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Optimisation and Evaluation of Ricebean (*Vigna Umbellata*) Extrusion Process for Downstream Food Processability

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ABSTRACT

Ricebean*(Vigna umbellata)*, a native bean of North-Eastern part of India has not been explored fully for development of convenience foods although it is loaded with various vitamins, minerals, dietary fiber, phytochemicals and bioactive compounds. The effect of extrusion parameters namely moisture content, barrel temperature and screw speed on expansion ratio, extrudate density, and breaking strength was investigated by using response surface methodology. It was observed that moisture content of flour had significant ($p<0.05$) affect on expansion ratio, extrudate density, and breaking strength of extrudates. The optimal combination of process parameters which resulted in extrudates with maximum expansion ratio but minimum extrudate density and breaking strength were 15 per cent moisture content, 110°C barrel temperature and 350 rpm screw speed. The value of water absorption index, water solubility index, swelling power, oil absorption index, bulk density, true density and colour for optimally extruded ricebean flour (OEF) was found significantly different ($p<0.05$) whereas value of proximate parameters were insignificant ($P>0.05$) than the native flour. The OEF was used for different downstream processings such as papadability, friability, steamability, cakeability, gravyability and porridgability and compared with that of native flour for their process quality parameters. The cake prepared with OEF had significantly ($p<0.05$) less baking time (25 min) than the cake of native ricebean flour (35 min). However, consistency and over all acceptability (OAA) of porridge from OEF was found significantly ($p<0.05$) higher than porridge of native ricebean flour. Hierarchical cluster analysis on OAA showed that porridgability and cakeability were most influential downstream processes.

Keywords: Extrusion; Processability; Dendrogram; Ricebean; Optimisation; Expansion ratio.

1. INTRODUCTION

Over last decade, extrusion technology has become an important tool for food processing which is being used extensively for manufacturing various types of snacks and breakfast foods based on corn, rice, wheat, millet, pulses etc. Extrusion is a process of high temperature short time (HTST), in which moistened foods materials are subjected to extreme mechanical shear in presence of heat and pressure; worked into viscous, plastic-like dough and cooked before being forced through the die[1].The opening of the die is facilitated to expand and shape of food materials and cutter of extruder sliced into desired length. The extrusion technology has been popular among food industries due to its advantageous features such as short process time, versatility, energy efficiency, low operating costs, high productivity, and low wastage[2]. Extrusion technology initially being used to produce snack and breakfast foods only from cereals such as corn, rice and wheat etc.. However , due to demand of nutritious and health foods in subsequent time; the pulses have been extruded along with cereals to improve the nutritional quality and health benefits of this snack and breakfast foods. The extrusion cooking of pulses is one of the simplest techniques to decrease the content of anti-nutritional factors such as enzyme inhibitors, tannin, phytic acid, saponin, and oligosaccharides, which eventually improve nutritional qualities by enhancing nutrients digestibility and bioavailability[3-4]. The products prepared from extrusion cooking of pulses or it's blends have better textural, sensory qualities with reduced cooking time[5]. There are a number of factors associated with extrusion cooking process which are directly or indirectly responsible for final extrudates qualities (nutritional, textural and functional quality) as well as quantity (yield). These factors are feed composition, particle size of feed, feeding rate, and moisture content of feed, type of extruder, die size, barrel temperature, die temperature and screw speed. Out of these factors, feed material composition, moisture content of feed material, barrel temperatures and screw speed are mainly affected the for textural quality or crispiness of extrudates[6]. The crispiness quality of extrudes are imitated by expansion ratio, density and breaking strength. Incorporation of pulse or bean flour into cereal flour resulted poor textural quality of extrudates because of reduction in expansion and increase in density, breaking strength[7] due present of protein and crude fibre. Expansion is an indicator physical parameter which influences the density, breaking strength, water absorption capacity and solubility and other functional properties of extrudates. Protein content of pulse flour decreases the extrudates expansion which leads to increase the density, breaking strength and decrease solubility and water absorption capacity[8]. Extrusion cooking

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is being performed for many pulses or beans to study the processing affect on nutritional and anti-nutritional factors but very limited works are being carried to study the influence of extrusion conditions on quality characteristics of bean extrudates. Although, the effect of extrusion cooking condition on extrudates quality characteristics of chickpea[9], redbean[10], pinto bean[11], black bean[12] are being studied extensively but such reports on ricebean (*Vigna umbellata*) extrusion are sparse.

Ricebean is an underutilised minor bean of India which is mainly available in South and South-Eastern Asian countries and to a limited extent in West Indies, USA, Queensland (Australia) and in East Africa[13]. In North-East India, it is conventionally used to prepare curry and deep fried snacks. Although extrusion technology has been used recently for manufacturing of convenience foods which include ready to eat (RTE) breakfast cereals, snacks and confectionery products[4], proteins and meat analogues (e.g., soy meat analogues), and baby foods (instant soups, weaning cereals, biscuits) but information to validate downstream process by using extruded flour from other beans as well as ricebean under single grain entity is scanty. Moreover, optimisation and verification of extrusion process for ricebean not only improve nutritional values but also expand the horizon for new downstream processing for development of processed products. Hence, this research work was undertaken so as to optimise extrusion process parameters and to establish this process for downstream processing such as papadablity friability, steamability, gravyability, cakeability and porridgeability. The term papadablity in the present context refers to papad making quality of ricebean flour and similarly the terms viz friability, steamability, gravyability, cakeability and porridgeability also refers respective product making ability from ricebean flour.

