Optimization of process parameters for preparation of rice extrudates from short and long *Indica* rice cultivars milled to varying degree of milling

Rubinder Singh Sandhu^{1,2} · Narpinder Singh² · RSS Kaler² · Baljit Singh³

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Abstract Extrusion behavior of extrudates prepared from short (PR113) and long (PUSA1121) *Indica* rice cultivars milled to 0–8% degree of milling (DOM) extruded at variable extrusion temperature (150–190 °C) and feed moisture (15–19%) was studied. The physico-chemical and functional properties of extrudates prepared from both the cultivars varied significantly with variation in DOM as well as extrusion variables. DOM showed more pronounced effect for all the responses studied for both the cultivars. Expansion, L^* , water absorption and overall acceptability increased whereas hardness, water solubility and bulk density decreased with increase in DOM. Extrusion temperature increase led to increase in expansion and water solubility and decreased L^* , bulk density and water absorption. Feed moisture showed significant positive effect on hardness and water absorption and negative effect on expansion, L^* and water solubility. Formation of amylose–lipid complexes were also observed during extrusion cooking for both the cultivars which showed negative correlation with DOM. Both the cultivars also

showed different behavior for these responses at same values of independent variables.

Keywords Extrudates · Degree of milling · Rice · Complex index · RSM and expansion ratio

Introduction

Rice (*Oryza sativa*) is one of the most commonly used cereals after maize and sorghum (Asare et al. 2010). It is milled to different DOM to remove brany layers so as to obtain white rice which is commonly used for direct consumption after boiling. The thickness of these brany layers is also different for different rice cultivars, thus DOM is also dependent upon the cultivar to be milled. In our earlier study the effect of different DOM and cultivars on various physicochemical, rheological, cooking properties and X-ray diffraction pattern of short and long *Indica* rice cultivars has been studied (Sandhu et al. 2018b). In that study it was observed that DOM led to removal of different brany layers (pericarp, testa and aleurone), containing varying concentration of different chemical constituents (lipids, proteins, minerals, etc.) for both the cultivars. Extrusion cooking of food is high temperature short time (HTST) process that involves combination of temperature, pressure, moisture and mechanical shear for cooking of food material rich in starch and protein that results in molecular transformation and other chemical reactions (Castells et al. 2005). Variation of product quality such as ER, hardness, color, solubility in water, water absorption, etc. with variation in processing conditions (feed composition, temperature of barrel, moisture of feed, speed of screw, feed rate) was also reported earlier (Singh et al. 1998; Singh and Smith 1999; Singh et al. 2014a, b).

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✉ Narpinder Singh
narpinders@yahoo.com

¹ Department of Food Technology, Ch. Devi Lal State Institute of Engineering and Technology, Panniwala Mota, Sirsa, Haryana, India

² Department of Food Science and Technology, Guru Nanak Dev University, Amritsar, Punjab, India

³ Department of Food Science and Technology, Punjab Agricultural University, Ludhiana, Punjab, India

Extrusion process involves increase in experimental load due to various combination of above processing various variables. Response surface methodology was reported to be an excellent tool for reducing experimental load and for the process optimization by various researchers (Afoakwa et al. 2006; Garg and Singh 2010; Singh et al. 2014a, b). Formation of complexes among the starch and lipids was also observed by addition of fatty acids or monoglycerides to wheat starch prior to extrusion and it affects various quality parameters of the prepared extruded product (Singh et al. 1998).

Rice is rich in starch leading to better expansion, having bland taste and low protein that limits non-enzymatic browning and is hypoallergenic (Bryant et al. 2001) makes the choice of rice as the raw material for current study. Combined effect of different chemical components removed during DOM along with extrusion variables on product quality for short and long *Indica* rice cultivars has not been investigated yet. Therefore, to study the effect of DOM, extrusion temperature and moisture content of feed on the extrusion behaviour of PR113 and PUSA1121 grits was the aim of present study.

Materials and methods

Preparation of feed for extrusion

Short (PR113) and long (PUSA1121) paddy grains were obtained from a local collection and breeding center (Partap Seeds, Jaitosirja, Batala, India). Brown rice (BR) and grains with varying DOM (2%, 4%, 6% and 8%) were obtained by adopting the method described in earlier study (Sandhu et al. 2018b). Rice with different DOM is made to grits by using a laboratory scale supermill (Newport scientific, Australia). To get uniform size grits, the fraction obtained from supermill is placed in the sieve shaker using sieves of different size and the fraction that passes through 14 mesh size sieve but retained on 32 mesh size sieve were selected for extrusion.

Extrusion

Rice grits were extruded in a co-rotating twin screw extruder (Model BC21, Cleextral, France). Response surface methodology (RSM) using Box Behnken Design with five center point was applied to reduce the experimental load. Grits were fed to the extruder at a rate of 20 kg/h using a volumetric feeder. The die used is having four openings with 2 mm opening diameter and extrudates were cut with a variable speed cutter having four blades. The screw and cutter speed were fixed at 500 rpm, and 5 rpm, respectively. Extrusion process was completed by passing the

feed through four barrel zones. The first three zones were maintained at constant temperature of 40, 70 and 100 °C, respectively, whereas the last zone was having variable temperatures as per the experimental design from 130 to 190 °C. Feed material, feed moisture and the temperature of the fourth barrel zone were varied as per the design (Table 1). Three replications were carried out for each test run and extrudates were cooled to room temperature and were stored at a temperature of 20 °C after sealing in big size zip pouches prior to further analysis.

Methods

Physical properties and hardness were evaluated from the whole extrudates. Rice extrudates were ground to obtain flour by passing all through 60 mesh size sieve and was evaluated for chemical and functional properties.

Physicochemical analysis of extrudates

The ER was calculated following the method of Gimenez et al. (2013). In short, six samples of extrudates were collected randomly for each experiment. Each extrudate was then measured for diameter from 10 different locations by using digital vernier caliper. ER was determined by

Table 1 Coded levels for the independent variables for experimental design

Run	Coded values			Actual values		
	X ₁ ^a	X ₂ ^b	X ₃ ^c	A ^a	B ^b	C ^c
1	1	0	− 1	8	160	12
2	0	1	− 1	4	190	12
3	0	− 1	− 1	4	130	12
4	− 1	0	− 1	0	160	12
5	0	0	0	4	160	15.5
6	1	1	0	8	190	15.5
7	0	0	0	4	160	15.5
8	− 1	0	1	0	160	19
9	0	− 1	1	4	130	19
10	0	0	0	4	160	15.5
11	− 1	− 1	0	0	130	15.5
12	0	1	1	4	190	19
13	0	0	0	4	160	15.5
14	− 1	1	0	0	190	15.5
15	1	0	1	8	160	19
16	1	− 1	0	8	130	15.5
17	0	0	0	4	160	15.5

Here, (X₁/A)^a is degree of milling (%); (X₂/B)^b is extrusion temperature (°C); (X₃/C)^c is feed moisture content (%)

dividing the mean diameter of the extrudate by diameter of die opening,

$$ER = D \times d^{-1}$$

where D is the mean diameter of extrudate (average of 10 determinations) and d is the diameter of die opening.

BD 'p' (gm/ml) was evaluated by using volumetric displacement method as explained by Patil et al. (2007). BD (w/v) was estimated as the ratio of weight of extrudates and the replaced volume in cylinder.

Hardness of the extrudates was determined with Texture Analyzer (TA-XT 2i, Stable Microsystems, UK) following the method as described by Singh et al. (2014a, b). Briefly, the hardness was indicated by the force required to break the sample by cylindrical compression probe (50 mm diameter).

The extrudate flour was used to evaluate color parameters (L^* , a^* and b^* values) using Ultra Scan VIS Hunter Lab (Hunter Associates Laboratory Inc, Reston, VA, USA) following the method explained by Shevkani et al. (2014). Total color change (ΔE) was determined by adopting the method described by Sandhu et al. (2018a) using white standard plate having $L = 97.71$, $a = -0.17$ and $b = 2.40$.

