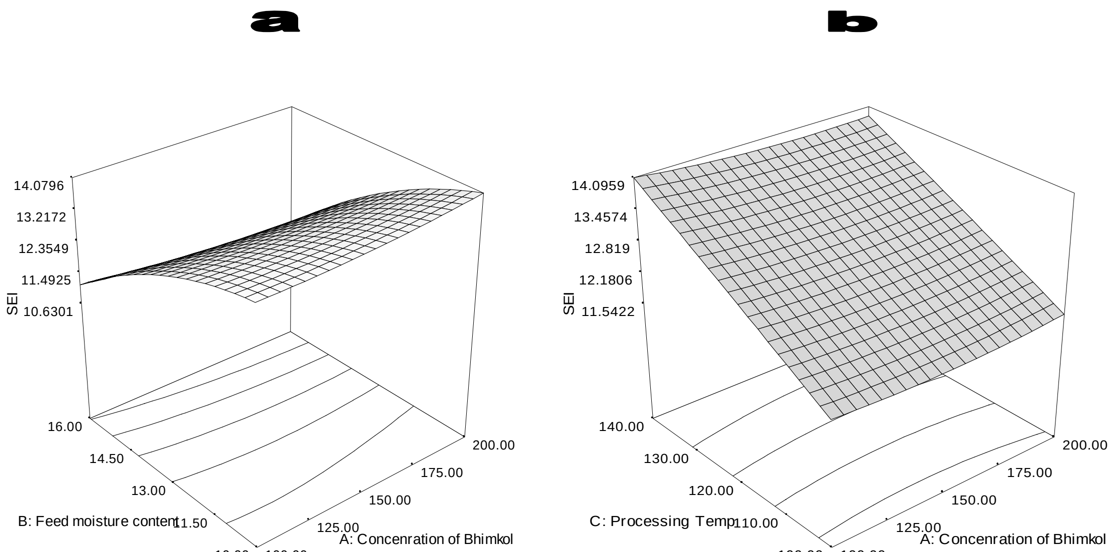

Fig 1: Effect of response variables on the SEI of the extrudates

sufficient enough for expansion by itself under the extrusion condition. Bulk density expressed as g/cm^3 is another measure of expansion besides SEI. Acceptable coefficient of determination (R^2=0.877) was obtained for significant model (P<0.05) with non-significant lack of fit (P>0.05) variations.

It was perceived from Fig 2 that with the increase in barrel temperature bulk density decreased which may be attributed to higher expansion but at higher temperatures its quadratic effect dominated. Guha and Ali (2006) reported decrease in BD values with gradual increase in barrel temperature for low amylose rice extrudates. Suksomboon *et al.* (2011) reported similar effect of barrel temperature on the BD of extrudates developed from Hom Nil rice. According to Altan *et al.* (2008a) with the gradual increase in BT, the rise in degree of superheating of water leads to better expansion and results in lower BD. At comparatively higher temperatures melt viscosity gets reduced hence bubble walls become too thin to contain the vapor pressure, resulting in more bubble fracture, thus increasing rate of collapse and overall expansion reduced, which is sufficient enough to favor the quadratic effect on BD (Fletcher *et al.,* 1985). The higher BD values were obtained at lower temperatures as shown in Fig 2. Increased feed moisture may reduce the elasticity of the dough through plasticization of the melt, resulting in reduced SME and therefore reduced gelatinization, decreasing expansion and accompanied by increase in bulk density of the extrudates (Ding *et al.,* 2006).

3.3 Effect of Extrusion Cooking on Breaking Strength (BS) of Extrudates

BS of extrudates ranged from 0.549 to 1.508 with an average of 0.934 respectively. ANOVA for the model of BS as fitted shows significance (P<0.05) and the lack of fit is non-significant (P>0.05). The response surface regression model on SEI yielded excellent fits with coefficient of determination (R^2 = 0.96) for *bhimkol* incorporated rice extrudates. BT and FMC were found to have the most significant effect. Liu *et al.* (2000) reported that increase in feed moisture reduced expansion and provided a dense product that required the higher force to break the sample. BS was found to have lower values for extrudates at higher barrel temperature as shown in Fig 2. Suksomboon *et al.* (2011) reported lower hardness values for extrudates developed from Hom Nil rice at higher barrel temperature. A decrease in BS of the extruded product was observed with increase in BT. Sacchetti (2005) reported direct correlation between hardness and density of extruded cereal blend. An increase in processing temperature will cause drop in melt viscosity favoring bubble growth, signifying better expansion and lower density to have softer extrudates.

