Optimization of extrusion conditions for puffed snacks from red glutinous rice using Response Surface Methodology

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Abstract

A variety of red glutinous rice from Mizoram locally known as *Tai sanghar* containing approximately 2.8 per cent amylose was extrusion cooked to prepare functional ready-to-eat snacks. Response surface methodology using a central composite rotatable design was employed to investigate the effects of feed moisture, screw speed and barrel temperature on the properties of red glutinous rice based extruded snacks. Studies revealed the range of optimum processing conditions for successful development of extruded glutinous rice based snacks were feed moisture 14 to 15.5 % and screw speed 445 to 550 rpm while holding optimal barrel temperature of 146 ^{0}C. These conditions led to snacks with desirable sensory characteristics. Significant regression models explained the effects of variation in processing conditions on the properties of responses showing the most significant effect due to changes in feed moisture content, and to a lesser extent by screw speed and barrel temperature. The information obtained from the study could assist food processors to predict the extrusion performance and optimum processing conditions of red glutinous rice.

INTRODUCTION

Expanded crisp porous snacks are becoming one of the most recognized snacks due to their ready-to-eat nature, pleasant taste, and appealing look. Starch is the principal component of extruded products, and primarily contributes for their structural features. The major starchy foods used as raw material for extrusion include wheat, maize, rye, rice, oat, barley, etc. Due to high content of starch, these snacks are low in nutrients and dietary fiber but are high in calories (Brennan et al., 2012). This necessitates the enrichment of snacks with protein, dietary fiber, and phenolics in order to improve their nutritional and functional property (Obradović et al., 2014). As a consequence various researchers have utilized whole grains, pomace, millets, pulses, pseudocereals and other naturally derived ingredients for the development of functional snacks. Similarly the colored glutinous rice varieties manifest themselves as an alluring alternative to enhance the nutritional profile of extruded snacks (Meza *et al.* 2019). They are commonly cultivated in Mizoram, India and have manifested significant long cultural importance and are used to make various traditional rice products. Its low amylose content and presence of pigments such as anthocyanins impart desirable eating quality to the products (Samyor *et al.* 2016). Glutinous rice was reported to be a suitable material for the production of extrusion cooked products such as breakfast cereals and snacks for their better expansion and low bulk density as compared to high amylose variety (Guha and Ali 2006). Recently, colored rice has been recognized as a functional food due to its attractive nutritional and functional health values (Suzuki et al., 2004; Fan zhu 2018).

Red glutinous rice varieties are now one of the persuasive sources of functional foods due to their high content of phenolic compounds, especially anthocyanins (Abdel-Aal et al. 2006; Yawadio et al. 2007). Anthocyanins are a group of water-soluble flavonoids having a reddish-purple color (Shen et al. 2009; Shao *et al*. 2018). They possess anti-oxidant and anti-inflammatory properties (Hu et al., 2003). This class of biologically active compounds are known to be greatly efficient in reducing the concentration of reactive free radicals (Adom and Liu 2002) and cholesterol levels in the human body (Lee et al., 2008).

Extrusion technology is one of the most versatile operations available to the food industry for transformation of raw materials into intermediate or finished products. It has been used for producing several food products including snacks, porridge, textured vegetable protein, confectioneries and pet foods (Toft, 1979). Extrusion processed foods can be broadly classified into two categories based on the application of heat as hot extruded products and cold extruded products.

The quality attribute of the extrudates depends on a number of factors like feed moisture, feed composition, particle size, presence of additives and variables such as screw speed, barrel temperature, feed rate, die geometry and type of extruder (Jin et al. 1995; Suknark et al. 1997; B. Singh et al. 2007). Therefore, extrusion cooking of food requires close control of several variables as changing these factors determines the degree of macromolecular transformations, which in turn influences the qualities of extruded products. The responses studied such as expansion, density, Water absorption index (WAI), Water solubility index (WSI) and hardness are crucial parameters to assess the quality of the extruded product (Patil et al. 2007).

Response surface methodology (RSM) has been used for the optimization of processing conditions, level of ingredients and formulations in extruded snack foods by several researchers (Altan et al., 2008; Seth et al. 2012; B. Singh et al. 2013). RSM is a statistical mathematical technique that uses quantitative data in an experimental design to determine and simultaneously solve multi-variate equations, optimize processes and products (Giovanni, 1983). RSM seeks to find the relation between responses and independent variables. It is also a useful tool to minimize the number of trials and provide a multiple regression approach to achieve optimization.

The study was conducted with the aim to examine the effect of feed moisture content, screw speed and barrel temperature on the product characteristics of red-colored glutinous rice-based extruded snacks using response surface methodology (RSM) and to optimize the extrusion condition for the preparation of glutinous rice-based snacks.

MATERIALS AND METHODS

Sample preparation

A local variety of glutinous rice from Mizoram '*Tai sanghar*' containing approximately 2.8 per cent amylose was procured through Krishi Vigyan Kendra (KVK), Mizoram, India. The rice grain was grounded to flour using a hammermill fitted with a sieve 1.5 mm. 5 percent salt was added to the rice flour.

