Puffing quality and sensory evaluation of reduced sodium puffed rice

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Received: 5 November 2018 / Accepted: 18 November 2019

RESEARCH ARTICLE

Abstract

The effect of partial replacement of NaCl by KCl on puffing quality parameters on microwave puffed rice was investigated. Reduced sodium and an increased intake of potassium based salt substitutes was formulated and mixed with water and the solution was infused in parboiled rice. The salt infused rice was dried in a fluidised bed dryer till it attains the optimum moisture content for puffing which should be around 10.5%. The salt concentrations were varied such that the total salt concentration was maintained as 3-5% of the total mass of rice. The preconditioned rice obtained by the process was puffed in microwave oven and expansion ratio, percentage of puffing and sensory values were measured. Maximum expansion ratios, percentage of puffing and sensory values were achieved at a mixture of 2.5% NaCl and 1.5% KCl. Sensory evaluation study indicated that salt substitute could be prepared with NaCl and KCl at a proportion of 62.5% of NaCl and 37.5% KCl. It was also obtained that both sodium chloride and potassium chloride has positive effect on expansion ratio and percentage puffing of puffed rice and the effect of sodium chloride is more than that of potassium chloride. However, in case of sensory perception the effect of potassium chloride is more than that of sodium chloride. Hence potassium based salt substitute can be applied to parboiled rice which can significantly reduce the percentage of NaCl maintaining similar taste without affecting the puffing quality.

Keywords: microwave puffing, puffed rice, expansion ratio, salt substitute, fuzzy logic

1. Introduction

Puffed rice is a popular snack product due to its taste, texture and nutritional profile. It is mainly appreciated for its crispness, lightness and qualities related to its cellular structures (Hoke *et al.*, 2007). Traditionally puffed rice is prepared by parboiling the paddy under the specified conditions followed by high temperature short time treatment of the parboiled rice (Chinnaswamy and Bhattacharya, 1983; Murugesan and Bhattacharya, 1991). Use of microwave energy in food processing is extensive (Ramaswamy and Tang, 2007) particularly in the field of ready-to-eat snacks. At the present, there is an increasing trend to use microwaves for food processing due to the fact that microwave heating is more efficient than the traditional heating processes with benefits that include: quicker start-up time, faster heating, energy efficiency, space saving, selective heating and final products with improved nutritive quality (Sumnu, 2001). Microwave puffing is advantageous over the other puffing techniques (sand puffing and hot air puffing) due to dielectric heating effect that can result higher temperature inside the product than on its surface. In addition to this, the heating of the product throughout the whole volume results in uniformity of heating which is required for higher expansion of product. Application of microwave energy for puffing includes sorghum popping (Mishra *et al.*, 2015), microwave popping of starchy snacks (Van der Sman and Bows, 2017), preparation of microwave-puffed cheese chip (Liu *et al.*, 2018), and microwave popped paddy (Devi and Das, 2018).

It is possible to use microwave energy for baking, puffing or popping. The microwave puffing process comprises of two steps i.e. preconditioning of parboiled rice and microwave heating. The preconditioning process involves incorporation of NaCl into the kernel followed by moisture condition at optimum level. This infusion of salt helps good expansion of the kernels. Chinnaswamy and Bhattacharya (1983) reported that adding salt solution to the milled rice increased the expansion ratio, not only with sodium chloride, but also with other salts (KCl, $CaCl_2$ and $NaHSO_3$). Sodium is an essential nutrient, and the physiological need of sodium is only around 0.2 mg/day (Gilbert and Heiser, 2005). Despite its nutritional contribution, excessive sodium intake has been implicated in conditions such as high blood pressure and cardiovascular diseases (Jessica *et al.*, 2008). Unlike sodium, which increases hypertension potassium has antihypertensive properties and much higher recommended maximum intake level than sodium (Geleijnse *et al.*, 1994). Reduced sodium diet and an increased intake of potassium-based salt substitutes can protect against stroke, high blood pressure, heart-rhythm problems, kidney failure, and even osteoporosis (Hall, 2003; Myers, 1989). Therefore, a lot of research has focused on the development of salt substitutes (Braschi *et al.*, 2009; Wick *et al.*, 2006). On this basis many commercial products were developed for the partial substitution of NaCl in different types of food materials (Kilcast and Ridder, 2007; Kremer *et al.*, 2009; Manabe, 2008; Mitchell *et al.*, 2011; Reddy and Marth, 1990; Riera *et al.*, 1996; Ruusunen and Puolanne, 2005). Studies with sensory perception of saltiness were reported bitter taste with KCl salt alone. This bitter taste of KCl could be significantly suppressed with proper combination of NaCl and KCl salts (Breslin and Beauchamp, 1997; Frank and Mickelsen, 1969; Rosett *et al.*, 1995). Sensory evaluation by fuzzy logic is very effective for analysing the linguistic data under versatile conditions leading to a very precise interpretation of food sensory quality (Vivek *et al.*, 2019). Application of fuzzy logic for sensory evaluation betel leaf essential oil incorporated apple juice (Basak, 2018), bread from wheat flour partially replaced by fermented chickpea flour (Shrivastava and Chakraborty, 2018), wine classification (Petropoulos *et al.*, 2017) and bread fortified with apple pomace (Lu *et al.*, 2017).

