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Puffing Characteristics of Preconditioned Pressure Parboiled Brown (Unpolished) Rice in Microwave Oven and Optimization of Process Parameters

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ABSTRACT

Puffed rice is prepared in India by roasting of parboiled preconditioned polished rice in hot sand bed. Polishing of rice takes time, decreases the head rice yield, nutrition, and increase the cost. Other methods used for rice puffing as hot air puffing, gun puffing are costly, and produce bulk quantity of puffed rice. Bulk production adds transportation and storage cost, and also increase the chances of sogginess. Microwave puffing of brown rice was attempted to provide an option for nutritious, and hygienic puffed rice. Full factorial design was chosen for experiment with three levels of microwave power (800, 900 and 1000 W), and four levels (20, 25, 30 and 35 s) of heating time. It was observed that microwave power and heating time had significant effect on quality (puffing percentage, expansion ratio, whiteness index, hardness) characteristics. Optimized conditions were found at 900 W microwave power for 35 s of heating for puffing of preconditioned brown rice in microwave oven. Puffing percentage, expansion ratio, whiteness index and hardness of microwave puffed brown rice at optimum conditions were 57.44%, 5.34, 58.31 and 11.28 N, respectively.

Keywords: Microwave puffing, brown rice, puffed brown rice

Puffed rice is known for its texture and taste. Puffed rice is traditionally produced from the conditioned parboiled polished rice. Parboiling process gelatinizes the rice kernel, seal the internal cracks and make rice kernel hardened (Bhattacharya, 2011). Conditioning process facilitates the salt infusion into the rice. In the conditioning process, parboiled polished rice is mixed with salt solution (3-4 %). During this process, rice moisture reaches around 35 % (w.b.). After salt infusion, rice is dried to puffing moisture content (10-11 %, w.b.). This whole conditioning process hardens the outer layer of rice (Mohapatra *et al*., 2012). The hardened layer acts as a miniature pressure vessel during puffing process and provides a barrier to the water vapour which builds the pressure for puffing. As the vapour pressure in the kernel increases more than the counterbalancing pressure of outer harder layer of rice, it expands with simultaneous cooking (Jha, 2005; Gulati and Datta, 2016). After puffing, the moisture content of rice reaches to 3-4% (w.b.). This process makes rice grain crispy and more digestible.

Expansion of rice after puffing is an important quality characteristic that depends upon rice physico-chemical properties. According to Joshi *et al*. (2014a), medium-hard grain (100 - 140 N) shows better expansion than less hard (86 N, Gurjari variety) and harder (160 N, GR-5 rice variety) grain, where hardness was measured at 12.5% (w.b.) moisture content. They compared 12 rice varieties with variation in physico-chemical properties, and reported 4.14 to be the maximum volumetric expansion. Other chemical factors also influence the puffing quality. High amylose content (>25%) variety gives better expansion, while increase in protein content reduces the expansion of the puffed product (Moraru and Kokini, 2003; Joshi *et al*., 2014a, Mishra *et al*., 2015). It means rice variety with low protein and high amylose content is preferable for puffing.

Various puffing methods like sand bed, hot air, gun, and microwave have been used for puffing of rice. These puffing methods influence the quality of puffed rice as well. This variation in the quality is due to the heating medium like surface heating (hot sand, hot air), volumetric heating (microwave); and in case of gun puffing it depends upon pressure and temperature inside the vessel. Sharma and Gujral (2011) and Swarnakar *et al*. (2019) compared microwave and sand heating for puffing barley and brown rice, respectively, and reported hot sand to give better puffing. Rapid and preheated medium enhances the puffing quality of grain (Joshi *et al*., 2014b).

In south-east Asia, rice puffing is generally carried out in hot sand bed. Sand bed is heated by burning of agricultural waste, wood, wooden chips or coal, which produces air pollution. Fine silica particles are also found in sand bed puffed rice (Kora, 2019). Hot sand bed puffing requires skilled labour for conditioning, regulation of heat, and proper turning and agitation of sand to prevent charring of puffed rice (Joshi *et al*., 2014b; Swarnakar and Das, 2018; Swarnakar, 2019). Some of other methods of rice puffing are hot air, hot oil and gun puffing. Hot air and gun puffing methods are costly as well-known gun puffing requires pressure vessel, and heating of air is an inefficient process (Joshi *et al.*, 2014b; Swarnakar *et al*., 2014). Bulk quantity production is a substantial drawback of these methods. These are the commercial methods and have to produce puffed rice in bulk quantity for economic reasons. Due to the hygroscopic nature of puffed rice, it absorbs moisture quickly which deteriorates its sensory value. As reported by Roopa *et al*. (2009), any puffed product loses its textural quality at more than 3 % (w.b.) moisture content. Bulk production of puffed rice also increases the cost of transportation and storage. On the other hand, oil puffed rice is susceptible to rancidity on prolonged storage (Joshi *et al*., 2014b).