Table 1. Experimental design with actual (coded) levels of variables along with corresponding response values

Run	MC (%)	BT (°C)	SS (rpm)	ER	ED (kg/ m^3)	BS (g)
1.	25 (+1)	140 (+1)	340 (-1)	2.73	169.4	1490
2.	20 (0)	150.23 (+α)	350 (0)	2.80	98.8	980
3.	20 (0)	125 (0)	350 (0)	2.90	223.4	2198
4.	25(+1)	110(-1)	360(+1)	2.57	285.0	2850
5.	20 (0)	125 (0)	350 (0)	2.86	231	2298
6.	15 (-1)	110 (-1)	340 (-1)	3.30	129.3	1293
7.	20 (0)	125 (0)	366.82 (+α)	2.95	225	2260
8.	20 (0)	125 (0)	333.18(-α)	3.11	173.4	1698
9.	15 (-1)	140 (+1)	340 (-1)	3.25	115	1155
10.	25 (+1)	110 (-1)	340 (-1)	2.70	232	2095
11.	28.41(+α)	125 (0)	350 (0)	2.38	277.4	2698
12	20 (0)	125 (0)	350 (0)	2.89	223.4	2180
13.	20 (0)	125 (0)	350 (0)	2.93	248.5	2122
14.	20 (0)	125 (0)	350 (0)	2.89	223.4	2310
15.	15 (-1)	110 (-1)	360 (+1)	3.10	158.5	1580
16.	20 (0)	125 (0)	350 (0)	2.95	223.4	2130
17.	15 (-1)	140 (+1)	360 (+1)	3.15	135.2	1349
18.	11.59(-α)	125 (0)	350 (0)	3.47	101.8	1018
19.	25 (+1)	140 (+1)	360 (+1)	2.62	210.9	1885
20.	20 (0)	99.77 (-α)	350 (0)	2.65	248.7	2384

MC - Moisture Content, BT - Barrel Temperature, SS - Screw speed, ER - Expansion ratio, ED - Extrudate density, BS - Breaking Strength, α-1.414

2. MATERIALS AND METHODS

2.1 The Extrusion Process

The total moisture of the flour was adjusted to the desired level and the mixture was allowed to equilibrate for 16h before extrusion. Extrusion cooking was done in a co-rotating twin screw extruder-EB-10 model (M/s. Basic Technologies Pvt. Ltd., Kolkata India). The extruder had a barrel length to diameter ratio of 8.56:1. The length of the die was 27mm with 3mm aperture. The samples were extruded at a screw speed of designed rpm and designed barrel temperature. Extrudates were collected when steady state (constant temperature and torque) was achieved. Extrudates were dried at 60 °C for 1hr and then packaged in polythene bags for further use.

2.2 Experimental design

A 3-level central composite rotatable design (CCRD) was created by using the three independent variables with six replications at central point (Table 1). These three variables and their range of study in parenthesis were moisture content (MC) denoted as X_1 (15 % – 25 %), barrel temperature (BT) denoted as X_2 (110 °C – 140 °C), and screw speed (SS) denoted as X_3 (340 rpm - 360 rpm). The extrusion quality was evaluated by determining the parameters such as expansion ratio (ER), extrudate density (ED), breaking strength (BS).

2.3 Analysis of Extrudates

2.3.1 Expansion Ratio

Expansion of extrudates was evaluated as expansion ratio(ER) and measured in terms of diameter, at three points on each piece of the extrudate to the die diameter by using a vernier caliper[2]. Measurements were taken on ten randomly selected pieces of extrudates.

ER= Mean diameter of extrudates/Diameter of die

2.3.2 Extrudate Density

Extrudate density (ED) was determined as per the procedure of Ding[2], *et al.* and expressed as kg/m^3. Ten replicates of extrudate were randomly selected from each experiment and measured for mass (m), length (Le) and diameter (D) and the average of these measurements was taken and ED was calculated as per following equation

$$ED = [(4 \times m)/(\pi \times D^2 \times Le)]$$

2.3.3 Breaking Strength

Breaking strength[14] of extrudate was determined by using a texture analyser TA-XT2 (Stable Micro Systems, Surrey, England), with a 50 kg load cell and a Warner–Bratzler shear cell (1-mm thick blade). The extrudates were analysed at a cross head speed of 0.2 mm/s. Single extruded cylindrical rod was placed across the Warner–Bratzler shear cell and cut into two pieces by the shear blade. Breaking strength is the breaking force required to cut the product into two pieces. The reported values were the average of 20 determinations.

2.3.4 Physico-chemical Analysis of Extrudates

Water absorption index (WAI) and water solubility index (WSI) were determined using powdered extrudates[2]. The bulk density (BD), true density (TD) and porosity were measured using flour of the extrudate[15]and results were expressed as kg/m^3. Color measurement (C), oil absorption index (OAI), swelling power (SP) were measured as per Bepary[15], *et al.*, Liadakis[16], *et al.*, and Tester and Marrison[17], respectively. Proximate composition was determined using standard AOAC procedures.

2.4 Verification of Rice Bean Extrudates for Downstream Food Processing

The flours prepared from native bean and the extrudates from optimised extrusion process were evaluated for the following downstream products/processes.

2.4.1 Papadability

The papads were prepared from both native and extruded flour and qualities for process were observed and products qualities such as expansion ratio and oil uptake ratio were studied[18]. The sensory evaluation was carried out as per 9-point hedonic scale to find out overall acceptability (OAA).

2.4.2 Friability

The thin dough was prepared by kneading the flour with water and other ingredients such as spices, salt and baking powder, groundnut oil was heated up to 180 °C and ball sized dough of 12 gm - 13 gm was fried till turns golden brown colour. The process for fried snacks was observed and products quality was judged by weight loss (%), BD (kg/m^3), C and OAA.