Excess dietary sodium causes various health problems and has been identified as one of the potential reasons for elevation of blood pressure and various cardiovascular diseases. The reduction of sodium level in puffed rice can be achieved by substituting NaCl with KCl but the bitter taste of KCl has prevented its solitary use as a salt replacement. Use of potassium chloride in conjunction with sodium chloride would suppress the bitterness of the puffed rice so that the sensory value will remain unaffected. Considering the above aspects, a study was undertaken with preconditioning of rice with different concentration of NaCl and KCl, and microwave puffing of the resultant rice. It was followed by optimisation of the salt ratio with respect to desirable puffing volume and sensory quality of the product. The present study discusses the effects of different salts on the puffing characteristics and sensory quality attributes (fuzzy logic technique) of the puffed rice, and optimisation of the process parameters following response surface methodology. The results would help to determine the reasonable mass ratios of NaCl and KCl for preconditioning of rice for obtaining reduced sodium puffed rice with high puffing quality and palatability.

2. Material and method

Raw materials

Pressure parboiled long variety rice (Lalat; average length breadth ratio of 3.1) was selected for this study because of its good puffing quality and availability. The raw material at 14 to 16% (w.b.) moisture content was collected from the local market of Kharagpur, West Bengal, India. It was packed in self-sealing polyethylene bags and stored at room temperature in airtight container for subsequent uses.

Preconditioning of rice for puffing

About 1 kg of parboiled rice was mixed thoroughly with 150 ml aqueous salt solution (weight : volume ratio = 6.67) containing desired amount of NaCl and KCl mixture. The resultant sample was allowed to temper for 6 to 8 h for equilibration. Different lots of sample of rice were prepared with different salt levels as stated below. Each batch of rice sample was then put in a fluidised bed dryer and simultaneously heated (curing). Curing is the process heating of salt soaked grain to achieve the desirable moisture level in the kernel and was employed for toughening or hardening of outer layer of kernel. The fluidised bed dryer consisted of a transparent chamber (partly cylindrical at top and partly conical at bottom) with screen at the bottom. Grain was put in this chamber and placed over an air plenum chamber through which hot air from blower (coupled in this system) was introduced. In the airflow channel, electrical heaters were provided to heat the air at specific temperature using electrical control systems. A mechanism of recirculation of air was available with this fluidised-bed dryer. Airflow rate could be varied in this system using butterfly valve at the blower inlet. The drying or curing of rice sample was continued at a particular air temperature (80 °C) and airflow rate (3.4 m/s) until the grains attained puffing moisture content. To avoid crack or fissure development in the kernel, tempering of grain was carried out intermittently. Tempering is the process of stopping the drying process intermittently that allows the moisture to equalise within the grain by diffusion. At certain intervals of time, samples were collected for determination of moisture contents and hardness of the kernel. The dynamic change in moisture content of the rice during this preconditioning process was monitored with an indirect measurement system. A correlation between hardness of the grain and its moisture content had been drawn from experimental data. The moisture of the rice kernels was measured by standard oven drying method (AOAC, 1990) and its corresponding hardness was measured with grain hardness tester (Kiya Seisakusho Ltd., Tokyo, Japan). At each 10 min intervals, rice sample was collected from the dryer and its hardness was measured. The drying-cum-curing process continued till the puffing moisture content around 10.5% (wb) arrived.

Soaking with salt solution facilitates diffusion of salt, and this salt favours to some changes in the kernel that influence puffing characteristics. Soaking the parboiled rice in salt solution allow moisture and salt to penetrate to the centre of the kernel. Hence, the conduction of heat to the centre of the kernel becomes faster which results in uniformity of the preconditioning process. The levels for salt were selected within 3-5% as too high salt (>5%) showed non-acceptance in sensory quality of the sample, and too low salt content (<3%) showed very poor puffing quality. Hence, total salt concentration in this study was maintained in that range. Thus, each salts in the salt mixture was varied so as to get the minimum (3% w/w) and maximum (5% w/w) range of salt concentration as stated. Precisely, five levels of each salt (NaCl and KCl) were taken, starting from 1.5% up to 2.5% (w/w) with interval of 0.25% (w/w).

Experimental design for salt substitute

The experiments were designed based on a user-defined model under response surface method to study the combined effect of mixture of NaCl and KCl salts. Designated software Design Expert Version 7.1.6 (STAT-EASE Inc., Minneapolis, MN, USA) was used for the design of experiments and statistical analyses. The two independent variables considered for the study were represented as X_{NaCl}, X_{KCl} and its coded form is represented as x_{NaCl} and x_{KCl} respectively. X_{NaCl}, X_{KCl} were expressed as percentage which represents the amount of NaCl and KCl (g) added per 100 g of parboiled rice. The range of NaCl and KCl with its coded and real value is presented in Table 1. The effects of process parameters on quality attributes of microwave puffing such as expansion ratio (Y'_{ER}), percentage puffing (Y'_{PP}) and overall sensory score (Y'_{SV}) of puffed rice was investigated. A total number of 17 combinations of variables were obtained. To accommodate the error sum of squares and the lack of fit of the developed regression equation between the responses and independent variables, five replications were considered at the central points of the coded variables. Hence, a total 22 experimental combination are obtained as shown in Table 2. All these experiments were carried out in a randomised order to minimise any effect of extraneous factors on the observed responses.