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

Where ΔL is $L_{\text{standard}} - L^*_{\text{sample}}$; Δa is $a_{\text{standard}} - a^*_{\text{sample}}$ and Δb is $b_{\text{standard}} - b^*_{\text{sample}}$.

Chemical composition i.e. Moisture content (MC), protein: nitrogen $\times 5.95$, LC, AC and FC were determined as per AACC Methods 08-01 (AACC 2000).

Both WSI and WAI were evaluated following the method developed for cereals as explained by Singh et al. (2014a, b). The ground extrudates were suspended in water at room temperature in pre-weighed centrifugal tubes, mixed by stirring these tubes on vortex shaker for 30 min and finally centrifuged at $3000 \times g$ for 15 min. The supernatants were collected in already weighed petri plates and dried in hot air oven. The dry solids in the supernatants gives the WSI and the weight of gel obtained after decanting supernatants gives WAI. Both are expressed as percentage of sample taken.

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

$$WAI (g/g) = \frac{\text{Weight of sediment}}{\text{Weight of dry solids}}$$

CI was evaluated following the method described elsewhere (Kaur and Singh 2000). The iodine solution used for estimation was prepared by dissolving 1.3 g of I_2 and 2 gm of potassium iodide in 50 mL deionized double distilled water, mix on vortex shaker and allow it to dissolve for overnight. The final volume was made up to 100 mL using

distilled water. 5 gm of sample was taken in centrifugal tubes and 25 mL of distilled water is mixed into it and centrifuged at 3000 rpm for 15 min. The supernatant was decanted in cleaned test tubes. 500 μ L supernatant and 15 mL distilled water were mixed to freshly prepared 2 mL iodine solution in a test tube. After proper mixing, absorbance was measured at 690 nm on UV-Vis spectrophotometer. Rice extrudates at 8% DOM were considered as control sample for both the varieties.

$$CI (\%) = \frac{\text{Absorbance of control} - \text{Absorbance of sample}}{\text{Absorbance of control}} \times 100.$$

The extrudates from both the cultivars were also subjected to sensory analysis for taste, texture, appearance/color and overall acceptability traits to find out the consumer acceptability. Thirty semi trained penalists (15 male and 15 female) of the age of 18 years and above different socioeconomic status from Amritsar (India) were selected to evaluate the extrudates on a 9-point Hedonic scale in which 1 represents extremely dislike, 5 represents neither like nor dislikes and 9 represents like extremely. Subjects were not informed about the sample history and all the tests were conducted under similar conditions.

Statistical analysis

Experimental data was analyzed using statistical software Design-Expert 8 (Stat-Ease Inc., Minneapolis, MN) and a second order polynomial model was established for the optimization of all dependent variables (Y_i):

$$Y_i = b_0X_i + \sum_{i=1}^3 b_iX_i + \sum_{i=1}^3 b_{ii}X_i^2 + \sum_{i=1}^3 \sum_{j=1}^3 b_{ij}X_iX_j$$

where b_0 , b_i , b_{ii} , b_{ij} are the coefficients for intercept, linear, quadratic and interaction effects, respectively and X_i and X_{ij} are coded values of independent variables (DOM, extrusion temperature and feed moisture), respectively. Analysis of variance (ANOVA) was used to determine statistical significance for each response. Three dimensional contour plots were plotted to support visualization of disparity in the observed responses corresponding to processing variables. The efficiency of the model was checked by lack of fit tests and R^2 . All the data reported is mean of three observations.

Result and discussion

Polynomial model equations in terms of coded values for each response for both the cultivars were developed using RSM and presented in Table 3. These equations represent

linear, quadratic and interaction affect of independent variables (degree of milling, extrusion temperature and feed moisture) on physico-chemical and functional properties of the extrudates obtained.

Expansion ratio

Extrudates from PR113 and PUSA1121 showed significant difference in ER (Table 2). PR113 showed higher expansion than PUSA1121 which might be due to higher content of amylose/starch and lower LC in short grain cultivar. An increase in ER with increase in amylose content in the native corn starch from 25% to 45% was reported by Thachil et al. (2014). The ER of extrudates from PR113 varied from 3.22 ± 0.16 to 3.89 ± 0.09 and from 3.01 ± 0.08 to 3.65 ± 0.16 for PUSA1121 (Table 2). Harper (1981) verified dependability of expansion of extrusion cooked starch products on the entrapment of water vapors by the starch matrix which led to bubble formation. Figure 1a–c shows the variation in ER for PR113 and Fig. 1d–f represents the variation in ER for PUSA1121, for independent variables; DOM, extrusion temperature and feed moisture. ER also showed significant increase with increase in DOM from 0 to 8% for both the cultivars as seen in Fig. 1, which may be due to decrease in LC and other constituents whereas increase in starch content with extended DOM. The increase in starch content favours more swelling of starch upon gelatinization which infact could be the reason of higher expansion with removal of lipids from rice cultivars. This was further supported by the findings that addition of coconut and fish oils to the corn starch extrusion feed led to reduction in the ER due to formation of complexes (Thachil et al. 2014). Further the effect of extrusion temperature on expansion was less significant than the effect of DOM and feed moisture (Fig. 1). However, it was observed that higher the temperature more is the expansion might be due to increase flashing of water. Our findings agree with the results of Guy and Horne (1988) who explained an increase in radial expansion of extrudates upon increasing the temperature. Although water present in the feed helped in the bubble formation, but in the current study reduction in the expansion of the extrudates was observed with elevation in the moisture content from both the cultivars. This might be due to the reason that lower vapor pressure in presence of higher moisture during extrusion resulting in a lower flashing of moisture and finally in a reduced expansion. To analyse the effects of independent variables model equations in coded form were developed as shown in Table 3. Equation 2 and 15 indicates the effects of the independent parameters on ER for PR113 and PUSA1121 respectively. These equations depicts significantly positive effect of DOM and negative effect of feed moisture on ER (Y_1) in

linear, interaction as well as quadratic terms whereas temperature showed only interaction and quadratic effect for both the cultivars. R^2 value > 0.91 (Table 3) implies that the models for both the cultivars are highly significant.

Hardness

Extrudates prepared from PR113 were less harder than those obtained from PUSA1121. The hardness values for PR113 varied from 35.82 ± 0.21 to 43.36 ± 0.18 N and from 37.56 ± 0.88 to 46.47 ± 1.13 N for PUSA1121 (Table 2). Thachil et al. (2014) also observed that extrudates prepared from high amylose corn showed less hardness as compared to the extrudates from native corn starch having lesser content. ANOVA results for model of hardness revealed that DOM showed more pronounced effects on hardness of extrudates followed by feed moisture content and temperature for both the cultivars. The negative coefficients of both DOM and temperature as seen from equation 3 and 16 (Table 3) represents that they led to decrease in hardness with increase in their value while the positive coefficients of feed moisture showed that increase in feed moisture led to an increase in the hardness of extrudates from both the cultivars. Coefficient of determination ' R^2 ' was 0.95 for PR113 and 0.97 for PUSA1121 and was very much desirable (Table 3). With extended DOM, loss in chemical constituents including lipids thus reducing the frequency for amylose–lipid complex formation might be the reason for the decrease in hardness results. Formation of complexes with addition of fatty acid or monoglycerides to wheat starch during extrusion leading to increase in crystallinity was also observed (Singh et al. 1998). The increase in extrusion temperature led to decrease in the melt viscosity, which was desirable for the growth of bubbles to produce low-density products, thus leading to lowering hardness of extrudates. Similar observations for the hardness of snacks prepared from the blend of barley tomato pomace with elevation in the temperature were made (Altan et al. 2008). Increase in the hardness value at higher moisture content of feed can be explained by the phenomena that water reduces the viscosity of starchy products by acting as plasticizer and therefore decreased mechanical energy dissipation inside the extruder barrel. This led to hindrance of bubble growth and the prepared extrudate were more dense/harder. Garg and Singh (2010) reported maximum hardness at 24% moisture content and lowest at feed moisture between 15 and 16.5%. The increase in the hardness value corresponding to elevation in moisture levels was also reported earlier (Ding et al. 2005; Altan et al. 2008).