2.4.3 Steamability

The 100 per cent rice flour was mixed with other ingredients (Spices and salt) and kneads them into thick dough with water. Same thick dough was also prepared from native and extruded ricebean flour by replacing 50 per cent rice flour. The dough was shaped into cylindrical form with 2.5 cm diameter and 5 cm length. The cylindrical shape dough was cooked under steam in pressure cooker for 10 min. The process for steam cake was observed and products quality was judged by weight gain (%), BD(kg/m^3), 'C' and OAA.

2.4.4 Cakeability

Cake batter was prepared with 100 per cent wheat flour with other baking ingredients[19]. Same batter was also prepared from native and extruded ricebean flour by replacing 50 per cent wheat flour. The batter was poured into aluminium pan and baked at 200 °C. The process for cake was observed and evaluate the baking time and products quality was judge by BD (kg/m^3), 'C' and OAA.

2.4.5 Gravyability

Ready to cook ricebean gravy powder was prepared by mixing the roasted ricebean flour with tomato powder, salt and spice powder. The gravy powder was cooked into gravy by boiling with water and then the process for gravy was observed and products quality was judged by consistency (%), BD (g/ml), 'C' and OAA. For determination of consistency, 10 ml gravy was allowed to pass through the 50 mm diameter borosil glass funnel and the time required for complete passing through was noted down. The same way, 10 ml distilled water was allowed to pass through the 50 mm diameter borosil glass funnel and the time required for complete passing through was noted down. The volume per second for gravy (Fs) and water (Fw) were found out and then, consistency (%) was calculated by following formula - consistency (%) = [(Fw-Fs)*100]/Fw.

2.4.6 Porridgability

Instant porridge powder was made with 100 per cent foxtail millet flour as described by Khan[20], *et al*. Bean blend instant porridge powder was prepared from native and extruded ricebean flour by replacing 50 per cent foxtail millet flour. The instant porridge powder was studied for quality parameters such as consistency (%), BD (g/ml), 'C' and OAA. The consistency was calculated in same way like gravy.

2.5 Statistical Analysis

Results obtained were statistically analysed using ANOVA and the sensory scores were further subjected to hierarchical cluster analysis as described by Steel[21], *et al.* to evaluate the influence of extrusion on sensory quality of downstream processes.

3. RESULTS & DISCUSSION

3.1. Effect of Extrusion Condition on ER

The regression equation for ER was determined in terms of coded variables as follows:

$$ER= 2.90 – 0.29X_1 – 0.059X_3 – 0.056X_2^2 + 0.052X_3^2 \quad (1)$$

The ER value under various conditions ranged between 2.38 and 3.47 (Table 1). The ANOVA of Eqn. (1) exhibited that the of F-value for X_1, X_3, X_2^2 and X_3^2 were significant ($p<0.05$) while F-value for X_2, X_1X_2, X_1X_3 and X_2X_3, X_1^2 were non-significant ($p>0.05$) (Table 2). The appropriate value of coefficient of variation (CV=1.68 %), R^2 (0.9824), adjusted R^2 (0.9666), predicted R^2 (0.8889), adequate precision (28.60) showed that the model has strong fitness. The coefficient of X_1 and X_3 was negative, thus increase in MC, SS may reduce ER. Since coefficient of X_2^2 was negative, a maximum ER will occur in the selected range of BT. It was observed from Fig. 1(a) that the increase in BT with MC till 19 per cent resulted in increased ER at 350 rpm of SS. Beyond this point of BT, further increase in the level of BT and MC reduced the ER.

Expansion is a vital part in extrusion process which

Table 2. ANOVA results of different models

Source	df	Expansion ratio			Extrudate density			Breaking strength		
		SS	'F'-value	'P'- value	SS	'F'-value	'P'- value	SS	'F'-value	'P'- value
Model	9	1.33	62.10	< 0.0001	59781.9	26.26	< 0.0001	5.46 x10^6	25.2	< 0.0001
X_1	1	1.18	493.7	< 0.0001	31378.5	124.07	< 0.0001	2.44 x10^6	101.3	< 0.0001
X_2	1	0.008	3.38	0.0957	13313.3	52.64	< 0.0001	1.35 x10^6	56.29	< 0.0001
X_3	1	0.048	20.07	0.0012	3896.5	15.41	0.0028	4.86x10^5	20.20	0.0012
X_1X_2	1	0.0008	0.33	0.5756	1227.6	4.85	0.0522	1.80x10^5	7.49	0.0209
X_1X_3	1	0.0005	0.19	0.6735	254.3	1.01	0.3397	55945.13	2.33	0.1582
X_2X_3	1	0.0018	0.75	0.4057	52.5	0.21	0.6583	25651.13	1.07	0.3261
X_1^2	1	0.0032	1.36	0.2711	3267.7	12.92	0.0049	3.05 x10^5	12.66	0.0052
X_2^2	1	0.045	18.73	0.0015	6152.4	24.33	0.0006	6.21x10^5	25.82	0.0005
X_3^2	1	0.039	16.39	0.0023	1960.6	7.75	0.0193	1.52 x10^5	6.31	0.0309
Res.	10	0.024	-	-	252.92	-	-	2.41x10^5	-	-
LOK	5	0.019	3.65	0.0907	2019.6	3.96	0.0785	2.08x10^5	6.32	0.0321
PE	5	0.0051	-	-	509.6	-	-	32851.33	-	-
Total	19	1.36	-	-	62311.0	-	-	5.70 x10^6	-	-

df : Degree of freedom, SS : Sum of square, Res. : Residual, LOK : Lack of fit, PE : Pure error, X1- Moisture Content, X2- Barrel Temperature, X3- Screw speed.