3.4 Effect of Extrusion Cooking on Rheological Properties of Extrudates

Acceptable coefficient of determination values (R^2 = 0.818 and 0.876) were obtained for significant models such as peak viscosity with significant (P<0.05) and final viscosity with non-significant lack-of-fit (P>0.05) variations. Ding *et al.* (2005) reported decrease in melt viscosity and reduced viscosity effect which favored better expansion. It was observed from Fig 3 that PV and FV gradually decreased with increase in BT (Guha and Ali, 2006; Guha *et al.,* 1998; Balasubramanian *et al.,* 2012a). The decrease in PV and FV may be explained by the fact that due to extrusion cooking water penetrates into the granules and weakens the hydrogen bonds in starch segments and reflects a degradative RVA profile (Balasubramanian *et al.,* 2012a; Balasubramanian *et al.,* 2012c). Increase in PV was observed with higher FMC which may be due to gelatinization, since during heating the rate of thinning declines which could be ascribed to the counter effect of swelling of partially gelatinized material (Schweizer *et al.,* 1986). Moraru and Kokini (2003) also reported that extrusion temperature plays the major role in changing the rheological properties of the extruded melts, which in turn affects the expansion volume.

3.5 Effect of Extrusion Cooking on Hunter *L, a, b* Values of Extrudates

The coefficient of determination (R^2) for the Hunter *L* color parameter and ΔE were 0.773 and 0.758 and lack of fit (P<0.05) found to be significant for both. The chosen processing condition did not influence significantly (P>0.05) either Hunter *a* or *b* color value, thus detailed analyses of the two color values are not further explained in this study. All the 3 variables were found to be significant and the effect of independent variables on Hunter *L* value is shown in Fig 4. Increase in processing temperature results in decrease in Hunter *L, a, b* value, due to Maillard browning of sugar present in *bhimkol* powder. Ilo and Berghofer (1999) also reported similar decrease in Hunter *L* value due to rise in extrusion cooking temperature of maize grits. Increase in BT results increased rate of browning reaction, which increased the total color difference, ΔE.

3.6 Sensory Evaluation

Level of ingredients not only affects the various quality aspects, but organoleptic qualities also. Extrudates having better viscosity profile and EI produced at different combination were subjected for sensory evaluation. The hedonic scale mean scores for