Table 2 Physico-chemical and functional properties of extrudates from PR113 and PUSA1121

Sample	Run	Product response						
		ER	Hardness (N)	BD (g/ml)	MC (%)	LC (%)	PC (%)	AC (%)
PR113	1	3.89 ± 0.09	35.82 ± 0.21	0.162 ± 0.01	7.41 ± 0.16	0.25 ± 0.11	7.28 ± 0.24	0.74 ± 0.07
	2	3.5 ± 0.11	37.19 ± 0.18	0.167 ± 0.03	7.36 ± 0.19	1.43 ± 0.07	7.48 ± 0.33	1.38 ± 0.13
	3	3.46 ± 0.08	39.63 ± 0.24	0.171 ± 0.09	7.48 ± 0.27	1.52 ± 0.14	7.51 ± 0.27	1.41 ± 0.16
	4	3.4 ± 0.18	42.18 ± 0.19	0.178 ± 0.07	7.44 ± 0.32	2.18 ± 0.16	7.79 ± 0.38	1.73 ± 0.12
	5	3.45 ± 0.11	40.54 ± 0.23	0.175 ± 0.05	7.49 ± 0.37	1.51 ± 0.09	7.49 ± 0.43	1.38 ± 0.14
	6	3.35 ± 0.15	36.28 ± 0.17	0.181 ± 0.04	7.46 ± 0.21	0.22 ± 0.12	7.22 ± 0.28	0.72 ± 0.15
	7	3.49 ± 0.14	38.72 ± 0.21	0.174 ± 0.07	7.55 ± 0.38	1.56 ± 0.08	7.44 ± 0.35	1.41 ± 0.11
	8	3.24 ± 0.17	43.36 ± 0.18	0.187 ± 0.06	7.54 ± 0.42	2.21 ± 0.13	7.81 ± 0.41	1.75 ± 0.08
	9	3.27 ± 0.13	41.08 ± 0.15	0.177 ± 0.07	7.88 ± 0.27	1.55 ± 0.06	7.55 ± 0.26	1.42 ± 0.13
	10	3.42 ± 0.18	39.87 ± 0.24	0.173 ± 0.08	7.45 ± 0.44	1.47 ± 0.15	7.47 ± 0.32	1.37 ± 0.09
	11	3.25 ± 0.12	42.63 ± 0.21	0.185 ± 0.06	7.52 ± 0.19	2.25 ± 0.11	7.82 ± 0.42	1.76 ± 0.16
	12	3.22 ± 0.16	39.11 ± 0.19	0.188 ± 0.07	7.62 ± 0.37	1.48 ± 0.10	7.45 ± 0.37	1.42 ± 0.10
	13	3.4 ± 0.15	40.15 ± 0.24	0.172 ± 0.08	7.48 ± 0.27	1.44 ± 0.06	7.51 ± 0.26	1.42 ± 0.06
	14	3.27 ± 0.13	40.91 ± 0.18	0.180 ± 0.05	7.46 ± 0.31	2.17 ± 0.13	7.76 ± 0.34	1.70 ± 0.13
	15	3.74 ± 0.10	38.64 ± 0.15	0.171 ± 0.06	7.51 ± 0.35	0.24 ± 0.07	7.31 ± 0.38	0.77 ± 0.18
	16	3.81 ± 0.18	37.99 ± 0.19	0.161 ± 0.08	7.45 ± 0.29	0.28 ± 0.09	7.34 ± 0.25	0.78 ± 0.12
	17	3.52 ± 0.14	39.36 ± 0.13	0.169 ± 0.09	7.47 ± 0.47	1.53 ± 0.07	7.48 ± 0.34	1.44 ± 0.11
PUSA1121	1	3.65 ± 0.16	37.56 ± 0.88	0.220 ± 0.08	7.43 ± 0.31	0.42 ± 0.09	7.57 ± 0.25	0.87 ± 0.08
	2	3.27 ± 0.08	39.93 ± 1.02	0.405 ± 0.05	7.41 ± 0.28	1.11 ± 0.06	7.85 ± 0.15	1.72 ± 0.16
	3	3.17 ± 0.14	40.58 ± 0.48	0.437 ± 0.11	7.61 ± 0.33	1.18 ± 0.12	7.88 ± 0.34	1.75 ± 0.12
	4	3.11 ± 0.11	44.66 ± 0.72	0.742 ± 0.04	7.44 ± 0.41	3.08 ± 0.18	8.09 ± 0.33	2.14 ± 0.24
	5	3.19 ± 0.10	40.13 ± 0.29	0.451 ± 0.07	7.50 ± 0.37	1.13 ± 0.07	7.84 ± 0.28	1.73 ± 0.13
	6	3.49 ± 0.09	38.24 ± 0.82	0.240 ± 0.04	7.47 ± 0.29	0.40 ± 0.06	7.53 ± 0.39	0.85 ± 0.07
	7	3.22 ± 0.14	41.91 ± 1.07	0.462 ± 0.05	7.46 ± 0.36	1.18 ± 0.10	7.87 ± 0.23	1.70 ± 0.14
	8	2.93 ± 0.10	46.47 ± 1.13	0.868 ± 0.07	7.37 ± 0.44	3.11 ± 0.16	8.12 ± 0.19	2.17 ± 0.17
	9	3.07 ± 0.09	42.78 ± 0.58	0.486 ± 0.09	8.12 ± 0.34	1.24 ± 0.11	7.90 ± 0.22	1.76 ± 0.10
	10	3.16 ± 0.15	40.52 ± 0.81	0.448 ± 0.12	7.49 ± 0.42	1.11 ± 0.18	7.82 ± 0.34	1.72 ± 0.09
	11	2.97 ± 0.12	45.77 ± 0.32	0.787 ± 0.04	7.55 ± 0.26	3.15 ± 0.09	8.13 ± 0.19	2.18 ± 0.18
	12	3.01 ± 0.08	39.95 ± 0.55	0.428 ± 0.08	7.76 ± 0.23	1.14 ± 0.07	7.87 ± 0.37	1.73 ± 0.11
	13	3.17 ± 0.11	41.08 ± 0.49	0.439 ± 0.03	7.49 ± 0.38	1.19 ± 0.13	7.85 ± 0.34	1.75 ± 0.21
	14	3.05 ± 0.14	43.89 ± 0.94	0.713 ± 0.09	7.47 ± 0.33	3.05 ± 0.19	8.06 ± 0.42	2.17 ± 0.15
	15	3.33 ± 0.18	40.07 ± 0.79	0.282 ± 0.07	7.62 ± 0.42	0.46 ± 0.05	7.61 ± 0.36	0.87 ± 0.08
	16	3.29 ± 0.15	39.26 ± 0.43	0.225 ± 0.04	7.48 ± 0.31	0.49 ± 0.08	7.58 ± 0.15	0.88 ± 0.06
	17	3.22 ± 0.12	41.18 ± 0.39	0.473 ± 0.08	7.51 ± 0.18	1.16 ± 0.12	7.84 ± 0.24	1.71 ± 0.10
Sample	Run	Product response						
		FC (%)	TCD	L*	C.I	WSI (%)	WAI (g/g)	OA
PR113	1	0.44 ± 0.08	17.67 ± 0.34	80.81 ± 0.34	0.00 ± 0.0	18.44 ± 0.57	7.25 ± 0.18	8.25 ± 0.58
	2	0.83 ± 0.00	23.08 ± 0.29	75.76 ± 0.28	12.97 ± 0.51	29.98 ± 0.62	5.88 ± 0.24	7.50 ± 0.72
	3	0.86 ± 0.03	20.31 ± 0.41	78.32 ± 0.32	14.51 ± 0.63	28.72 ± 0.77	5.95 ± 0.26	7.00 ± 0.46
	4	0.97 ± 0.12	23.45 ± 0.22	75.88 ± 0.29	17.05 ± 0.72	39.29 ± 0.51	4.53 ± 0.18	7.20 ± 0.52
	5	0.85 ± 0.06	18.07 ± 0.58	80.63 ± 0.38	12.43 ± 0.81	26.98 ± 0.75	6.68 ± 0.17	7.60 ± 0.81
	6	0.43 ± 0.10	20.84 ± 0.17	77.68 ± 0.25	0.00 ± 0.00	16.86 ± 0.49	7.69 ± 0.22	7.80 ± 0.29
	7	0.82 ± 0.11	18.73 ± 0.39	79.91 ± 0.26	12.75 ± 0.29	27.14 ± 0.58	6.22 ± 0.15	7.40 ± 0.88
	8	1.01 ± 0.09	26.62 ± 0.52	72.54 ± 0.27	14.95 ± 0.42	35.79 ± 0.59	5.27 ± 0.21	6.40 ± 0.63
	9	0.68 ± 0.04	23.71 ± 0.21	75.19 ± 0.34	12.07 ± 0.57	26.37 ± 0.49	6.91 ± 0.19	6.50 ± 0.75
	10	0.88 ± 0.07	19.35 ± 0.16	79.27 ± 0.36	12.01 ± 0.38	27.28 ± 0.42	6.59 ± 0.21	7.50 ± 0.41
	11	1.02 ± 0.11	23.09 ± 0.28	75.86 ± 0.31	16.68 ± 0.72	36.09 ± 0.71	4.92 ± 0.17	6.70 ± 0.44
	12	0.85 ± 0.10	26.39 ± 0.24	72.18 ± 0.27	10.04 ± 0.25	28.07 ± 0.52	6.62 ± 0.23	7.10 ± 0.89
	13	0.87 ± 0.08	18.44 ± 0.15	80.22 ± 0.34	12.68 ± 0.43	27.59 ± 0.51	6.90 ± 0.18	7.40 ± 0.67
	14	0.98 ± 0.14	23.51 ± 0.43	75.25 ± 0.23	15.38 ± 0.48	37.99 ± 0.68	4.72 ± 0.14	7.20 ± 0.36
	15	0.45 ± 0.05	20.42 ± 0.26	78.34 ± 0.31	0.00 ± 0.00	15.64 ± 0.37	7.87 ± 0.22	6.90 ± 0.58
	16	0.47 ± 0.07	17.39 ± 0.13	81.29 ± 0.37	0.00 ± 0.00	16.10 ± 0.35	7.47 ± 0.25	7.00 ± 0.64
	17	0.83 ± 0.06	18.21 ± 0.34	80.46 ± 0.36	11.81 ± 0.26	27.11 ± 0.49	6.36 ± 0.19	7.30 ± 0.43

