Changes in sensorial and microstructural characteristics of puffed brown rice in hot sand bed puffing with change in preconditioning

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Abstract: Puffed rice is produced from preconditioned polished rice heated at about 250°C. In this study, puffed rice was produced from parboiled brown rice (unpolished rice) in sand heating method at different preconditioning levels by varying salt content (0%-6% (w/w)) to evaluate its quality and acceptability because the bran layer resists the expansion during the puffing which can affect its acceptability. As mentioned in previous studies, quality parameters hardness, expansion, and sensory qualities were considered. Fuzzy logic technique was used to evaluate the sensorial acceptability of puffed brown rice. Sensory parameters such as taste, texture, and color were considered. Gradual increase in salt up to 4% showed improvement in the expansion and decreased the hardness of puffed brown rice. After 4% salt, both quality parameters showed a constant trend. Microstructural study showed puffed brown rice cross-section is similar to puffed polished rice. However, the puffed brown rice surface showed fissures of the bran layer, whereas polished puffed rice showed a smooth surface. The cross-sectional view showed that air voids get wider at higher salt levels. Sensorial evaluation using the fuzzy logic technique showed that color is the least essential quality attribute, and taste and texture were in the first and second ranks, respectively. Most acceptable puffed brown rice was produced at 4%-5% salt content.
Keywords: grain puffing, puffed rice, brown rice, puffed brown rice, microstructure, sensory

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1 Introduction

Puffed rice is a Ready to Eat and high-demand product in Southeast Asian countries. Similar products like popcorn, puffed wheat, puffed amaranth, popped rice, flaked rice, puffed gram, and many more are broadly used as snacks or ingredients. Expanded or puffed cereal products provide a healthy option of snack for people. Puffed rice is preferred in Southeast Asian countries due to its low cost, availability, ease of digestion, and sensory quality. Puffed rice is prepared by roasting or high-temperature heating of preconditioned milled parboiled rice at about 250°C (Dutta et al., 2015; Saha and Roy, 2022). During the

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parboiling, rice starch is gelatinized and changes its crystalline structure into an amorphous form; therefore, grain becomes harder (Bhattacharya, 2011). After parboiling, milled parboiled rice is conditioned with salt. Sodium chloride is a common salt used for the preconditioning process. Conditioning process modifies the rice's outer surface and improves its thermal properties (Dash and Das, 2019a). These changes help to accommodate more water vapor inside the grain, which creates massive pressure during the final heating or puffing process. Several techniques are available for this stage of heating, such as hot sand, hot air, microwave heating, and gun puffing (Mohapatra and Das, 2011; Mishra et al., 2014; Swarnakar et al., 2014). During heating, when the temperature reaches to glass transition temperature level, rice starch gets softened, and moisture in the rice grain generates vapor. Water vapour builds pressure inside the soft starch globules. Due to this, high-pressure rice grains expand, and moisture flashes out to the softened grain (Hoke et al., 2005; Joshi et al., 2014; Gulati and Datta, 2016). This process provides evaporative cooling, which makes the grain harder, crispier, and easier to digest.

In Southeast Asian countries, puffed rice is produced from the heating of conditioned milled parboiled rice in a hot sand bed at the cottage industry level or by farmers (Mishra et al., 2014; Saha and Roy, 2022). Sand bed is a popular puffing method due to the easy availability of sand and wood, dried leaves, and husk as fuel for heating. Due to the health conciseness of people, brown rice is gaining popularity (Mir et al., 2016; Swarnakar et al., 2019; Pathaw et al., 2023). Brown rice has a rich nutritional value compared to polished rice. During rice polishing, rice loses valuable minerals, protein, fiber, fat, and other nutrients of the bran layer (Mohapatra and Bal, 2007; Lamberts et al., 2007). These nutrient losses increase with the increase in the degree of milling (Lamberts et al., 2007). However, broken grains are also one of the significant concerns along with time, energy, and labor cost. The use of brown rice provides a solution to these drawbacks.

Nevertheless, brown rice showed less expansion during puffing. The bran layer of rice provides resistance during the expansion of rice in the puffing process. Therefore, the final product shows poor textural quality (Chandrasekhar, 1989). Puffed rice is known for its textural quality. In this work, puffed rice is produced using brown rice. As documented, salt content improves the quality of expanded rice due to thermal characteristics (Devi and Das, 2017; Dash and Das, 2019b). Improved thermal conductivity enhances the heat flow in rice grain toward the center. Therefore, rice achieves puffing temperature in a short time. Salt also acts as a taste enhancer. Variations in salt content can enhance the quality of puffed brown rice. Consumer acceptability is a major priority for any food product. The sensorial quality of puffed brown rice will differ from puffed polished rice due to the bran layer or maybe sand bed method not produce the same product quality. Therefore, this work aims to check the acceptability of puffed brown rice produced from the hot sand bed puffing method compared to commercially available puffed rice. Microstructure analysis was also carried out for puffed brown rice to study the effect on structural changes during brown rice puffing at different salt content.

2 Materials and methods

2.1 Material

For this study, Heera rice variety was procured from the local market of the Indian Institute of Technology, Kharagpur, India. It is a long and slender variety with a length and length-to-breadth ratio of 3.15 (Bhattacharya, 2011). It is a popular variety for puffing in the local region. Physical properties of Heera rice are shown in Table 1.

Table 1 Physical properties of Heera rice

Characteristic parameters	Brown rice
Length[1]	6.93±0.24 mm
Width[1]	2.20±0.12 mm
Breadth[1]	1.83±0.10 mm
Length to breadth ratio[1]	3.15±0.19 mm
True density[2]	1379.56±28.89 kg m^{-3}
Bulk density[2]	763.20±2.92 kg m^{-3}
Hardness[1]	9.35±0.9 kg

Note: 1— 15 observations, 2—5 observations, moisture content (wet basis) = 10.77%.

2.2 Puffing process

Preconditioned brown rice was puff in the hot sand bed, that is described in three steps as follows: parboiling, preconditioning and puffing.

2.2.1 Parboiling

About 7-8 kg paddy was soaked in water at room temperature for 24 h. After draining the water, paddy was steamed in the open atmosphere. This steamed paddy was sun-dried and dehusked in a laboratory rubber-roll dehusker equipped with an aspirator (Satake Engineering Co. Ltd., Japan, Type – THU class-35A S. No. 1011990).

2.2.2 Preconditioning

The preconditioning process increases the thermal conductivity of rice and hardens the outer surface. During this process, preheated (about 80°C) parboiled rice is mixed with salt solution (100 mL for 2 kg brown rice) and kept for one hour. During the salt solution mixing, the moisture content of rice increases up to about 45% db. Afterward, it was cured in a half-round metal pan heated from the bottom with proper turning and agitation at 80°C-90°C (maximum grain temperature). Curing process carried out up to 10%-11% moisture content, i.e., optimum moisture level for puffing. Figure 1 shows the moisture reduction profile during salt-mixed parboiled brown rice (4% (w/w) salt content) preconditioning. These conditions help rice puffing by enhancing heat penetration towards the grain center. Brown rice was agitated during heating for even distribution of heat. Preconditioning process might facilitate the proper distribution of moisture and salt inside the grain, which helps in producing sufficient vapor pressure during the final heating or puffing process, for the study salt content was varied from 0% to 6%.