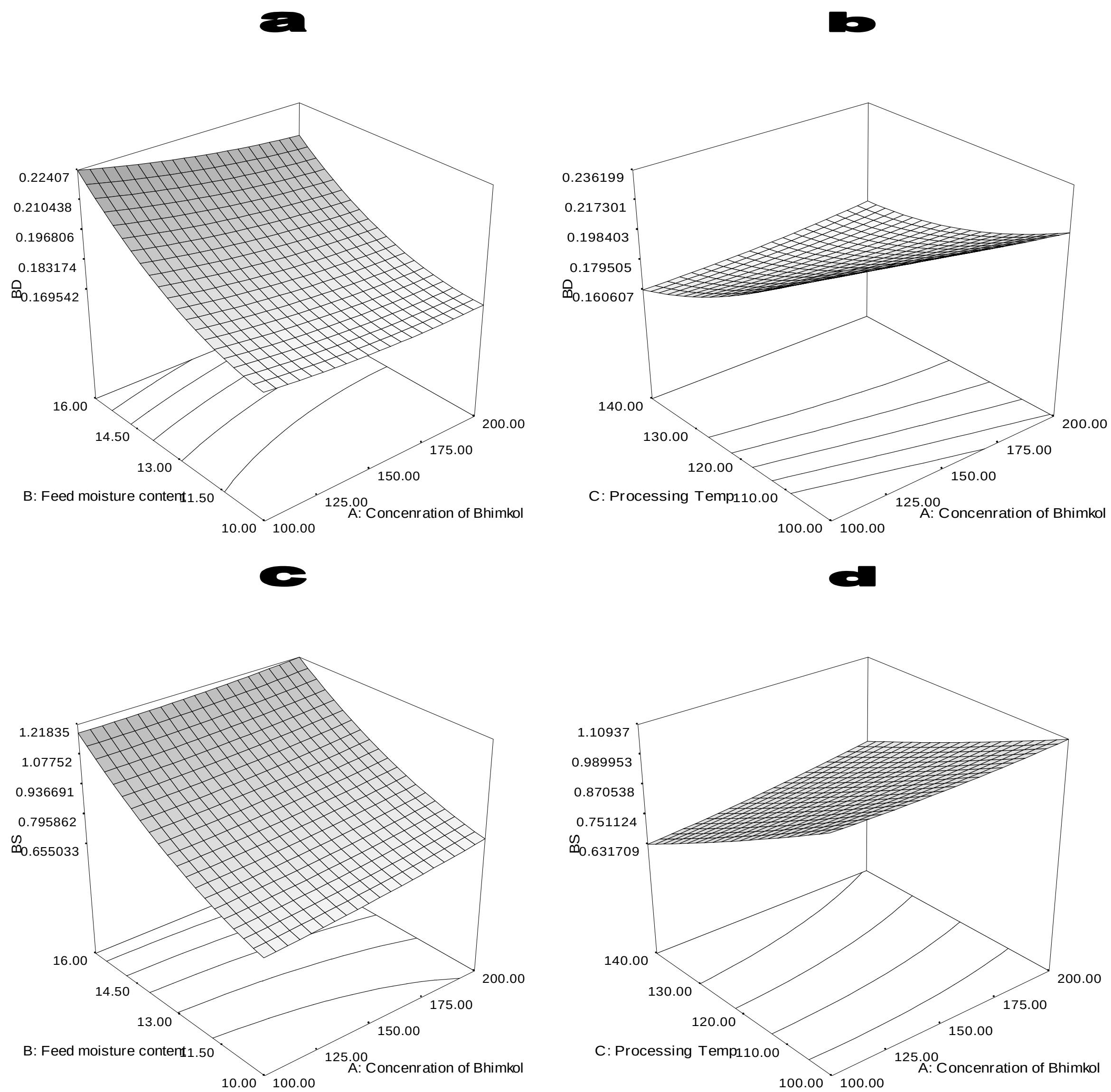

Fig 2: Effect of response variables on the on BD (a-b) and BS (c-d) of the extrudates

the extrudates are shown in the Fig 5. Sensory evaluations (overall acceptability) of extrudates made of low-amylose rice (incorporated with *bhimkol* powder) using single screw food extruder were found to be in the range between 6 and 8. All the extrudates scored in the liking range.

3.7 Multiple Response Optimizing

In order to optimize processing condition for extrusion cooking of low-amylose rice blend by numerical optimization, which finds a point that maximizes the desirability function, equal importance of 3 was given to all the 3 parameters. However, based on their relative contribution to quality of final product the importance given to different responses was 4, 4, 3, 3, 3 and 3 for SEI, BD, BS, PV, FV, Hunter L and ΔE values respectively. The optimal combination for BP,

Table 3: Optimized parameters in the response optimizer

Response	Goal	Lower Limit	Upper Limit	Lower Weight	Upper Weight	Importance
SEI	Maximum	9.181	15.416	1	1	4
BD	Maximum	0.129	0.268	1	1	4
BS	Minimum	0.549	1.589	1	1	3
PV	Minimum	460	978	1	1	3
FV	Minimum	110	152	1	1	3
L	Minimum	46.47	61.39	1	1	3
ΔE	Minimum	3.698	16.555	1	1	3