Table 2 continued

Sample	Run	Product response						
		FC (%)	TCD	L*	C.I	WSI (%)	WAI (g/g)	OA
PUSA1121	1	0.53 ± 0.05	26.66 ± 0.24	72.31 ± 0.28	0.00 ± 0.00	16.40 ± 0.62	6.77 ± 0.11	7.60 ± 0.43
	2	0.84 ± 0.10	30.33 ± 0.19	68.65 ± 0.25	15.76 ± 0.29	28.19 ± 0.77	5.61 ± 0.17	7.30 ± 0.52
	3	0.87 ± 0.07	29.83 ± 0.33	69.04 ± 0.22	17.14 ± 0.33	26.39 ± 0.53	5.78 ± 0.25	7.10 ± 0.38
	4	1.11 ± 0.11	31.07 ± 0.37	67.83 ± 0.28	20.31 ± 0.41	35.77 ± 0.68	4.18 ± 0.29	7.00 ± 0.61
	5	0.85 ± 0.06	28.82 ± 0.51	70.11 ± 0.24	15.52 ± 0.28	25.07 ± 0.43	5.92 ± 0.18	7.30 ± 0.57
	6	0.51 ± 0.04	29.83 ± 0.28	68.92 ± 0.26	0.00 ± 0.00	15.56 ± 0.57	6.99 ± 0.26	7.40 ± 0.46
	7	0.82 ± 0.07	29.06 ± 0.34	69.87 ± 0.29	15.84 ± 0.44	25.31 ± 0.81	5.91 ± 0.15	7.20 ± 0.61
	8	1.12 ± 0.09	32.04 ± 0.53	66.58 ± 0.24	17.81 ± 0.21	31.17 ± 0.39	4.97 ± 0.12	6.30 ± 0.53
	9	0.88 ± 0.11	29.91 ± 0.21	68.54 ± 0.23	14.67 ± 0.46	23.81 ± 0.42	6.23 ± 0.24	6.50 ± 0.42
	10	0.84 ± 0.10	29.44 ± 0.46	69.46 ± 0.29	15.07 ± 0.19	24.98 ± 0.55	6.06 ± 0.13	7.20 ± 0.38
	11	1.16 ± 0.13	31.85 ± 0.19	66.97 ± 0.31	19.74 ± 0.51	32.59 ± 0.36	4.62 ± 0.22	6.80 ± 0.66
	12	0.86 ± 0.08	31.62 ± 0.27	67.29 ± 0.27	12.55 ± 0.37	25.78 ± 0.61	6.08 ± 0.27	7.00 ± 0.74
	13	0.83 ± 0.05	28.00 ± 0.54	70.98 ± 0.26	15.29 ± 0.45	25.51 ± 0.67	6.12 ± 0.16	7.20 ± 0.67
	14	1.08 ± 0.09	32.25 ± 0.36	66.66 ± 0.24	18.15 ± 0.38	34.11 ± 0.72	4.48 ± 0.13	7.00 ± 0.54
	15	0.54 ± 0.04	30.57 ± 0.28	68.21 ± 0.30	0.00 ± 0.00	14.28 ± 0.43	7.45 ± 0.27	6.70 ± 0.48
	16	0.55 ± 0.08	26.80 ± 0.35	72.15 ± 0.32	0.00 ± 0.00	15.10 ± 0.29	7.19 ± 0.18	7.00 ± 0.44
	17	0.85 ± 0.07	27.85 ± 0.14	72.13 ± 0.27	15.22 ± 0.24	25.18 ± 0.34	5.93 ± 0.23	7.10 ± 0.52

ER elongation ratio, BD bulk density, MC moisture content, LC lipid content, PC protein content, AC ash content, FC fiber content, TCD total color Difference, L* color value for lightness, CI complex index, WSI water solubility index, WAI water absorption index, OA overall acceptability based on sensory score

