Review

Optimum Conditions of Rice Puffing

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Abstract

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The presented paper reviews the existing literature dealing with rice puffing and optimum conditions of this process. The rice pre-treatment procedures and puffing conditions (dry heat, microwave, gun-puffing) are considered. The optimum composition of the raw material is also mentioned.

Keywords: rice; puffing

Puffed rice is very popular in many countries as a cereal breakfast component or as a light food. It is prepared from treated (hydro-heated) milled rice by heating in high temperature air, oil, sand, or also from raw milled rice in microwave field or by the puffing gun.

During puffing, rice kernels increase their volume several times and a fully heat-treated crisp, porous, ready-to-eat product is created. Regardless of the puffing process two important parameters should be taken into account: the selection of an appropriate sort of rice, and the use of a proper hydro-heat treatment of raw rice.

Raw rice (paddy) is the rice in the husk. Raw rice wetted in water, heated in steam and dried is treated rice (special steamed rice). Wetted rice heated in sand is rice treated with dry heat. Milled rice is partially or fully free of the hull. The corresponding milled rice is regarded as treated by heat in steam or by dry heat.

The goal of this study was to review in detail the influence of the main quality parameters of the rice sorts, the conditions of hydro-heat treatment of rice and further treatment procedures on the quality of the puffed product. The quality of puffing is given by the expansion ratio (ratio of the expanded rice volume and volume of the original prepared rice) – the higher the expansion ratio, the higher the quality of the final product. Optimum selected sort, optimum treatment of rice kernels and optimum conditions during puffing gun or microwave heating combined with vacuum can assure the optimum conditions for puffing.

CONDITIONS OF PARBOILING, MILLING AND PUFFING

Chinnaswamy and Bhattacharya (1983a) studied optimum conditions of parboiling, milling and puffing for the preparation of expanded

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rice on a small laboratory scale. The experiments were carried out with Intan variety of paddy. It was obtained from the market in bulk, cleaned, dried [12–13% moisture (wet basis, w.b.)] and stored in metal containers in the laboratory at room temperature. All experiments were conducted 5 to 10 months after the harvest of the lot. For parboiling, 0.5–2 kg of paddy was added to 2–3 l of tap water previously heated to 80°C, the vessel was covered with jute sacks and left overnight (Bhattacharya & Indudhara Swamy 1967). The water was drained off and the paddy was cooked either by steaming (steam-parboiled paddy) or by heating with sand as done in industry [dry-heat-parboiled paddy (DH-parboiled paddy)].

Soaked paddy was steamed on a wire mesh tray for 10 min in an autoclave. Various steam pressures (0–3 bar gauge) were tested initially, and the pressure of 1.5 bar gauge was selected for the subsequent studies. For parboiling by sand heating, the method was essentially that of Ali and Bhattacharya (1976b) for the production of flaked rice. Briefly, about 250 g of fine sand was heated to the desired temperature (200–300°C) in a hand-operated, rotating, cylindrical, electrically heated laboratory coffee roaster of about 1 kg capacity. About 130 g of soaked paddy was poured quickly into the roaster and the latter was rotated at a rate of 80–100 rpm for the desired time (0.5–4.5 min) or until a few grains started to pop. The sand was sieved out and the paddy was cooled and tempered for 30 min. The steam-parboiling method was adopted for all studies of other process variables, as it was simpler than the dry-heat-parboiling method.

Paddy parboiled by the above methods was air-dried in the laboratory for 1–2 days (to reach 10.5–11% moisture, w.b., in the milled rice) and then milled to 8–10% degree of milling for routine studies, or to the degree of milling desired. Any broken rice was removed with an indented plate.

To test the effect of the moisture content of milled parboiled rice on its expansion volume, the parboiled paddy was collected at different times during air-drying, milled and used.

Milled parboiled rice (20 g adjusted to 10.5–11% moisture) was heated with 10–20 times its weight of preheated sand (200–300°C) for 10–11 s, i.e. until the crackling sound just ceased, in the same manner and in the same roaster as described above. Based on the preliminary experiments, 300 g of sand heated to the temperature of 250°C was used for all subsequent experiments.

To study the effect of salt on the expansion volume, 0.5 ml of various salt solutions was sprinkled on 20 g of milled parboiled rice, the sample was mixed thoroughly with a glass rod for 5 min and the rice was expanded.

The expansion ratio was determined by measuring the bulk volume of 20 g of the original parboiled rice and that of the resulting expanded rice in 50 ml and 200 ml graduated measuring cylinders.