Puffing of rice, therefore, requires a clean, hygienic, energy efficient and easy process. Microwave heating is now-a-days becoming popular for heating of food (Chandrasekaran *et al*., 2013). Microwave provides rapid heating that is suitable for puffing of food grain (Maisont and Narkrugsa, 2009, 2010; Mishra *et al*., 2015; Devi and Das, 2017, 2018; Swarnakar *et al*., 2019; 2020). Microwaveable popcorn is a popular commercialized product under this category. Studies in microwave puffing of food grains were done at different power levels in a microwave oven based on on-off cycle. Microwave oven on-off time depends upon maximum output power of magnetron. This kind of power level variation gives intermitted heating, takes more time for puffing and create a chance to evaporate moisture of preconditioned rice at a lower temperature than the puffing temperature. Long microwave heating also gives a negative impact on expansion during the heating treatment (Mohapatra and Das, 2011; Swarnakar *et al*., 2014). When rice temperature reaches to puffing temperature during intermitted heating, moisture may not be sufficient to build adequate vapour pressure for good expansion in remaining un-puffed rice. Slow evaporation may also soften the outer layer of rice which can give adverse effect on puffing. Continuous heating of rice can be helpful for producing proper and adequate vapour pressure inside the rice kernel for puffing as in other methods. Microwave heating involves two parameters *viz.,* microwave power level and heating time. These two parameters affect the quality of the final product. Several researchers have mentioned that the optimum combination of microwave power and heating time is important for a good quality of product, as variations in these variables lead to negative effect on quality of the product (Mohapatra and Das, 2011; Swarnakar *et al*. 2014).

Puffing of parboiled polished rice is a common practice. Chandrasekhar and Chattopadhyay (1991) suggested 6 % polishing is necessary for good quality of puffed rice. They also mentioned that unpolished rice gave inferior quality than polished rice in puffing. Polishing of rice involves higher cost, requires more processing time, and simultaneously reduces its nutritive value. Nutrition reduction is directly proportional to the degree of polishing (Lamberts *et al*., 2007). Brown rice has several health benefits as a good source of phytochemicals, protein, fat, and fibre (Munarko *et al*., 2020). Mir *et al*. (2016a) mentioned that brown rice retains these nutritive properties after puffing. Thus, puffing of brown rice could be beneficial for health.

In this study microwave power and heating time was optimized for puffing of prepacked preconditioned brown rice (ready to puff) to achieve healthy and fresh puffed rice. Experiments were carried out at different power levels with use of different microwave ovens to avoid intermittent heating.

MATERIALS AND METHODS

The study was conducted at the Agricultural and Food Engineering Department, Indian Institute of Technology, Kharagpur during 2016-17.

Pressure Parboiling of Paddy

High amylose content paddy variety IR 1010 (amylose content 25.11 %) was selected for the study and procured from the local market of Kharagpur, Paschim Medinipur, West Bengal. As recommended by Mahanta and Bhattacharaya (2010), high amylose content rice varieties are suitable for puffing after pressure parboiling. Paddy (about 2 kg) was parboiled at optimized steaming pressure and time (303 kPa and 14 min) after soaking of 7 min in normal water at room temperature (Swarnakar *et al*., 2020). Same parboiling setup was used for parboiling as described by Swarnakar *et al*. (2020). After parboiling, paddy was dried in hot oven at 80°C up to 14 % (w.b.) moisture content. Dried parboiled paddy was dehusked in a rubber roll sheller (Model: Model THU35A, Satake Engineering, Japan), and the brokens were separated using a laboratory grader (Burrows equipment Company, Illinois, USA).