In order to achieve the relationship between input factors and responses polynomial model was fitted to the data and the models in the form of Equation 1 was developed.

$$Y_k = \beta_{k0} + \sum_{i=1}^{n} \beta_{ki} X_i + \sum_{i=1}^{n} \beta_{kii} X_i^n + \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \beta_{kij} X_i X_j \quad (1)$$

Where β_{k0}, β_{ki}, β_{kii} and β_{kij} are constant regression coefficients and X is the coded independent variables For two factors, the model proposed for response (y) is represented in Equation 2.

$$y = b_0 + b_1x_1 + b_2x_2 + b_{11}x_1^2 + b_{22}x_2^2 + b_{12}x_1x_2 \quad (2)$$

Where x_1 and x_2 were coded independent variables, b_0 is the intercept term, b_1 and b_2 are linear coefficients, b_{11} and b_{22} are quadratic coefficients, and b_{12} is the interaction term coefficient. The significance of all terms in the polynomial

Table 1. Process variables of salt substitute and its levels.

Process variables	Actual and coded levels				
	-1	-0.5	0	+0.5	+1
NaCl	1.5	1.75	2	2.25	2.5
KCl	1.5	1.75	2	2.25	2.5

Table 2. Expansion ratio, percentage of puffing and sensory value at different combination of NaCl and KCl.

Sl no	Mass of NaCl (g/100 g parboiled rice)		Mass of KCl (g/100 g parboiled rice)	
	Real values	Coded values	Real values	Coded values
1	1.75	-0.5	2.00	0
2	2.25	0.5	2.25	0.5
3	1.75	-0.5	2.25	0.5
4	1.50	-1	2.50	1
5	2.50	1	2.50	1
6	2.00	0	2.50	1
7	2.00	0	2.00	0
8	2.00	0	2.00	0
9	2.00	0	2.25	0.5
10	1.75	-0.5	1.75	-0.5
11	2.00	0	2.00	0
12	2.00	0	2.00	0
13	2.50	1	1.50	-1
14	2.00	0	2.00	0
15	2.00	0	2.00	0
16	2.25	0.5	2.00	0
17	1.50	-1	1.50	-1
18	1.50	-1	2.00	0
19	2.00	0	1.50	-1
20	2.25	0.5	1.75	-0.5
21	2.50	1	2.00	0
22	2.00	0	1.75	-0.5

functions were assessed statistically using F-value and *P*-value (Prob > F).

Puffing of pre-conditioned rice using microwave energy

Microwave puffing was carried out using commercially available domestic microwave oven (Samsung, model: M197DL, Noida, India) using special packaging materials consisted of a parchment paper envelope (160 × 98 mm) covered with another envelope. A measured amount of pre-conditioned rice (weighing around 20 g) was taken inside this packet, sealed and put on the turntable inside the oven. It was subjected to heating at a power level of 850 W for a heating period of 35 s. The obtained microwave puffed rice was analysed to obtain the puffing quality parameters such as percentage of puffing and expansion ratio.

Puffing quality

Puffing quality of the product is measured in terms of percentage of puffing (%) and expansion ratio was estimated.

Percentage of puffing

The percentage of puffing was estimated as the ratio of number of rice puffed to the total number of pre-conditioned rice initially taken multiplied with 100. The approximate number of pre-conditioned rice (N_i) was calculated from the ratio of weight of rice taken for puffing (W_i) to the average weight of single kernel (m_i). The total number of un-puffed grain was estimated similarly as the ratio of un-puffed grain weight (W_u) to the average mass of single un-puffed kernel (m_u). Mathematically these are expressed

$$N_i = \frac{W_i}{m_i};\ N_u = \frac{W_u}{m_u} \quad (3)$$

$$PP = \frac{N_i - N_u}{N_i} \times 100 \quad (4)$$

Expansion ratio

Expansion ratio (ER) of puffed rice was determined as the ratio of true volume of the puffed rice to the true volume of rice taken for puffing (Nath *et al.*, 2007. Since the puffed rice is highly porous body, air comparison pycnometer was not suitable. This was done by sand filling technique. Puffed rice was filled is a graduated measuring glass-cylinder. It was followed by pouring clean and dry fine sand into the cylinder with gentle tapping several times (about 25 times) to facilitate covering the puffed rice along with voids in the bed. The total volume of puffed rice plus sand was noted. Sand and puffed rice were separated by a sieve, and the volume of sand was determined with the same measuring cylinder. The difference between total volume and volume of sand gives the true volume of puffed rice (V_a). The same procedure was followed to estimate true volume of parboiled rice (V_b) initially taken.

Expansion ratio after puffing can be calculated by using Equation 5.

$$ER = \frac{V_a}{V_b} \quad (5)$$

Sensory evaluation by fuzzy logic

Sensory evaluation of puffed rice was carried out using fuzzy logic technique. The different samples were ranked according to their sensory scores. Subjective sensory evaluation of twenty-two puffed rice samples were conducted with 25 members of trained judges who had adequate background knowledge of product quality. Additionally, these judges were familiarised with the quality attributes of the product before they started the evaluation process. The following parameters were considered for studying the sensory perception of puffed rice:

- colour: in terms of degree of browning;
- aroma: burning smell;
- taste: saltiness or burnt flour or bitterness;
- texture: crispiness and hardness.

For most of the food product these four properties are considered to be the most important sensory parameters. Colour is the first parameter that attracts consumer towards the food followed by its aroma, whereas, taste and texture are the most important parameters considered during consumption of the product. Ranking of food products and their quality attributes will be based on the Triplets obtained from the sensory score of the samples. Higher the sensory score better is the food quality and vice versa. The collective results from the judges were analysed using MATLAB (MATLAB and Statistics Toolbox Release 2011b, version 7.13.0, Natick, MA, USA).

With the help of Fuzzy logic the different samples were ranked according to their sensory scores. Ranking of food products and their quality attributes will be based on the following evaluations.