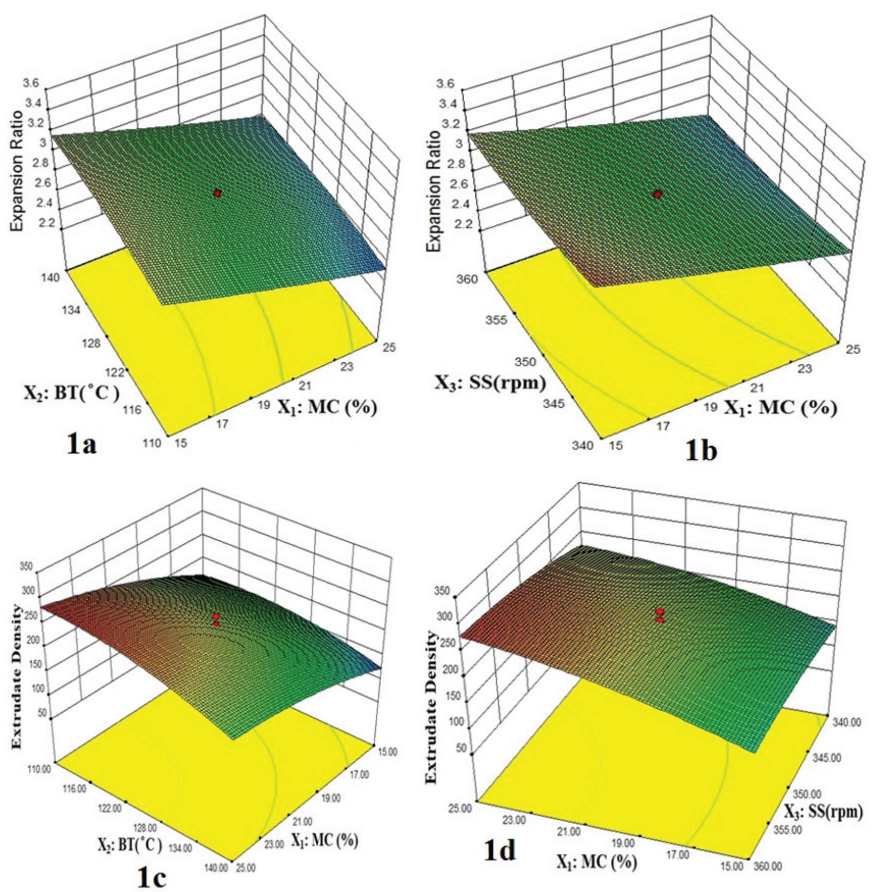

Figure 1. Effect extrusion conditions on expansion ratio, extrudate density and breaking strength. (MC - moisture content, BT - barrel temp., SS - screw speed).

generally happens at high temperature and low moisture condition. The events that occurred during expansion process are biopolymer structural transformations, nucleation, extrudate bulge, bubble augmentation and crumple, with bubble dynamics contributing to expansion. There are two predominant factors (dough viscosity and elastic force) that plays crucial role in expansion process. At the condition of low temperature and low moisture, the elastic force played dominant role[22-23].The growth of bubble in expansion process is dominated at high moisture content and high temperature which is provoked by the pressure variation along with the developing bubble core and atmospheric pressure repelled mainly with viscous bubble wall[2, 24]. An increase in the BT will decrease the melt viscosity, which lead to growth of the bubble during extrusion. Moreover, the quantity of superheating steams is increased inside the extruder barrel as temperatures increased which endorse to superior expansion. The decrease in ER with increased in moisture content is mainly due to reduction in temperature of plasticised dough and also reduced friction between the dough and the screw/barrel, and have a negative impact on the starch gelatinisation and reduce the

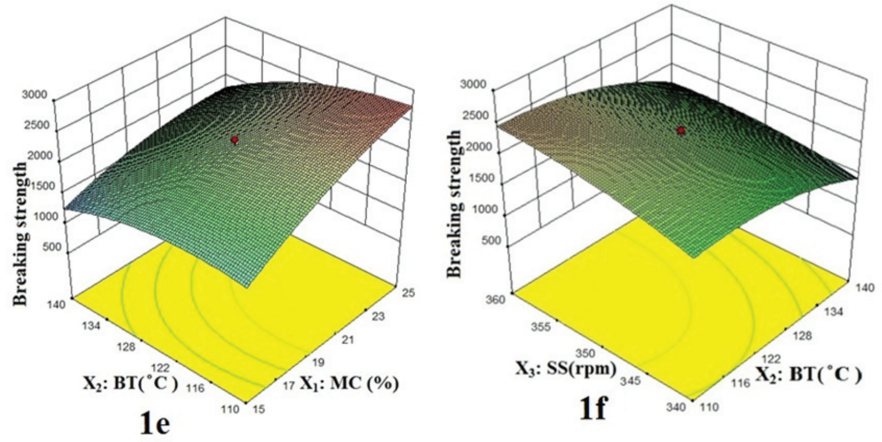

Figure 1. Effect extrusion conditions on expansion ratio, extrudate density and breaking strength. (MC-moisture content, BT-barrel temp., SS-screw speed).

product expansion[25]. The (Fig. 1b) displayed that the increase in SS with MC till 19 per cent increased the ER at 125˚C of BT. After this BT point, reduction of ER occurred with increase of SS and MC levels.