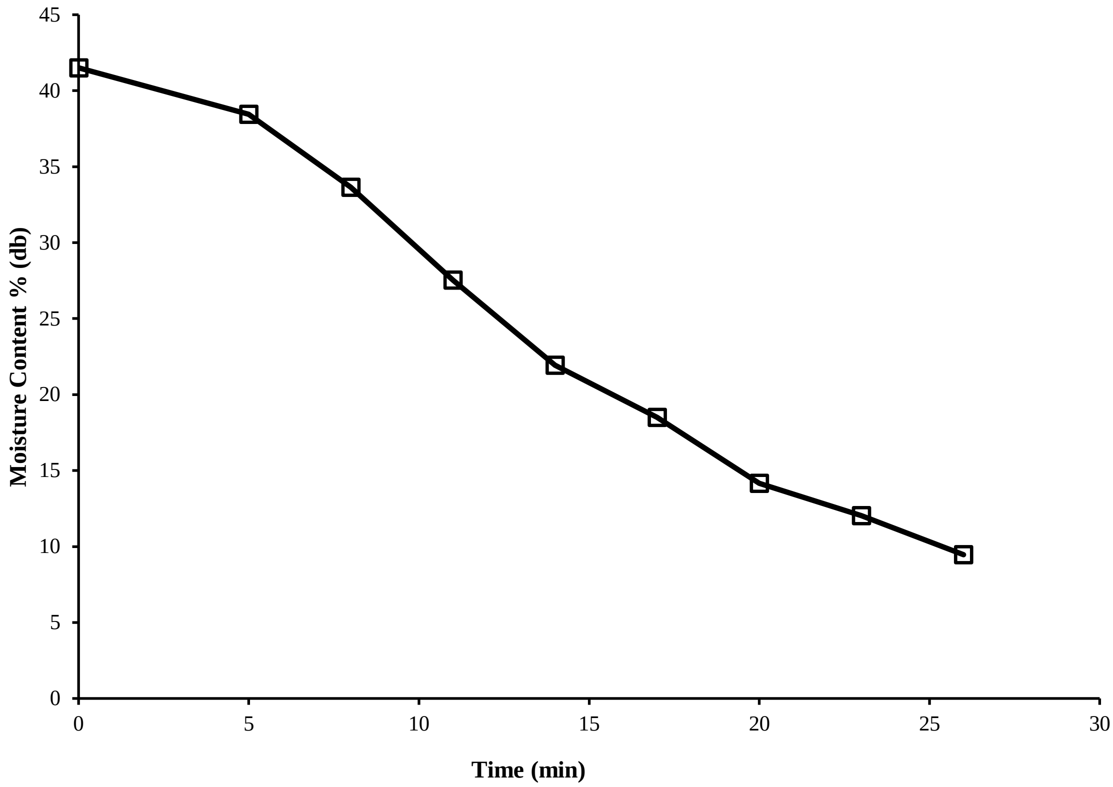


Figure 1 Moisture content (db) variation with time during preconditioning (4% (w/w) salt content)

2.2.3 Puffing

Preconditioned brown rice was puffed in the hot sand bed. About 100 g of preconditioned brown rice was dropped in preheated sand of 210°C-240°C. For puffing, sand and preconditioned brown rice were agitated for 8 to 10 s. After that, puffed brown rice was separated with the help of a metal sieve to prevent charring. Figure 2 shows the steps involved in the puffing process of brown rice.

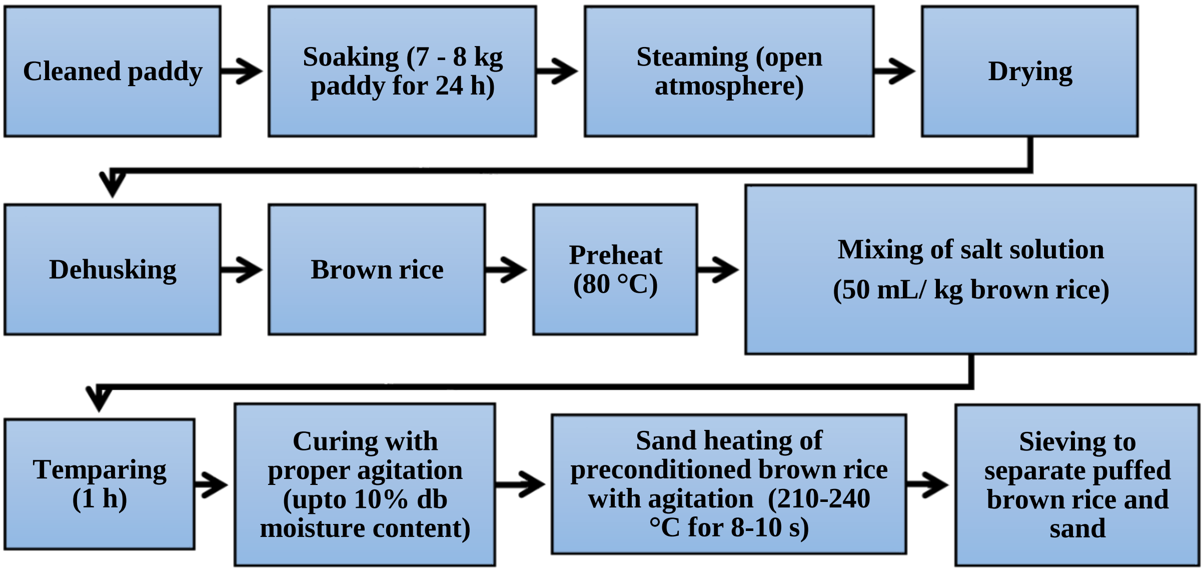


Figure 2 Flow chart of the brown rice puffing process

2.3 Quality parameters of puffed brown rice

2.3.1 Hardness

A compression test was used in a texture analyzer (TA-XT2i, Stable Microsystem Texture Analyzer, UK) to measure the hardness of parboiled and puffed brown rice. A 35 mm diameter aluminum cylindrical probe in a 25 kg load cell with 10 and 5 mm s^{-1} pre- and post-speed, respectively, were used for the purpose. The maximum force required to rupture the puffed brown rice and parboiled brown rice was the hardness of the respective grains.

2.3.2 Expansion ratio

Expansion ratio can be defined as the ratio of puffed brown rice to preconditioned brown rice volume. Volume was measured according to the Mohapatra and Das (2011) method. Puffed brown rice was poured into the measuring cylinder, and voids were filled with cleaned and dry sand with the help of ten gentle tapings. Afterward, sand was sieved from puffed brown rice. The volume difference between the volume of puffed brown rice along the sand and the separated sand volume was the volume of puffed brown rice. Preconditioned brown rice volume was also measured using the same technique. Number of preconditioned grains taken was equal to the number of puffed brown rice taken during this measurement. The expansion ratio was calculated using the following equation.

$$Expansion\ ratio = \frac{Volume\ of\ puffed\ brown\ rice}{Volume\ of\ preconditioned\ brown\ rice} \quad (1)$$

2.3.3 Microstructure analysis

The microstructure of puffed brown rice was examined using a scanning electron microscope (JSM 5800, JEOL, Japan). A razor blade was used to prepare cross-sections of puffed brown rice. Prepared sample mounted rigidly on a specimen holder called a specimen stub. For the microstructure study, specimens must be electrically conductive. Therefore, samples were coated with gold.

2.4 Sensory evaluation using fuzzy logic

Sensory evaluation was conducted to evaluate puffed brown rice acceptability using fuzzy logic. Das (2005) and Debjani et al. (2013) reported the method used for sensory evaluation. Semi trained fifteen judges panel (four females and eleven males) formed from among the research students of the Indian Institute of Technology, Kharagpur, India. Panelists were 24 to 30 years old, healthy, non-smoker, and puffed rice familiar.