Pre-puffing Conditioning of Pressure Parboiled Brown Rice

Preconditioning of parboiled unpolished or brown rice was carried out by mixing 200 g parboiled brown rice with 40 ml salt water of concentration of 3.5% (w/w) (Swarnakar *et al*., 2019). The mixed product was kept at room temperature (25 ºC) for an hour. During this period, brown rice was manually agitated for proper distribution of salt. Salt-mixed brown rice was then dried in fluidized bed dryer (Lab Dryer, Basic Technology Pvt. Ltd., India) at temperature of 75.6 °C up to puffing moisture content 11.6% (w.b.) (Swarnakar *et al*., 2019). Preconditioned brown rice was packed in sealing pack (254× 354 mm) for subsequent experiments.

Microwave puffing of preconditioned brown rice

Ten grams of preconditioned brown rice was packed in a paper envelope (245 mm ×100 mm), and sealed with adhesive tape. The packet of preconditioned brown rice was kept at the centre of a microwave oven turntable. Puffing of preconditioned brown rice was carried out at three levels of microwave power (P) and four levels of heating time (T). Levels of microwave power and heating time were selected by trial experiments. Heating of more than 35 s started charring puffed brown rice. Different microwave ovens were used for each power level to avoid intermittent heating. These power levels were 800 W (Model: MS23F301TAK, SAMSUNG, India, capacity: 23 l, power consumption: 1150 W), 900 W (Model: MC32J7055VB, SAMSUNG, India, capacity: 32 l, power consumption: 1400 W), and 1000 W (Model: M197DL, SAMSUNG, India, capacity: 24 l, power consumption: 1400 W) for four levels of heating time of 20, 25, 30 and 35 s.

Puffing Quality Characteristics

Analysis of puffed brown rice was carried out with whole puffed samples of each experiment. Quality characteristics of puffed brown rice were measured in three replicates, except for hardness. As puffed products show high variation in hardness value, six replicates were considered. Mean value was considered for the analysis.

Puffing percentage (PP)

Puffing percentage was the percentage of grain puffed or expanded in the preconditioned brown rice sample during microwave heating (Mohapatra and Das, 2011). It was calculated as:

$$\text{PP} = \frac{\text{Number of puffed brown rice in the sample}}{\text{Total number of brown rice in the sample}} \quad \ldots(1)$$

Expansion ratio (ER)

Expansion ratio of puffed brown rice is the volume ratio of puffed brown rice and preconditioned brown rice. Volume of puffed brown rice was measured by pouring puffed brown rice into a graduated cylinder (100 ml), and intergranular void spaces of puffed brown rice were filled with sand by ten gentle tapping. Sand used in volume measuring process was dry, fine and cleaned as mentioned by Swarnakar *et al*. (2014). After filling void spaces of puffed brown rice, the total volume of sand and puffed brown rice mixture in the cylinder was noted. Sand and puffed brown rice were then separated by sieving, and volume of sand was noted. Difference of total volume and volume of sand was the volume of puffed brown rice. Volume of same number of preconditioned brown rice puffed during microwave heating was measured by similar approach (Mohapatra and Das, 2011).

The ER was calculated as:

$$\text{ER} = \frac{\text{Volume of puffed brown rice}}{\text{Volume of preconditioned brown rice}} \quad \ldots(2)$$

Whiteness index (WI)

Colour of the puffed brown rice was measured in terms of CIE Lab coordinate by keeping the head of Colorimeter (Chroma meter CR-400, Konica Minolta, Japan) on the surface of puffed brown rice filled dish. Whiteness index (Eq. 3) of puffed brown rice was calculated as mentioned by Hsu *et al*. (2003):

$$WI = 100 - \sqrt{(100-L)^2 + a^2 + b^2} \quad \ldots(3)$$

Where L, a and b are CIE colour coordinates.

Hardness (H)

Hardness of the puffed brown rice was measured by Texture Analyzer (TA-XT2i, Stable Microsystem Texture Analyzer, UK) with probe diameter of 25 mm, 25 kg load cell and crosshead speed of 10 mm.s^{-1} (Nath *et al.*, 2007).

Optimization

Experiments were carried out according to the full factorial design. Table 1 is showing the experimental plan in actual and coded value of processing variables. Optimization of processing variables was carried in Design Expert 7.0 (Stat-Ease INC., 2009, USA) software. The responses were the puffed rice properties PP, ER, WI, and H.

Effect of processing variables on response was investigated through response surface using the regression Eq. 4. The regression equation was obtained by eliminating the insignificant (p>0.05) terms maintaining equation hierarchy. Analysis of variance (ANOVA) was used to examine significance of model terms on each response.

