J Food Sci Technol (July–August 2010) 47(4):414–419
DOI: 10.1007/s13197-010-0068-3

ORIGINAL ARTICLE

Effect of processing paddy on digestibility of rice starch by *in vitro* studies

Chitra M. · Vasudeva Singh · Ali S. Z.

Revised: 14 December 2009 / Accepted: 19 December 2009

Abstract Paddy (*Oryza sativa* L) (variety 'IR – 64'), was parboiled, puffed by sand roasting and flaked by edge runner and roller flaker and variations in physical and physicochemical properties were studied. Moisture contents were lower (5.8–10.8%) in processed rice products compared to raw materials (11.8%). Ratio of rice to sand in the case of puffed rice preparation was optimized. The equilibrium moisture content was 27.4% in raw rice while it was much higher (38.9–81.0%) in processed rice. Sedimentation volume was lowest (6.2 ml) in raw rice and highest (18.8 ml) in popped rice. Starch content was 84.8 and 76.5–83% in raw and processed rice, respectively. *In vitro* starch digestibility was highest in roller flaker flakes and lowest in raw milled rice. Among the ready to eat products, popped rice showed least starch digestibility (~30%).

Keywords Rice starch. Paddy. Dry heat parboiling. Edge runner flakes. Roller flakes. Sand roasting. Pre gelatinization

Chitra M. · Singh V. · Ali S. Z.
Department of Grain Science and Technology,
Central Food Technological Research Institute
(Council of Scientific and Industrial Research),
Mysore - 570 020, India

Singh V. (✉)
E-mail: singhva2003@yahoo.co.in

Introduction

Paddy production in the world is 660 millions tonnes, out of which India produces around 144.6 million tonnes (Anon 2007). About 14.46 million tonnes (10% of production) is being utilized for the production of rice products like popped, expanded and flaked rice in the country (Narasimha, 1995). High amylose rice is preferred for extruded rice noodles (Juliano and Sakuria 1985) and puffed (expanded and popped) rice (Arya 1990). Flaked or beaten rice is a very popular traditional product in India and other rice consuming countries. This product is consumed as snack after toasting/frying and spicing or after soaking in water and seasoning with spices and vegetables (Ananthachar et al. 1982). The traditional process of making flaked rice involves roasting of soaked paddy and flaking in an edge runner (Ghose et al. 1960). Changes in the nature of protein during flaking of rice have been studied (Mujoo et al. 1998). Comparative properties of rice flakes from edge runner and roller flaker have been previously studied (Ekanayaka and Narasimha 1997). Both expanded and popped rice are prepared by high temperature short-time (HTST) treatment. The expanded rice is made from parboiled milled rice while popped rice is made by direct puffing of raw paddy (Murgeshan and Bhattacharya 1986). Rice is an important source of starch. Boiling and pressure cooking causes significant increase in *in-vitro* starch digestibility (Rosario and Jayashree 2000). The formation of insoluble amylose-lipid complexes was suggested as a reason for the lower starch availability in *invitro* and *in vivo* of drum dried wheat flour slurry compared with boiled wheat flour. Incompletely gelatinized steam flaked and dry autoclaved products of wheat were digested more slowly *in vitro* and elucidated lower glucose responses as compared with completely gelatinized drum dried, extrusion cooked or boiled samples (Holm et al. 1985). The more severe the processing condition, the more rapid the digestion of starch (Jorgen et al. 1987). Soluble amylose content decreased drastically in pressure parboiled and parboiling under pressure, in roasted parboiled and normal parboiled aromatic and in non – aromatic rice (Shashikala et al. 2005). Loss of thiamine (%) was less in parboiled rice, but loss of oryzanol was slightly high at different degree of milling (Vasudeva Singh et al. 2004). Cooking time of rice decreased from de-husked rice to milled rice, however volume expansion increased with increase in degree of milling; distortions in cooked grains were less in rice milled in abrasive polisher compared to friction polisher; solid loss, length to breadth ratio increased with increase in degree of milling (Meera et al. 2004). Various food grain starches were modified with acid as well as α amylase enzyme and always enzyme hydrolysis was fast compared to acid hydrolysis (Vasudeva Singh and Ali 2006). In view of the high consumption of raw rice, parboiled, flaked and puffed rice especially in Southern India, it was considered appropriate to compare the digestibility of starch and physico-chemical characteristics of these products.