Samples were randomly presented to judges for evaluation. Puffed polished rice was used as a control sample. Four samples of puffed brown rice containing 0%, 2%, 4%, and 6%, abbreviated as S0, S2, S4, and S6, respectively, during analysis were served to judges. Quality attributes were chosen as suggested by Mohapatra and Das (2011) for sensory evaluation (Table 2). For sample and quality attributes, judges were asked to tick mark corresponding boxes on a five-point scale. Five-point scale for the sample was "Not satisfactory," "Fair," "Medium," "Good," and "Excellent". For quality attributes, it was "Not at all important", "Somewhat important", "Important", "Highly important" and "Extremely important".

Table 2 Quality attributes of puffed brown rice

S. No.	Quality attributes	Description
1	Color	Brownness and whiteness
2	Texture	Hardness and crispiness
3	Taste	Saltiness

The fuzzy analysis comprises calculating the overall score for the samples and quality attributes and similarity analysis of samples. A five-point membership function was used. A triplet membership function associated with a five-point scale is shown in Figure 3. The coordinate of the abscissa, where the value of the membership function is 1, is represented by the first triplet. The distance to the left and right of the first number where the membership function is zero corresponds to the second and third values of the membership function, respectively.

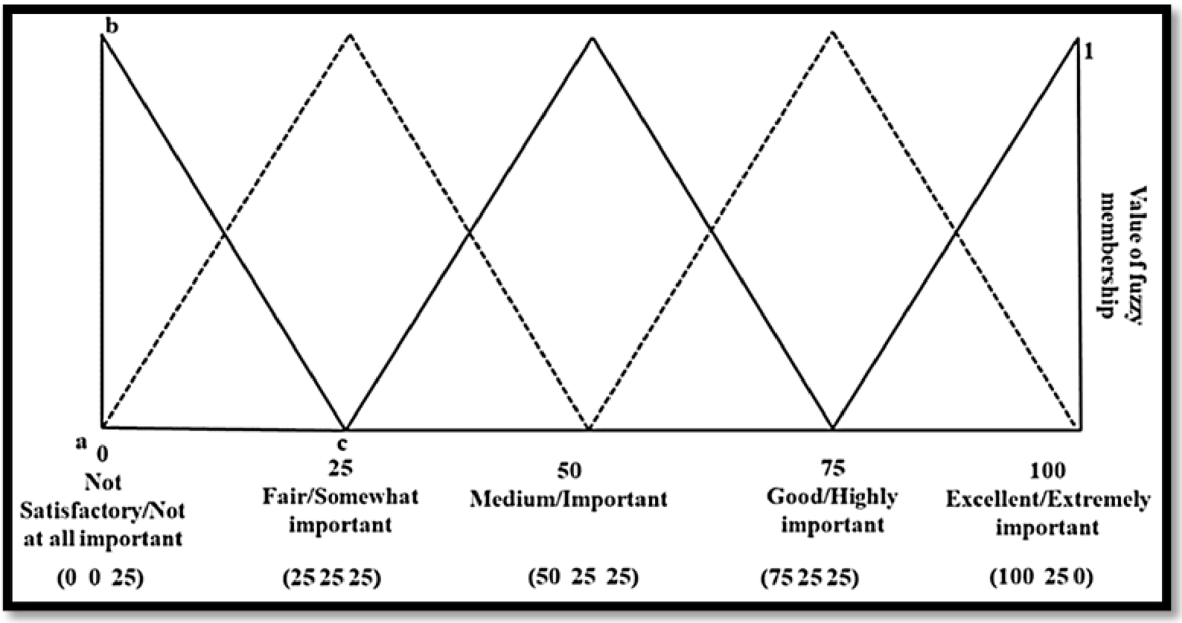


Figure 3 Distribution pattern of triangular membership function for five-point sensory scale

2.4.1 Triplets of samples

Triplet for samples has been obtained by summing the sensory score given by judges for particular quality attributes of the sample. After that, the triplet has been calculated as mentioned below in Equation 2 for color. In the similar manner triplet of other quality, attributes were calculated for other samples.

$$SC = \frac{NS(0\ 0\ 25)+F(25\ 25\ 25)+M(50\ 25\ 25)+G(75\ 25\ 25)+E(100\ 0\ 0)}{NS+F+M+G+E} \quad (2)$$

where *SC* is the triplet of sample color (quality attribute), *NS* is the 'Not satisfactory', *F* is the 'Fair', *M* is the 'Medium', *G* is the 'Good', *E* is the 'Excellent', sum of the respective score given by judges.

Sensory score given by judges for color of sample S0

NS – 8, F- 6, M – 1, G – 0, E – 0

$$SC = \frac{8(0\ 0\ 25) + 6(25\ 25\ 25) + 1(50\ 25\ 25) + 0(75\ 25\ 25) + 0(100\ 0\ 0)}{8 + 6 + 0 + 0 + 0}$$

$$SC = (13.333\ \ 11.666\ \ 25)$$

2.4.2 Triplets of general quality attributes

Triplets for general quality attributes of puffed rice have been calculated using Equation 3. Here sums of the score of quality attributes given by judges were used

$$QC = \frac{NI(0\ 0\ 25)+SI(25\ 25\ 25)+I(50\ 25\ 25)+HI(75\ 25\ 25)+EI(100\ 0\ 0)}{NI+SI+I+HI+EI} \quad (3)$$

where, *QC* is the triplet for color in general (for quality attributes), NI is the- 'Not at all important', SI is the - 'Somewhat important', I is the - 'Important', HI is the - 'Highly important', EI is the - 'Extremely important', sums of the respective score given by judges for color.

Score given by the judges for color quality attributes NI – 2, SI – 3, I – 8, HI – 2, EI – 0

Therefore, triplet for color quality attribute

$$QC = \frac{2(0\ 0\ 25) + 3(25\ 25\ 25) + 8(50\ 25\ 25) + 2(75\ 25\ 25) + 0(100\ 0\ 0)}{2+3+8+2+0}$$

$QC = (41.666\ \ 21.666\ \ 25)$

Similarly for taste and texture (83.333 25 11.666) and (71.666 25 18.333) respectively, were found.

2.5.3 Triplets of overall sensory score

Equation 4 was used to calculate triplets for the samples' overall sensory score.

$$Overall\ sensory\ score = SC * QC_{rel} + STe * QTe_{rel} + STa * QTa_{rel} + SF * QF_{rel} \quad (4)$$

$$QC_{rel} = \frac{QC}{Q_{sum}},\ QTe_{rel} = \frac{QTe}{Q_{sum}},\ QTa_{rel} = \frac{QTa}{Q_{sum}}, QF_{rel} = \frac{QF}{Q_{sum}}$$

where, STe is triplet of sample for texture attribute, STa is triplet of sample for taste attributes as discussed in section 2.4.1.

Q_{sum} is the sum of first digit of quality attributes triplet i.e., color, taste, and texture.

$$QC_{rel} = \frac{41.666\ \ 21.666\ \ 25}{41.666 + 83.333 + 71.666} = (0.211\ \ 0.110\ 0.127)$$

Below mentioned rule has been applied to multiplication for overall sensory score (Equation 5).

$$(xyz) * (pqr) = (x * p\ \ x * q + p * y\ \ x * r + p * z) \quad (5)$$

A triplet ($a\ b\ c$) for the overall sensory score was calculated accordingly to Das (2005) and Debjani et al. (2013). Overall sensory score (Equation 5) represents by triangle ABC (Figure 4). As shown in Figure 4, Triangle ABC will be within the range [0-100] if (a+c) is less than 100. The centroid (y_a) of tringle ABC was the overall sensory score on the sensory scale (Equation 6).