Table 1. Experimental plan with actual and coded value of variables

Run	Microwave power, W		Heating time, s	
	Actual value	Coded value	Actual value	Coded value
1	800	-1	20	-1
2	800	-1	25	-0.333
3	800	-1	30	+0.333
4	800	-1	35	+1
5	900	0	20	-1
6	900	0	25	-0.333
7	900	0	30	0.333
8	900	0	35	+1
9	1000	+1	20	-1
10	1000	+1	25	-0.333
11	1000	+1	30	+0.333
12	1000	+1	35	+1

$$Y = b_0 + b_1X_1 + b_2X_2 + b_{12}X_1X_2 + b_{11}X_1X_1 + b_{22}X_2X_2 \quad \ldots(4)$$

Where,

X_1 and X_2 = Processing variables,
b_o = A constant term,
b_1, b_2 = Linear term coefficient,
b_{12} = Interaction term coefficient, and
b_{11}, b_{22} = Square term coefficients in respective equation.

Optimization was done according to criteria as shown in Table 2 The property PP and ER were considered to be more important than WI and H as these are primary quality characteristic of puffing process in microwave heating (Joshi *et al*., 2014b). In Design Expert 7.0 software least, importance is represented by 1 or +, and most important is represented by 5 or +++++. The importance level of three or +++ is default importance that was used for WI and H. The PP and ER considered slightly more important than WI and H, and, therefore, 4 or ++++ was used for these parameters.

Optimum conditions were selected by the high overall desirability (D) value, which is the geometric mean of individual desirability ($d_i(y_i)$) of the variables (Eq. 5), and its value varies in between 0 to 1 (Montgomery, 2017).

$$D = [d_1(y_1) \times d_2(y_2) \ldots\ldots\ldots \times d_k(y_k)]^{1/k} \quad \ldots(5)$$

An experiment was carried out using the optimized processing conditions to validate the optimized level of processing variables.

Table 2. Optimization criteria for different variables and responses

Sl. No.	Variable	Goal	Importance
1.	P, W	Range	-
2.	T, s	Range	-
3.	PP	Maximize	4
4.	ER	Maximize	4
5.	WI	Maximize	3
6.	H, N	Minimize	3

Note: P – Microwave power, W; T – Heating time, s; PP- Puffing percentage; ER – Expansion ratio; WI – Whiteness index; H- Hardness, N

Two tail t-test was carried out to compare the response of validation experiment to the optimized values of responses found during the optimization process. The null hypothesis was that there was no significant difference between the mean of actual and predicted values. The hypothesis was checked at 95 % of confidence level ($p \leq 0.05$).

RESULTS AND DISCUSSION

Microwave Puffing of Pressure Parboiled Brown Rice

Table 3 presents the mean values of puffing characteristics of brown rice at different levels of microwave power and heating time. The ER of puffed brown rice showed less value at a higher level of heating time and power. These results were in agreement with Mir *et al.* (2016b), who had observed that puffing of brown rice in hot sand at temperature greater than 230 °C produces an inferior expansion of puffed brown rice. A similar trend was observed by Mohapatra and Das (2011) for polished rice puffed in a microwave. Brown rice puffed in microwave oven had 5 times higher expansion ratio than that of traditionally puffed polished rice expansion.

A higher microwave energy level showed a negative impact on expansion. Puffing percentage also followed a similar trend. Hardness of puffed brown rice reported by Mir *et al*. (2016b) was about 16 N in hot sand. During microwave puffing of brown rice, hardness varied around 12 N which makes it more acceptable. Whiteness index of microwave puffed brown rice was found to be about 58 at optimum conditions. Hardness and whiteness index are important quality measures for puffed rice. Earlier studies considered colour in colour coordinates of L (lightness), a (red to green), and b (yellow to blue), while the present study considered derivative WI. Mir *et al.* (2016b) mentioned colour values of puffed brown rice (hot sand bed method) as L* 67.78, a* 7.13, and b* 23.27, although they did not take this parameter during optimization. Devi and Das (2017) used the browning index to study the effect of salt and moisture content in microwave popping of paddy, and reported it to vary between 12.83 to 17.89.

Fitting of Models

Analysis of variance and regression equations of obtained results for microwave puffing quality characteristics PP, ER, WI and H at different power and heating time are shown in Table 4 and 5, respectively. Regression equations were obtained after eliminating the insignificant terms ($p>0.05$) without damaging model hierarchy. Model of PP and ER were found significant at 99.99 % ($p<0.001$) confidence level, and model of WI and H were significant at 95 % confidence level ($p<0.05$).