Figure 1: Red glutinous rice *Tai Sanghar* variety

Experimental design

RSM was used to investigate the effect of extrusion condition on product responses. Statistical software Design Expert 11 (Stat-ease inc, Minneapolis, MN, USA) was used to design the experiment. The central composite rotatable design for three independent variables was performed (Myers 1971). The independent variables include different levels of feed moisture content (13-19 %), screw speed (349-601 rpm) and barrel temperature (116-184 ^{0}C) which were established based on the results of preliminary trials. Response variables were specific mechanical energy (SME), bulk density, expansion ratio, water absorption index (WAI), water solubility index (WSI) and hardness. A polynomial equation was fitted to the data to obtain a regression equation. Response surface plots were generated with the same software.

Extrusion cooking

Extrusion cooking was carried out using a co-rotating twin-screw extruder (Clextral, Firminy, France). The extruder barrel diameter was 25 mm and its length to diameter ratio (L/D) was 16:1.

The barrel of the extruder was divided into four zones. The temperature of the first, second, third and fourth zone was maintained at 40^{0}C, 70^{0}C, and 100^{0}C, respectively, during the experiments, while the temperature at the fourth zone of the barrel was changed according to the experimental design. The diameter of the die was 1.5 mm. The feed moisture content was varied by injecting water into the extruder with a pump. The die of the extruder was attached with a cutter with four-bladed knives that cut at a constant speed. The extrudates were cooled, packed in polyethylene bags and stored in a dry place.

Determination of product responses

Specific Mechanical Energy (SME)

Estimation of SME (Wh/kg) was carried out from the extruder and processing parameters such as rated screw speed (600 rpm), power motor rating (7.5 KW), actual screw speed, % motor torque and mass flow rate (kg/h) using the formula given by Pansawat et al (2008):

$$\text{SME (Wh/kg)} = \frac{\text{Actual screw speed (rpm)}}{\text{Rated screw speed (rpm)}} \times \frac{\text{\% motor torque}}{100} \times \frac{\text{motor power rating}}{\text{mass flow rate(kg/h)}} \times 1000$$

The % motor torque was taken in triplicates from the digital display of the extruder. The motor power rating is the maximum power of the motor corresponding to 100% torque on the screw shaft. Rated screw speed is the highest possible rotational speed of the extruder screw.

Density (g/cc):

The density (g/cc) of extrudates was determined by the rapeseed displacement method using a 100 ml measuring cylinder by volumetric displacement as described by Patil et al (2007). The weight of 10 gm sample was measured for its volume using rapeseed to fill the air spaces between extrudates and gently tapped for five times. The ratio of sample weight and volume in the cylinder was computed as bulk density (Pan et al 1998).

$$\text{Density} = \frac{\text{Weight of sample (g)}}{\text{Volume displaced (ml)}}$$

Expansion Ratio:

The Expansion Ratio was calculated by the ratio of the diameter of extrudate and diameter of die (Fan et al 1996). The mean diameter of five random snacks was taken using a Vernier caliper.

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

Water absorption index (WAI)

WAI is the measurement of the volume taken up by polymer of starch after allowing it to swell in excess water. It was analyzed using the following procedure (Anderson et al 1969). In a 50 ml pre weigh centrifuge tube, finely ground sample (2.5 g) was placed and mixed with 30ml of distilled water at 30^0C. The suspension were mixed properly by stirring it recurrently for 30 minutes followed by centrifugation at 3000 rpm for 15 minutes. The portion of liquid i.e. supernatant were gently poured into pre weighed petri plates. WAI was calculated from the weight of the remaining gel as, grams of gel obtained, per gram of the sample.

$$\text{WAI} = \frac{\text{Weight of sediment}}{\text{Weight of sample}}$$

Water solubility index (WSI)

WSI indicates the quantity of free polysaccharides discharged by the granules of starchy food after suspension in excess water. WSI is measured as the weight of dry solids obtained after evaporation of the liquid portion from WAI experiment as conducted by (Anderson et al 1969).

$$\text{WSI} = \frac{\text{Weight of dissolved solids in supernatant}}{\text{Weight of sample}} \times 100$$

Hardness

Texture analyzer (TA-XT2) was used in compression mode to record the amount of force required to break extruded snacks. P_{50} compression probe (50 mm diameter cylinder aluminum) was used to measure the force it takes to break the sample which corresponds to hardness. The test was operated at 1.0 mm/s pre-test speed, 2.0 mm/s test speed and 10.0 mm/s post-test speed at distance of 5 mm. The extruded sample of uniform size and shape were selected, the average of three readings were taken.

Consumer Acceptance test

The extruded snacks obtained were then tested for consumer acceptance by youth panellists (n=300) on 9-point hedonic scale.