Heat expansion condition

The initial studies (Chinnaswamy & Bhattacharya 1983a) were devoted to determining the optimum conditions of heat expansion of milled parboiled rice with the laboratory roaster. For this purpose, dry-heat-parboiled (DH-parboiled) rice prepared for heat expansion after salting was obtained and used. These results showed that for the laboratory roasting conditions, heating 20 g of rice with 300 g of sand preheated to 250°C for about 10 s gave the maximum expansion ratio 7.6.

However, sand temperature, sand quantity, and rice quantity are interrelated and the same effect can be received by different combinations of conditions. At too high temperatures or too high sand to rice ratio, the rice was slightly to moderately charred which may explain the decrease of the expansion ratio. The rpm of the roaster (10–100) did not seem to have a significant effect on the expansion ratio; for routine experiments it was maintained at about 90 (about 15 rotations for a batch lasting 10–11 s). Too coarse sand gave low expansion, perhaps due to a poor heat transmission, but otherwise the mesh size of sand did not appear to have any significant effect.

In comparison, Roberts *et al*. (1951) found that the optimum temperature was 200–220°C and 250 to 300°C for heating in oil and air, respectively.

Effect of parboiling condition

In the industry, water is first brought to boil in a drum, heating is discontinued and the paddy is put into water for overnight soaking (Figure 1) (Chinnaswamy & Bhattacharya 1983a).

This appeared, from experience, to be an unnecessarily high temperature for optimal soaking (Bhattacharya & Subba Rao 1966; Bhattacharya & Indudhara Swamy 1967). Therefore,

50 kg paddy (14% M)
|
Soak overnight in just-boiled water in covered drum (3% M)
|
Drying
|
Roast 1.5 kg with fine sand (1:2) in a shallow iron pan over a strong fire at 240–250°C, for 22 s (100°C, 15% M)
|
Sieve
|
Parboiled paddy
|
Temper 1 h, shade dry 1 hour (13% M)
|
Mill in Engelberg huller → husk-bran for fuel
|
Milled parboiled rice
|
Preheat 10 kg without sand in an iron pan over a low fire for 5 min (80°C, 10.5% M)
|
Temper 30 min
|
Mix 40 ml saturated salt solution to 800 g rice (11% M)
|
Roast with sand (1:10) in an iron pan at 240–250°C for 11–13 s
|
Sieve
|
Expanded rice (1–2% M)

Figure 1. Flow sheet of expanded rice-making process in a local industry in Mysore. Figures in parentheses indicate temperature and moisture (M) contents of the material at the end of the respective treatment

several lots of paddy were soaked overnight in water preheated to different temperatures (60–98°C). As expected, too low temperatures gave insufficient soaking, resulting in white-bellied parboiled rice and a reduced expansion. Soaking in 80°C water (no further heating) however, gave just as good results as in just-boiled water.

It is commonly considered that any parboiled rice is suitable for the expansion by heat. However, Roberts *et al.* (1954) who tested steaming soaked paddy at various temperatures between 65°C and 140°C, noted that the expansion ratio of the resulting milled rice remained minimal up to the steaming temperature of about 100°C, then rose steeply to 125°C and levelled off.

By our opinion, the substantial feature of any treatment is the increase of humidity inside the kernel centre and the formation of a dry solid layer on the kernel surface. This creates the miniature pressure vessel that can work as a puffing gun (inside the kernel is overheated water and during the rupture of the surface the expansion occurs).

When soaked paddy was steamed under different pressures, the expansion ratio of the resulting parboiled rice was minimal with mildly parboiled rice (nearly equal to that of raw rice) but increased up to about 1.5 bar gauge pressure and then levelled off. These results were quite similar to those of Roberts *et al.* (1954).

However, the maximum expansion ratio obtained by the above procedure (just over 5) was much less than that obtained in the industry, as was the case in the laboratory with the salted DH-parboiled rice produced industrially with the same variety of paddy (about 7.5). Therefore, soaked paddy was parboiled by sand roasting under various conditions. The DH-parboiled rice yielded a much higher expansion ratio than did steam-parboiled rice, the optimum conditions being heating soaked paddy at 250°C for 2.5 min.

The essential difference between dry-heat-parboiled and steam-parboiled rice is a lower starch re-association, or retrogradation in the former (Ali & Bhattacharya 1976a, b).

Effect of the moisture content in milled rice

Optimum expansion was obtained at around 10.5% moisture (w.b.) in milled rice (Chinnaswamy & Bhattacharya 1983a). In comparison, the optimum moisture in the work of Roberts *et al.* (1951) was 8–14% and 8–9% for heating in oil and air, respectively.

