

Optimization of Process Variables for Extrusion of Rice – Bengal Gram Blends

D J Nithya^{1*}, K A S Bosco², M Saravanan², R J Mohan³ and K Alagusundaram⁴
Indian Institute of Crop Processing Technology, Thanjavur -613005, Tamil Nadu, India.

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Extrusion-cooking is advantageous for vulnerable foods and offers a chance to use raw materials which have not previously displayed great economic importance or have even been regarded as waste. Rice and pulse milling by-products due to the low price and easy conversion to processed products result in increasing demand for conversion of these by-products into useful products. It delivers good profit for the processors and in turn providing the consumer a healthy pulse based product to choose from, which is now lacking in the market. This study focuses on optimizing the process variables and to study the extrudate characteristics from blends of bengal gram and rice using single screw extruder. Central composite rotatable design was used to design the experiment with the die head temperature (150-190°C), screw speed (80-100 rpm) and bengal gram level (5-25%) as independent variables. The effect of the variables on the product responses (bulk density, water absorption index, water solubility index, expansion ratio, colour) was carried out. The changes in die head temperature and bengal gram composition were found to have significant effect to the product responses while compared to change in screw speed which is found to have a lesser significant effect to the product response.

Keywords: rice, bengal gram, single screw extruder, response surface methodology.

Introduction

Rice and pulse milling industries are the major processing industries in southern parts of India. Rice brokens and rice bran are the major by-products of rice milling industries while in pulse milling industries, pulse powder and pulse brokens are the major by-products. Except rice bran which is used for extraction of oil, the by-products are sold at low cost low prices and are used as animal feed. It is unknown that these by-products have similar nutritional value as whole grains and pulses. Extrusion-cooking is gaining increasing popularity in the global agro-food processing industry, particularly in the food sectors. Exposure to high temperatures in extrusion cooking for only a short time will restrict unwanted denaturation effects on, for example, proteins, amino acids, vitamins, starches and enzymes. Cereal grains are generally used as a major raw material for development of extruded product due to their good expansion and high starch content. Rice flour has become as attractive ingredient in the extrusion industry due to its bland taste, attractive white colour, hypoallergenicity and ease of digestion²⁰. Pulse which is rich in protein content can be incorporated into rice flour to develop a protein rich extruded snack.

Various blends: wheat- black soybean⁴¹, rice flour-carrot pomace-pulse flour²³, rice flour - green gram⁹, rice flour –chickpea⁸, rice flour – fish³⁹, cassava bran and starch¹⁵, cowpea – groundnut⁷, soy-sorghum-millet-rice flour³⁸, carrot pomace-gram flour rice flour⁴⁵, rice flour-amaranthus flour¹⁷, chickpea flour²⁸, corn-yam¹⁰, rice grit – durum flour-defatted hazelnut flour-fruit waste⁴⁶, Gum based cereal pulse⁴³, millet – soybean¹³, corn-millet-soybean³⁷, soyabean-acha flour⁵, barley-tomato pomace and barley - grapes^{1,2}, buckwheat flour-corn-wheat flour³⁵ and wheat - okara³⁶ affecting the process parameters like expansion ratio, bulk density, water absorption index and water solubility index were studied and reported. The objective of the present work was aimed understanding firstly the effect of changes in characteristics of the feed formulation (blend ratio) to the extruder and extrusion conditions (die head temperature and screw speed) on the physical properties (bulk density, water absorption Index, water solubility index, expansion ratio, colour) on the extrudates.

Materials and methods

Sample Preparation

Parboiled rice brokens and roasted bengal gram brokens were purchased from rice and pulse milling industries, Thanjavur, Tamil Nadu, India. They were

*Author for correspondence
E-mail:neethu_jacynth@yahoo.co.in

cleaned and dry milled to flour using pin mill and stored in air tight containers. The moisture content of the flour was adjusted as desired (14%) by spraying calculated amount of water and mixing continuously in the planetary mixer (Model, Berjaya, I/BSP-BM5). To equilibrate the moisture content, samples were packed in polyethylene bags and kept in the refrigerator overnight. The samples were brought to the room temperature before extrusion.