Materials and methods

The enzymes, like α-amylase from human salivary (EC 3.2.1.1), pepsin from porcine stomach mucosa, (pepsin A, EC 3.4.2.3.1), pancreatin from porcine pancreas (P-1625) were procured from Sigma Chemicals, USA. All other chemicals used were of analytical grade.

Milling: Paddy (O*yza sativa* L) procured from a local cottage industry was shade dried to about 14% moisture content (w.b) and rice was prepared by shelling and milling. One kg of paddy was shelled in the laboratory Satake rubber-roll sheller (Satake Engineering Company Ltd, Tokyo, Hiroshima).

Brown rice obtained was milled in a Mc-Gill miller (McGill, Houston, USA) for 1min, with 1.8 kg weight. Crude bran obtained was sieved through 18 mesh sieve (850 micron) to remove husk particles. Degree of milling was then calculated. This sample was taken as raw milled rice sample.

Normal parboiled rice: Paddy (~2 kg) was soaked in boiling water (~98°C) as per the method of Shashikala et al. (2005) and the parboiled paddy prepared was shade dried in the laboratory at room temperature (23–32°C) for 1–4 days. The milled rice was prepared after shelling and milling as described earlier and this was considered as the normal parboiled rice.

Pressure parboiled rice: The pressure parboiled rice was prepared as described previously (Ali and Bhattacharya 1982, Chinnaswamy and Bhattacharya 1986). About 2 kg of paddy was soaked at room temperature for 20 to 30 min, water was drained-of, and paddy was spread on a wire mesh tray and steamed in an autoclave under a pressure of 24.53×10^4 N/m^2 for 30 min. It was dried and milled as described earlier. The resultant milled rice was pressure parboiled rice.

Dry roasted parboiled rice: Dry roasted parboiled rice was prepared as described earlier (Shashikala et al. 2005). About 3 kg paddy was soaked in water at ~98°C (the temperature after mixing was 70–75°C) and kept overnight as before. The water was drained and the soaked paddy was roasted in the laboratory roaster (Indlab Grain Roaster, ~5 kg capacity, Indlab Furnaces, Mysore, Karnataka). For roasting, sand and soaked paddy in the ratio of 4:1 were taken. When the temperature of sand reached to 245–250°C, the soaked paddy was added to the roaster instantaneously and roasted for 1 min and the mixture temperature was 135–145°C. The mixture was then dropped on a sieve of ~ 36 mesh (420 micron) size and separated paddy was shade dried, shelled and milled to obtain dry roasted parboiled rice.

Popped rice: About 1 kg of paddy was moistened to a ~14% moisture and tempered (equilibrated) overnight. It was then subjected to high temperature short time (HTST) treatment in hot sand (temperature of sand ~250° C) for 25–30 sec as described by Hsieh and Bor (1991). The paddy to sand ratio taken was 1:10. The mixture was then poured on to a sieve of ~12 mesh size, all the sand particles were removed and popped rice was poured on to a measuring cylinder and expansion ratio was calculated by taking the ratio of the volume of popped rice to volume of processed paddy (initial volume).

Expanded rice: Milled parboiled rice (by dry heat parboiling) was the starting material for expanded rice preparation. This rice was preheated without sand at 80–90°C in the roaster for 2 min, mixed with saturated salt solution (~5 ml/100 g) and tempered for 30 min and roasted in hot sand (1:10) at 240–250°C for 15–25 sec. Rice expanded several folds, it was then sieved in 36 mesh sieve, poured hot in to a measuring cylinder, before noting the volume, the jar was jerked on a table, such that full compact of the material takes place and expansion ratio was calculated (Ali and Bhattacharya 1982, Chinnaswamy and Bhattacharya 1986) and sample was collected in polythene bag.