Optimization

For optimization, statistical calculations were used to generate overlaid contour plots from the regression models which gave no significant lack of fit and high R^2 value. In order to attain an optimized product with improved quality and functional properties, a proper choice of optimum conditions is necessary. Out of 20 samples, three samples with the highest sensory scores were chosen and the range of their values for SME, density, ER, WAI, WSI and hardness were used as a criterion for graphical optimization. Finally, validation of experiments was carried out to confirm the adequateness of the models for predicting the optimum processing conditions. A good agreement between the actual values and the predicted values indicated the validation of the results.

RESULTS

The effect of extrusion conditions on the physical and functional properties of extruded snacks was studied using RSM. RSM is a collection of mathematical and statistical techniques useful for analyzing problems where several independent variables influence dependent variables or responses. RSM reduced the number of experimental runs needed to provide sufficient information for statistically acceptable results. It seeks to find a relation between independent variables and responses.

Table 1: Effect of extrusion conditions on product responses

Extrusion conditions			Product responses						
Feed Moisture	Screw speed	Barrel Temperature	SME	Bulk density	Expansio n ratio	WAI	WSI	Hardness	Overall acceptabil ity
(%)	(rpm)	(C)	(Wh/kg)	(g/cc)		(g/g)	(%)	(N)	(Out of 9)
14	400	130	252	164	4.028	0.986	76.38	49.92	6.2
18	400	130	244	205	3.721	1.324	67.82	81.28	5.7
14	550	130	266	110	4.7	0.898	75.84	53.14	6.6
18	550	130	240	175	3.98	1.123	58.13	73.84	6.3
14	400	170	240	141	4.498	0.908	70.87	51.35	6.8
18	400	170	228	164	4.053	1.205	78.87	67.45	6.2
14	550	170	262	103	4.836	0.826	79.59	49.94	8.1
18	550	170	238	142	4.34	1.062	78.41	61.29	5.7
13	475	150	260	111	4.946	0.887	79.29	49.74	7.9
19	475	150	230	167	4.183	1.348	70.11	88.65	5.5
16	349	150	240	160	3.576	1.019	78.41	56.05	6.8
16	601	150	264	116	4.096	0.848	73.02	52.13	6.6
16	475	116	255	185	4.262	1.083	62.07	66.16	6.8
16	475	184	245	120	4.553	0.889	79.91	50.95	7.4
16	475	150	255	120	4.525	0.947	77.93	53.14	7.6
16	475	150	257	135	4.519	0.931	77.74	55.24	7.3
16	475	150	253	127	4.504	0.934	78.93	54.76	7.5
16	475	150	255	129	4.505	0.895	75.75	53.24	7.2
16	475	150	256	137	4.513	0.891	76.16	55.79	7.3
16	475	150	254	141	4.509	0.934	79.01	57.84	7.5

Data obtained with respect to the effect of extrusion conditions on product responses of glutinous rice-based extruded snacks are given in Table 1. Analysis of variance (ANOVA) was conducted to assess the significant effects of the independent variables on the product responses and which of the responses were significantly affected by varying processing conditions. The regression coefficients for each of the response variables are given in Table 2.

Table 2: Regression coefficients for fitted models.

Parameters	SME	ER	BD	WAI	WSI	Hardness
Intercept of model	2.077*	4.51*	132.12*	0.92*	77.59*	54.99*
Feed moisture (A)	-8.82**	-0.24**	19.19**	0.14**	-2.55**	10.61**
Screw speed (B)	6.03**	0.18**	-15.92**	-0.06**	-0.81*	-1.34**
Barrel temperature (C)	-3.72**	0.13**	-15.62**	-0.05**	4.36**	-3.93**
AB	-3.75**	-0.06**	5	-0.02**	-2.29**	-1.93**
AC	-0.25	0.01	-5.5*	-0.004	4.13**	-3.08**
BC	2.75	-0.04	3	0.008	2.31**	-0.42
A^2	-4.39**	0.02	3.76	0.07**	-1.09**	5.03**
B^2	-1.56**	-0.24**	3.41	0.009	-0.73-	-0.31
C^2	-2.27**	-0.03*	8.53**	0.03**	2.40**	1.27**

** Significant at p≤0.01; * Significant at p≤0.05

Figure 2: Glutinous rice based snacks extruded at different processing conditions

Optimization

Graphical multi-response optimization was done to obtain optimum processing conditions for the development of extruded snacks. Based of sensory evaluation, three samples with the highest overall acceptability were selected. The minimum and maximum range of values were obtained from the selected samples for graphical optimization. Overlay contour plots were developed by superimposing the contour graphs of selected product responses using Stat-ease Design-Expert version 11 which helps to find the overlaid area that satisfied all constraints. The optimum range of processing conditions for the development of the best product quality is indicated by the dark portion of the overlaid area (Fig 3). The optimized conditions obtained for glutinous rice-based extruded snacks were found to be in the range of feed moisture 14 to 15.5 %, screw speed 445 to 550 rpm while holding optimum barrel temperature of 146 ^{0}C as shown in Fig 3.