Effect of the degree of milling, cracked and broken rice grains

It was found that a minimum of 6% degree of milling of rice is necessary to promote optimal expansion, apparently due to the removal of the barrier generated by the bran layer. Above this value, the continued milling had no appreciable effect (Chinnaswamy & Bhattacharya 1983a).

Cracks in milled rice reduced the expansion ratio, probably because the generated steam escaped through the cracks thus lowering the pressure for expansion. Similarly, broken rice also resulted in a lower expansion than did whole grains (5.3 and 7.3, respectively).

Effect of salt addition

Salt solution is invariably added to milled rice before it is heat-expanded in the industry. The effect on expansion was investigated (Chinnaswamy & Bhattacharya 1983a).

Salt appreciably increased the expansion ratio. Interestingly, not only sodium chloride but also other salts had the same effect. Gerkens and D'Arnaud (1963) in his studies of the heat expansion of cooked starch postulated that salt helped the expansion by facilitating the heat conduction inward and the exit of moisture outwards. It is interesting to note that, while salt increased the expansion ratio of both steam-parboiled and dry-heat-parboiled rice, the former had an uneven blistered surface but the latter was smooth. The reason for this difference is not yet understood.

Effect of the age of paddy

The age of paddy seemed to have a small effect on the expansion ratio. Initially, the expansion increased a little with age after which it decreased (Chinnaswamy & Bhattacharya 1983a). Interestingly, this behaviour resembles the changes in the hydration and viscosity properties of rice upon ageing (Indudhara Swamy *et al.* 1978).

Optimum puffing conditions for different varieties

Chinnaswamy and Bhattacharya (1983a) showed that there is a wide variety difference in the expansion ratio of rice. Whether the poor expansion of certain varieties could be improved by changing the puffing conditions was studied with two poor-expanding varieties. It was found that the optimum moisture content and optimum puffing temperature remained unchanged irrespective of the variety.

Murugesan and Bhattacharya (1991) studied the effects of some pre-treatments on the puffing expansion of rice. In their earlier study, it was noted that although 14% moisture content in paddy was optimum for the puffing expansion, pre-drying it in the sun to 9% moisture before finally adjusting the moisture to 14% enhanced its popping yield by as much as 30%. Soaking paddy in 2% common salt (NaCl) solution also increased the expansion by about 15%. Being of possible practical use, the effects of these two factors were studied here in greater detail.

The experiments were carried out with Intan variety of paddy, commonly used in the puffed rice industry, purchased from the market. For pre-drying, paddy was put in a thin layer on a wire-mesh tray and was exposed to: (*i*) the sun; (*ii*) vacuum in a vacuum oven, provided with fused calcium chloride as desiccant, at ambient temperature; and (*iii*) hot air at 45, 60 or 75°C in a cabinet dryer. Samples were withdrawn at intervals and tempered in tightly-rolled polyethylene bags for 1–2 days before the moisture adjustment and popping. Paddy with different initial moistures [30% (fully soaked), 17% (exposed to 90% RH) and 13% (untreated)] was similarly pre-dried.

Salt treatment was done either by soaking paddy in 2% NaCl solution for up to 3 days followed by drying at 50°C, or by mixing salt solution (10 ml) with paddy (60 g) and tempering.

All experimental paddy, whatever the treatment(s), was adjusted to the respective optimum moisture content for the best popping expansion, see 14% moisture for unsalted paddy and 17% moisture for salted paddy, as a final step before popping, by exposing for 2 days in a humidity chamber maintained at 28°C and 75% RH or 90% RH, respectively. Paddy was popped as described elsewhere.

Effect of pre-drying

The beneficial effect of pre-drying on the popping of rice was confirmed (Murugesan & Bhattacharya 1991). The pre-heating to the moisture content of 9% increased the expansion ratio in all drying methods. In fact it was seen that the increase of the expansion ratio was independent of the drying method adopted except if the drying air was too hot (above 70°C) which provided much worse results (surface layer could break at high air temperature – a remark of the authors of this study).

Effect of salting and pre-drying

Since soaking of paddy in 2% NaCl solution increased its popping expansion by about 15%, it was investigated whether salt soaking and pre-drying could be combined for a greater benefit (Murugesan & Bhattacharya 1991). The results were paradoxical. The expansion was indeed raised over that of unsalted paddy and remained high up to a moisture content of 17% – the optimum for popping salt-soaked paddy. But, on further drying, the expansion surprisingly decreased with the moisture content decreasing to 13%, then it increased with a further moisture content decrease to 9%, and then it finally decreased again. Thus pre-drying to 9% moisture did have a beneficial effect here too, but only after an inexplainable initial drop between 17% and 13% moisture. This result was repeatedly verified.