Triplets for sensory score of the samples

Figure 1 shows the distribution pattern of five-point linguistic scales, viz. poor/not at all important, fair/somewhat important, good/important, very good/highly important, and excellent/extremely important. As for example, triangle a b c represents membership function for poor/not at all important category, triangle g i j represents distribution function for excellent/extremely important category, etc. Triangular membership function distribution pattern of sensory scales can be represented by a set of triplets. First number of the triplet denotes the coordinate of the abscissa at which the value of the membership function

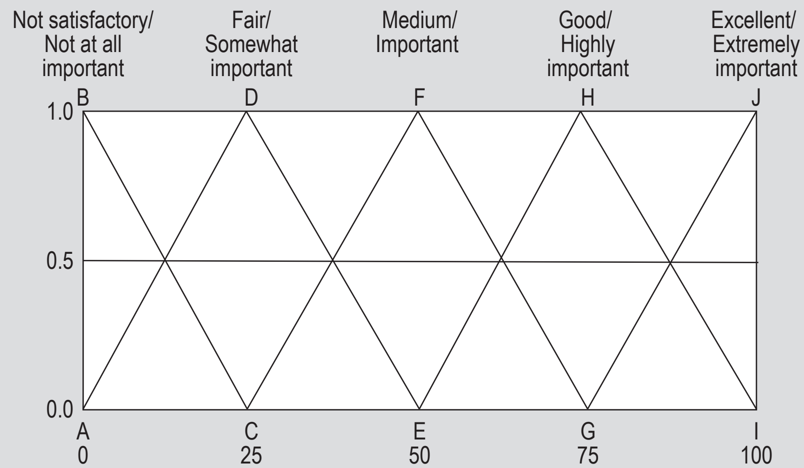

Figure 1. Triplet associated with the five-point linguistic scale.

is 1. Second and third numbers of the triplet designate the distance to the left and right, respectively, of the first number where the membership function is 0. Table 3 shows the distribution pattern of five point sensory scales, as per not satisfactory/not at all important, fair/somewhat important, medium/important, good/highly important, and excellent/extremely important. For a particular puffed rice sample, the triplet corresponding to a particular linguistic attribute (colour, aroma, taste and texture.) can be obtained from the sum of linguistic scores, triplets associated with linguistic scale (Table 3), and the number of judges. The overall quality of puffed rice sample were expressed by a triplet (a, b, c) and were represented by a triangle ABC.

Triplets for sensory score of quality attribute

The triplet for sensory scores for a particular quality attribute of every sample was obtained from the sum of sensory scores, triplets associated with sensory scale and number of judges. For example, in case of colour attribute of a sample, when total number of judges is ($n_1 + n_2 + n_3 + n_4 + n_5$) and n_1 judges give 'Not satisfactory' score, n_2 judges give 'Fair' score, n_3 judges give 'Medium' score, n_4 judges give the score as 'Good' and n_5 judges give 'Excellent,' the triplets for the sensory scores for colour will be calculated as expressed in Equation 6:

$$SiC = [n_1(0\ 0\ 25) + n_2(25\ 25\ 25) + n_3(50\ 25\ 25) + n_4(75\ 25\ 25) + n_5(100\ 25\ 0)] / (n_1 + n_2 + n_3 + n_4 + n_5) \quad (6)$$

Where, 'i' is the serial no. of samples.

Similar triplet values were obtained for each of the quality attributes of all the samples, and the triplet for the sensory score of quality attributes (e.g. *QC*, for colour and similarly *QF* (flavour), *QTs* (taste) and *QTx* (texture)) were calculated from the general weightage given by the judges to the quality attributes of the sample in general.

Triplets for relative weightage of quality attribute

In order to find out triplets for overall sensory score of the samples, it's necessary to find out relative weight age of quality attributes. For this, sum (Q_{sum}) of first digit of triplets of *QC, QF, QTs* and *QTx* is obtained.

Triplet for relative weightage of quality attributes e.g. colour (QC_{rel}) can be evaluated by applying Equation 7.

Table 3. Triplets associated with sensory scales.

Sl. no	Parameters of linguistic scale	Triangle representing membership function	Triplet value
1	Not satisfactory / Not at all important	ABC	(0 0 25)
2	Fair / Somewhat important	ADE	(25 25 25)
3	Medium / Important	CFG	(50 25 25)
4	Good / Highly important	EHI	(75 25 25)
5	Excellent / Extremely important	GJI	(100 25 0)

$$QC_{rel} = QC/Q_{sum} \quad (7)$$

Similarly, relative weightage of other quality attributes, viz., flavour (*QV*), Taste (*Qts*), and texture (*QTx*) can be calculated.

Triplet for overall sensory score of the sample

Triplet for sensory score for each quality attribute was multiplied with the triplet for relative weightage of that particular attribute and the sum of resultant triplet values for all attributes was taken to find out the triplets for the overall sensory scores of samples. In this case, for any sample number 'r', SOr can be evaluated as presented in Equation 8.

$$SOr = SrC \times QC_{rel} + SrF \times QF_{rel} + SrTs \times QTs_{rel} + SrTx \times QTx_{rel} \quad (8)$$

Where, each of terms on right hand side of the equation represents a triplet. The rule applied for multiplication of triplet (a b c) with (d e f) is presented in Equation 9.

$$(a\ b\ c) \times (d\ e\ f) = (a{\times}d\ \ a{\times}e{+}d{\times}b\ \ a{\times}f{+}d{\times}c) \quad (9)$$

Using the similar procedure, overall sensory scores for all the samples can be determined.