Table 3: Optimized process parameters for highly acceptable extrudates

Extrusion conditions			Product responses					
Feed Moisture	Screw speed	Barrel Temperature	SME	Bulk density	Expansion ratio	WAI	WSI	Hardness
14	550	170	262	103	4.84	0.826	79.59	49.94
13	475	150	260	111	4.95	0.887	79.29	49.74
16	475	150	255	120	4.52	0.947	77.93	53.14

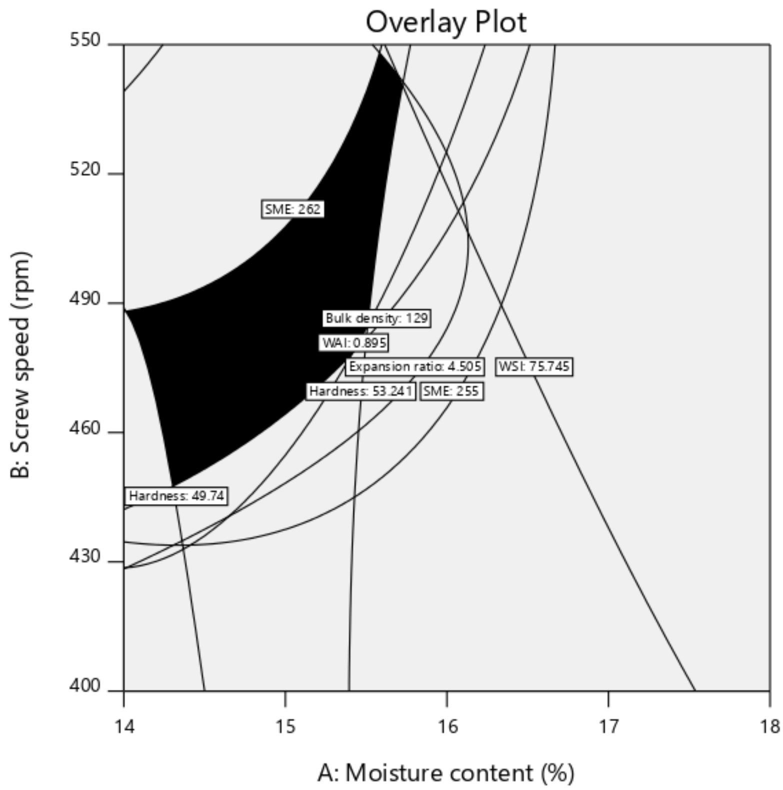

Fig 3: Optimum region identified by the overlaid contour plots of the responses: SME, bulk density, expansion ratio, WAI, WSI and hardness at different levels of moisture content and screw speed while holding optimal barrel temperature at 146.2^{0}C.

Validation

Validation was conducted for confirming the correctness of the model equations for predicting the optimum response values. The actual values obtained and the predicted values are almost similar. It can be observed that variation between actual response values and predicted values was less than 5 %. The results proved the validation of the RSM model and indicate that the model was adequate for predicting optimum conditions in the production of glutinous rice-based extruded snacks.

Table 4: Predicted response vs actual response

Values	Response				
	Density (g/cc)	ER	WAI (g/g)	WSI (%)	Hardness (N)
Predicted	132.12	4.51	0.92	77.59	54.99
Actual	130.63	4.67	0.91	74.72	56.27
Variation %	1.13	3.54	1.08	3.69	2.33

DISCUSSIONS

Effect of extrusion conditions on product responses

Specific Mechanical Energy (Wh/kg)

SME is the total mechanical energy supplied to the extruded material to obtain 1 kg of extrudate (Guha et al 1997). It provides knowledge about extruder efficiency. Higher input of SME is usually associated with a greater degree of starch gelatinization and better expansion. Therefore, high input of SME is desirable for expanded extrudate products like snacks (Meng et al. 2010).

The calculated values of SME for glutinous rice-based extruded snacks varied between 228-266 Wh/kg. The low values of SME were obtained at high feed moisture content and low screw speed. Therefore, SME was observed to be inversely related to feed moisture. High moisture produces a lubricating effect that causes a reduction in feed viscosity resulting in less energy use and subsequently reduced the SME (Pathania et al 2013). Increase in screw speed results in high shear rate and less residence time which increases SME. An increase in temperature generally results in a decrease in SME values which can be explained by the increased in gelatinization of starch and reduction in apparent viscosity of the plasticized mass (Guha et al. 1997). The results are in agreement with findings of Altan et al (2008) and B. Singh et al (2015) in barley and potato extrudates.