Applying salt solution to pre-dried (9% moisture) or not dried paddy was worse (with increasing concentration, the expansion ratio decreased). Apparently, the deposition of salt on the grain surface was harmful; it would have to penetrate inside to be of benefit. Even partial penetration was not good enough, the full benefit of salt being shown only in the sample fully soaked in 2% salt solution when the moisture content increased up 30%. Yet, paradoxically, salt hardly penetrated the bran layer during soaking. The chloride content in brown rice increased from 9–10 µg/g in untreated rice to the 904 µg/g after 3 days of the soaking of paddy in 25% salt solution, but in milled rice it remained constant at 9–16 µg/g irrespective of the time and the concentration of salt during soaking.

These results showed that the possibility of salting as a means to improve commercial popping yield was probably remote, for the superficial application of salt was far from being beneficial while full soaking (3 days) was clearly impractical for full benefit.

Effect of soaking in water

In an attempt to explain the peculiar results of salt soaking, paddy was soaked in water instead of in salt solution and dried (Murugesan & Bhattacharya 1991). A similar curve was obtained, except that at all moisture contents the expansion ratio was lower. This curve, too, was repeatedly verified. When paddy with 17% initial moisture (grain exposed to 90% RH) was pre-dried at 50°C, the suppression of popping expansion was much lower; the curve valid for a non-hydrated sample had the same shape. These results showed that the deleterious effect of wetting was proportional to the extent of wetting. However, when the two wetted samples were initially air-dried in the room to 13–14% moisture content and then pre-dried at 50°C, the difference between the unmoistened and to 90% RH exposed samples disappeared. The curve for the water-soaked sample was substantially raised, although still a little suppressed. Clearly, part of the harmful effects of wetting was caused by the high-temperature drying of wet paddy. In any case, it was clear that wetting of paddy with water (above 14% moisture) should be avoided in industry, although the deleterious effect of any accidental wetting could be partly reversed by the initial slow air-drying of the grain.

Factors responsible for the effects of pre-drying, soaking and salting

The reasons for these peculiar results were explored (Murugesan & Bhattacharya 1991). One possibility was the grain cracking. Pre-dried paddy cracked when its moisture content increased to 14% before popping. Cracking was severe (about 60%) when the moisture adjustment was made by adding water, less so when paddy was exposed to 75% RH (about 20%), and still less when paddy was gradually hydrated by a successive exposure to 60% RH and then 75% RH (about 15%). However, the popping expansion remained virtually the same in all the cases (15.0–15.3), showing that it was not a relevant factor in the expansion increase. The same results also confirmed the earlier observation that cracks in rice had little effect on its popping.

Chandrasekhar and Chattopadhyay (1991) studied rice puffing in relation to its variety characteristics and the processing conditions. The product was prepared from parboiled (hydro-thermally treated) milled rice by high-temperature short-time (HTST) heating of the milled rice dried in air, oil or sand, and also by gun puffing of raw milled rice. After puffing, rice grains expand in manifold was to a thoroughly cooked, ready-to-eat, crisp and porous product. Apart from proper puffing technique, two important aspects for producing good quality puffed rice are the selection of proper paddy varieties, and the utilisation of proper hydrothermal treatment of paddy (rough rice). It is well known to the processors in the cottage industry that all paddy varieties do not expand equally well and, therefore, they invariably choose, by historical evaluation, specific varieties for their trade.

Various researchers (Roberts *et al*. 1951; Antonio & Juliano 1973; Chinnaswamy & Bhattacharya 1983b; Villareal & Juliano 1987) studied different variety characteristics that affect the expansion, e.g., total amylose and hot water insoluble amylose contents, protein content and length vs. width ratio; however, contradictions exist among the findings reported by them which calls for further investigation.

A proper hydrothermal treatment of moist paddy in terms of optimum combination of the steaming pressure and the time to produce good quality puffed rice was investigated by Roberts *et al*. (1954) and Chinnaswamy and Bhattacharya (1986), but their findings did not provide the quantitative evaluation of the method adopted.