Flaked rice: Initial method of preparation was similar to those adopted for preparation of expanded rice to obtain the roasted parboiled paddy. The hot paddy (18 to 20% moisture) was fed to the edge runner immediately and the unit rotated at 300 rpm (the unit consists of a perforated, round, as flat thick sieve with a raised edge. An idle roller is mounted at the edge of the sieve and the roasted paddy is flaked during passage between the edge and the roller. The dried husk and part of the bran layers were removed through the rotating sieve and the rice grains were flattened by repeated pressing as they pass between the idle roller and the edge of the sieve (Narayanaswami 1956, Ghose et al. 1960, Mujoo et al. 1998). The flaking was done for ~45 sec. It was then sieved hot.

Roller flakes: The roller flakes were prepared by shelling the hot parboiled paddy immediately in the centrifugal sheller where the husk was separated simultaneously by aspiration. The shelled brown parboiled rice was tempered for 2–4 h or some times over night and then milled in Mc-Gill miller or cone polisher this hot or warm rice was flattened in between the heavy rollers (Mujoo et al. 1998).

Grinding: Raw milled rice and rice products prepared were ground in a laboratory hammer mill and passed through 60 mesh screen and were taken for further experiments. Moisture content of the samples and equilibrium moisture content (EMC) on soaking in water at room temperature (27°C) were determined as per the procedure of Indudhara Swamy et al. (1971).

Physical properties of rice and its product: The length and breadth were measured for 10 grains by using a scale and weight for 100 grains of raw milled rice and different parboiled rice were noted. Bulk density was calculated for popped and expanded rice products. Sedimentation test for pre-gelatinized products was carried out as per Bhattacharya and Ali (1976).

Starch estimation: Starch was estimated by polarimetric method (Richter *et al.* 1968). About 5 g sample was taken in a 250 ml beaker and 50 ml of 1.124% hydrochloric acid was added while stirring (twice in 25 ml aliquots) and mixed properly for 3 min. The solution was then heated for 15 min in boiling water bath (time was counted when the temperature of the contents reached 96°C). Twenty to thirty ml of cool refrigerated water were added. The contents were transferred to a 100 ml volumetric flask and kept at 20°C. Dissolved protein was precipitated by addition of 3 ml each of Carrez I (15% $K_4Fe(CN)_6$ solution) and Carrez II (30% $ZnSO_4$ solution). Volume was made up to the mark with distilled water and the optical rotation of the filtrate was read in a polarimeter (PERKIN-ELIMER-243, source-Sodium, wave length-589 nm). Starch content was calculated as per the formula.

$$\text{Starch content (\%)} = \frac{100 \times \alpha \times 100}{(\alpha_D)20^{o} \times L \times E}$$

where α=optical rotation of sample, $(\alpha_D)^{20^\circ}$ = specific rotation of potato starch (=185.9), L= Length of sample tube in dm (= 0.1), E = weight of sample in g.

Susceptibility of starch to in vitro enzyme hydrolysis/ in vitro digestibility of various rice products: Susceptibility of starch by *in vitro* enzyme hydrolysis was estimated in uncooked samples as per Casiraghi et al. (1993) method.

Statistical analysis: All experiments were replicated thrice and standard deviations have been reported. The one way ANOVA test was carried out to ascertain the variation between varieties for the respective attributes monitored.

Results and discussion

Moisture content, EMC and sedimentation volume: The moisture content of raw rice used was ~12%. All parboiled rice samples showed moisture content ranging from 10.3 to 10.8% (Table 1). The puffed rice products (expanded as well as popped) had less moisture content compared to other products due to HTST treatment. Expanded rice had ~ 5.8% moisture content and popped rice ~ 8.7%. This may be due to the absorption of moisture from the surroundings, as it is well known that the pre-gelatinized products absorb moisture because they are highly hygroscopic in nature. Both types of flakes had ~ 9% moisture content.