The H and PP of microwave puffed brown rice followed

Table 3. Properties of microwave puffed preconditioned brown rice

Sl. No.	P, W	T, s	PP	ER	WI	H, N
1.	800	20	10.78	4.26	44.32	12.86
2.	800	25	26.86	4.68	51.25	12.24
3.	800	30	27.71	4.32	52.79	11.26
4.	800	35	46.34	4.36	55.11	11.11
5.	900	20	14.58	5.20	56.23	12.29
6.	900	25	24.31	5.64	55.98	12.19
7.	900	30	50.72	5.82	57.75	12.24
8.	900	35	61.50	5.12	56.61	11.50
9.	1000	20	21.37	3.80	53.64	12.18
10.	1000	25	37.25	4.54	57.01	12.73
11.	1000	30	48.63	4.29	52.81	11.06
12.	1000	35	63.82	4.49	54.55	11.37

**Values in parentheses are coded value of corresponding levels*

Note: P – Microwave power, W; T – Heating time, s; PP- Puffing percentage; ER – Expansion ratio; WI – Whiteness index; H- Hardness, N

Table 4. ANOVA of puffed brown rice quality characteristic model terms

Sl. No.	Source of variation	PP	ER	WI	H
1.	Model	68.24***	15.04**	7.46*	7.21*
2.	P	18.29**	0.61^{ns}	7.90*	0.01^{ns}
3.	T	118.20***	0.95^{ns}	6.24*	14.41**
4.	PT	-	1.77^{ns}	9.37*	-
5.	P^2	-	64.72**	12.50*	-
6.	T^2	-	7.16*	1.27^{ns}	-

**** significant at 0.001 level, ** significant at 0.01 level, * Significant at 0.05 level, ns – insignificant, P – Microwave power, W; T – Heating time, s; PP- Puffing percentage; ER – Expansion ratio; WI – Whiteness index; H- Hardness, N*

linear relationship, while ER and WI followed quadratic relationship with processing variables. Values of R^2, predicted R^2, and adjusted R^2 of PP, ER and H showed good agreement except (adjusted R^2 - predicted $R^2 \leq 0.2$) for WI and adequate precision value (more than 5). Predicted residual sum of squares (PRESS) and coefficient of variation (CV) also showed good fit of models. The CV value less than 10 % shows good fit of model (Giri and Prasad, 2007). All models showed less than 10 % CV value, except for PP.

Quality Characteristics Analysis of Microwave Puffed Brown Rice

Puffing percentage

Figure 1 shows the response surface of PP at different power levels and heating times. The PP varied from 10.78 to 63.82 %. Processing parameters i.e., microwave power ($p<0.01$) and heating time ($p<0.05$) were found significant for PP, and showed a positive effect. The PP increased linearly with increase in the processing variable. Heating time of brown rice in microwave oven was more effective than power as shown in Fig. 1. This was also revealed from the Table 2 with F value of heating time being 118.2, and was much higher than microwave power F value (18.29). So, the time of heating in puffing was more important than the microwave power level for PP. Similar results were observed by Swarnakar *et al*. (2014) and Mom *et al*. (2020) during microwave popping of paddy. A higher level of exposer time gives sufficient opportunity to puff un-puffed brown rice.

Expansion ratio

Response surface of preconditioned brown rice expansion during its puffing showed curvi-linear nature (Fig. 2). Initial levels of processing variables showed positive effect on ER upto 900 W and 25 s. According to Moraru and Kokini (2003), higher heating power level produces vapour rapidly and increases the vapour pressure inside the grain for puffing and helps in the expansion. Statistically linear terms of processing variables ($p>0.05$) were insignificant (Table 4). The square terms of microwave power ($p<0.01$) and heating time ($p<0.05$) both were found to be significant for ER (Table 4). These terms