Few authors attempted at the quantitative assessment of the degree of starch gelatinisation in processed foods. Tanaka and Yukami (1969) assessed the degree of gelatinisation of starch in precooked rice by incubation with β-amylase followed by the estimation of the maltose produced. Birch and Priestley (1973) attempted to quantify the degree of gelatinisation in rice based on the amylose/iodine blue value after dispersion in two different concentrations of alkali and related this to a hydrogen bonding effect observed in the infrared absorption spectrum of rice. These methods, however, are relatively slow and complicated. Ferrel and Pence (1964) used the amylograph to study the extent of cooking in steamed rice and reported that viscosity decreased if the paste was kept at 95°C for 20 min as steaming or other cooking pre-treatment of rice increased until it reached zero. In the present study, the extent/degree of rice starch gelatinisation that took place during parboiling was correlated with Brabender hot-paste peak viscosity values. It is a common practice for the processors in the rice puffing industry to add common salt solution to milled parboiled rice and dry it before puffing. Optimum milling and addition of salt treatments for obtaining maximum expanded rice were also studied during the present investigation.

Paddy varieties and properties

Samples of 12 paddy varieties consisting of short, medium, and long types including some traditionally known well puffing varieties were chosen and collected for studying the variety characteristics (Chandrasekhar & Chattopadhyay 1991). Their varieties were dried in shade to 12–13% moisture content (wb), cleaned and stored in metal containers till further use. However, to study the effect of parboiling, milling and salting on puffing, "Panloi", a commercially used well puffing variety (L = 7.19 mm; W = 2.55 mm; T = 1.71 mm) was used. The physical properties, the dimensions of rice varieties and chemical composition used in the experiment are given in the original paper.

Parboiling and milling

Paddy samples of 500 g each were soaked in hot water at 70°C to attain approximately 30% moisture content (w.b.). Each fully soaked paddy sample of 500 g was then subjected to steaming at various steam pressures (0.5–2.0 bar and time periods 5–25 min) to obtain normal parboiled rice samples with different extents/degrees of starch gelatinisation (Chandrasekhar & Chattopadhyay 1991).

In another series, two 500 g paddy samples were washed with water and then subjected to steam at 2.5 bar gauge pressure for 20 and 30 min, respectively, to obtain pressure parboiled rice samples (as traditionally known in India).

Each sample was then dried in shade to 12–13% moisture content (w.b.), husked in a Satake testing husker (Type – THU) and further milled in a Satake Polisher (Type – TM-05) to approximately 10% by weight bran polish removal for the complete removal of bran.

Milling to different degrees of polish

In order to study of Chandrasekhar & Chattopadhyay (1991) the effect of the degree of milling on the quality of puffed rice, samples of different degrees of polish were prepared by milling the brown rice samples for different periods of time. Accordingly, samples at 9 levels of polish (1.64; 2.8; 4.0; 4.5; 5.63; 5.81; 6.85; 8.35 and 10%) were prepared from the pressure parboiled paddy samples.

Amylograph technique

The standard model Brabender amylograph (Brabender OHG, Duisburg) was used to measure the peak viscosities of parboiled rice samples showing their extents/degrees of starch gelatinisation (Chandrasekhar & Chattopadhyay 1991). Rice was ground to pass through the 40 mesh screen of No. 3 Wiley mill. A 15% slurry was prepared by placing 60 g ground rice (adjusted in respect of the moisture content) in a Waring blender and approximately 300 g of the required 400 g (adjusted for the actual weight and moisture content of the rice) of distilled water was added. The mixture was mixed 1.5 min and transferred to the amylograph bowl. The remaining water was used to rinse the blender and then transferred to the amylograph bowl. The slurry was initially heated to 30°C. The chart was then adjusted to zero minute marking and the slurry was heated to 95°C at a rate of 1.5°C/min. The paste was held at this temperature for 20 min to obtain the peak viscosity value.

The samples were used on the day of grinding. The Brabender viscograph used was fitted with a 250 p.cm sensitivity cartridge and the rpm were kept constant at 75 during the experiments.

Brabender hot paste peak viscosity measurements were carried out for all of the 16 rice samples with different extents/degrees of rice starch gelatinisation obtained by normal parboiling treatment as well as two rice samples obtained by pressure parboiling treatment. Each measurement was made in two replicates.

Salt treatment

Sodium chloride (NaCl) and calcium chloride ($CaCl_2$) were used as additives (0.5, 1.0, 1.5, 2.0, 2.5 and 3.0% by weight) to study their effects on the puffing quality of rice (Chandrasekhar & Chattopadhyay 1991). Each salt was added to the parboiled milled rice sample in the form of saturated solution and the mixture was thoroughly mixed before drying to the moisture content required for puffing (10.5–11% w.b.).