Experimental Design

Response surface methodology (RSM) which involves design of experiments, selection of levels of variables in experimental runs, fitting mathematical models and finally selecting variables levels by optimizing the response was employed in the study²¹. The central composite rotatable design (CCRD) is a powerful tool for optimization and drastically reduces the number of experiments for studies involving more than two independent variables. In the present study CCRD (design expert 8.0.4.1) was used to design the experiments comprising three independent processing variables at five different levels. In all twenty experiments were conducted with six experiments at centre point to calculate the repeatability of the method³⁰. The experiments were conducted in a randomized order to minimize the effects of unexplained variability in the observed responses due to extraneous factors³¹. The processing variables were; bengal gram level (BGL %: 5 to 25 with 5 % interval) of the feed formulation expressed as percent wet basis (w.b.) percent bengal gram, die head temperature (DHT °C: 150 to 190 with 10 °C interval) and screw speed (SS rpm : 80 to 100 with 5 rpm interval) of the extruder. An attempt was made to understand the effect of variations in the processing variables on some properties of the extrudates produced from the blends of rice flour and bengal gram flour. The coded and actual values are given in table 1.

Extrusion Cooking

Extrusion cooking was carried out in a single screw extruder (Model, Brabender, Plasticoder, Germany) with 2 cm diameter and 40 cm barrel length to dia ratio 20:1. The extruder was fitted with a round die nozzle having 0.42mm diameter. The feed zone temperature was maintained at 80 °C while the compression zone at 120 °C and die zone temperature was maintained at 160 and 180 °C. The extruder feeder screw was run at 80 rpm and 100 rpm while the feed rate was maintained at the speed of 1:4 of the

Table 1—Experimental design for the experiment

Run no.	Coded levels			Actual levels		
	BGL %	SS rpm	DHT (°C)	BGL %	SS rpm	DHT (°C)
1	0	-2	0	15	80	170
2	-1	-1	-1	10	85	160
3	-2	0	0	5	90	170
4	2	0	0	25	90	170
5	0	0	0	15	90	170
6	1	1	-1	20	95	160
7	1	-1	1	20	85	180
8	0	0	2	15	90	190
9	-1	-1	1	10	85	180
10	0	0	0	15	90	170
11	0	2	0	15	100	170
12	0	0	0	15	90	170
13	-1	1	-1	10	95	160
14	1	1	1	20	95	180
15	-1	1	1	10	95	180
16	0	0	0	15	90	170
17	1	-1	-1	20	85	160
18	0	0	-2	15	90	150
19	0	0	0	15	90	170
20	0	0	0	15	90	170

Note : Since the run No. 5, 10, 12, 16, 19 and 20 are same combination, it is followed once

extruder screw rpm. Die pressure was measured using a dynisco pressure transducer (Dynisco Europe D-74078) readings were recorded every 20 seconds and it was reported in Nm. The extrudates were collected and allowed to cool to room temperature. The samples were packed in HDPE bags and stored at 26 °C till analysis.

Expansion ratio

Expansion ratio was determined by measuring the cross sectional diameter of the extrudates using vernier digital caliper³³. The expansion ratio of the extrudate was calculated using

$$\text{Expansion Ratio} = \frac{\text{Extrudate diameter}}{\text{diameter of Die hole}}$$

Bulk density

The bulk density (g/cm³) of the extrudates was obtained using the method given by Alvarez-Martinez *et al* (1988)³,

$$\text{Bulk density} = \frac{4M}{\pi D^2 L}$$

where,

M- Mass of the extrudate (g), D- Diameter of the extrudate (cm), L- Length of the extrudate (cm)

Moisture retention

The moisture content dry basis of the feed and extruded samples was determined by AOAC method⁶. Moisture retention (%) was calculated using

$$\text{Moisture Retention} = \frac{\text{Product Moisture}}{\text{Feed Moisture}} \times 100$$

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

Water absorption Index was determined by the method given by Anderson (1982)⁴. The extruded products were milled to the particle size of 200-250 μ m. The sample of 2.5 g was dispersed in 30g of distilled water was centrifuged at 4000 rpm for 15 min. The supernatant was decanted and the solid content and sediment was weighed.