3.2 Effect of Extrusion Condition on ED

The regression equation for ED was determined in terms of coded variables as follows:

$$ED=229+47.93X_1-31.22X_2+16.89X_3-15.06X_1^2-20.66X_2^2+11.66X_3^2 \quad (2)$$

Table 1 reveals that the experimental values of ED for extrudates processed under different extrusion conditions ranged from 98.8 kg/m^3 to 285 kg/m^3. The adequate and superb fitness of model was justified by the significant value of F (26.26), non-significant value of 'lack of fit' (3.96) and acceptable values of R^2 (0.9594), adjusted R^2 (0.9229), predicted R^2 (0.7421), and adequate precision (17.11). The positive coefficient value of $X_1$and X_3 reflects that increase in MC and SS may increase ED. The negative coefficient of X_2 hints that increasing the level of BT may reduce ED. Negative coefficient of X_1^2, X_2^2 and X_3^2 implies for maximum occurrence of ED in the range of MC, BT and SS selected for study. The term X_1, X_2, X_3, X_1^2, X_2^2, and X_3^2 were statistically significant ($p<0.05$) whereas the term X_1X_2, X_1X_3 and X_2X_3 had insignificant ($p>0.05$) value of 'F' in the ANOVA of Eqn. (2) from Table 2. It was experienced from (Fig. 1(c)) that the increase in BT with MC decreased ED at 350 rpm of SS. The decrease was prominent at low moisture. The decrease in ED under this condition is due to higher gelatinisation of starch. High BT facilitates higher degree of starch gelatinisation which lowered melt viscosity of dough inside barrel. High pressure development causes maximum expansion and hence reduces ED. The increased in MC under irrespective of BT caused sharp increase in ED. The increase in MC under continuous shearing changes the amylopectin molecular structure which reduce the melt elasticity. Decreasing the melt elasticity causes less pressure differences and less bubble growth result in less expansion and increased in ED value[26,27]. It is also shown in (Fig. 1(d)) that the increase in SS with MC was increased ED at 125 °C of BT. The high SS and MC, there is less starch gelatinisation as well as more decrease in melt elasticity which causes less pressure difference at orifice of die, result in less expansion and more ED.

3.3 Effect of Extrusion Condition on BS

The regression equation for BS was shown as coded variables

$$BS= +2209.73 + 422.38X_1-314.88X_2+188.64X_3-150.12X_1X_2-145.38X_1^2-207.60X_2^2-102.60X_3^2 \quad (3)$$

The BS value under various conditions ranged between 980 and 2850g (Table 1). From processors as well as consumers point of view, the BS is an important extrusion factor. The extruded products with low BS will break easily during downstream processing and transportation while products with high BS are hard to bite and chew. ANOVA (Table 2) of Eqn3 exhibited that the of 'F'-value for X_1, X_2, X_3, X_1X_2, X_1^2, X_2^2 and X_3^2 were significant ($p<0.05$) while 'F'-value for X_1X_3, and X_2X_3 were non-significant ($p>0.05$). The values of CV (8.17), R^2 (0.9578), adjusted R^2 (0.9198), predicted R^2 (0.7127), and adequate precision (17.16) showed that the model has strong fitness. The coefficient of X_1 and X_3 was positive, thus increase in MC, SS may increase BS whereas the coefficient of X_2 was negative, and thus increase in BT may reduce BS. The coefficient of X_1X_2 was negative means increase in MC and BT in interactive terms may increase BS. Since coefficients of X_1^2, X_2^2, X_3^2 were negative, a maximum BS will occur in the selected range of MC, BT and SS. It was observed from (Fig. 1e) that the increase in BT with MC till 19 per cent of MC was decreased the BS at 350rpm of SS. After this point of MC, the increase in magnitude of these two variables was responsible for increased the BS value. At higher temperature and lower moisture content, the starch of feed materials become more gelatinised which gives more expansion, thereby its honeycomb and crunchy structure is formed & helps to get more fragile. This results in low BS. It was observed from (Fig. 1f) that the increase in SS with BT (till 125 °C), increased the BS at 20 per cent of MC. Further increase in the level of these two factors decreased the value of BS. At high SS and low BT, there may be less starch gelatinisation and more reduction in melt elasticity which causes less pressure difference at orifice of die and result in less expansion and more BS[28,29].

3.4 Optimisation and Validation of Optimum Process

The extrusion process conditions were optimised by numerical optimisation method which considered the desirability function of maximum value with equal importance to all process variables and responses (Table 3). The optimum process condition which gave the extrudates with high ER but low ED and BS were 15 per cent MC, 110 °C BT and 350rpm SS. The optimal process conditions recommended by software and the forecast responses were confirmed by tangible experiment of extrusion process. The experimental values for ER, ED and BS values were determined and compared with the predicted

Table 3. Numerical optimization criteria and experimental verification of predicted optimization.

(a) Numerical optimisation criteria

Variables and responses	Goal		Lower limit	Upper limit	Lower limit	Upper limit	Importance
X_1: Moisture Content (%)	Is in range		15	25	1	1	3
X_2: Barrel Temperature (°C)	Minimize		110	120	1	1	3
X_3 : Screw speed (rpm)	In target=350		348	358	1	1	3
Y_1 : Expansion ratio	In target=3.25		2.85	3.47	1	1	3
Y_2 : Extrudate density	Is in range		9.88	18	1	1	3
Y_3 : Breaking Strength	Is in range		980	1800	1	1	3
Desirability 0.899							
Prediction and verification	X_1	X_2	X_3	Y_1	Y_2	Y_3	
(b) Predicted solution	15	110	350	3.14	164.21	1599.13	
(c) Experimental Proof	15±0.04	110±2	350	3.15±0.22	167.4±5.4	1614.12±0.98	

values of the model (Table 3). The predicted values and the experimental values obtained were in concurrence with each other, thus validating the robustness of the optimised values.