Bulk density

BD indicates same effect of DOM, extrusion temperature and feed moisture as indicated for hardness for both the cultivars. Extrudates with higher ER from both PR113 and PUSA1121 showed lower BD and vice versa. Correlation among BD, ER and hardness was also observed earlier (Altan et al. 2008). BD for extrudates from PR113 ranged from 0.161 ± 0.08 to 0.188 ± 0.07 g/mL and between 0.220 ± 0.08 and 0.428 ± 0.08 g/mL for PUSA1121 (Table 2). Lower BD of extrudates from PR113 than that of PUSA1121, might be due to its higher starch and lower lipid contents, leading to less formation of amylose–lipid complexes. Extrusion of grits from rice milled to (8% DOM) at higher temperature and lower feed moisture produced the extrudates with the lowest BD while the highest value was obtained for brown rice grits extruded at lower temperatures and higher feed moisture for both the cultivars. Both PR113 and PUSA1121 showed decrease in the lipids, proteins and fiber etc., with corresponding increase in starch content with extended DOM, producing more expanded product thus lowering BD. Higher extrusion temperature decreased BD of extrudates for both the cultivars. Case et al. (1992) also reported that volume of extruded products increased with increase in starch gelatinization resulting in decreased BD. The negative coefficients of DOM and extrusion temperature as seen from equation 4 and 17 (Table 3) describes significantly negative effect of these variables whereas positive effect of

moisture on BD of the product was observed. Pan et al. (1998) also reported increase in BD corresponding to an increase moisture content of the feed material at lower extrusion temperature during extrusion cooking. Positive correlation of BD with moisture content of feed has also been reported by Garg and Singh 2010. ANOVA revealed more pronounced effect of DOM and feed moisture than temperature. Sefa and Saalia (1997) concluded that degree of puffing of snacks can also be measured by taking into consideration the ER and the BD of the product and also stated the inverse correlation among ER and BD. Similar effects of different process variables that includes extrusion temperature, feed moisture, diameter of die and the feed composition was also observed by other researchers and reported their effect on ER and BD along with other dependent variables (Sefa and Saalia 1997; Asare et al. 2010). Significance of models for both the cultivars can also be verified from R^2 (Table 3).

Chemical composition

The extrudates chemical composition for both the cultivars (moisture, lipid, protein, ash and fibre content) is reported in Table 2. The maximum moisture content reported for the extrudates from PR113 was 7.66% and 8.12% for PUSA1121, suggesting a safe level for long storage. In one of the previous study by Afoakwa et al. (2006) it has been established that moisture content between 6 and 10% extends the shelf life of foods in dry food systems. The

Fig. 1 Response surface plot for expansion ratio of extrudates from PR113 (a, b, c) and PUSA1121 (d, e, f) as a function of interaction between DOM (%), barrel temperature (°C) and moisture content (%).

The range of DOM varies from 0 to 8%, Temperature from 130 to 190 °C and Moisture content from 12 to 19%

other parameters studied (LC, PC and AC) were found to have comparable values to already reported previous research work (Sandhu et al. 2018b) and these indices showed different effects with extrusion parameters (independent variables). Percent LC, PC, AC and FC varied from 0.22 ± 0.12 to 2.25 ± 0.11 , 7.22 ± 0.28 to 7.82 ± 0.42 , 0.72 ± 0.15 to 1.76 ± 0.16 and 0.43 ± 0.10 to 1.02 ± 0.11 for PR113 whereas from 0.40 ± 0.06 to 3.15 ± 0.09 , 7.53 ± 0.39 to 8.13 ± 0.19 , 0.85 ± 0.07 to 2.18 ± 0.18 and 0.51 ± 0.04 to 1.16 ± 0.13 for PUSA1121, respectively (Table 2). ANOVA predicted highly significant ($P < 0.001$) effect of DOM in linear as well as quadratic terms on all these indices for both the cultivars (Table 3). With extended DOM, reduction in these indices was observed in the extrudates obtained from both PR113 and PUSA1121, might be due to the reason that these constituents were more concentrated in the brany layers removed during milling (Sandhu et al. 2018b). In broader terms, comparing the results of current study for these indices with the results reported for the feed material in previous study (Sandhu et al. 2018b), it was observed that all the LC and PC decreased more significantly than the other constituents during extrusion corresponding to similar DOM of feed material may be due to lipid migration and denaturation of proteins at higher extrusion

temperatures. Extrusion temperature also showed significant negative effect for LC and PC (Table 3). The higher the extrusion temperature more loss in lipids was observed, which may be due to less bonding of starch and lipid at these processing conditions leading to migration of lipids. Furthermore, De Pilli et al. (2005) found that high extrusion temperature favors the melting of amylose–lipid complexes formed during first three zones of extruder and also promotes migration of lipid fraction. The negative effect of extrusion temperature on PC might be attributed to denaturation of proteins at higher temperature. However, effect of moisture was not significant for all the studied indices (Table 3). A higher R^2 values 0.99 for LC and $R^2 = 0.97$ for PC was obtained for both cultivars, explaining goodness of fit for the obtained models.

Total color difference (TCD)

Total color difference (ΔE) was more pronounced for PR113 than PUSA1121 and varied between 17.39 ± 0.31 to 26.62 ± 0.24 and from 26.66 ± 0.18 to 32.04 ± 0.16 , respectively (Table 2). Color values, lightness (L^*), redness (a^*) and yellowness (b^*) also varied for both the cultivars. L^* values were higher for PR113 while PUSA1121 showed higher redness (a^*) and yellowness

Table 3 Model equations for various responses of extrudates from PR113 and PUSA1121 using RSM