Overall score of the puffed rice sample

Overall score of the puffed rice samples were evaluated by finding the location of centroid of the triangle ABC by using Equation 10:

$$Y_2 = a - (b - c) / 3 \quad (10)$$

Higher the value of Y_2 better is the quality. All calculations for sensory score, Y_2 (0-100) of puffed rice samples were calculated using fuzzy logic MATLAB program. Approximately overall quality of a sample in linguistic term, not satisfactory (0-10), Fair (10-30), Satisfactory (30-50), Good (50-70), Very Good (70-90), Excellent (90-100). The sensory score finally obtained was used as dependent variable or response for the experiments.

Statistical analysis

The experiments were designed using Design-Expert 10 software (State-Ease Inc.) and fitted to a second-order polynomial equation to develop the model between independent and dependent variables. The statistics significance of the model and parameters of the model were evaluated at significance level $P<0.01$.

3. Results and discussion

Two salts, viz., NaCl and KCl were taken in different ratio as shown in Table 2. Three dependent variables, viz., expansion ratio (Y'_{ER}), percentage of puffing (Y'_{PP}) and overall sensory value (Y'_{SV}), were expressed individually as a function of the independent variables. Optimum formulation of the independent variables for maximum response was evaluated thereafter.

Effects of salt substitute on expansion ratio

The expansion ratio at various combinations of salts was varied between 5.2-7.3 with the different combinations of NaCl and KCl. The mathematical relationship describing the effect of the independent variables on expansion ratio (y'_{er}) in terms of coded and actual factors is expressed by Equation 11 and 12.

$$y'_{er} = 7.41 + 0.89x_{NaCl} + 0.19x_{KCl} - 0.50x_{NaCl^2} + 0.10x_{KCl^2} - 0.18x_{NaCl} \cdot x_{KCl} \quad (11)$$

$$Y'_{ER} = -5.99 + 11.13X_{NaCl} + 0.13X_{KCl} - 1.98X_{NaCl^2} + 0.41X_{KCl^2} - 0.705X_{NaCl} \cdot X_{KCl} \quad (12)$$

Where x_{NaCl} and x_{KCl} are the dimensionless coded values of independent variables X_{NaCl} and X_{KCl} respectively.

The analysis of variance of expansion ratio is presented in Table 4. It is evident from this table that, the model is highly significant having F-value of 223.85. The response could be explained by the second-order model ($P<0.0001$). The predicted R^2 value of 0.976 was obtained which was in reasonable agreement with the adjusted R^2 value of 0.981. The 'lack of fit' F-value is 0.94 and *P*-value of 0.568 implies the lack of fit is insignificant relative to the pure error which signifies the goodness of fit of the model.

The linear terms x_{NaCl} and x_{KCl}, and among the quadratic terms x_{NaCl^2} and the interaction term $x_{NaCl} \cdot x_{KCl}$ are significant ($P<0.001$) model terms. The comparative effect of each factor on the moisture content could be observed by the F-values in the ANOVA (Table 4) and also by the magnitude of coefficients of the coded variables (Equation 11). The corresponding variables would be more significant if the absolute F-value becomes greater and the *P*-value becomes smaller (Atkinson and Donev, 1992). Consequently, the larger the magnitude of F-value and the smaller the *P*-value, the higher the significance of the corresponding coefficient. In contrast, *P*-values>0.05 indicate model terms are not significant. It was observed that F-value of X_{NaCl} was greater than that of X_{KCl}. This indicates that the effect of NaCl was more than KCl for the expansion of rice. Positive sign with the coefficients of

Table 4. ANOVA for expansion ratio parameter.

Source	Sum of squares	Df (degrees of freedom)	Mean square	F-value	*P*-value prob > F
Model	7.17	5	1.43	223.85	<0.0001
X_{NaCl}	5.99	1	5.99	934.95	<0.0001
X_{KCl}	0.30	1	0.30	46.86	<0.0001
$X_{NaCl} X_{KCl}$	0.13	1	0.13	20.67	0.0003
X_{NaCl}^2	0.69	1	0.69	108.07	<0.0001
X_{KCl}^2	0.025	1	0.025	3.86	0.0670
Residual	0.10	16	6.402E-003		
Lack of fit	0.069	11	6.281E-003	0.94	0.5686

x_{NaCl} and x_{KCl} (Equation 11) indicates the positive effect of NaCl and KCl on expansion ratio i.e. an increase in concentration of NaCl and KCl increased the expansion ratio. Negative sign of the coefficient of interaction term $x_{NaCl} \cdot x_{KCl}$ indicates that interaction term has negative effect on expansion. Previous studies showed that soaking in salt solution induced faster puffing and higher expansion ratio in paddy (Chandrasekhar and Chattopadhyay, 1991; Devi and Das, 2017).

In order to visualise the combined effect of NaCl and KCl on expansion ratio of puffed rice, response surfaces plot was generated with the fitted equations (Figure 2).The figure indicates expansion ratio of the pre-conditioned rice increased with the increase in concentration of NaCl and KCl up to a certain limit; followed by negligible effect with further addition of salts.