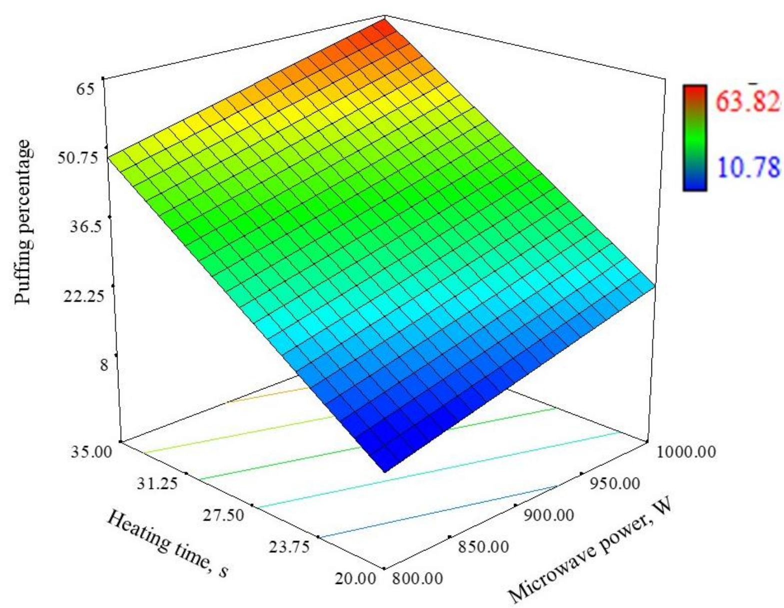

Fig. 1: Effect of microwave power and heating time on puffing percentage of preconditioned brown rice

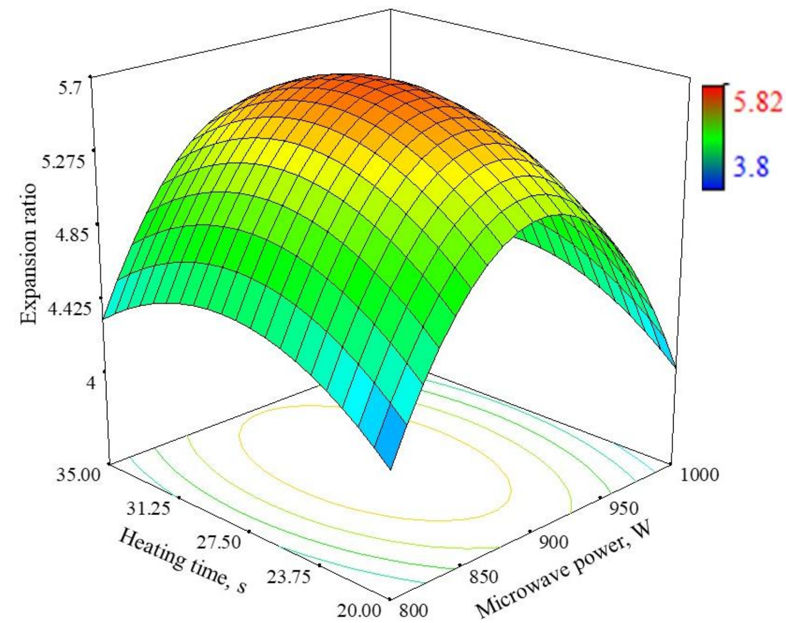

Fig. 2: Effect of microwave power and heating time on expansion ratio of puffed brown rice

showed the adverse effect on ER as the coefficients of these terms were negative. Insignificant linear term of power level and heating time were included in the ER equation to maintain its hierarchy. The quadratic term of power level showed more impact on ER as compared to the quadratic term of heating time. This was also revealed from the F values of quadratic terms (Table 4). Thus, the power level had more influence than the exposure time. Mohapatra and Das (2011) had also reported same findings during microwave puffing of preconditioned polished rice. Higher heating time allowed moisture to escape from un-puffed grain. Therefore, longer exposer time showed high PP with less expansion.

Whiteness index

Figure 3 shows the variations in WI of puffed brown rice with microwave puffing processing variable. The response surface indicated that both microwave power ($p<0.05$) and heating time ($p<0.05$) had effects on whiteness of puffed brown rice (Table 4). Maximum and minimum WI observed in puffed brown rice was

Table 5. Regression equations of quality characteristic of puffed brown rice with processing variables

Sl. No.	Equation	R^2	Predicted R^2	Adjusted R^2	Adequate precision	CV	PRESS
1.	$PP = -106.44+0.072P+2.756T$	0.938	0.903	0.924	22.89	13.58	340.88
2.	$ER = -88.679 - 0.197P + 0.391T - 1.103 \times 10^{-3} P^2 - 6.919 \times 10^{-3} T^2$	0.904	0.704	0.849	10.66	5.01	1.21
3.	$WI = -374.476 + 0.828P + 3.422T - 3.540PT - 3.958 \times 10^{-3} P^2$	0.832	0.338	0.736	9.95	3.45	95.75
4.	$H_a = 14.239 - 0.084T$	0.615	0.483	0.576	7.59	3.43	2.24