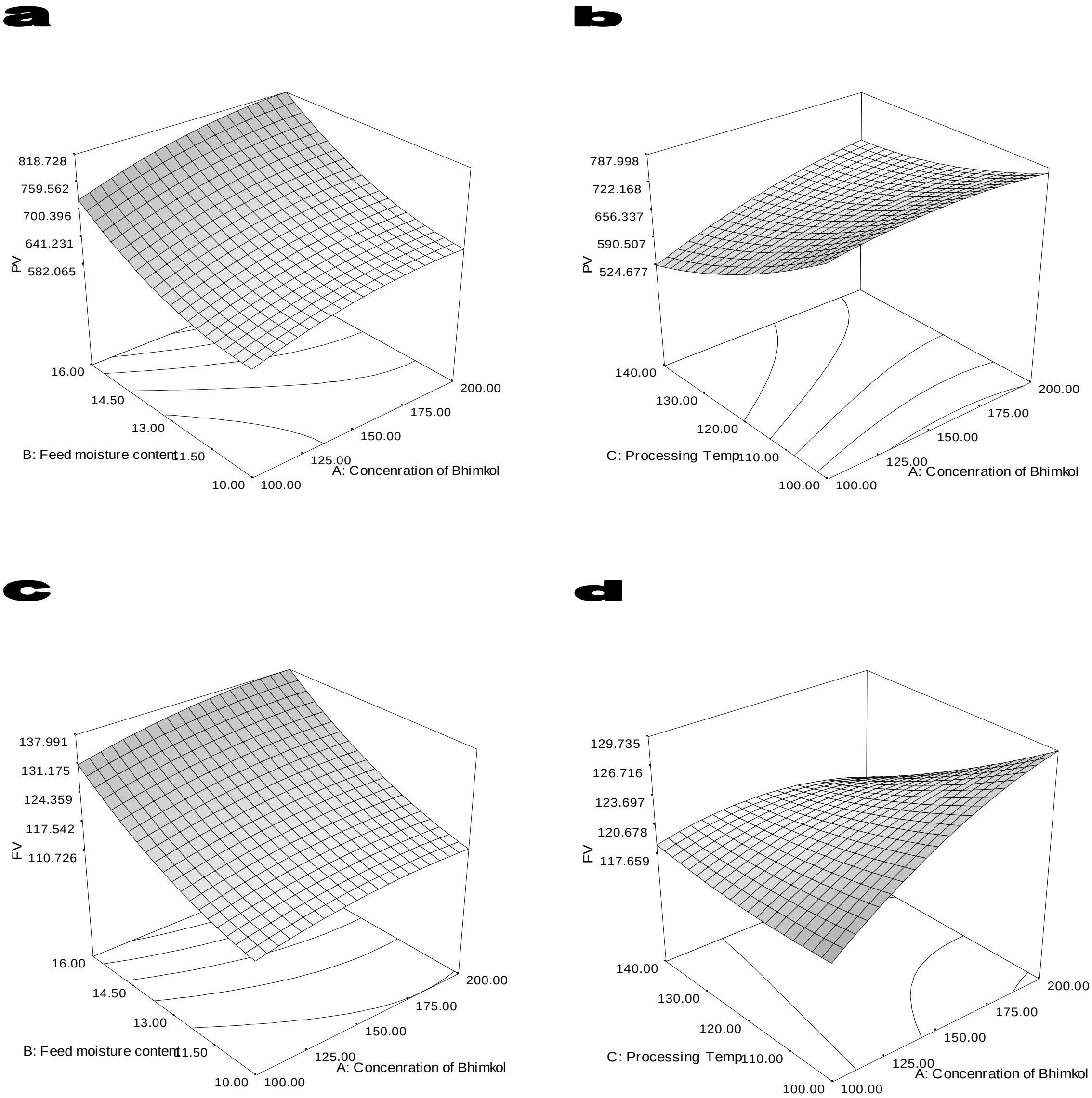

Fig 3: Effect of response variables on the PV (a-b) and FV(c-d) of the extrudates