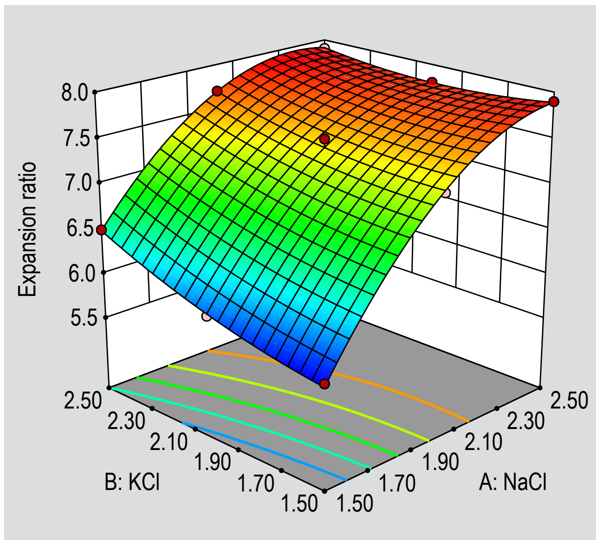

Figure 2. Response surface plot for showing the effect of NaCl and KCl on expansion ratio.

Effects of salt substitute on percentage of puffing

The percentage of puffing value was varied between 70.41% and 90.19% for the entire range of salt concentration (Table 5). Experimental data were well correlated with quadratic relationship as evident from statistical significance for the linear, quadratic and interaction terms. Percentage of puffing in terms of coded factors is represented in Equation 13 while in terms of actual factor it is represented in Equation 14.

Table 5. ANOVA for percentage of puffing parameter.

Source	Sum of squares	Df (degrees of freedom)	Mean square	F-value	*P*-value prob > F
Model	442.27	5	88.45	102.13	<0.0001
X_{NaCl}	285.52	1	285.52	329.67	<0.0001
X_{KCl}	103.79	1	103.79	119.84	<0.0001
$X_{NaCl} X_{KCl}$	27.42	1	27.42	31.66	<0.0001
X_{NaCl}^2	22.03	1	22.03	25.44	0.0001
X_{KCl}^2	0.16	1	0.16	0.19	0.6712
Residual	13.86	16	0.87		
Lack of fit	11.97	11	1.09	1.53	0.3340

$$y'_{pp} = 80.38 + 6.17x_{NaCl} + 3.72x_{KCl} + 2.68x_{NaCl^2} - 0.23x_{KCl^2} - 2.54x_{NaCl} \cdot x_{KCl} \quad (13)$$

$$Y'_{PP} = 39.38 - 10.22X_{NaCl} + 31.437X_{KCl} + 10.72X_{NaCl^2} - 0.91X_{KCl^2} - 10.16X_{NaCl} \cdot X_{KCl} \quad (14)$$

The results of the analysis of variance, goodness-of-fit and the adequacy of the models were summarised in Table 5. The determination coefficient (R^2=0.966) was showed by ANOVA of the quadratic regression model, indicating that only 3.4% of the total variations were not explained by the model. The value of the adjusted determination coefficient of 0.955 and predicted determination coefficient of 0.842 suggested that the regression model is suitable to explain the observed behaviour. In addition to this low coefficient of the variation indicated a very high degree of precision and a good deal of reliability of the experimental values. The model was found to be adequate for prediction within the range of experimental variables. The lack of fit F-value of 1.09 having *P*-value 0.334 implies the lack of fit is not significant relative to the pure error. This also indicates that the developed model was adequate for predicting the response.

The *P*-values of the coefficients were estimated and analysed to check the significance of each coefficient. From the ANOVA for percentage of puffing of rice in microwave puffing (Table 5) it was obtained that first order linear effect was significant for NaCl concentration and KCl concentration (P<0.0001). Second order quadratic effect was significant only for NaCl concentration (X_{NaCl^2}) and NaCl and KCl concentration interactive effect ($x_{NaCl} \cdot x_{KCl}$) was also have significant effect (P<0.0001) on percentage puffing.

Among the two independent variables the variable NaCl concentration has the larger magnitude of F-value indicating higher the significance than KCl concentration i.e. percentage puffing was greatly affected by NaCl concentration. It can be seen from Equation 13 that the first-order variable, NaCl concentration and KCl concentration had positive effect of increasing percentage puffing. Percentage puffing was negatively correlated by the second-order variable of KCl concentration and the interaction term of NaCl concentration and KCl concentration whereas second-order variable of NaCl had positive effect on percentage puffing.

Figure 3 shows the response surface plots and contour plot displaying the interaction effects of NaCl and KCl on percentage puffing. From Figure 3, it is evident that an increase in NaCl and KCl concentration caused an increased percentage puffing. It was observed that beyond a certain level of salt concentration this change became insensitive.

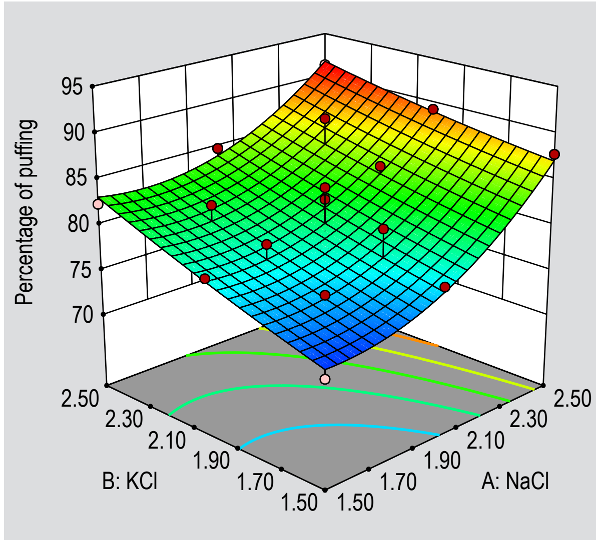

Figure 3. Response surface plot for showing the effect of NaCl and KCl on percentage of puffing.