3.5 Effect of Optimum Extrusion Process on Physico-chemical Properties

The moisture, WAI (cold and hot), WSI (cold and hot), SP (cold and hot), OAI, BD, TD and color 'C' (L, a, b values) observations for extruded flour was found significantly different ($p<0.05$) than the native flour whereas value of carbohydrates, protein, fat, crude fibre, and ash were insignificant ($P>0.05$). The value of carbohydrate, protein, crude fibre, TD, porosity, WAI (30˚C), WSI (30˚C), OAI (30˚C), 'b' (redness) increased in case of extruded flour than the native ricebean flour. However, the value of fat, ash, WAI (90˚C), WSI (90˚C), SP (30˚C and 90˚C), BD, L (lightness), and 'a' (Greenness) decreased than native ricebean flour (Fig. 2). The value of physico-chemical parameters were in agreement with the reported values[4,9,30].

The extrusion process causes the gelatinisation of starch which lead to an increase in soluble starch content, resulting in higher WAI (30˚C) and WSI (30˚C)[2,31]. The change in amylopectin chain the length distribution in starch and increase protein denaturation causes more WAI and WSI at 30 °C[26]. In raw bean flour hydrophobic group especially protein's non-polar lateral chains is mainly responsible oil absorption but due to extrusion the secondary structure is lost which lowered the OAI[26]. The decrease in 'L', 'a', and increase in 'b' is mainly because of Maillard reaction which is evident at higher temperature and screw speed as the flours and higher protein content and also high temperature combined with intermediate moisture favorably leads to non-enzymatic browning[25].

3.6 Verification of Rice Bean Extrudates for Downstream Food Processing

The results obtained for different downstream processing of products based on flours from native bean and optimally extruded bean are described below and evaluated for their hierarchy.

3.6.1 Papadability

In dough preparation stage, the extruded flour absorbed more volume of water than native ricebean flour thus kneading was difficult due to development of stickiness. The papad dough prepared from extruded flour lacked in the property to form thin papad due to difficulty in rolling, resulting in thick papad. However, this thick papad required less drying time, frying time and low oil uptake ratio. The reduction in oil uptake is due to high WAI for extruded flour whereas reduction in frying time is due to low gelatinisation enthalpy of extrudates because of formation amylose-lipid complexes[18,32.] The expansion percentage for both extruded and native bean papad was significantly ($p<0.05$) lower than commercial papad (Table 4). This may be because of presence of hull in ricebean flour. The OAA of extruded papad was significantly ($p<0.05$) lower than commercial papad but it is comparable with native bean papad. The low value OAA was due to dark colour and slight hard texture. Hence, incorporation of 100 per cent extruded flour from whole grain is not suitable for papad preparation.

3.6.2 Friability

The deep fried product from extruded flour (ExFP) was found significantly lower ($p<0.05$) in weight loss and values of 'L', 'a' and 'b' parameters (Table 4) when compared to one which was prepared from *besan* (BaFP).The lower value in 'L', 'a', 'b' for ExFP is probably because of non-enzymatic browning as well as caramelisation. Extruded process denatures protein which produces more number of lysine molecule expose from its three dimensional structure. Therefore, more number of lysine molecule take parts in non-enzymatic browning[33, 34]. The OAA of ExFP was significantly ($p<0.05$) lower than BaFP but it is comparable with fried products from native bean (NaFP). The low value OAA was due to dark colour and slight hard texture. The dough prepared from extruded flour engrossed more water than native ricebean flour and *besan*. During frying, it was observed that the dough from extruded flour had