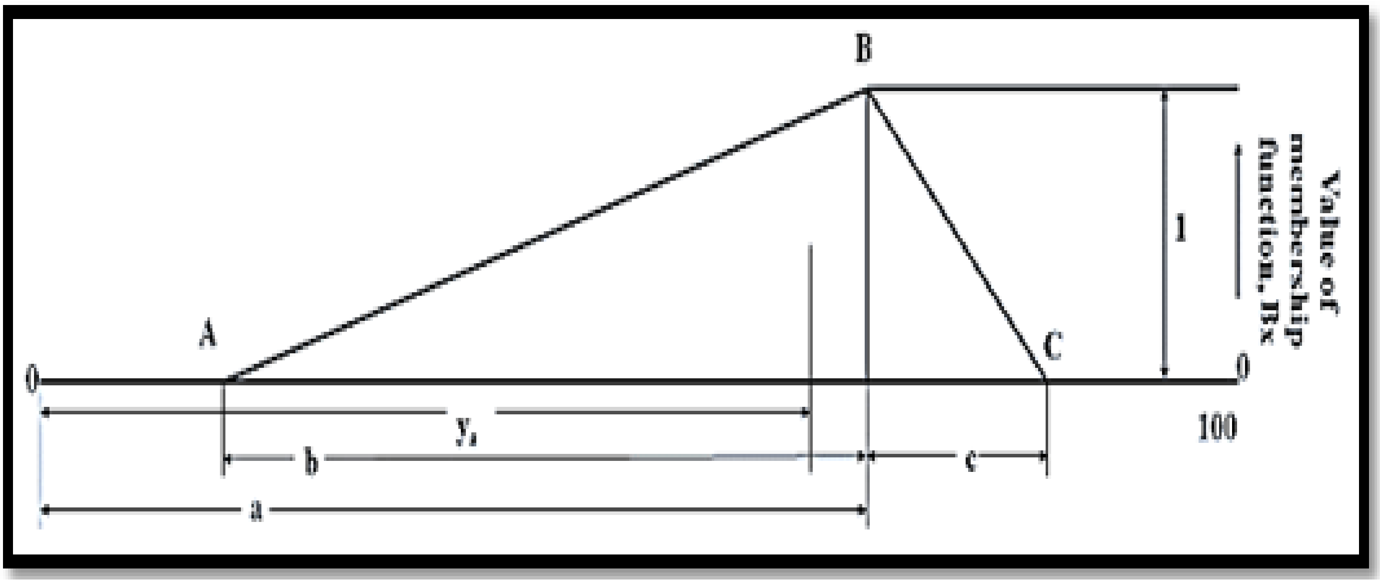


Figure 4 Graphical representation of overall sensory score as tringle ABC

$$Overall\ sensory\ score = \frac{1}{3}(3a - b + c) \quad (6)$$

For the determination of quality attributes ranking Equation 7 was used in triplets of quality attributes (Equation 3).

2.4.4 Calculation of sample similarity values

Figure 5 shows the triangular 6-point standard sensory scale. The symbol F1, F2, F3, F4, F5, and F6 represents the 'Not satisfactory/Not at all necessary', 'Fair/Somewhat necessary', 'Satisfactory/Necessary', 'Good/Important', 'Very good/Highly important' and 'Excellent/Extremely important', respectively. Maximum value of the membership function is 1.

Value of membership function through F1 to F6 are defined by a set of 10 number as mentioned below (Equation 7).

F1 = (1; 0.5; 0; 0; 0; 0; 0; 0; 0; 0)

F2 = (0.5; 1; 1; 0.5; 0; 0; 0; 0; 0; 0)

F3 = (0; 0; 0.5; 1; 1; 0.5; 0; 0; 0; 0)

F4 = (0; 0; 0; 0; 0.5; 1; 1; 0.5; 0; 0)

F5 = (0; 0; 0; 0; 0; 0; 0.5; 1; 1; 0.5)

F5 = (0; 0; 0; 0; 0; 0; 0; 0; 0.5; 1)

F6 = (0; 0; 0; 0; 0; 0; 0; 0; 0:5; 1) (7)

Number of each membership function shown in the bracket is the maximum value of the fuzzy membership function between 0 to 10, 10 to 20, 20 to 30, 30 to 40, 40 to 50, 50 to 60, 60 to 70, 70 to 80, 80 to 90 and 90 to 100.

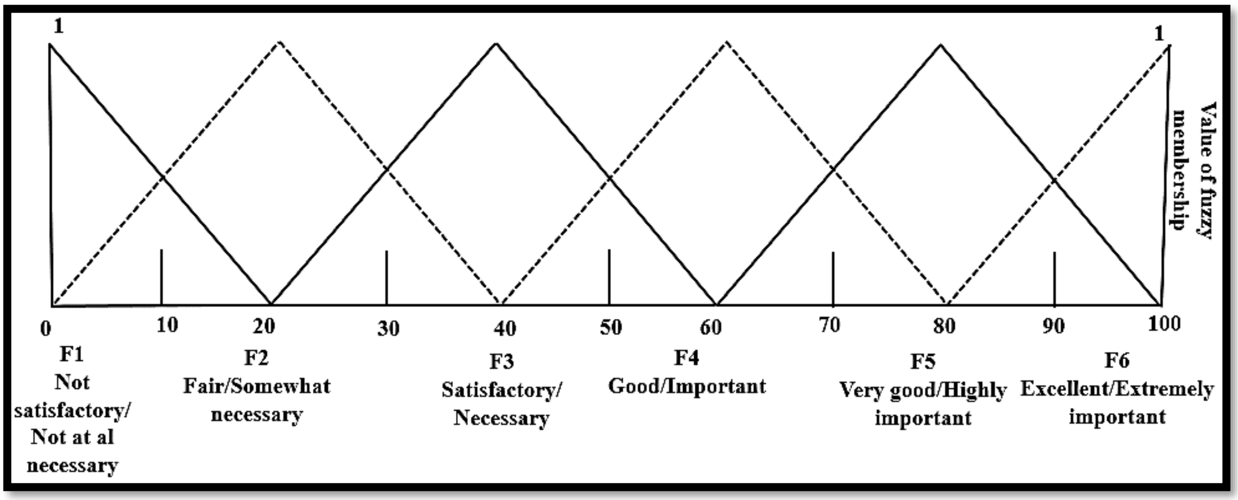


Figure 5 Six-point standard sensory scale

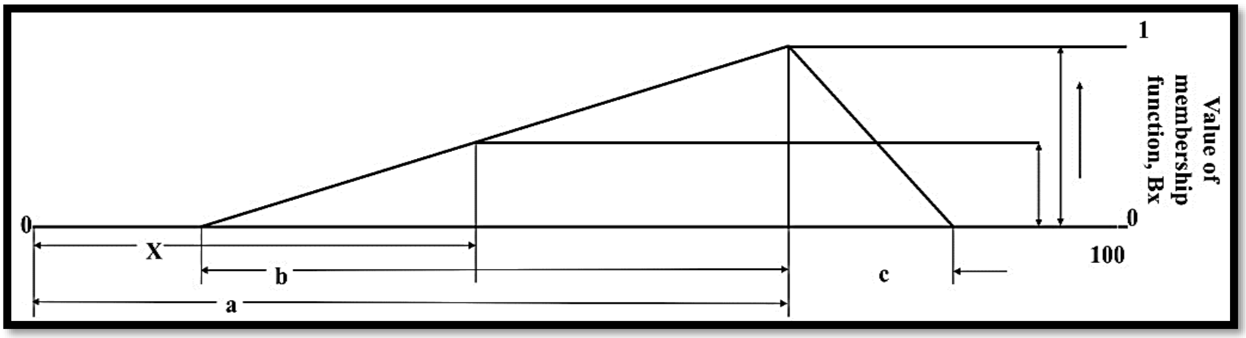


Figure 6 Graphical representation of triplet (a b c) and its membership function

The graphic depiction of the total membership function triplet (a b c) is shown in Figure 6. Where value "a" is on abscissa when overall membership function is 1. Value of the overall membership function is zero when (a-b) is less than "a" value and (a+c) is greater than "a" value. Overall membership function is defined in Equation. (8).