Effects of salt substitute on sensory score

The data obtained from the sensory evaluation by fuzzy logic was analysed for regression analysis. It was observed that the overall sensory values were ranged between 54.25 and 76.68. The maximum sensory value of the puffed rice was obtained when 2.5 g of NaCl and 1.5 g of KCl was used and minimum was obtained when 1.5 g of NaCl and 2.5 g of KCl was used in the formulation. The quadratic model was fitted to the experimental data and statistical significance for linear quadratic and interaction terms was calculated for the sensory value parameter. The model F-value of 17.31 implies that the model is significant (P<0.0001). The coefficient of determination values (R^2) and adjusted R^2 were 0.914 and 0.884, respectively. These results imply that the response surface model can explain more than 91% of the variation in the response variables studied. Therefore, the R^2-values of the response models are sufficiently high, to indicate that the response surface model is workable and can be used for estimation of the mean response and the subsequent optimisation stages. The lack of fit (which measures the fitness of the model) having F-value 0.84 and *P*-value 0.625 (P>0.05) was found to be non-significant indicating that the number of experiments were sufficient for determining the effect of independent variables on response (sensory value). Hence, the developed model is adequate for predicting the response.

The response surface models for the sensory value in terms of coded values and actual values are presented in Equation 15 and 16 respectively.

$$y'_{sv} = 65.87 + 3.18x_{NaCl} - 6.35x_{KCl} - 0.77x_{NaCl^2} - 2.75x_{KCl^2} - 2.9x_{NaCl} \cdot x_{KCl} \quad (15)$$

$$Y'_{SV} = 24.16 + 41.92X_{NaCl} + 54.454X_{KCl} - 3.096X_{NaCl^2} - 10.99X_{KCl^2} - 11.6X_{NaCl} \cdot X_{KCl} \quad (16)$$

The NaCl concentration and KCl concentration were both had a significant (P<0.05) effect on the sensory value of puffed rice (Table 6). The sensory value was significantly affected by the linear and interaction terms. Quadratic terms showed no significant effect on sensory values (P>0.05). The comparative effect of each factor on sensory value could be observed by the F-values in the ANOVA and also by the magnitudes of coefficients of the coded variables. From the F-values of Table (6) and the coefficient values of x_{NaCl} and x_{KCl} of Equation 15 it was observed that KCl is the most influencing factor for sensory value followed by NaCl. The linear coefficients (Equation 15) indicate that the sensory value is positively correlated with NaCl content and negatively correlated with KCl content. That means an increase in the NaCl concentration resulted in a higher sensory value and increase in the KCl concentration resulted in a lower sensory value. The lower sensory value at higher concentration of KCl is due to development of bitterness in puffed rice. On the other hand, the quadratic coefficient of all independent variables and interactive coefficient ($x_{NaCl} \cdot x_{KCl}$) showed a negative correlation with sensory value of puffed rice.

In the response surface plot (Figure 4), the sensory score was expressed as a function of both the independent variables i.e. NaCl and KCl concentration in preconditioned rice. This figure clearly shows the positive and negative effects of NaCl and KCl concentration, respectively. In Figure 4, the maximum predicted sensory score of 76.7 was obtained at highest concentration of NaCl and lowest concentration of KCl and the zone of maximum response was indicated by the surface confined in the smallest ellipse towards lower right corner in the contour diagram.

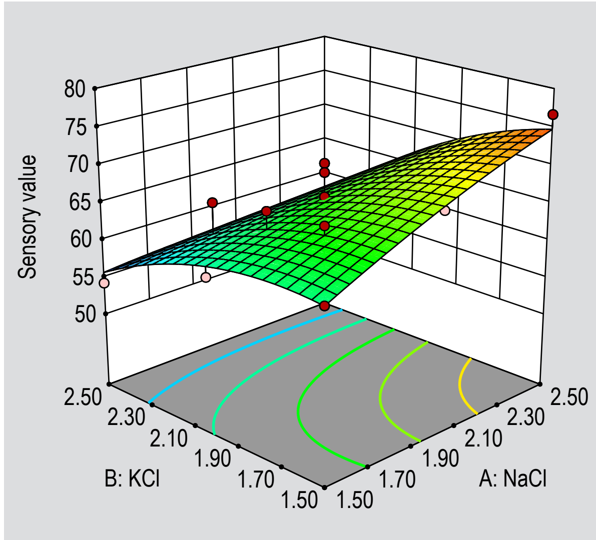

Figure 4. Response surface plot for showing the effect of NaCl and KCl on sensory value.

Optimisation of concentration of salt concentration in pre-conditioning

Numerical optimisation technique was used for optimisation of NaCl and KCl content in pre-conditioned process. Three responses, viz., expansion ratio, percentage of puffing and sensory were maximised with respect to input variables like salt concentration. Numerical analysis of response surface indicates maximum expansion ratio of 7.28, percentage of puffing, of 87.84% and sensory values of 74.77 could be achieved with combination salts (2.5% NaCl and 1.5% KCl) in the rice. Maximum desirability value under optimised condition was estimated to be 0.917.

Pre-conditioning process was carried out with 2.5% NaCl and 1.5% KCl mixture followed by puffing the rice in a domestic microwave oven. The experiments were carried out in triplicate and evaluations of responses were made. Observed mean values of these responses have been compared to corresponding values obtained with

Table 6. ANOVA for sensory value.