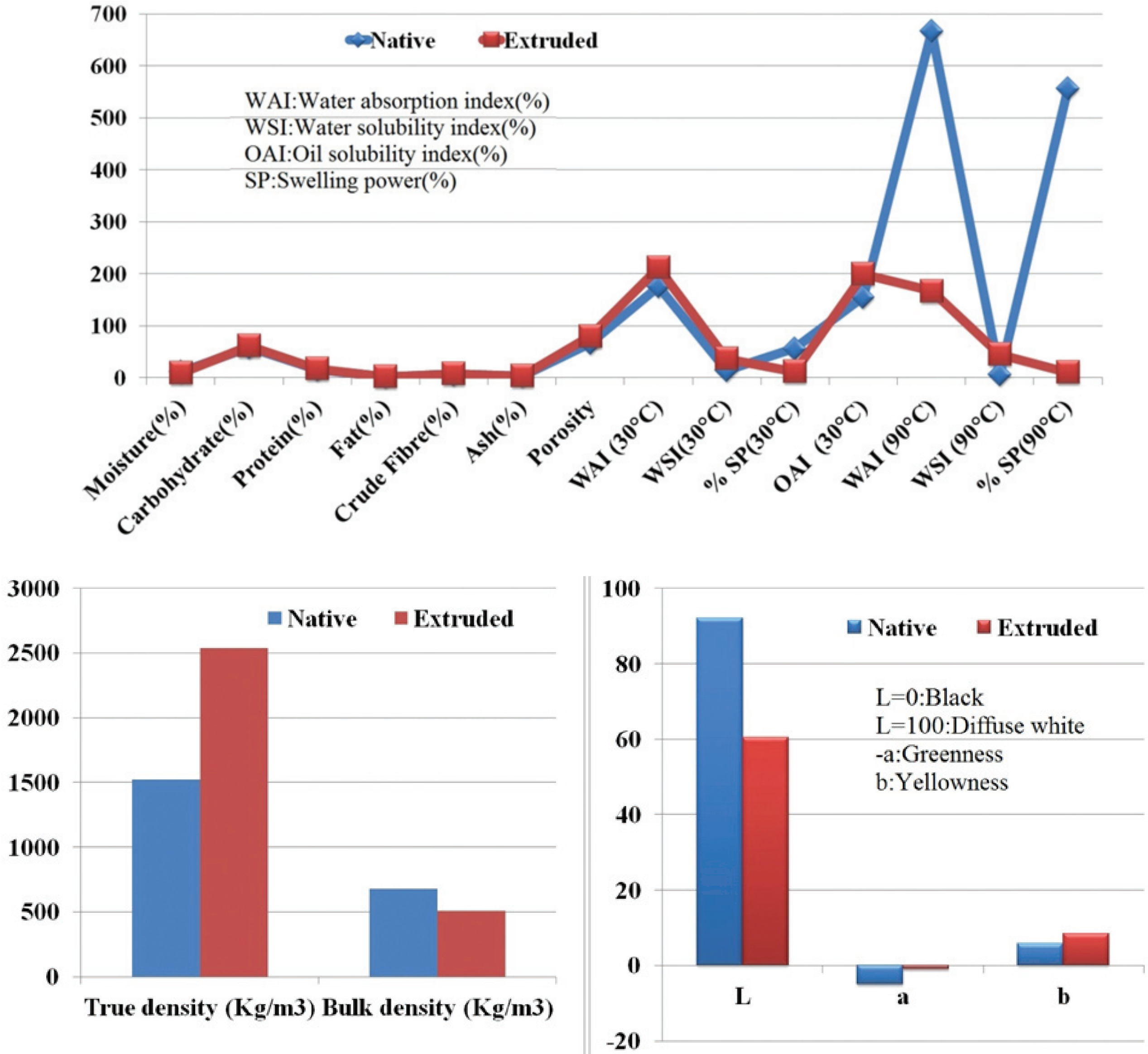

Figure 2. Comparison of Physico-chemical properties of extruded ricebean flour with native ricebean flour.

less frying time (8 min) and less oil uptake but product had rough surface with brown red colour.

3.6.3 Steamability

The spiced cake with 50 per cent incorporation of extruded ricebean flour (ExSC) had significantly ($p<0.05$) low percentage of weight gain, BD, ‘L’, and ‘b’ than steam cake with 50 per cent incorporation of native ricebean flour(NaSC) (Table 4). OAA of ExSC was found insignificantly low when compared with NaSC and rice flour. The lower value of BD is indicator of good texture.

3.6.4 Cakeability

The cake with 50 per cent incorporation of extruded ricebean flour (ExC) had significantly ($p<0.05$) low baking time than the cake with 50 per cent incorporation of native ricebean flour (NaC) and 100 per cent wheat flour(WhC). The baking time is lowered due to low gelatinisation enthalpy of extrudates because of formation amylose-lipid complexes[11]. The BD and ‘L’ ‘a’ ‘b’ values for ExC and NaC were significantly ($p<0.05$) low (Table 4) than that of WhC because of Millard reaction[34,35]. The OAA of ExC was similar with WhC. The extruded ricebean flour improved the quality of cake due to increase in smoothness, moistness etc. and decrease in roughness which gives better taste, mouthfeel and texture than the WhC. As a result similarity in OAA values was observed. During baking of NaC, there was overflowing of batter from pan during peak baking time but such incident was not observed in baking of ExC.

3.6.5 Gravyability

In the stage of gravy powder reconstitution, it was observed that gravy powder from extruded flour (ExGP) was required more quantity of water than gravy powder from native flour (NaGP) for getting similar BD value. Adding flour into hot water generally form lumps if flour directly comes in contact

Table 4. Effect of extrusion on downstream processed food quality

Downstream process	Quality characteristics					
1. Papadability	**Expansion (%)**	**Oil Uptake ratio**	**L**	**a**	**b**	**OAA**
Commercial Papad	11.33±1.23	2.50±0.24[a]	65.8±7.84	8.72±1.35[a]	21.58±1.56	8.17±0.20
Native RB papad	2.77±0.12	2.95±0.36	35.05±0.66	18.5±1.68	13.07±0.73[a]	7.31±0.24[a]
Extruded RBpapad	3.84±0.22	2.60±0.25[a]	30.5±2.16	11.2±1.37[a]	11.08±2.07[a]	7.48±0.37[a]
2. Friability	**Weight loss (%)**	**BD(Kg/m^3)**	**L**	**a**	**b**	**OAA**
Besan	20.46±2.66	2715±950[a]	38.32±4.94[a]	25.67±1.35	20.45±1.68[a]	7.8±0.30
Native RB	11.28± 1.13	2291 ±880[a]	33.57±3.36[a]	23.40±1.21	18.03±2.65[ab]	6.9±0.44[a]
Extruded RB	15.01±2.01	2224±780[a]	31.36±2.11[a]	19.93±0.78	15.2±1.36[b]	6.9±0.35[a]
3. Steamability	**Weight gain (%)**	**BD(Kg/m^3)**	**L**	**a**	**b**	**OAA**
Rice Flour	4.72±0.15[a]	1792±85[a]	64.98±7.61[a]	-0.48±3.23[a]	36.7±3.11	7.49±0.59[a]
50% Native RB	4.60±0.13[a]	1738±70[a]	52.72±5.92[a]	2.96±1.35[a]	21.02±0.92	7.13±1.51[a]
50% extruded RB	4.18±0.14	1589±50	38.36±5.40	3.12±1.38[a]	14.86±2.39	6.73±0.79[a]
4. Cakeability	**Baking Time (min)**	**BD(Kg/m^3)**	**L**	**a**	**b**	**OAA**
Wheat Flour 100%	30±3[a]	550±63	49.6±0.88	26.3±0.87	22.3±0.65	7.98±0.16[a]
50% Native RB	35±2[a]	690±55[a]	34.9±0.59[a]	17.77±1.85[a]	13.32±0.28[a]	7.37±0.15
50% Extruded RB	25±2	810±71[a]	35.78±2.02[a]	19.36±0.57[a]	12.56±1.69[a]	8.03±0.23[a]
5. Gravyability	**Consistency (%)**	**BD (g/ml)**	**L**	**a**	**b**	**OAA**
Native RB	90.06±0.25	0.92±0.01[a]	33.95±3.98	7.55±0.57	18.52±2.51[a]	8.00±0.15[a]
Extruded RB	80.06±0.20	0.93±0.01[a]	40.625±5.21	10.55±0.58	22.62±3.52[a]	7.49±0.77[a]
6. Porridgability	**Consistency (%)**	**BD (g/ml)**	**L**	**a**	**b**	**OAA**
50% Native RB	75.62±1.17	0.95±0.01[a]	73.12±11.3[a]	-3.8±1.03[a]	8.2±0.476[a]	8.15 ±0.20
50% Extruded RB	91.44±0.04	0.95±0.01[a]	74.42±7.15[a]	-3.8±0.62[a]	7.8±0.54[a]	8.47±0.12