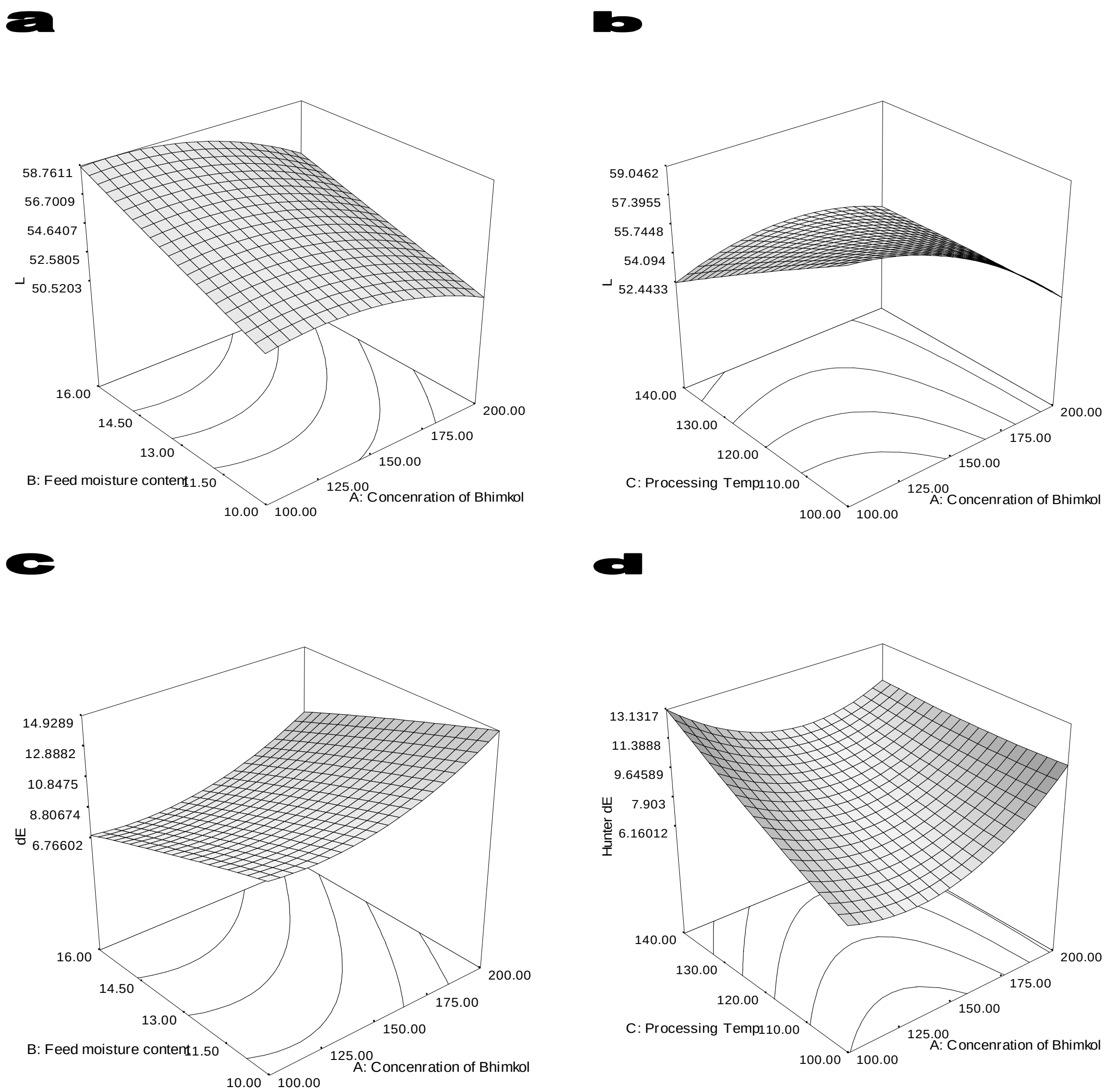

Fig 4: Effect of response variables on the Hunter L-value (a-b) and Hunter ΔE (c-d) of the extrudates

Table 4: Optimized solution obtained using the response optimizer

Optimal solution			Predicted responses						
X_1 (g/kg)	X_2 (%)	X_3 (^oC)	SEI	BD g/cm^3	BS N/ mm^2	PV	FV	L	ΔE
135	12.5	140	14.54	0.15	0.55	531.05	112.56	48.63	5.29

FMC and BT, was 13.5 g/100g, 12.5% and 140 ^oC (Table 4), respectively which corresponds to run-17. The overall desirability, which ranges from zero outside of the limits to one at the goal, was 0.754.