Source	Sum of squares	Df (degrees of freedom)	Mean square	F-value	P-value prob > F
Model	452.32	5	90.46	17.31	<0.0001
X_{NaCl}	75.74	1	75.74	14.50	0.0015
X_{KCl}	302.56	1	302.56	57.91	<0.0001
$X_{NaCl} X_{KCl}$	35.69	1	35.69	6.83	0.0188
X_{NaCl}^2	1.84	1	1.84	0.35	0.5614
X_{KCl}^2	23.17	1	23.17	4.43	0.0514
Residual	83.60	16	5.22		
Lack of fit	54.23	11	4.93	0.84	0.6259

the optimisation process and the relative deviation was obtained (Table 7). The relative deviation for expansion ratio, percentage of puffing and sensory value were varied between 1.01-2.87%. The results demonstrated a good relationship between the predicted and experimental values, confirming the validity of the model.

Changes in micro-structure of pre-conditioned rice with optimum salt concentration

Micro-structure of the kernels without and with different salts (2.5% w/w NaCl and 1.5% w/w KCl) are discussed in Figure 5A-B. The inner endosperm structure of pre-conditioned rice without salt shows a continuous structure of fused starch, no sign of agglomeration and cluster. This occurred due to irreversible swelling and fusion of starch granules. The structure was hard as a result of strong adhesion in starch. In preconditioned rice (parboiled rice soaked in salt solution and dried in fluidised bed dryer to achieve desirable moisture content for puffing), the granular starch lost its regular polyhedral and crystalline forms and transformed the internal structure continuous. The smooth surface of the pre-conditioned rice added with salt showed a sharp breaking structure of the cluster and clustering of mass took place with sign of interlocking. SEM micrograph (Figure 5B) indicated that addition of salt and prolong heating of kernel caused more densification of the surface; possibly through starch-salt interaction that ultimately led to developed impervious surface. SEM study of native brown rice had polygonal rice starch granules whereas in parboiled rice, the starch granules were slightly fused and the polygonal shape was lost (Sittipod and Shi, 2016).

4. Conclusions

Partial replacement of NaCl with KCl is beneficial from the health aspect of the consumers. The effects of mixtures of NaCl and KCl salts on puffing quality were analysed. It was followed by optimisation of their concentration with respect to maximise the responses i.e. expansion ratio, percentage of puffing and sensory quality. Maximum expansion ratio, percentage of puffing and sensory values was achieved with mixture of salts (2.5% NaCl and 1.5% KCl). Considering the extent of salts on three responses, effect of NaCl was higher compared to KCl with respect to expansion ratio and percentage puffing. However, effect of KCl was found to be more on sensory perception attributes. Mixture of NaCl and KCl in the mass ratio of 5:3 corresponding to 2.5 and 1.5% NaCl and KCl, respectively resulted in good quality puffed rice. Substitution of 37.5% KCl with NaCl was feasible for pre-conditioning of rice to obtain reduced sodium puffed rice. The effect of NaCl was found to be more on the expansion ratio and percentage of puffing than that of KCl. Excessive addition of mixture of salts showed

Table 7. Predicted and actual responses at optimum level of NaCl and KCl.

Observation	Expansion ratio	Percentage of puffing	Sensory value
Predicted values	7.82	87.12	74.77
Experimental values	7.9	89	76.98
Relative deviation	1.01%	2.11%	2.87%

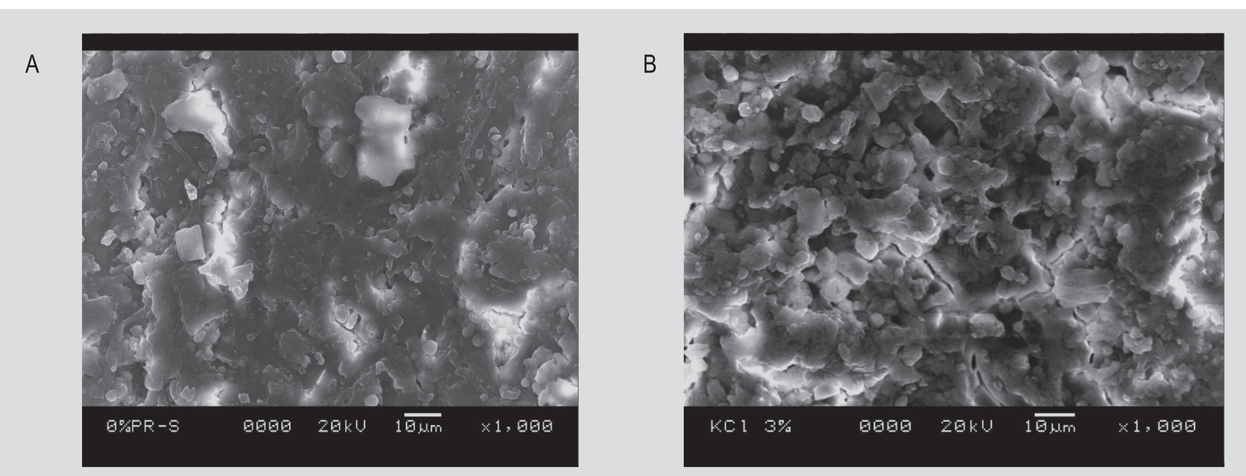

Figure 5. Surface microstructure of pre-conditioned rice at moisture content (10.5% wb) (A) without NaCl, (B) with mixture of 2.5% NaCl and 1.5% KCl.

negligible effect on these responses. Higher sensory score could be obtained with increase in concentration of NaCl and decrease in KCl concentration in the pre-conditioned rice.

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