RB, ricebean; BD, bulk density; L=0,Black;L=100,diffuse white; +a, redness; -a, greenness, +b, yellow; OAA-Overall acceptability
Value = Mean ± SD (n = 3). The values with the same superscript in a column not significantly different at p ≤ 0.05.

with hot water gelatinised and prevents the water to reach inside portion of flour. Extruded flour does not form lump as flour had already gelatinised. Moreover, there was severe lump formation for NaGP in this stage while mixing powder with hot water. Such clumps were not observed in case of ExGP. The consistency, 'L', 'a' value for ExGP was significantly ($p<0.05$) different from NaGP whereas BD, 'b' and OAA for ExGP was insignificant ($p>0.05$)

3.6.6 Porridgability

The porridge powder with 50 per cent incorporation of extruded ricebean flour (ExPP) had lump free reconstitution whereas porridge powder with 50 per cent incorporation of native ricebean flour (NaPP) had lump while mixing with hot water. The consistency and OAA of ExPP was found significantly ($p<0.05$) higher (Table 4) than NaPP whereas BD, 'L' 'a' of ExPP was insignificant ($p>0.05$). Consistency of ExPP has increased due to increase in water absorption index of extruded flour.

3.6.7 Hierarchical cluster analysis

The clusters identification of closely related products was done by hierarchical cluster analysis (HCA). Based on OAA, HCA clusters of closely related products/processes were brooked to two main clusters (Fig. 3). The first cluster of HCA groups include the products namely papad, gravy, steam spiced cake and fried snacks. It had subgroups that include papad, gravy and fried snacks. The second cluster of HCA groups was included porridge and cake. The significance influence of downstream processing on OAA can be clearly visualised on dendrogram which clearly shows that porridgability and gravyability are the suitable downstream processes that have maximum impact on OAA.

4. CONCLUSION

Response surface methodology was found to be quite

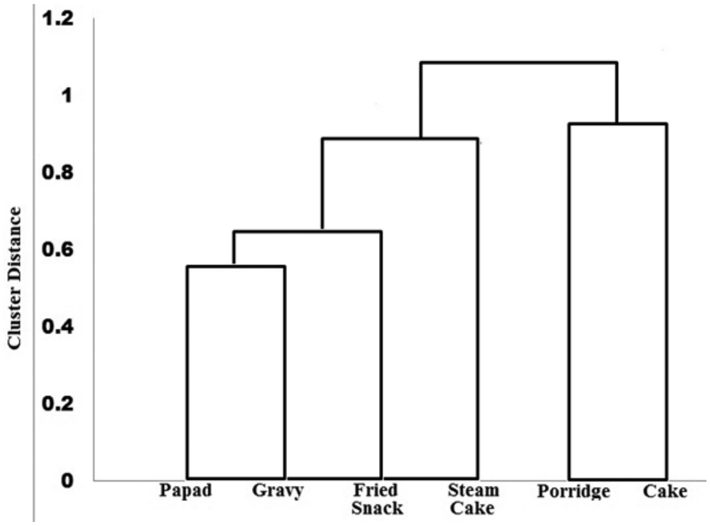

Figure 3. Dendrogram obtained from hierarchical analysis (HCA) of OAA of downstream process products from extruded flour.

useful in optimizing the process parameters of ricebean extrusion. The process parameters, moisture content (MC), barrel temperature (BT), and screw speed (SS) were studied for their effect on expansion ratio (ER), extrudate density(ED) and breaking strength (BS). The optimised process parameters were 15 per cent MC, 110 °C BT and 350 rpm SS which resulted in the extrudates with maximum ER but minimum ED and BS. The flour of the optimised extrudes (OEF) had higher ER, porosity, WAI (30 ^{O}C), WSI (30 ^{O}C), OAI (30 ^{O}C), 'b' (redness) than the native flour. The OEF was used to evaluate for its downstream processibilty using various processes. The cake made with OEF had significantly ($p<0.05$) low in baking time (25 min) than the cake of native ricebean flour (35 min). It also had significantly increased consistency and lump free batter can be achieved while mixing with hot water. Hierarchical cluster analyses illustrated that porridgability and cakeability were most potential for downstream processes and be used for commercialisation.

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