$$B_x = \frac{x-(a-b)}{b}\ for\ (a-b) < x < a$$

$$B_x = \frac{(a+c)-x}{c}\ for\ a < x < (a+c)$$

$$B_x = 0 \quad (8)$$

Overall membership function value can be found at x = 0, 10, 20, 30, 40, 50, 60, 70, 80, 90 and 100 by using Equation 8. Overall membership value of fuzzy scale will be given by a set of 10 number, which are, 'maximum values of B_x at 0 <x <10, 10 <x <20, 20 <x <30, . . ., 80 <x <90, 90 <x<100.'

Similarity value is defined in Equation 9 below.

$$sm(F,B) = \frac{FB'}{maximumof\ (FF'andBB')} \quad (9)$$

FB′ is product of matrix F with transpose of matrix B. FF′ is the product of matrix F with the transpose of F matrix and BB′ is the product of matrix B with the transpose of matrix B.

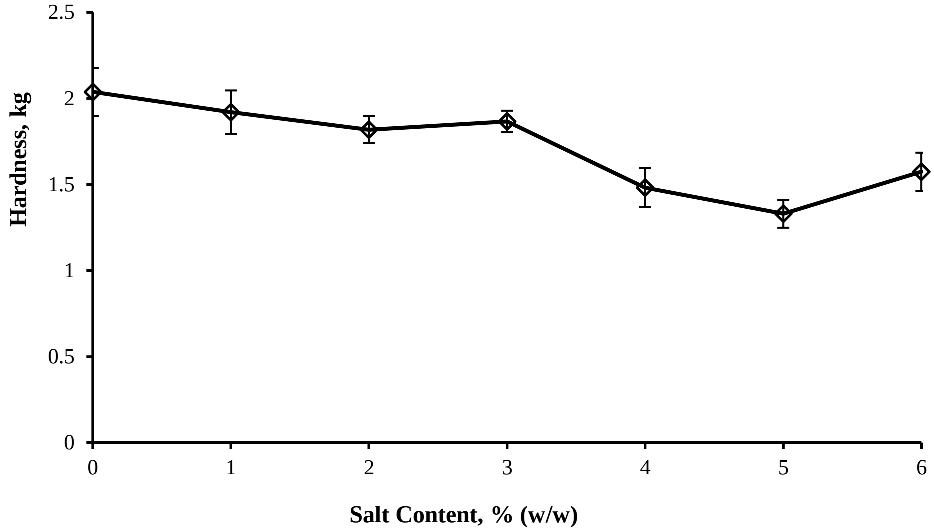
For each of the standard fuzzy scale's F1, F2, F3, F4, F5, and F6, similarity values were calculated, and the highest similarity value was recorded. For example, in case of, if the similarity value of any puffed brown rice sample is highest in F6 then the sample comes under the excellent category. Table 5 is showing the similarity value of the sample.

3 Result discussion

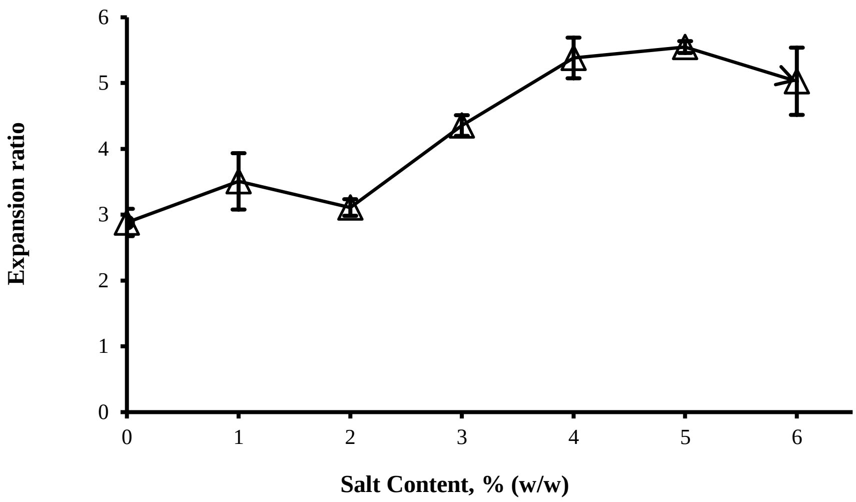
3.1 Effect of preconditioning on puffed brown rice textural quality

3.1.1 Hardness and expansion

Hardness and expansion ratio of puffed brown rice at different salt content is shown in Figures 7 (a) and (b), respectively, and Figure 8 shows the puffed brown rice produced at different salt contents. Hardness and expansion of any puffed product are very vital quality parameters. The maximum force experienced during the initial compression cycle, or first bite, is the hardness. The hardness of puffed brown rice decreases as the amount of salt increases; on the other hand, it improves the expansion. This trend changes after 5% salt content. More than 5% salt in preconditioned brown rice produces the harder and less expanded product. Higher salt content improves brown rice's thermal conductivity, which helps in temperature increment and produces high-pressure vapor in the rice starch globules, as discussed in the previous section. These conditions produce big wide air voids, as depicted in Figure 9. Chandrasekhar and Chattopadhyay (1990) and Gulati and Datta (2016) also observed air void size increment due to increases in the expansion of puffed rice.



(a)Hardness



(b) Expansion ratio

Figure 7 Variation with salt content in hardness and expansion ratio

When preconditioned parboiled brown rice is heated, rapid vaporization of moisture creates void space and air cells. Puffed brown rice showed a thick wall, whereas it was absent in the 0% salt content sample. Therefore, this wall or layer was formed in the preconditioning process. As salt amount increases, this wall shows more expansion and merges with the inner structure. Air cells are also observed in this dense outer wall. In 0% salt content puffed brown rice, air cell does not appear. It started to appear from the next salt level. The size of air cells and the density of these cells increase with salt content. In the sample of 4% and 5% salt content, dense outer wall almost disappeared and merged with the central porous structure. The size of air cells in the center of the endosperm decreases as salt content increases. Same pattern was observed by Mariotti et al. (2006) and Gulati and Datta (2016) during rye and rice puffing, respectively. Low salt content produces wide and fewer air cells. The trend of air cells also follows the same pattern as in the dense outer wall. These conditions at low salt levels increase the hardness of puffed brown rice and decrease its expansion. Salt content of more than 5% produces a porous outer surface of preconditioned rice (before puffing), as Das et al. (2015) reported for polished rice. Maybe due to this reason, expansion in puffed brown rice was less and showed the opposite trend. This porosity allows vapor to escape from the grain in the expansion process and builds less pressure inside it, resulting in poor expansion.