$$\text{Water Absorption Index (WAI)} = \frac{\text{Weight of sediment}}{\text{Weight of dry solids}}$$

$$\text{Water Solubility Index (WSI)} = \frac{\text{Weight of dissolved solids in supernatant}}{\text{Weight of dry solids}} \times 100$$

Total Color Difference (ΔE)

Colour flex meter (Hunter Lab, Model: 45°/0°) was used for the measurement of colour. It works on the principle of collecting the light and measures energy from the sample reflected across the entire visible spectrum. The meter uses filters and the mathematical models rely on “standard observer curves” that define the amount of red, green and blue primary light required to match a series of colours across the visible spectrum and mathematical model used is called as hunter model. It provides a reading in terms of L,

a and b where L indicates whiteness and darkness. Chromatic portion of the solids is defined by: a (red), -a (green), b (yellow) and -b (blue). L_0 , a_0 and b_0 are the values obtained for the standard tile. The color of the samples was measured after grinding the sample to fine flour (particle size < 200 μ) using the mill. The total colour difference was measured by

$$\Delta E = \sqrt{(L - L_0)^2 + (a - a_0)^2 + (b - b_0)^2}$$

Results and discussions

The results were obtained and analysed using response surface methodology. The product responses of the different extrusion conditions are given in table 2. The analysis of the results using ANOVA is shown in table 3.

Expansion Ratio

Air pockets are formed during the extrusion process and give a porous expanded structure to the product, which is used to describe the expansion properties^{44,47}. Expansion ratio shows the viscous and elasticity property of melted starch²⁴. The data on expansion ratio was found to be low ($P \leq 0.01$) with the increase in bengal gram level. The temperature has less effect compared to bengal gram level ($P \leq 0.05$). There is no significant effect on the screw speed with the expansion ratio. The reduction in the expansion ratio may be due to the increase in the protein content. Previous studies^{27,38} has also indicated that the high protein interactions and formation of intermolecular disulphide bonds in the protein upon heat treatment

Table 2—Extrusion Conditions and product responses

Extrusion Conditions			Product responses				
BGL (%)	SS (rpm)	DHT (C)	Expansion Ratio	Bulk Density (g/cm ³)	WAI (g/g dry weight)	WSI %	Color
15	80	170	2.34	0.228	5.93	12.56	27.00
10	85	160	2.44	0.185	5.84	10.96	34.53
5	90	170	2.52	0.183	5.67	9.11	33.98
25	90	170	2.18	0.143	5.67	11.99	36.85
15	90	170	2.44	0.218	5.86	12.80	30.82
20	95	160	2.22	0.176	5.52	10.05	37.62
20	85	180	2.36	0.177	5.33	10.72	34.02
15	90	190	2.52	0.178	6.01	11.75	30.34
10	85	180	2.41	0.206	5.99	12.57	34.60
15	100	170	2.35	0.206	5.99	12.57	34.60
10	95	160	2.30	0.197	5.67	9.95	37.89
20	95	180	2.41	0.215	5.81	12.59	30.63
10	95	180	2.45	0.206	5.99	12.57	34.60
20	85	160	2.31	0.253	5.16	10.67	37.13

BGL- Bengal Gram Level, SS- Screw Speed, DHT- Die Head Temperature

Table 3—ANOVA for extrusion response

Co-efficient	Expansion Ratio	Bulk Density	WAI	WSI	Colour
Intercept	***	**	***	**	**
Linear					
BGL	***	***	**	**	**
SS	NS	NS	NS	NS	NS
T	**	**	*	**	*
Interaction					
BGL x SS	**	**	*	NS	NS
BGL x T	**	**	**	**	NS
SS x T	NS	NS	NS	NS	NS
Quadratic					
BGL x BGL	**	***	**	**	NS
SS x SS	NS	NS	***	NS	*
T x T	**	NS	NS	**	NS
R ²	0.92	0.79	0.84	0.75	0.78
P	***	**	***	**	**

NS – Not significant, *-Significant at $P \leq 0.10$ level, **-. Significant at $P \leq 0.05$ level, ***-Significant at $P \leq 1.0$ level