Puffing technique

Chandrasekhar and Chattopadhyay (1991) puffed salted and dried samples in hot air at about 250°C in the continuous heated air fluidised bed puffing machine developed for this purpose (Chandrasekhar & Chattopadhyay 1988).

Paddy variety characteristics in relation to puffing quality

The estimated physical and chemical characteristics of the samples of 12 rice varieties (namely, bulk and particle densities, total amylose, hot water insoluble amylose and protein contents) as well as the expansion ratios of these samples as obtained after puffing are given in Table 1. The correlations obtained, if any, between these properties and the expansion ratios are shown in Table 2 (Chandrasekhar & Chattopadhyay 1991).

As seen in Table 2, the shape of rice (namely, L:W ratio) correlated well with the expansion ratio (ER), but the bulk and particle densities did not show any significant correlations. The possible reason for a comparatively high ER with rice varieties having a higher L:W ratio as suggested by previous

Table 1. Properties of 12 rice varieties and their expansion ratios after puffing (Chandrasekhar & Chattopadhyay 1991)

Serial number	Variety	Bulk density (kg/m^3)	Particle density (kg/m^3)	Total amylose (% d.b)	Hot water insoluble amylose (% d.b)	Protein (% d.b)	Expansion ratio*
1	Palmal	831	1467	27.58	11.96	5.43	9.71
2	Panloi	780	1465	28.32	10.35	6.15	9.55
3	Kaviraj Sal	780	1454	26.59	11.16	6.17	9.28
4	Mugai	788	1464	26.92	10.51	5.08	9.12
5	Bashkata	772	1468	31.06	12.74	5.43	8.95
6	Masuri	770	1453	26.92	14.44	6.35	8.81
7	Kakhura	825	1464	31.30	11.31	5.65	7.66
8	Patnai	783	1458	31.22	15.50	5.43	7.41
9	Lata Sal	825	1458	31.55	14.26	6.83	7.41
10	Bhutia (black)	832	1465	26.26	9.75	7.15	7.17
11	Maul	790	1466	31.55	18.78	7.35	5.34
12	Bhutia (white)	812	1451	23.95	9.22	8.40	4.82

*Paddy washed with water and then subjected to steam at 2.5 kg/cm^2 for 30 min during hydrothermal treatment

Table 2. Correlation coefficients between different rice properties (Chandrasekhar & Chattopadhyay 1991)

Serial number	Properties of rice	Correlation with expansion ratio
1	L:W ratio	0.69
2	bulk density	0.28
3	particle density	0.27
4	protein	–0.79

investigators (Chinnaswamy & Bhattacharya 1983b) is that higher amylose contents for longer varieties are responsible for producing higher expansion ratios. This could not be elaborated in the present study. All the rice varieties chosen in the study had high amylose contents and did not show any definite relationship between L:W ratio and total amylose content.

Although the analysis revealed a consistent variation of amylose content with a respective variety, it can be seen in Table 1 that the varieties chosen for the study had all high amylose contents ranging between 23.95–31.55% (db), and almost all of them (except two varieties) showed comparatively higher expansion ratios (7–10).

Hot water-insoluble amylose content of the rice varieties studied in the present case also showed a definite relation to the ER similar to the pattern obtained for total amylose content.

The correlation analysis further showed a negative relation between protein content and ER (r = –0.79) in the rice varieties studied. A higher protein content in the grain seemed to inhibit the puffed volume expansion and, as the protein content increased, the starch content automatically decreased showing the observed effect.

Quantification of the extent of rice starch gelatinisation in relation to puffing

The extent/degree of starch gelatinisation as obtained by varying the intensity of the hydrothermal treatment with different steaming pressures and periods was correlated with Brabender hot paste peak viscosity values, and their effects on the ER of puffed rice produced were also studied (Chandrasekhar & Chattopadhyay 1991).

The variation of Brabender hot paste peak viscosity values of parboiled rice samples with steaming pressures and periods confirmed the data reported by previous investigators (Ferrel & Pence 1964). For all the steaming pressures studied, the slopes of the peak viscosity curves were higher during the initial period of steaming, and thereafter the curves slowly flattened showing a higher initial rate of starch gelatinisation. As the steaming pressure increased, the higher extent/degree of starch gelatinisation resulted in a shorter period of time. The peak viscosity values obtained with pressure-parboiled samples were comparatively low. Also, the increasing trend of the Brabender viscosity values after reaching 95°C indicated in all the cases that the intensity of hydrothermal treatment applied in the study produced samples either completely cooked or overcooked.