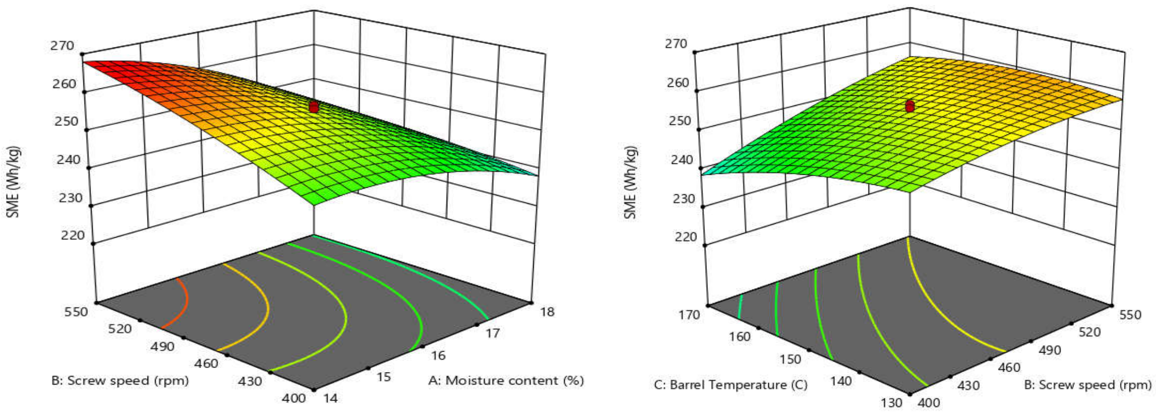

Fig. 4: Effect of extrusion variables on SME of glutinous rice.

Bulk Density (g/cc)

Bulk density which indicates porosity is an important parameter in determining the quality of extruded puffs and snacks. During extrusion cooking, as the food material gets heated in the barrel of an extruder, the moisture often gets heated above its boiling point so that when the food material exits the extruder die, a part of the moisture would quickly flash off as steam resulting in puffing with large alveoli and low density. However, if enough heat is not generated to flash off sufficient moisture for puffing (either due to low barrel temperature or high feed moisture), it resulted in a less expanded product with high density and collapsed cells. Low bulk density is generally associated with puffing and crispiness which is desirable for acceptable extruded snacks.

The glutinous rice extrudates showed bulk densities in the range of 103 to 205 g/cc. It was observed that the extrusion conditions viz. feed moisture, screw speed, and the temperature had a significant effect on the bulk density of extrudate as shown in Fig. 5. Increased feed moisture leads to a sharp increase in extrudate density having a more compact texture and less porous structure. High feed moisture resulted in the dough with reduced elasticity due to plasticization of the melt and therefore reduced gelatinization and increased density (Mercier and Feillet 1975, Thymi et al. 2005). However, low feed moisture level resulted in high viscosity which related directly to the shear stress of the plasticized mass and the increased degree of gelatinization (van Langerich 1990). An increase in screw speed and temperature had a slightly negative effect on the extrudate density. High barrel temperature raises the level of thermal input which leads to better gelatinization. The high shear provided due to increased screw speed combined with high temperature leads to more structural breakdown and reduced viscosity which favors bubble growth during extrusion thereby leading to a decrease in density (Guha et al 1997).

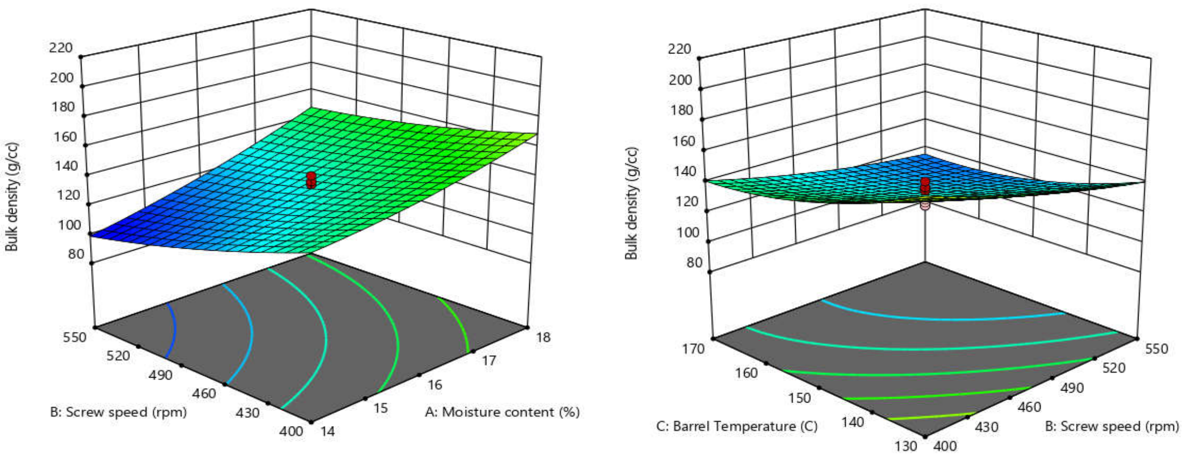

Fig. 5: Effect of extrusion variables on bulk density of glutinous rice

Expansion ratio

Expansion Ratio (ER) is a measure of the extent of puffing as a result of extrusion. It is the most significant physical property of puffed snacks. HTST extrusion process forms pockets of air cells that give porous expanded structure which is a highly desirable and important property of extrudates. Since porosity is used to describe the expansion properties, therefore expansion ratio and bulk density are inversely related to each other. Higher the bulk density, lower the expansion ratio (Jin et al 1995; Bhattacharya 1997).