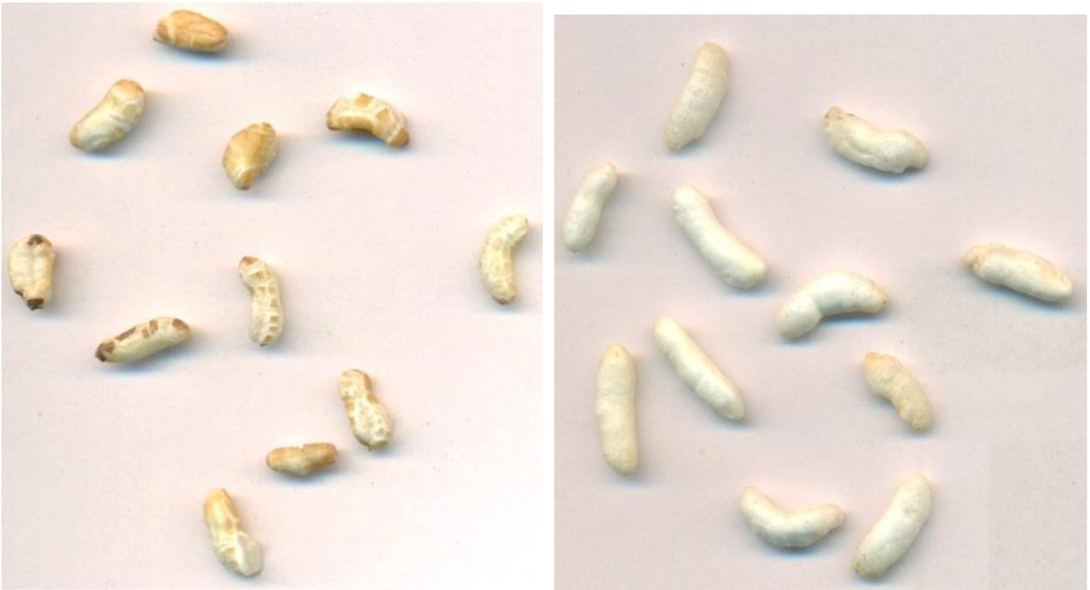
(a)0% Salt content

(b)1% Salt content

(c)2% Salt content

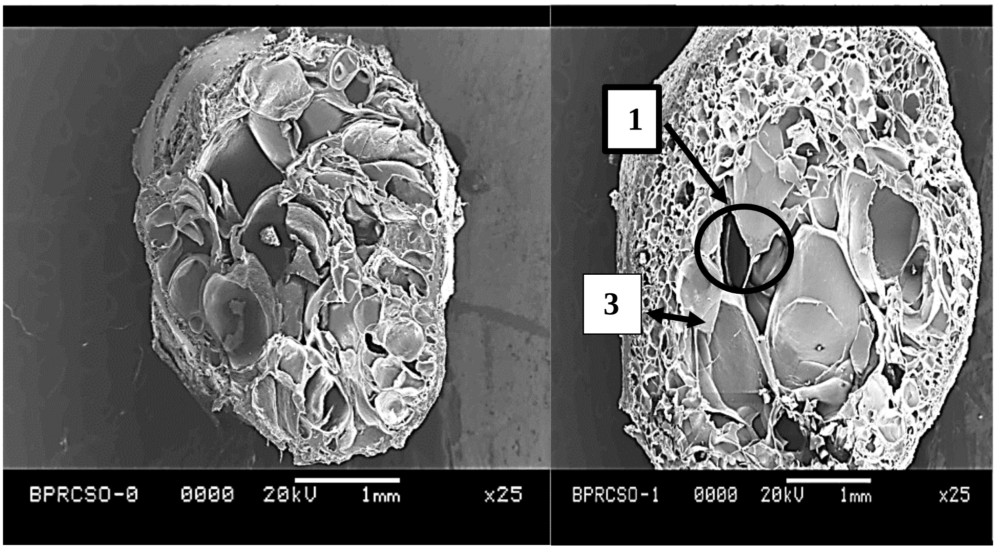
(d) 3% Salt content

(e) 4% Salt content (f) 5% Salt content

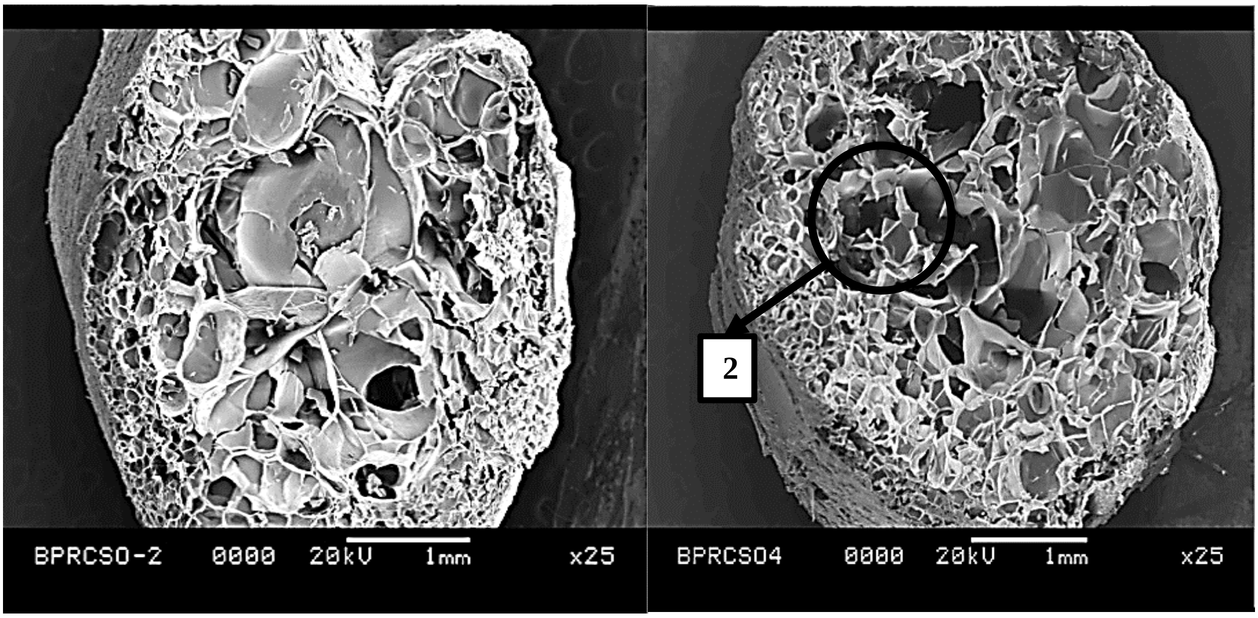


(g) 6% Salt content (h) Puffed polished rice (4% Salt)