3.8 Physicochemical and Nutritional Characteristics of Optimized Extruded Flour

The single-screw extruder was operated at the optimum combination of process variables, ie SS = 350 rpm, BT=140°C, FMC=10 % and BP=100 g/kg, for the production of extrudates from low-amylose rice.

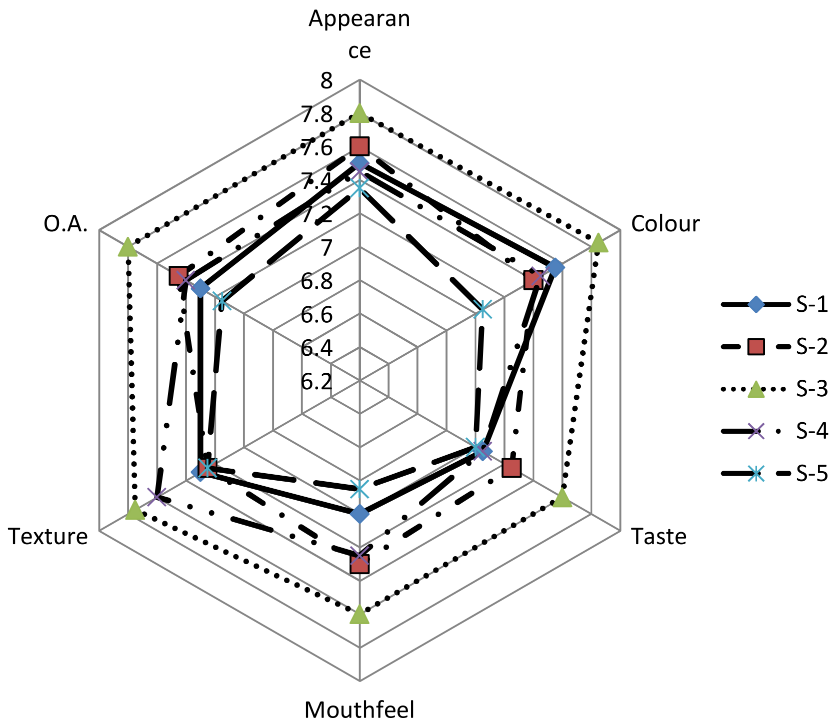

Fig 5: Sensory score for *bhimkol* powder incorporated *low-amylose* rice extrudates.

Table 5: Nutrition profile of *bhimkol* incorporated low amylose extrudates

Sl. No	Nutritional Information	Values (100g)
1	Energy, Kcal	398.50 ± 4.2
2	Moisture, %	7.02 ± 0.2
3	Protein, g	8.12 ± 0.19
4	Fat, g	0.62 ± 0.007
6	Crude Fiber, g	1.79 ± 0.05
7	Ash, g	1.08 ± 0.02
8	Carbohydrate, g	81.44 ± 2.13
9	Mg, mg	13.25 ± 0.02
10	K, mg	21.7 ± 0.05

Extrudates were cooled and dried at room temperature (50°C) for 1h, then milled to pass through a 65-US mesh (0.21 mm) screen, packed in plastic bags and stored at 4°C. This flour was recognized as optimized extruded flour. The WAI and WSI values were found to be 448.16 g/100g and 44.43 g/100g respectively. Guha and Ali (2006) also reported higher WSI of rice extrudates from low amylose rice variety. Extrudates were found to have better nutrition profile (Table 5) and considerable amount of Mg (13.25 mg) and K (21.7 mg) respectively.

4. Conclusion

Temperature and feed moisture content had the most significant effect on the extrudates. The optimal conditions of 10% feed moisture content and 140 °C barrel temperature for 10% incorporation of *bhimkol* flour showed higher preference levels of texture, color and pasting properties compared to other selected extrudates. Due to high mineral content, seeded banana flour has a great potential as a food ingredient in making different ready to eat cereal products as well as snack foods. The addition of minerals by incorporating *bhimkol* (seeded banana) provides opportunities for the processing industry to add up healthier consumption appeal. This study thus standardized an extruded product using low amylose rice and seeded banana flour (*Musa balbisiana*, ABB) which can provide both nutrition and health benefits.

Acknowledgement

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