Expansion ratio for glutinous rice-based extruded snacks varied between 3.576 to 4.836 (Table 1). A high expansion ratio was obtained at low feed moisture content, high screw speed and barrel temperature (Fig. 4). Moisture content showed the most pronounced effect on the expansion ratio. This could be partly due to a decrease in viscosity with an increase in moisture. In low feed moisture (14%), low viscosity causes a drag force which enhances pressure on the die and resulted in a higher expansion ratio of the extrudates (Seth et al 2015). The increase in ER with an increase in temperature and screw speed is explained by the fact that higher barrel temperature and screw speed could cause more degree of gelatinization and the superheated steam produced causes the snack to expand more. Higher temperature and shearing reduces the viscosity of dough mass and increases the vapor pressure of the moisture and thus the degree of puffing (Hsieh et al. 1989). Our results are in agreement with studies conducted by Emir et al 2003; Ding et al 2005; Guha et al 2006; Seth et al

2012, who reported a direct relation between ER with barrel temperature and screw speed, while there is an inverse relation with feed moisture content.

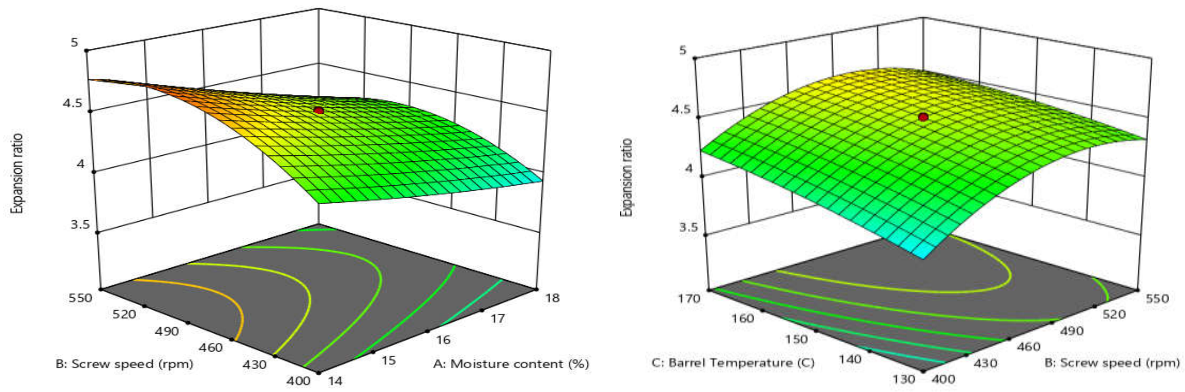

Fig. 4: Effect of extrusion variables on Expansion ratio of glutinous rice

Water Absorption Index (g/g)

WAI determines the amount of water (in grams) that is bound to one gram of dry grounded sample (Anderson et al 1969). It measures the amount of water absorbed by the starch after swelling in excess water, which corresponds to the weight of the gel formed (Mason and Hoseney 1986). It depends on the availability of hydrophilic groups that binds water and on the capacity of gel formation of the macromolecules (Gomez and Aguilera 1983). WAI reveals the amount of modification in native starch during extrusion cooking and it can be used as an index of gelatinization (Anderson et al. 1969). Starches that undergo a higher degree of gelatinization and degradation of granules results in reduced WAI.

The WAI of extrudates ranged from 0.826 to 1.348 g/g (Table 1). WAI was shown to be positively affected by feed moisture and negatively affected by screw speed and barrel temperature. Our results are in agreement with the findings of Ding et al 2005; Joshi et al 2014 and Singh et al 2015. High WAI was shown by products extruded at high moisture and low temperature which was also reported by Anderson et al (1969) and Mercier and Feillet (1975). The reduction in water holding capacity can be due to the degradation of starch molecules and a decrease in molecular size. At high moisture, low screw speed and low temperature, there is lesser degradation of polymer chains and more availability of hydrophilic groups resulting in higher values of WAI (Gomez and Aguilera 1983). WAI was found to increase with feed moisture because water reportedly acts as a plasticizer during extrusion cooking and reduces starch degradation resulting in an increased WAI (Hagenimana et al 2006; Suksomboon et al 2011). Fig. 5 depicts the effects of extrusion conditions on WAI in three-dimensional response surface plots.