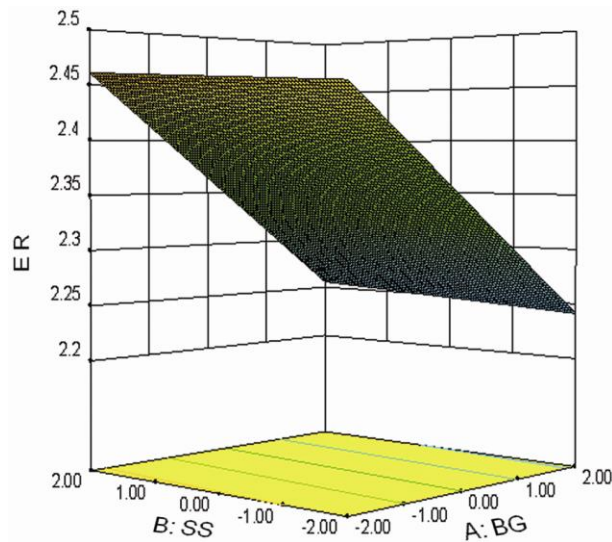


Fig. 1—Effect of screw speed and bengal gram level on expansion ratio of extrudate

that renders the swelling of extrudate and decrease the expansion ratio. The expansion ratio values ranged from 2.18 to 2.44 (table 2, figure 1). Studies^{29,22,25} have reported that the extrudate expansion is also affected by moisture content and temperatures. Rayas-Duarte *et al* 1998³⁵, reported that screw speed and process temperature affect the expansion ratio of the extrudate. They have also reported that the differences in the physical characteristics of the extrudates depend on the intrinsic properties of the solid matrix that expands as it exist the die. The solid

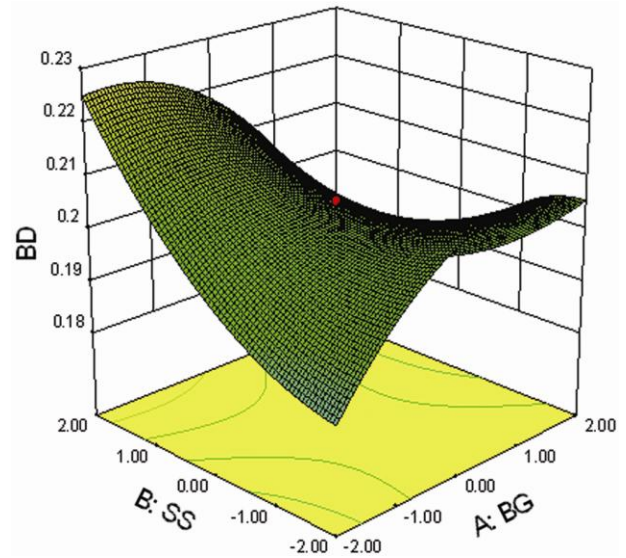


Fig. 2—Effect of screw speed and bengal gram level on bulk density of extrudate

matrix is in-turn affected by amylopectin ratio present in the dough. Garber *et al* 1997¹⁴ expressed that the amount of energy transferred from the screw to the dough control the amount of expansion of extrudates. They have also reported that a low product temperature result in gelatinization which reduced expansion.

Bulk Density

The bulk density of the extrudate ranged between 0.143 to 0.255 g/cm³ (table 2, figure 2). The results show that higher screw speed resulted in lower bulk density. This result is also reported by Lin *et al* 2003²⁵. Atlan *et al* 2008a¹ has reported that the bulk density of barley flour and tomato pomace ranged between 0.370 to 1.11 g/cm³. They have also reported that screw speed does not have influence on bulk density of extrudates. The volume of the extrudate reduces with the increase in the bengal gram content, results in the lower in the bulk density. More protein content yields lesser the expansion ratio and so higher the bulk density. Similar results were reported by Seth and Rajamanickam, 2012³⁸ and Shannon *et al* 2010⁴⁰ that there is relation of protein to expansion of extrudates. Rinaldi *et al* 2000³⁶, Hsieh *et al* 1991¹⁶, Lue *et al* 1991²⁶ and Jin *et al* 1995¹⁹ has reported that bulk density increases due to increase in microstructure of extrudate as the expansion ratio decreases.