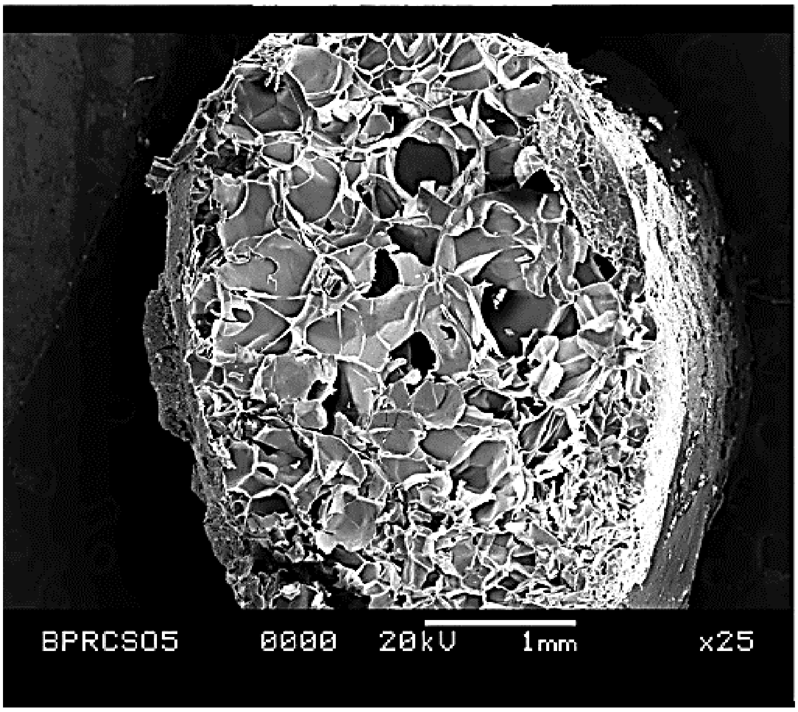
Figure 8 Puffed brown rice with the different salt content and puffed polished rice (commercially available)



(a) 0% Salt content (b) 1% Salt content



(c) 2% Salt content (d) 4% Salt content



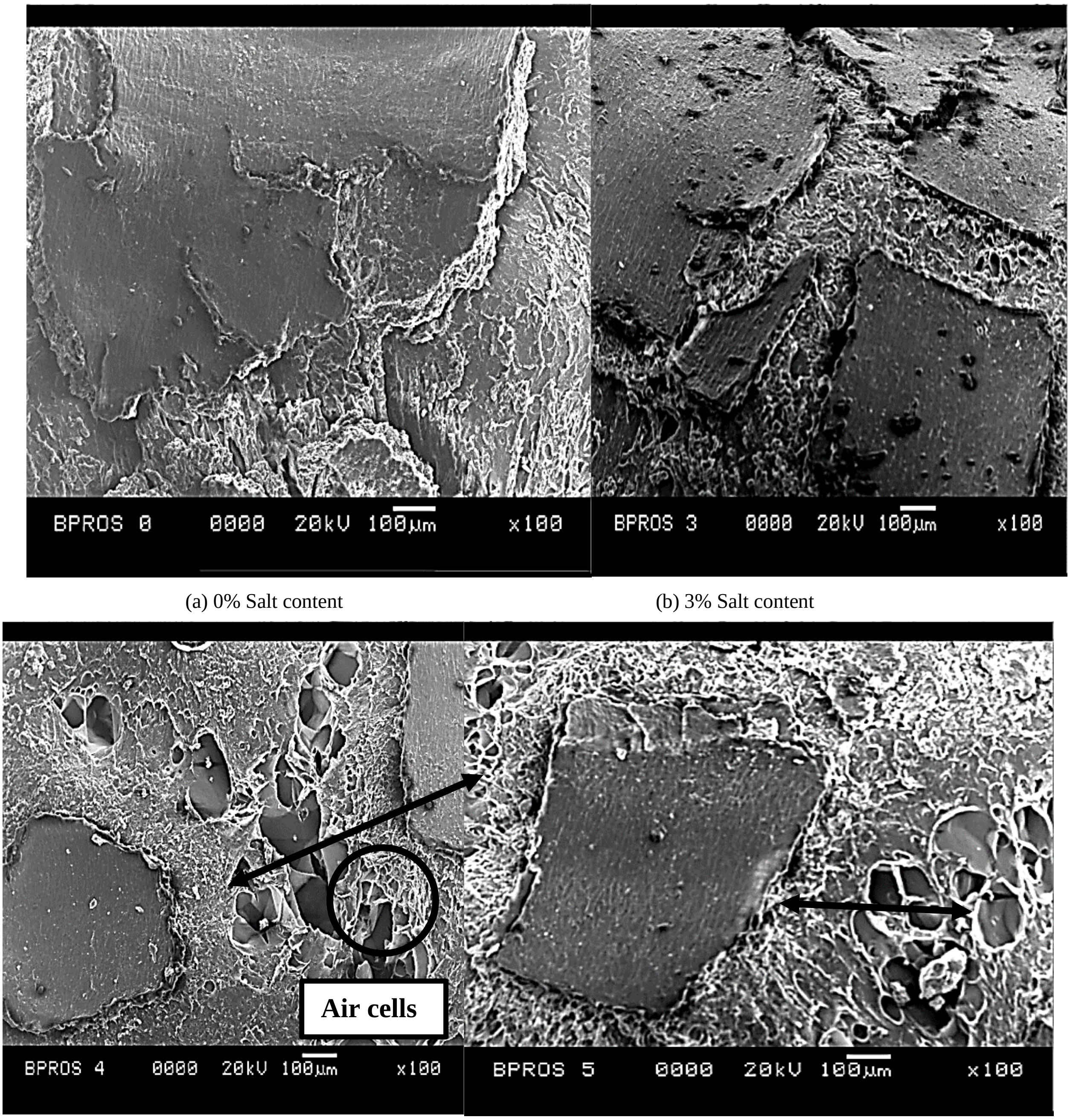
(e) 5% Salt content

1. Air cells; 2.Void spaces; 3.Dense outer wall

Figure 9 Cross-sectional area of puffed brown rice

3.1.2 Surface structure of brown puffed rice

Figure 10 shows the surface of the puffed brown rice. It differs from the puffed polished rice structure. Generally, the puffed rice surface appears relatively smooth, but in the case of brown rice puffing, it gives a slightly abrasive texture due to the presence of the bran layer. The bran layer hinders the puffing and restricts the expansion (Chandrasekhar and Chattopadhyay, 1991). As expansion occurs in rice, this bran layer starts to crack or produce fissures, as shown in Figure 10. These fissures become wider when the expansion increases at higher salt content. As stated above, this is due to higher vapor pressure generated inside rice kernels. This also can revel from air cells indicated in Figure 9. The same trend was observed in the bran layer fissure; the size and number of air cells on the surface gets increased with salt content.



(a) 0% Salt content (b) 3% Salt content

(c) 4% Salt content (d) 5% Salt content

Figure 10 Surface structure of puffed brown rice

3.2 Sensory evaluation

3.2.1 Quality attributes preference in general for puffed brown rice

Table 3 shows the preference score of quality attributes for puffed brown rice. Color was found to be the least important sensory parameter among these three-quality attributes. According to the judge's taste and texture are more critical sensory attributes for puffed brown rice. The major influencing factor for taste in puffed brown rice is salt. Taste was found to be the most important sensory attribute. Therefore, variation in the preconditioning salt will affect acceptability more as its influencing magnitude is more for the taste. Texture was found to be the second preferred sensory attribute for puffed brown rice. Texture represents hardness and crispiness, which are expansion-related attributes. As discussed earlier, the expansion of puffed rice modifies its internal structure and improves textural quality.

Table 3 Ranking of quality attributes

Quality attributes	Score	Rank
Color	42.77	3
Texture	69.44	2
Taste	78.88	1

3.2.2 Overall sensory score for puffed brown rice samples

The overall sensory score for samples of puffed brown rice is depicted in Table 4. The overall sensory score increases with the amount of salt content. Puffed brown rice produced at 0% salt showed the least overall sensory score due to the least expansion and absence of salt. As salt content increases, puffed brown rice's expansion and taste likeness also improves. Therefore, samples S4 (4% salt) and S6 (6% salt) were the most acceptable. The acceptability of these samples was the same as SM (market puffed rice). The market puffed rice was produced from polished rice at about 4% salt content. According to the judge’s evaluation, salt content of between 4%–6% is the optimum range for the production of puffed brown rice. These results are similar to Mohapatra and Das (2011) and Swarnakar et al. (2019).