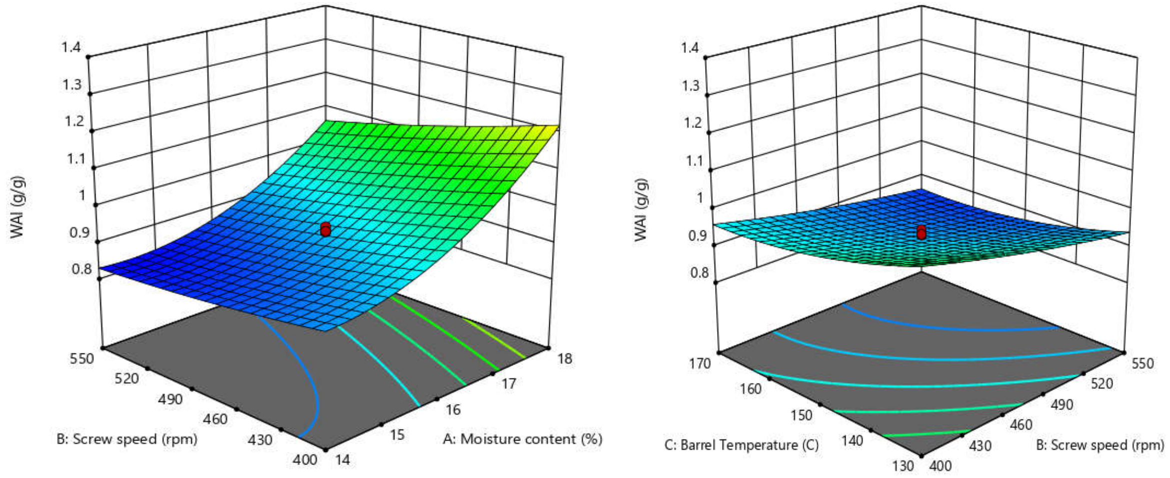

Fig. 5: Effect of extrusion variables on WAI of glutinous rice

Water Solubility Index (%)

WSI measures the degree to which the powdered extruded material dissolves in water. It is determined by the quantity of soluble materials which increases due to the starch degradation. In other words, WSI determines the extent to which starch conversion occurs due to extrusion cooking which corresponds to the total soluble polysaccharides released (Ding et al 2005; Balasubramanian et al. 2014). High WSI indicates good starch digestibility as it indicates the level of gelatinization and dextrinization (Guha et al 1997). WSI also indicates the extent of degradation of molecular components (Kirby et al 1988).

The WSI of extrudates ranged from 58.127 to 79.911 (Table 1). Feed moisture and barrel temperature exhibit a more pronounced effect on WSI as shown in Fig. 6. The coefficients of the regression equations show that barrel temperature had the highest (positive) effect on WSI which indicates that WSI increases with barrel temperature. This can be due to a higher extent of dextrinization due to extremely high heat treatment. At low feed moisture, the drag force increases leading to starch degradation resulting in high WSI. Mercier and Feillet 1975 and Gandhi et al 2018 also reported an increase in WSI with the increase in barrel temperature and decreasing feed moisture. High values of WSI are more desirable in extruded puffed snacks (Guha et al. 2003), therefore a combination of high barrel temperature and low moisture using low amylose variety is desirable to achieve high WSI.

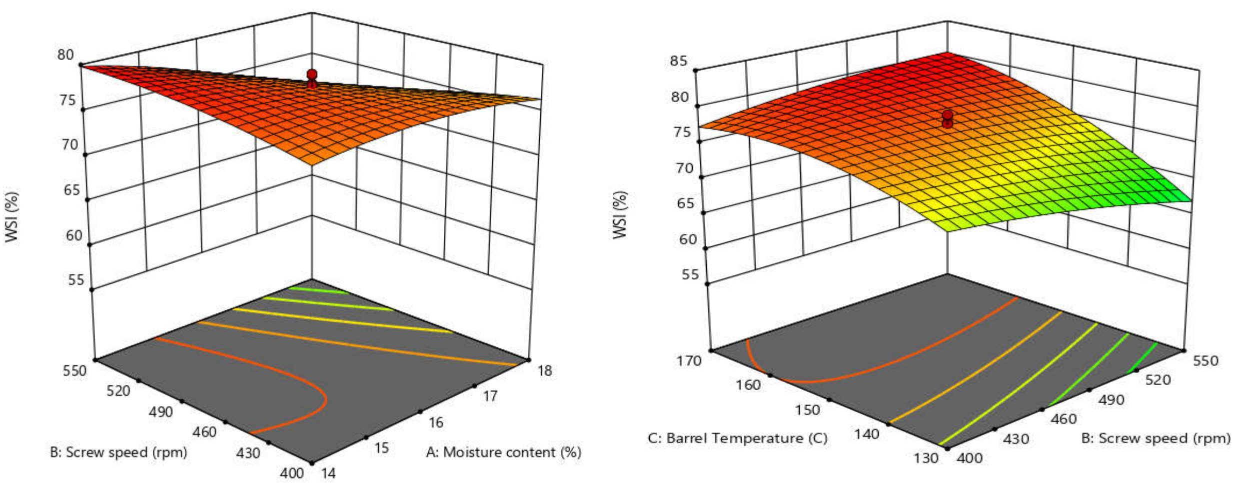

Fig. 6: Effect of extrusion variables on WSI of glutinous rice

Hardness

The hardness of an extruded product is the peak force required for a probe to penetrate the extrudate. During HTST extrusion process, the effects of both elastic swell and bubble growth contribute to a structural change of starch (Padmanabhan and Bhattacharya 1989). The expansion due to bubble growth and swelling as the raw materials exit the die of the extruder results in the crispness of extrudates while reduced starch conversion and compressed bubble enlargement resulted in a dense and hard product (Ding et al 2005). An extruded product with minimal hardness is mainly more desirable to the consumers.