Sample	Response	Model equation in coded form	Eq. no	Significant model terms (ANOVA)
PR 113	Y_1	$3.46 + 0.20A - 0.056B - 0.097C - 0.12AB + 2.500E^{-3}AC - 0.022BC + 0.084A^2 - 0.12B^2 + 0.027C^2$	(2)	$R^2 = 0.9190$ A, C, AB, B^2
	Y_2	$39.73 - 2.54A - 0.98B + 0.92C + 2.5E^{-3}AB + 0.41AC + 0.12BC + 0.24A^2 - 0.51B^2 + 0.036C^2$	(3)	$R^2 = 0.9635$ A, B, C
	Y_3	$0.17 - 6.875E^{-3}A - 2.75E^{-3}B + 5.625E^{-3}C + 6.25E^{-3}AB + 3.75E^{-3}BC + 1.45E^{-3}A^2 + 2.7E^{-3}B^2 + 4.5E^{-4}C^2$	(4)	$R^2 = 0.9504$ A, B, C, AB, BC
	Y_4	$1.50 - 0.98A - 0.037B + 0.012C + 5.0E^{-3}AB - 9.186E^{-3}AC + 5.0E^{-3}BC - 0.27A^2 + 2.09E^{-3}B^2 - 7.09E^{-3}C^2$	(5)	$R^2 = 0.9988$ A, B^2 , C^2
	Y_5	$7.48 - 0.25A - 0.039B + 7.5E^{-3}C - 0.015AB + 2.5E^{-3}AC - 0.018BC + 0.053A^2 + 3.5E^{-3}B^2 + 0.016C^2$	(6)	$R^2 = 0.9941$ A, B, A^2
	Y_6	$1.40 - 0.49A - 0.019B + 0.013C + 2.5E^{-3}AC + 7.5E^{-3}BC - 0.16A^2 - 2.0E^{-3}B^2 + 5.5E^{-3}C^2$	(7)	$R^2 = 0.9979$ A, A^2
	Y_7	$0.85 - 0.27A + 7.5E^{-3}B - 0.014C - 7.50E^{-3}AC + 0.050BC - 0.11A^2 - 0.019B^2 - 0.026C^2$	(8)	$R^2 = 0.9792$ A, A^2
	Y_8	$18.56 - 2.54A + 1.17B + 1.58C + 0.76AB - 0.11AC - 0.021BC + 0.66A^2 + 1.99B^2 + 2.82C^2$	(9)	$R^2 = 0.9790$ A, B, C, B^2 , C^2
	Y_9	$80.10 + 2.32A - 1.22B - 1.56C - 0.75AB + 0.22AC - 0.11BC - 0.52A^2 - 2.05B^2 - 2.68C^2$	(10)	$R^2 = 0.9811$ A, B, C, AB, B^2 , C^2
	Y_{10}	$12.34 - 8.03A - 0.63B - 0.93C + 0.37AB + 0.53AC - 0.12BC - 4.33A^2 + 0.063B^2 - 1.75E^{-3}C^2$	(11)	$R^2 = 0.9958$ A, B, C, A^2
PUSA 1121	Y_{11}	$27.22 - 10.27A + 0.70B - 1.32C - 0.28AB + 0.17AC + 0.11BC - 0.73A^2 + 0.27B^2 + 0.80C^2$	(12)	$R^2 = 0.9991$ A, B, C, A^2 , C^2
	Y_{12}	$6.55 + 1.36A - 0.041B + 0.38C + 0.10AB - 0.029AC - 0.056BC - 0.23A^2 - 0.12B^2 - 0.092C^2$	(13)	$R^2 = 0.9805$ A, C
	Y_{13}	$7.44 + 0.31A + 0.30B - 0.38C + 0.075AB - 0.14AC + 0.025BC - 0.051A^2 - 0.21B^2 - 0.20C^2$	(14)	$R^2 = 0.9114$ A, B, C
	Y_1^*	$3.19 + 0.21A + 0.040B - 0.11C + 0.030AB - 0.035AC - 0.040BC + 0.067A^2 - 0.058B^2 - 3.5E^{-3}C^2$	(15)	$R^2 = 0.9683$ A, C, A^2 , B^2
	Y_2^*	$40.96 - 3.22A - 0.78B + 0.82C + 0.24AB + 0.17AC - 0.54BC + 1.09A^2 - 0.29B^2 + 0.14C^2$	(16)	$R^2 = 0.9742$ A, B, C, A^2
	Y_3^*	$0.45 - 0.27A - 0.019B + 0.032C + 0.022AB - 0.016AC - 6.5E^{-3}BC + 0.063A^2 - 0.026B^2 + 0.011C^2$	(17)	$R^2 = 0.9948$ A, B, C, A^2
	Y_4^*	$1.15 - 1.33A - 0.045B + 0.020C + 2.50E^{-3}AB + 2.50E^{-3}AC - 7.50E^{-3}BC + 0.61A^2 + 9.25E^{-3}B^2 + 4.25E^{-3}C^2$	(18)	$R^2 = 0.9997$ A, B, A^2
	Y_5^*	$7.84 - 0.26A - 0.022B + 0.014C + 5.0E^{-3}AB + 2.50E^{-3}AC - 0.023A^2 + 4.250E^{-3}B^2 + 0.027C^2$	(19)	$R^2 = 0.9961$ A, B, A^2 , C^2
	Y_6^*	$1.72 - 0.65A - 0.012B + 6.25E^{-3}C - 5.0E^{-3}AB - 7.50E^{-3}AC - 0.21A^2 + 0.013B^2 + 5.25E^{-3}C^2$	(20)	$R^2 = 0.9995$ A, A^2
	Y_7^*	$0.84 - 0.29A - 0.021B + 6.25E^{-3}C + 1.00E^{-2}AB + 2.5E^{-3}BC - 0.025A^2 + 0.012B^2 + 0.012C^2$	(21)	$R^2 = 0.9980$ A, B, A^2
	Y_8^*	$28.63 - 1.67A + 0.71B + 0.78C + 0.66AB + 0.74AC + 0.30BC + 0.61A^2 + 0.95B^2 + 0.85C^2$	(22)	$R^2 = 0.9190$ A, B, C, B^2
	Y_9^*	$70.31 + 1.69A - 0.65B - 0.90C - 0.73AB - 0.71AC - 0.21BC - 0.64A^2 - 0.99B^2 - 0.94C^2$	(23)	$R^2 = 0.9180$ A, C, B^2 , C^2
	Y_{10}^*	$15.39 - 9.50A - 0.64B - 1.02C + 0.40AB + 0.63AC - 0.19BC - 5.71A^2 - 0.21B^2 - 0.15C^2$	(24)	$R^2 = 0.9976$ A, B, C, A^2
	Y_{11}^*	$25.21 - 9.04A + 0.72B - 1.46C - 0.27AB + 0.62AC + 0.041BC - 1.25A^2 + 0.38B^2 + 0.45C^2$	(25)	$R^2 = 0.9986$ A, B, C, AC, A^2 , C^2
	Y_{12}^*	$5.99 + 1.27A - 0.082B + 0.30C - 0.017AB - 0.028AC + 4.25E^{-3}BC - 0.13A^2 - 0.043B^2 - 0.019C^2$	(26)	$R^2 = 0.9944$ A, C, A^2
	Y_{13}^*	$7.20 + 0.20A + 0.16B - 0.31C + 0.05AB - 0.05AC + 0.07BC - 0.11A^2 - 0.038B^2 - 0.19C^2$	(27)	$R^2 = 0.9390$ A, B, C, C^2

Where Coded value A is DOM, B is barrel temperature and C is MC. Y_1 , Y_2 , Y_3 , Y_4 , Y_5 , Y_6 , Y_7 , Y_8 , Y_9 , Y_{10} , Y_{11} , Y_{12} , Y_{13} respectively, for PR113 and Y_1^* , Y_2^* , Y_3^* , Y_4^* , Y_5^* , Y_6^* , Y_7^* , Y_8^* , Y_9^* , Y_{10}^* , Y_{11}^* , Y_{12}^* , Y_{13}^* respectively, for PUSA1121 represents expansion ratio, hardness, bulk density, lipid content, protein content, ash content, fiber content, total color difference, L*, water solubility index, water absorption index and overall acceptability of the extrudates. R^2 = coefficient of determination

(b*). Difference in composition of the two cultivars might have attributed to difference in color attributes. Singh et al. (2014a, b) also reported the contribution of proteins and mineral matter to yellowness and redness in cereal flours. It was observed that DOM and extrusion temperature effects TCD more than the feed moisture for both the cultivars. With extended DOM, L* value increased whereas redness decreased due to removal of brany layers (Table 2). More pronounced effect of independent variables was found on lightness (L*) of the extrudates. Zhong et al. (2014) also found similar effect of DOM on L*, a* and b* values of Chinese rice cultivars. The results (Table 2) revealed that L* value ranged from 72.18 ± 0.27 to 81.29 ± 0.37 for PR113 and from 66.58 ± 0.24 to 72.31 ± 0.28 for PUSA112. Equation 10 and 23 (Table 3) reflects that all independent variables significantly affected L* value. However, DOM had positive effect while temperature and feed moisture showed negative effect on Y_o. Responses of independent variables on L* are presented in Fig. 2a–f for both PR113 and PUSA1121. Higher extrusion temperature also led to decrease in the brightness (L*) of extrudates as it may had supported maillard reaction between reducing sugars and free amino groups (Hagenimana et al. 2006). Brightness of the extrudates increased with increase in moisture content while decrease in a* value, similar to the findings of Hagenimana et al. (2006).

Complex index

Degree of amylose–lipid complex formed was measured by binding of iodine to the free starch and denoted as CI. CI values for PR113 ranged from 10.04 ± 0.25 to 17.05 ± 0.72 , whereas PUSA1121 showed higher CI, 12.55 ± 0.37 to 20.31 ± 0.41 (Table 2), which might be due to difference in LC of both the cultivars. Similar observation was made for different DOM, with extended DOM the value of CI decreased due to removal of brany layers containing lipids (Table 2). Kaur and Singh (2000); Singh et al. (2000); Thachil et al. (2014) also reported an increase in CI corresponding to higher levels in fatty acid/oil content and advocated the amylose–lipid complex formations. The effect of DOM was more significant on CI both in linear and quadratic terms (Table 3). Negative coefficients of all the independent variables (DOM, barrel temperature and feed moisture content) depicts that an increase in these variables decrease the value of CI (Equation 11 and 24, Table 3). However, the effect of extrusion temperature was less pronounced than DOM and feed moisture. Melting of amylose–lipid complexes at higher temperature during extrusion cooking could be the reason for decrease in CI at higher extrusion temperature. Suppressing effect of temperature and moisture on starch–lipid complex formation has already been explained by

previous researchers (Mercier et al. 1980; Bhatnagar and Hanna 1994). De Pilli et al. (2008) also reported significantly negative effect of feed moisture on CI during extrusion cooking of almond flour. R² values of 0.99 for both the cultivars signified the model and was highly desirable.