Note: P – Microwave power, W; T – Heating time, s; PP- Puffing percentage; ER – Expansion ratio; WI – Whiteness index; H- Hardness, N; CV - Coefficient of variation; PRESS - Predicted residual sum of squares

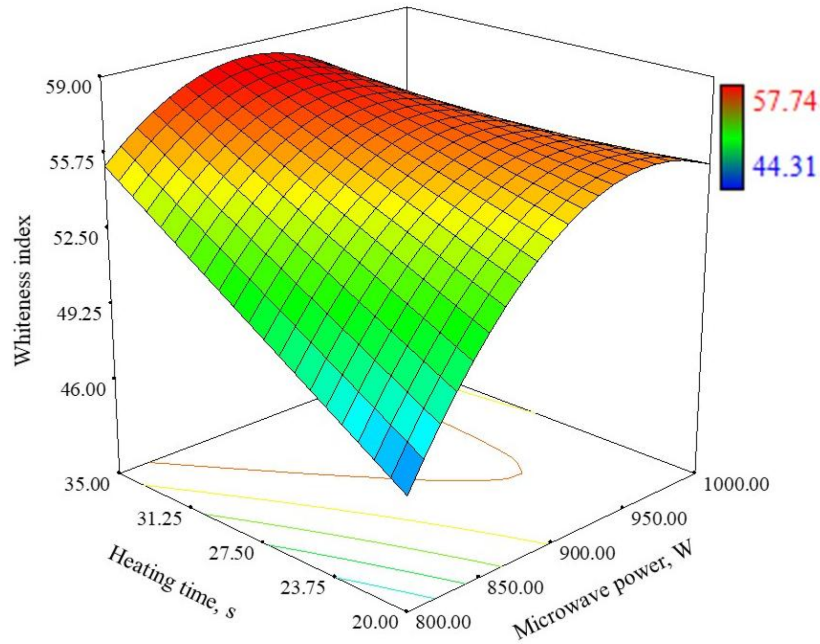

Fig. 3: Effect of microwave power and heating time on whiteness index of puffed brown rice

57.74 and 44.31, respectively. The WI followed a quadratic relationship with significant interaction effect of processing variables ($p<0.05$) (Table 5). Whiteness increased with increase in microwave oven power from 800 W to 900 W whereas it showed a constant trend with increase in heating time and power level beyond 900 W. The F value of linear terms of power level and heating time (Table 4) were almost same (7.61 and 6.01, respectively). Thus, the influences of these processing variables on WI were equal at initial levels. Quadratic term of microwave power had the highest F value (12.04), followed by interaction effect (9.37). The quadratic term of heating time was found to be insignificant ($p>0.05$). Therefore, the trend of WI did not change for the longer heating time. Improvement in the WI was due to the expansion in the puffed brown rice. Expansion of grain exposes the inner white endosperm which provides the white appearance to puffed grain (Mir *et al*., 2016a).

Hardness

Hardness (Fig. 4) had a linear relationship with the processing variables. Microwave power effect was found to be insignificant ($p>0.05$) on the H of puffed brown rice. Linear term of heating time was observed to be significant ($p<0.01$) for H of puffed brown rice in microwave puffing (Table 4). Hardness increased linearly as heating time progressed (Fig. 4). Thus, only heating time was responsible for H of puffed brown rice, and longer heating produced more hard puffed brown rice.

Optimization of Processing Parameters

Numerical optimization was carried out to optimize the P and T for puffing of brown rice with the help of the regression models depicted in Table 5, obtained using Eq. 4. Range of processing variables was kept in the experimental range i.e., P: 800 – 1000 W and T: 20 – 35 s. Limitations are mentioned in the earlier concerned section for these variables. Optimum conditions were obtained for maximum PP, ER, and WI; and for minimum H. Optimum condition was selected at the high desirability value of 0.89 (Eq. 5).