The hardness values of extruded snacks ranged from 49.916 to 88.652 N (Table 1). Feed moisture exhibits the most significant effect on extrudate hardness as shown in Fig. 7. The positive regression coefficient of feed moisture level in the quadratic model indicated that hardness increases with an increase in moisture level. This can be possibly due to the fact that water acts as a plasticizer to the extruded material and reduce its viscosity resulting in compressed bubble growth and denser extrudates. Earlier findings by Ding et al 2005 and Pardhi et al 2016 also reported that an increase in moisture content resulted in hardness of the extruded products.

Screw speed and barrel temperature also had a significant effect on hardness. Negative coefficients of screw speed and barrel temperature indicate that hardness decreased with an increase in these two variables as depicted in Fig. 7 for response surface plots. A decrease in hardness due to an increased level of screw speed and temperature can be expected as they decrease the melt viscosity hence favoring bubble expansion to produce low-density extrudates. The lower the bulk density, the lower the hardness of extrudates.

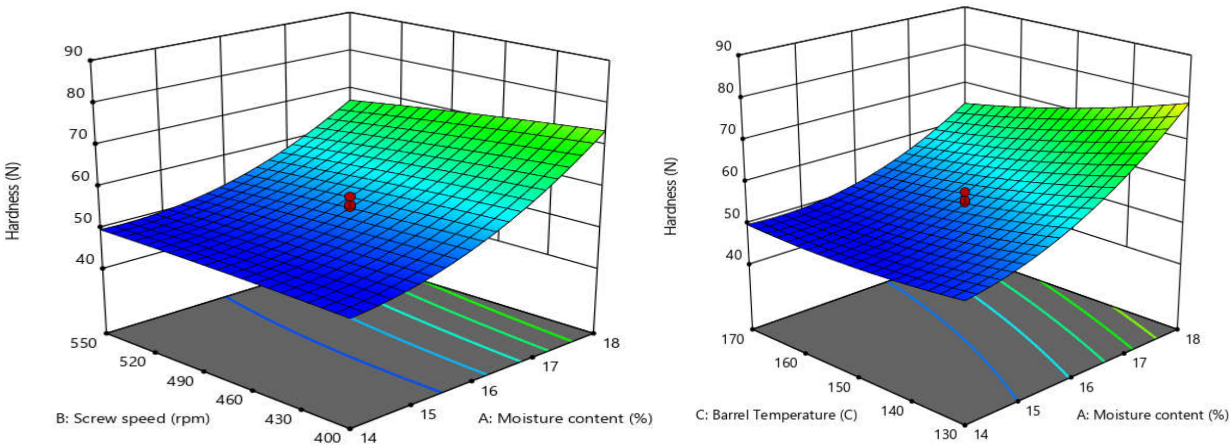

Fig. 7: Effect of extrusion variables on the hardness of glutinous rice

Conclusion

Crispy extruded snacks are gaining popularity as one of the most widely consumed snacks. However, due to its high glycaemic load, it requires nutritional and functional improvement. Colored glutinous varieties offer a suitable material for the development of extruded snacks due to better expansion and functional benefits. RSM studies revealed the significant effects of variation in extrusion processing conditions viz feed moisture, screw speed and barrel temperature on the functional properties of glutinous rice-based extruded snacks. Regression coefficient studies suggest that feed moisture content had the most significant effect on the responses and had a directly proportional effect on density, WAI and hardness and inverse effect on SME, ER, and WSI. While barrel temperature had a slightly lesser effect and have a positive effect on ER and WSI while negatively affecting SME, BD, WAI and hardness; an increase in screw speed resulted in increased

SME and ER while a decrease in BD, WAI, WSI and hardness. The processing conditions for the development of glutinous rice-based extruded snacks obtained by graphical optimization were feed moisture 14 to 15.5 %**,** screw speed 445 to 550 rpm while holding optimum barrel temperature of 146 ^{0}C. Present investigation can act as an efficient framework in providing a discrete outlook to the local food processors for the development of novel and versatile food commodities from these unexplored indeginous rice varieties. Subsequently, the functional properties of red glutinous rice could potentially contribute to the nutritional and functional enrichment of products as well as improvement in texture and expansion properties with importance to the snacks food industry.

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