WSI and WAI

WSI determines the amount of free polysaccharide or polysaccharide release from the granule on addition of excess water whereas, WAI measures the volume occupied by the granule or starch polymer after swelling in excess of water (Oikonomou and Krokida 2011). WSI varied from 15.64 to 39.29% for PR113 and from 14.28 to 35.77% for PUSA1121 with variation in DOM, extrusion temperature and feed moisture (Table 2). PR113 with higher amylose showed the lower WSI than PUSA1121. The same phenomena may also responsible for the lowering of WSI with extended DOM, as with extended DOM proportion of amylose content in the feed material increases while LC decreases due to removal of brany layers. Comparable to our finding, Guha and Ali (2006) also reported higher WSI for lowest amylose rice cultivar among the three rice cultivars which further increases at higher extrusion temperature. On the other hand, WSI showed significant increase with increase in temperature (Table 2). The rate of starch degradation increases with increase in temperature at lower moisture content resulting in the product with increased WSI could be the reason for this. Gelatinization of starch at high temperature has also been reported during extrusion cooking of corn starch (Thachil et al. 2014). Positive relationship among WSI and extrusion temperature also reported for the extruded products (Ding et al. 2005). Extrusion cooking of brown rice (0% DOM) at higher temperature and lower feed moisture contents gives the product with highest WSI value (Table 2). Lower moisture during extrusion also causes more shear fragmentation of the starch that led to the breakdown of higher molecules to simpler ones thus increasing their solubility. Decrease in WSI with increase in feed moisture has also been reported for extrusion of rice, wheat and oat flour (Singh and Smith 1997; Silva et al. 2009). The negative co-efficient of the linear term for DOM and moisture content as evident from Equation 12 and 25 (Table 3), signify that WSI decreases with increase in these variables whereas positive coefficients of the linear term for barrel temperature revealed that WSI increases with elevation in extrusion temperature. Significant linear effect of DOM, extrusion temperature and moisture content and quadratic effect of DOM and moisture content on WSI, for both the cultivars was also observed (Table 3). Singh et al. (2007) also depicted

Fig. 2 Response surface plot for L^* value of extrudates from PR113 (a, b, c) and PUSA1121 (d, e, f) as a function of interaction between DOM (%), barrel temperature ($^{\circ}\text{C}$) and moisture content (%). The

range of DOM varies from 0 to 8%, Temperature from 130 to 190 $^{\circ}\text{C}$ and Moisture content from 12 to 19%

similar positive effects of temperature and negative effect of MC on rice extrudates.

WAI values for PR113 ranged from 4.53 ± 0.18 to 7.87 ± 0.22 and for PUSA1121 it varied from 4.18 ± 0.29 to 7.45 ± 0.27 (Table 2). As depicted from Equation 13 and 26 (Table 3) WAI (Y_{12}) increases with increase in DOM and feed moisture while temperature depicted negative correlation with WAI for both the cultivars. PR113 showed higher WAI in comparison to PUSA1121, probably due to its higher starch and lower lipids, proteins and fiber content, as water is more readily absorbed by starch in comparison to other constituents. The same hypothesis further justifies increase in WAI values with extended DOM. Similarly, Singh et al. (1998) found significant decrease in WAI on addition of wheat germ oil in the wheat starch. The probable reason for increase in WAI with every next level of feed moisture may be that water acts as plasticizer in extrusion cooking thus reducing starch degradation leading to increased capacity for absorption of water, while, the elevated temperatures favors in increase of starch degradation. Singh et al. (2007) confirmed the positive relationship of WAI with feed moisture. The

negative effect of extrusion temperature may be due to decreased capability of absorbance of water after formation of amylose- lipid complexes, favoured by temperature. De Pilli et al. (2008) correlated gelatinization of starches with temperature and proposed that native starch has limited binding capacity with lipids and extrusion cooking of starch at higher temperature favors gelatinization of starch that makes the availability of amylose to form complex with lipids. Due to formation of complexes ability of starch to absorb water also reduces thus decreasing WAI. The significance of model can be justified from high R^2 values; 0.98 for PR113 and 0.99 PUSA 1121.

Sensory analysis

Taste, texture, appearance and overall acceptability were studied for extrudates from both the cultivars. Overall score of sensory characteristics ranged from 6.4 ± 0.63 to 8.25 ± 0.58 with an average value of 7.23 for extrudates from PR113 while from 6.3 ± 0.53 to 7.6 ± 0.43 with average of 7.04 for PUSA1121 (Table 2). The sensory scores of PR113 were found to be higher than PUSA1121.

PR113

PUSA1121

Fig. 3 Response surface plot for overall acceptability of extrudates from PR113 (a, b, c) and PUSA1121 (d, e, f) as a function of interaction between DOM (%), barrel temperature (°C) and moisture

content (%). The range of DOM varies from 0 to 8%, Temperature from 130 to 190 °C and Moisture content from 12 to 19%

Sensory scores for texture and appearance of BR extrudates from PR113 were higher than PUSA1121. A significant increase in sensory scores was observed for texture and appearance of both the cultivars with extended DOM. The sensory observations were in agreement to the instrumental values obtained for hardness and color parameters from both the cultivars as observed in previous sections. Positive coefficient of DOM (A) and extrusion temperature (B) represents that both of these variables led to increase the overall acceptability of the extrudates whereas negative coefficient of feed moisture content (C) decreased overall acceptability (Equation 14 and 27, Table 3). Contour plots as in Fig. 3a–c gave graphical representation of the effect of these variables on overall acceptability for PR113 and Fig. 3(d and e) illustrates these effects for PUSA1121. From the contours (a to e) it can be seen that DOM and moisture has more pronounced effect on the acceptability of extrudates than extrusion temperature for both the cultivars. Thus sensory results also support the instrumental results.

Optimization and validation

The extrusion process was optimized for the independent variables (DOM, extrusion temperature, feed moisture) using design expert software using numerical optimization technique. To obtain optimum product, the criteria applied for numerical technique optimization includes the selection of (1) maximum ER as extruded product were liked more if puffed properly and less harder; (2) maximum lightness (L^*) as darker color extrudates were not accepted by the consumers; (3) maximum sensory score for overall product acceptability as marketing of any product was highly based on its acceptability by the consumers; (4) minimum hardness was also a crucial factor. The independent variables were kept in range as per the design i.e. DOM (0–8) %, extrusion temperature (130–190) °C and feed moisture content (12–19) %. The optimum conditions obtained through numerical optimization for the development of extrudates were 8.0% DOM, 159.54 °C extrusion temperature and 12.80% moisture content for PR113 and 8.0% DOM, 164.82 °C extrusion temperature and 12.50% feed

moisture for PUSA1121. The predicted results at optimum conditions were ER 3.87 and 3.63, L^* value 80.59 and 71.83, Hardness 36.14 N and 37.97 N and overall acceptability scores 8.01 and 7.48 with a desirability of 0.924 and 0.934, for PR113 and PUSA1121 respectively. Extrudates from both the cultivars were prepared at the optimized values of independent variables (DOM, extrusion temperature and feed moisture) and analyzed for selected responses in triplicates to determine the repeatability of optimized results. It has been observed that the experimental values obtained and the predicted response values are very close to each other, with a maximum variation of 4.11% for both the cultivars (Supplementary Table 1). Thus the optimized results are repeatable too.