The data show that to produce maximum expansion of puffed rice, an optimum existed for the steaming time at each steaming pressure, i.e., 20 min at 0.5 bar with the reduction of 5 min in steaming time corresponding to 0.5 bar increase in steaming pressure. However, beyond 2 bar of the steaming pressure the ER decreased due to the excessive grain bursting and other grain deformations caused during steaming. Normal parboiling at 1.5 bar steaming pressure for 10 min corresponding to the peak viscosity of 425 BU produced the highest ER of 7.5 for puffed rice among normal parboiled samples. Pressure parboiled samples at 2.5 bar steaming pressure for 30 min, corresponding to the peak viscosity of 240 BU, produced highest ER of 9.7 for puffed rice.

Optimum milling and salt treatment for obtaining maximum expanded puffed rice

The expansion ratios of puffed rice obtained from rice samples having different degrees of milling increased to a certain value and then stagnated (Chandrasekhar & Chattopadhyay 1991). It was observed that a minimum of about 6% degree of milling was necessary to produce optimum expansion of puffed rice, beyond which the degree of milling showed no appreciable effect on ER. This might be due to the higher resistance offered by the existing bran covering at a lower degree of milling against the spontaneous release of high-pressure steam formed inside the grain at the time of puffing.

The increase of ER of puffed rice with the addition of $NaCl/CaCl_2$ at different percentages was observed. The result shows that the addition of $NaCl/CaCl_2$ up to 2% by weight increased ER by maximum value 9.56 beyond which no significant difference in ER was observed. The above findings confirmed the results of Gerkens and D'Arnaud (1963) who observed that salt helped to increase the starch expansion by facilitating the heat conduction inwards and the moisture exit outwards. Two percent salt addition was also found to be optimum during the sensory evaluation of the puffed rice samples. It was also interesting to note that the addition of salt produced a smoother surface of the puffed rice while rice puffed without the addition of salt showed an uneven blistered surface.

TECHNICAL ASPECTS OF THE GUN-PUFFING OF RICE

Some authors presented in their papers several different procedures of puffed rice production. Keesenberg (1978) reported that puffed rice is produced from hulled milled white rice. During puffing, the individual kernels of rice increase their volumes by 12 up to 18 times due to the hydrothermal pressure process followed by an instant pressure drop. Puffed rice is ready for consumption, easily digestible and is a good semi-product for further treatment. Puffing guns are used for the realisation of this process. The puffing gun is composed of a rotating horizontal cylinder having the length of 1.2 m and the inner diameter of 200 mm. The cylinder is closed on one side and the steam inlet is placed at this point. On the opposite side a heavy cast iron lid is placed. The cylinder is filled at the start of the process with 6–7 kg of rice. It is necessary to use the first class white glazed rice with the moisture content about 13%. After closing, the cylinder rotates and is heated over the total length by gas burners for about 6 min. The pressure inside the cylinder rises up to about 8 bars and the temperature to 115°C. Overheated steam is led into the cylinder at the end of the process and the pressure is raised to 13 bars. At this moment, the machine is prepared for the final stage of the process. The closing mechanism of the lid is quickly opened by a quick hit of the cylinder downwards. The lid is captured with an hydraulic shock absorber. The rice is released by the shock pressure drop and escapes from the cylinder into free space. By this way, the explosion of the sound level of 110 dB is created. The rice kernels are expanded during the pressure drop and puffed rice is thus produced. The whole process takes about 8 minutes and the production of the gun is about 50–60 kg of rice per hour. The gas consumption is about 10–12 m^3/h.

Chandrasekhar and Chattopadhyay (1988) dealt with the heat transfer during fluidised bed puffing of rice grains. In order to enhance the production of puffed rice, a puffing machine working on the principle of hot air fluidised bed puffing was designed and fabricated. The understanding of the heat transfer process that takes place at the time of puffing was required for the design and development of this puffing machine.

The experiments were conducted with a local variety of paddy known as "Panloi". It was obtained from the farmer in bulk, cleaned, sun dried to 12% to 13% moisture content (w.b.), and stored in metal containers in the laboratory at room temperature. The parboiling and milling of paddy and the preconditioning of rice was done by the method used by Chinnaswamy and Bhattacharya (1983a). Rice with the moisture content of 10.5% (w.b.) was used for all further studies.