Water absorption Index (WAI) and Water Solubility Index (WSI)

Water absorption index measures the amount of water absorbed by starch and can be used as a index

of gelatinization of starch, as native starch do not absorb water at room temperature. WAI also shows the type of proteins, degree of denaturation and fibre. The WAI ranged between 5 to 6 g/g dry sample in the extrudates. It was observed (table 2) that bengal gram level did not have any influence on WAI, while higher screw speed yielded in high WAI. The amount of water absorbed by the extrudate has been used as an indirect estimation of porosity of the extrudate. In extruded breakfast cereals, a slow rate of water absorption is desirable to maintain crispness, while in snack products, mouth feel and firmness are important¹¹. WAI of extrudate may be interpreted on the basis of starch – water – protein interactions that govern the solid phase structure³⁵. Atlan *et al* 2008a¹ has reported that WAI decreased as the temperature increased which is probably due to decomposition or degradation of starch. Singh *et al* 2007⁴² reported that addition of pea grits in rice flour decreased WAI which may be due to dilution of starch in rice pea blends. Colonna *et al* 1989¹¹ reported compact starch structures formed during extrusion due to high screw speed reduce water penetration into the matrix and result in low WAI. WSI determines the amount of free polysaccharide or polysaccharide released from the granule after addition of excess water². Water solubility index refers to the quantity of soluble molecules which is related to dextrinization ie it is used as indicator of starch conversion during extrusion¹². The WSI of extrudates ranged between 9 to 12.5 %. It was found that lower bengal gram level and higher screw speed yielded in lower water solubility index (table 2 and figure 3). Similar results were reported by Atlan *et al* 2008a¹, WSI increased with increased screw speed and level of tomato pomace added. They have also reported that increase in screw speed induced a sharp increase of specific mechanical energy, the high mechanical shear degraded macromolecule and so molecular weight of starch granules decreased and hence increased WSI. Lin *et al* 2003²⁵ reported that high feed moisture and low screw speed had highest WAI and low WSI. The same was also reported by Pan *et al* 1998³⁴ and Jean *et al* 1996¹⁸.

Color

Colour is an important quality directly related to the acceptability of the product. It was observed that there was colour difference which is due to the increase in the bengal gram content ($P \leq 0.05$)

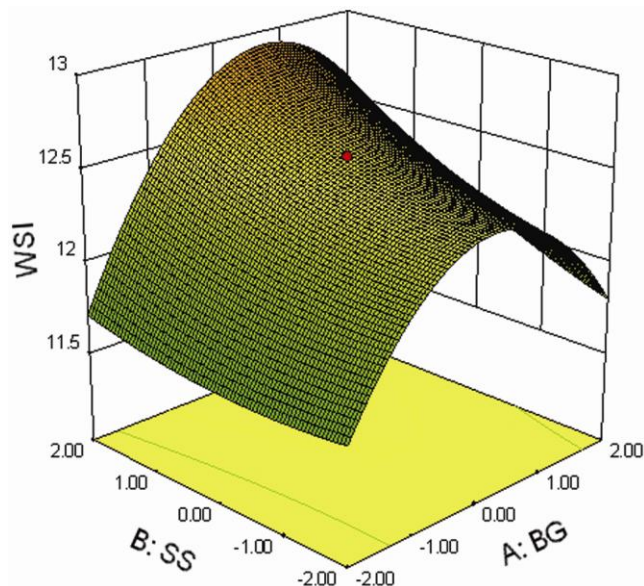


Fig. 3—Effect of screw speed and bengal gram level on water solubility index of extrudate

(table 2). The increase in total colour difference is due to the increase in the bengal gram content. There is no significant effects found in increase in the colour difference for the increase in screw speed and die head temperature.

Conclusion

From the study it can be concluded that rice flour added with 5 to 10 % Bengal gram developed and extruded at 170°C die head temperature, screw speed of 80 to 100 rpm will yield a good quality ready to eat extruded product. Since bengal gram increase the flavour of the extrudates, it will be highly welcomed by the children.

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