Conclusion

The effect of DOM, extrusion temperature and moisture content on physico-chemical and functional properties of extrudates from PR113 and PUSA1121 rice cultivars were observed. The polynomial equations computed can be used to predict extrudate properties (ER, TCD, L^* value, Hardness, BD, WSI, WAI, CI, LC, PC, AC, FC and overall acceptability). ER which was dependent upon composition of rice and is hindered by LC due to formation of complexes with amylose. Color and texture of were among the key parameters affecting the acceptability of the extrudates for both the cultivars. Extended DOM led to removal of various chemical constituents from BR of both the cultivars in varying proportion which greatly effected color and texture of the extrudates. Both the cultivars differ in the loss of constituents with DOM. This advocates the need of different DOM for whitening of BR from different rice cultivars. Numerical optimization also predicted that extrudates from both the cultivars milled to 8% DOM gave the best results in terms of maximum ER, maximum L^* value, maximum overall acceptability and minimum hardness. Also the extrudates obtained at optimized parameters from both the cultivars showed variations in responses due to difference in their composition. PR113 with high amylose and lower LC as well as PC gave extrudates with higher expansion, brighter color, lower hardness and better acceptability than those from PUSA1121.

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References

- AACC International (2000) Approved methods of the American Association of Cereal Chemists, 10th edn. Method 08-01. The Association, St. Paul, MN
- Afoakwa EO, Budu AS, Merson AB (2006) Application of response surface methodology for optimizing the pre-processing conditions of bambara groundnut (*Voandzeia subterranea*) during canning. *Int J Food Eng* 2:1–25
- Altan A, McCarthy KL, Maskan M (2008) Evaluation of snack foods from barley–tomato pomace blends by extrusion processing. *J Food Eng* 84(2):231–242
- Asare EK, Sefa-Dedeh S, Afoakwa EO, Sakyi-Dawson E, Budu AS (2010) Modelling the effects of feed moisture and ingredient variations on the physical properties and functional characteristics of extruded sorghum-groundnut-cowpea blends using response surface methodology. *Int J Food Eng* 6(4):1–17
- Bhatnagar S, Hanna MA (1994) Amylose-lipid complex formation during single-screw extrusion of various corn starches. *Cereal Chem* 71(6):582–586
- Bryant RJ, Kadan RS, Champagne TE, Vinyard BT, Boykin D (2001) Functional and digestive characteristics of extruded rice flour. *Cereal Chem* 78:131–137
- Case SE, Hamann DD, Schwartz SJ (1992) Effect of starch gelatinization on physical properties of extruded wheat and corn based products. *Cereal Chem* 69(4):401–404
- Castells M, Marin S, Sanchis V, Ramos AJ (2005) Fate of mycotoxins in cereals during extrusion cooking: a review. *Food Addit Contam* 22:150–157
- De Pilli T, Severini C, Baiano A, Derossi A, Arhaliass A, Legrand J (2005) Effects of operating conditions on oil loss and properties of products obtained by co-rotating twin-screw extrusion of fatty meal: preliminary study. *J Food Eng* 70(1):109–116
- De Pilli T, Jouppila K, Ikonen J, Kansikas J, Derossi A, Severini C (2008) Study on formation of starch–lipid complexes during extrusion-cooking of almond flour. *J Food Eng* 87(4):495–504
- Ding QB, Ainsworth P, Tucker G, Marson H (2005) The effect of extrusion conditions on the physicochemical properties and sensory characteristics of rice-based expanded snacks. *J Food Eng* 66(3):283–289
- Garg SK, Singh DS (2010) Optimization of extrusion conditions for defatted soy-rice blend extrudates. *J Food Sci Technol* 47(6):606–612
- Gimenez MA, González RJ, Wagner J, Torres R, Lobo MO, Samman NC (2013) Effect of extrusion conditions on physicochemical and sensorial properties of corn-broad beans (*Vicia faba*) spaghetti type pasta. *Food Chem* 136(2):538–545
- Guha M, Ali SZ (2006) Extrusion cooking of rice: effect of amylose content and barrel temperature on product profile. *J Food Process Preserv* 30(6):706–716
- Guy RCE, Horne A (1988) Extrusion and co-extrusion of cereals. In: Blanshard JMV, Mitchell JR (eds) *Food structure—its creation and evaluation*. Butterworths, London, pp 331–349
- Hagenimana A, Ding X, Fang T (2006) Evaluation of rice flour modified by extrusion cooking. *J Cereal Sci* 43(1):38–46
- Harper JM (1981) *Extrusion of foods*, vol I. CRC Press, Boca Raton, pp 1–19
- Kaur K, Singh N (2000) Amylose-lipid complex formation during cooking of rice flour. *Food Chem* 71(4):511–517
- Mercier C, Charbonniere R, Grebaut J, De La Gueriviere JF (1980) Formation of amylose lipid complexes by twin-screw extrusion cooking of manioc starch. *Cereal Chem* 57:4–9
- Oikonomou NA, Krokida MK (2011) Literature data compilation of WAI and WSI of extrudate food products. *Int J Food Prop* 14(1):199–240

- Pan Z, Zhang S, Jane J (1998) Effects of extrusion variables and chemicals on the properties of starch based binders and processing conditions. *Cereal Chem* 75(4):541–546
- Patil RT, Berrios JDJ, Tang DJ, Swanson BG (2007) Evaluation of methods for expansion properties of legume extrudates. *App Eng Agric* 23(6):777–783
- Sandhu RS, Kamboj R and Singh B (2018a) Textural, color and sensory attributes of high fiber cookies supplemented with oatmeal flour. In: *IJCA: Proceedings on International Conference on Advanced Engineering and Technology ICAET*, vol 4, pp 21–24
- Sandhu RS, Singh N, Kaler RSS, Kaur A, Shevkani K (2018b) Effect of degree of milling on physicochemical, structural, pasting and cooking properties of short and long grain Indica rice cultivars. *Food Chem* 260:231–238
- Sefa DS, Saalia FK (1997) Extrusion of maize-cowpea blends in a modified oil expeller. *J Sci Food Agric* 73(2):160–168
- Shevkani K, Singh N, Rana JC, Kaur A (2014) Relationship between physicochemical and functional properties of amaranth (*Amaranthus hypochondriacus*) protein isolates. *Int J Food Sci Technol* 49(2):541–550
- Silva MCD, Carvalho CWPD, Andrade CT (2009) The effects of water and sucrose contents on the physicochemical properties of non-directly expanded rice flour extrudates. *Food Sci Technol* 29(3):661–666
- Singh N, Smith AC (1997) A comparison of wheat starch, whole wheat meal and oat flour in the extrusion cooking process. *J Food Eng* 34(1):15–32
- Singh N, Smith AC (1999) Rheological behaviour of different cereals using capillary rheometry. *J Food Eng* 39(2):203–209
- Singh N, Cairns P, Morris VJ, Smith AC (1998) Physical properties of extruded wheat starch additive mixtures. *Cereal Chem* 75(3):325–330
- Singh N, Kaur K, Singh H, Singh H (2000) Effect of starch-lipids inclusion complex formation on functional properties of flour in tandoori roti. *Food Chem* 69(2):129–133
- Singh B, Sekhon KS, Singh N (2007) Effects of moisture, temperature and level of pea grits on extrusion behaviour and product characteristics of rice. *Food Chem* 100(1):198–202
- Singh B, Hussain SZ, Sharma S (2014a) Response surface analysis and process optimization of twin screw extrusion cooking of potato based snacks. *J Food Process Preserv* 39(3):270–281
- Singh N, Shevkani K, Kaur A, Thakur S, Parmar N, Virdi AS (2014b) Characteristics of starch obtained at different stages of purification during commercial wet milling of maize. *Starch Starke* 66:668–677
- Thachil MT, Chouksey MK, Gudipati V (2014) Amylose lipid complex formation during extrusion cooking: effect of added lipid type and amylose level on corn based puffed snacks. *Int J Food Sci Technol* 49(2):309–316
- Zhong Y, Liu W, Xu X, Liu C, Tu Z (2014) Correlation analysis between color parameters and sensory characteristics of rice with different milling degrees. *J Food Process Preserv* 38(4):1890–1897

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