Thus, the ranking of puffed brown rice is S4>S6>SM>S2>S0.

Table 4 Overall sensory score of puffed rice samples

Samples	S0	S2	S4	S6	SM
Overall score	24.78	36.66	57.63	57.03	56.73
Rank	5	4	1	2	3

3.2.3 Similarity analysis for puffed brown rice samples

Table 5 shows the similarity values of puffed rice samples. Highest value shows the corresponding category of the sample. Such as, the similarity value of “Fair” category for S0 sample is maximum; therefore, S0 sample’s acceptability belongs to the Fair category on the sensory scale according to judges. It means that the samples of 4% and 6% salt content were similar to market samples. Both the samples belonged to the same category on sensory scale. Therefore, the ranking of samples according to these values

S0 (Fair,0.8369) < S2 (Satisfactory, 0.8599) < S6 (Good, 0.7284) < S4 (Good, 0.7045) < SM (Good, 0.7337).

Table 5 Similarity values of the sample

Scale Factor	Sample				
	S0	S2	S4	S6	SM
Not Satisfactory, F1	0.5138	0.1806	0.0182	0.0204	0.0267
Fair, F2	0.8369	0.7401	0.2018	0.2288	0.2602
Satisfactory, F3	0.3838	0.8599	0.5249	0.5612	0.5427
Good, F4	0.0620	0.4705	0.7045	0.7284	0.7337
Very Good, F5	0.0000	0.0680	0.4753	0.5122	0.5431
Excellent, F6	0.0000	0.0000	0.1256	0.1296	0.1441

Note: *Bold number indicating highest value

4 Conclusion

Puffed rice prepared from polished rice loses its nutrient quality and takes time and energy. In this work, sensory acceptability and microstructural changes of puffed brown rice were compared with the puffed polished rice. Expansion in puffed brown rice increases with salt content up to 4% afterward, showing an opposite trend. Color was found to be the least important sensory attribute. Taste was found in the first rank, and texture was the second rank. Most accepted puffed brown rice (4% salt content) and commercially available puffed rice produced from polished rice were similar in sensory parameters. Puffed brown rice containing 6% salt also showed similar sensorial acceptability, but this sample's expansion was less compared to the 4% and 5% salt samples. Therefore, 4%-5% salt content can produce optimum quality puffed brown rice. It means puffed brown rice has the potential to replace puffed polished rice.

Declaration of Competing Interest

In regard to this manuscript, the authors certify that they have no conflicts of interest.

Reference

Bhattacharya, K. R. 2011. *Rice Quality: A Guide to Rice Properties and Analysis*. Woodhead Publishing India Private Limited, New Delhi, Elsevier.

Chandrasekhar, P. R., and P. K. Chattopadhyay. 1991. Rice puffing in relation to its varietal characteristics and processing conditions. *Journal of Food Process Engineering*, 14(4): 261-277.

Chandrasekhar, P. R., and P. K. Chattopadhyay. 1990. Studies on microstructural changes of parboiled and puffed rice. *Journal of Food Processing and Preservation*, 14(1): 27-37.

Chandrasekhar, P. R. 1989. Some studies on heated air bed fluidized bed puffing characteristic of rice. Ph.D. diss., IIT Kharagpur, India.

Das, H. 2005. *Food Processing Operations Analysis*. New Delhi: Asian Books.

Das, S. K., M. J. Rangnath, and K. K. Dash. 2015. Pre-conditioning of parboiled rice kernels with different concentrations of NaCl and KCl: Its microstructure and microwave puffing characteristics. In *2015 ASABE Annual International Meeting*, Held at New Orleans Marriott, USA, 27 July 2023.

Dash, K. K., and S. K. Das. 2019a. Optimization of fluidized bed preconditioning for microwave puffed rice using integrated artificial neural network and genetic algorithm approach. *Journal of Food Process Engineering*, 42(6): e13158.

Dash, K. K., and S. K. Das. 2019b. Puffing quality and sensory evaluation of reduced sodium puffed rice. *Quality Assurance and Safety of Crops and Foods*, 11(8): 757-768.

Debjani C., S. Das, and H. Das. 2013. Aggregation of sensory data using fuzzy logic for sensory quality evaluation of food. *Journal of Food Science and Technology*, 50(6): 1088–1096.

Devi, M. K., and S. K. Das. 2017. Kinetics of color changes of popped rice during microwave popping: Effect of salt and moisture content. *Journal of Food Process Engineering*, 40(6): 533-541.

Dutta, A., R. Mukherjee, A. Gupta, A. Ledda, and R. Chakraborty. 2015. Ultrastructural and physicochemical characteristics of rice under various conditions of puffing. *Journal of Food Science and Technology*, 52(11): 7037-7047.

Gulati, T., and A. K. Datta. 2016. Coupled multiphase transport, large deformation and phase transition during rice puffing. *Chemical Engineering Science*, 139: 75-98.

Hoke, K., H. Jirina, and M. Houska. 2005. Optimum conditions of rice puffing. *Czech Journal Food of Science*, 23(1): 1–11.

Joshi, N. D., D. Mohapatra, D. C. Joshi, and R. F. Sutar. 2014. Puffing characteristics of parboiled milled rice in a domestic convective–microwave oven and process optimization. *Food and Bioprocess Technology*, 7(6): 1678-1688.

Lamberts, L., E. D. Bie, G. E. Vandeputte, W. S. Veraverbeke, V. Derycke, W. D. Man, and J. A. Delcour. 2007. Effect of milling on color and nutritional properties of rice. *Food Chemistry*, 100(4): 1496–1503.

Mariotti, M., C. Alamprese, M. A. Pagani, and M. Lucisano. 2006. Effect of puffing on ultrastructure and physical characteristics of cereal grains and flours. *Journal of Cereal Science*, 43(1): 47–56.

Mir, S. A., S. J. D. Bosco, M. A. Shah, and M. M. Mir. 2016. Effect of puffing on physical and antioxidant properties of brown rice. *Food Chemistry*, 191:9-146.

Mishra, G., D. C. Joshi, and B. K. Panda. 2014. Popping and puffing of cereal grains: a review. *Journal of Grain Processing and Storage*, 1(2): 34-46.

Mohapatra, D., and S. Bal. 2007. Effect of degree of milling on specific energy consumption, optical measurements and cooking quality of rice. *Journal of Food Engineering*, 80(1): 119-125.

Mohapatra, M., and S. K. Das. 2011. Effect of process parameters and optimization on microwave puffing performance of rice. *Research Journal of Chemistry and Environment*, 15(2): 154-161.

Pathaw, P. M. S., S. Bhattacharya, and C. L. Mahanta. 2023. Properties of heat moisture treated red rice paddy and its puffed product. *Cereal Chemistry*, 100(3): 784-797.

Saha, S., and A. Roy. 2022. Selecting high amylose rice variety for puffing: A correlation between physicochemical parameters and sensory preferences. *Measurement: Food*, 5: 100021.

Swarnakar, A. K., M. K. Devi, and S. K. Das. 2014. Popping characteristics of paddy using microwave energy and optimization of process parameters. *International Journal of Food Studies*, 3(1): 45-59.

Swarnakar, A. K., P. P. Srivastav, and S. K. Das. 2019. Optimization of preconditioning process of pressure parboiled brown rice (unpolished) for microwave puffing and its comparison with hot sand bed puffing. *Journal of Food Process Engineering*, 42(3): e13007.