Optimum operating condition was found to be of 900 W (closest to optimised value of 908.33 W) microwave power applied for 35 s of heating (Table 6) with predicted optimum quality parameter at respective condition. These optimum conditions were similar to microwave puffing (880 W for 33 s) for rice reported by Mohapatra and Das (2011).Optimum puffing percentage obtained for brown rice was 57.44 per cent. This was less compared to their puffing percentage of 97-99 per cent. Therefore, it needs to be improved.

Three experimental runs were carried to validate the performance of optimum operational parameters, and

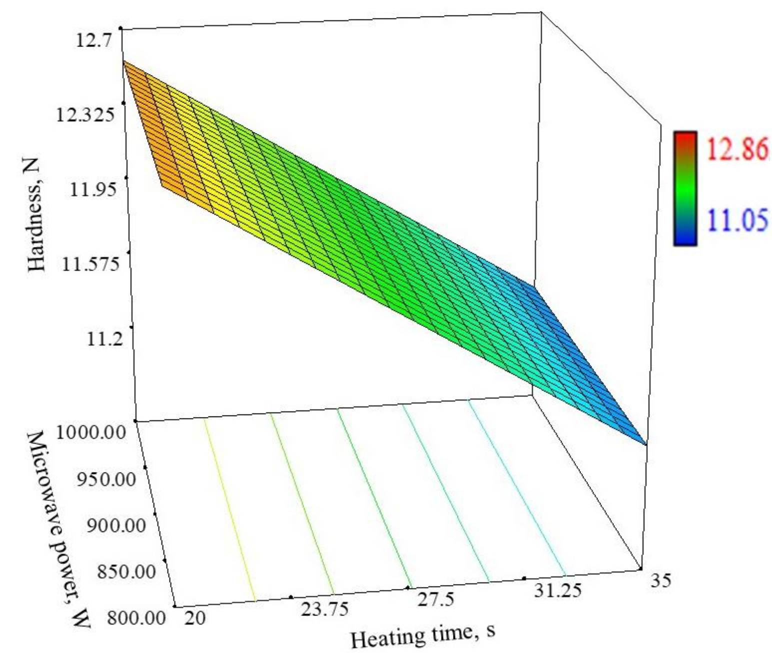

Fig. 4: Effect of microwave power and heating time on hardness of puffed brown rice

the results were compared through the t-test assuming equal mean. No significant differences between the actual and predicted values were found (Table 7) for ER and WI ($p \leq 0.05$). However, the mean difference between the actual and predicted PP, and H were satisfactory. Giri and Prasad (2007) also reported optimization of microwave-vacuum drying for button mushroom. The value of H showed a significant difference during validation of optimum conditions.

CONCLUSIONS

Microwavable ready-to-puff packet of brown rice puffed at different values of microwave power and heating time exhibited that both parameters had significant effects on quality of puffed brown rice. Microwave power level and heating time showed quadratic relationships with expansion ratio and whiteness index of puffed brown rice, while puffing

Table 6. Solution for optimum condition

Sl. No.	P, W	T, s	PP	ER	WI	H, N	D
1.	908.33	35.00	57.44	5.34	58.31	11.29	0.89

Note: P – Microwave power, W; T – Heating time, s; PP- Puffing percentage; ER – Expansion ratio; WI – Whiteness index; H- Hardness, N; D - Desirability

Table 7. Validation of optimized puffing condition

Sl. No.	Dependent variable	Predicted value	Actual value ± SD	Mean difference	p-value (2 tailed)
1.	PP	57.45	58.43±1.22	0.98	0.234^{ns}
2.	ER	5.35	5.21±0.06	0.14	0.018*
3.	WI	58.31	56.38±0.47	1.93	0.002**
4.	H, N	11.29	10.85±1.59	0.44	0.164^{ns}

*Note: ** significant at 0.01 level, * Significant at 0.05 level, ns Insignificant, SD = Standard deviation, P – Microwave power, W; T – Heating time, s; PP- Puffing percentage; ER – Expansion ratio; WI – Whiteness index; H- Hardness, N* percentage and hardness followed linear relationships. Optimum conditions for puffing of brown rice in the microwave oven were determined to be 900 W (nearest rating to optimized value of 908.33 W) microwave oven power for 35 s heating time. Expansion of puffed brown rice in microwave oven was 5 times that of traditionally puffed polished rice expansion. It was concluded from this study that microwave puffing of brown rice can be an option for regular puffing of rice as it is more nutritious, hygienic, and provide fresh product. Puffing percentage of brown rice in microwave heating was found to be low (57 %), which needs to be improved.

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