A small testing equipment was constructed using a transparent tube with the diameter of 5 cm. Of the same diameter was the testing column in the puffing full-scale equipment. The same air flow speed was achieved as that in the full scale equipment used. The flow of air was maintained by means of an axial ventilator and a control valve. The amount of 90 g of rice was placed into the tube. This mass of rice should be kept in the tube to assure the capacity of the equipment at 20 kg/h. Puffing time was prolonged with the decreasing air temperature and the lag time inside the column was much longer for lower air temperatures. The residence time of rice kernels in the column finished on the kernel expansion. The density of the kernel quickly decreased and particles flew out of the column (the remark of the authors of the study). The experiments were conducted at the air temperatures of 200–270°C and the residence times between 16.5–7 s for the puffing of rice kernels. Higher expansion ratios were received at temperatures between 240–270°C and the residence times between 9.7–7 s. At lower temperatures, the expansion ratio was lower and at temperatures higher than 270°C the browning of the rice was observed while further rise of the expansion ratio was not apparent.

As the air temperature increased from 200°C to 270°C, the value of the grain surface temperature did not change appreciably. The puffing of rice grain took place when the surface grain temperature attained a value of around 170°C. The values of the grain average temperature or the grain centre temperature showed slightly decreasing trends with increasing air temperature. The grain average temperature decreased from 164°C (air temperature 200°C) to 147°C (air temperature 270°C). Also the grain centre temperature decreased from 158°C (air temperature 200°C) to 125°C (air temperature 270°C). The lower values of the grain average or the grain centre temperatures obtained at higher air temperatures may be caused by a comparatively, shorter exposure time for puffing.

Chih Chia Chang and Tung Chien (1997) prepared a study of microwave popping ratio of dried rice. A possible method of the rice treatment is the application of microwave. The authors present in their study dried rice prepared from polished rice that was made microwave pop-able, in order to increase the rice added value and shelf life. The popped rice is a ready-to-eat food. After being mixed with hot water, it can be served as rice gruel.

The objective of this study was to determine the optimal processing conditions for the microwave pop-able dried rice. The amylose contents of TCW70, TC189 and TNuS19 rice were 1.4, 18.3 and 25.4%, respectively. The rice samples were stored at 4°C for six months before use. After being steam gelatinised, the rice was dehydrated to a water content of 12 ± 1% by two-step drying at 90°C and 70°C. The response surface methodology (RSM) was subsequently used to evaluate the effects of the rice variety, storage time, and alcohol and sodium chloride additions on the microwave popping ratio of dried rice after heating at 700 W/1 min.

The microwave popping ratio of dried rice increased with an increase of the storage time and the amounts of alcohol or sodium chloride added. Among these, the addition of sodium chloride was the most effective, followed by the addition of alcohol while the storage time had the least effect on the microwave popping ratio. The microwave popping ratios of TCW70 and Tc189 were almost the same, and both were higher than that of TNuS19. The optimal processing conditions for the dried TCW70, TC189 and TNus19, were, respectively, as follows: sodium chloride of 2.9, 2.7 and 3.0%, alcohol additions of 5.1, 4.1 and 4.2%, and storage time for 20.3, 16.6 and 0 days. The above given dried rice sorts had optimal microwave popping ratios of 400, 410 and 200%, respectively.

CONCLUSION

The following procedures of the rice treatment result from the above mentioned literature. Paddy was cleaned and dried to 12–13% of moisture (w.b.) in air flow or in the shadow or sunshine, or in the vacuum chamber containing a desiccative substance, or by hot air in the drying chamber. Dry rice was placed into metal containers and stored in laboratory at room temperature or chilled (at 4–5°C).

The treatment of rice involved wetting in hot water for some time to reach the moisture content of about 30%. Water was then removed and the wetted paddy was cooked in steam (steam treatment) or heated in sand (dry heat process). The final effect of the treatment depends on the steam pressure and the duration of the steam treatment. After the treatment, rice was dried to the moisture content optimum for puffing (10.5–14%). Then rice was milled to some milling degree (minimum milling degree 6%). An increase of the expansion ratio was reached by salting or alcohol treatment. The salting can be done by wetting rice in the salt solution of specific concentration for a specific time followed by drying to the moisture convenient for puffing, or by a thorough mixing of saturated salt solution with treated milled rice. Puffing can be achieved with the treated rice by different procedures. In India, the most frequent way is puffing in hot sand (temperature of sand about 250°C). The second method is puffing in hot air (250–300°C) or in oil (200–220°C). Puffing of rice can also be done in the microwave field. Another method is puffing by means of the puffing gun.

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