Parboiled rice had high EMC compared to raw rice and the flaked and the popped products had more EMC than the parboiled products (Table 1). In milled rice being an un-gelatinized grain (raw or uncooked) the absorption of moisture was less, which was indicated by low EMC value. In normal parboiled rice, the endosperm gets cooked inside the husk and this paddy while drying undergoes retrogradation. This made the rice to absorb more moisture, which was indicated by the higher EMC value (Sashikala et al. 2005) During pressure parboiling, because of high pressure of the steam, the degree of gelatinization was very high (Ali and Bhattacharya 1982) (Bhattacharya and Ali 1985) and this paddy on drying, undergoes retrogradation to a greater extent. Hence the absorption of moisture was more which was indicated by higher value of EMC to the extent of 24% higher than normal parboiled and 36% higher than the milled rice.

When the paddy was subjected to dry heat parboiling, the paddy gets the property of parboiled rice. Here also similar phenomenon occurred as in the case of pressure parboiled rice, and the value of EMC was equivalent to that

Table 1 Moisture content, EMC- S and sedimentation volume of raw and processed rice samples

Sample name	Moisture content, (% wb)	Equilibrium moisture content, (%)	Sedimentation volume, (ml)	Starch content, (%)
Raw milled rice	11.9 ± 0.10	27.4 ± 0.29 ^{a}	6.2 ± 0.20 ^{a,b}	84.8 ± 0.10^{a}
Normal parboiled rice	10.8 ± 0.21^{c,d}	38.9 ± 0.29 ^{a}	7.1 ± 0.36^{a}	79.3 ± 0.23^{a}
Pressure parboiled rice	10.3 ± 0.19 ^{a}	63.1 ± 0.21^{c,d}	11.5 ± 0.20^{a}	76.9 ± 0.26^{c,f}
Dry roasted parboiled rice	10.7 ± 0.28 ^{a}	64.1 ± 0.54 ^{a}	14.5 ± 0.30^{a}	81.3 ± 0.23^{a}
Expanded rice	5.8 ± 0.31 ^{a}	77.5 ± 0.37 ^{e,g,h}	17.1 ± 0.42^{a}	77.4 ± 0.26^{e,f}
Popped rice	8.7 ± 0.43 ^{a}	81.0 ± 0.41 ^{a}	18.8 ± 0.28^{a}	76.5 ± 0.43^{a}
Improved edge runner flakes	9.1 ± 0.29 ^{a}	78.3 ± 0.30 ^{g,h}	15.5 ± 0.23 ^{g,h}	82.6 ± 0.20^{g,h}
Roller flaker flakes	9.2 ± 0.29 ^{a}	78.2 ± 0.29 ^{a}	16.1 ± 0.46^{a}	83.0± 0.23^{a}

Means with different superscript s within the same column are not significant ($p > 0.05$) (n=3)

Table 2 Physical properties of rice and parboiled rice

Product	Length , mm	Breadth, mm	Weight of 100 grain, g
Raw milled rice	6.9 ± 0.0 [a,b]	2.1 ± 0.10 [b,c,d]	2.16 ± 0.05 [a]
Normal parboiled rice	6.8 ± 0.10[a]	2.2 ± 0.1 2 [a,c,d]	2.06 ± 0.01 [c, d]
Pressure parboiled rice	7.4 ± 0.10[c, d]	2.2 ± 0.10 [a,b,d]	2.05 ± 0.02 [d]
Dry roasted parboiled rice	7.3 ± 0.10 [a]	2.2 ± 0.10 [a,b,c]	2.04 ± 0.02 [a]

Means with different superscript s within the same column are not significant ($p > 0.05$) (n=3)

of pressure-parboiled rice or higher by only 1% (Table 1). Major difference was in dehydration, which occurred fast in dry heat parboiling compared to pressure parboiling. When this rice was used for the preparation of expanded or popped rice, EMC values of expanded or popped rice further increased by 13 to 16% compared to dry roasted and pressure parboiled rice. An interesting observation is, compared to normal parboiled rice, the EMC increased by almost 50% due to the effect of HTST as well as the porous nature of the puffed products. Even the degree of gelatinization, followed by the retrogradation to different extents was clearly seen by the highest values of EMC, which was ~80% in different types of flaked rice. Therefore, it can be concluded that the type of hydrothermal treatment carried out will have an effect on the gelatinization and in turn on the level of retrogradation and on EMC.

With the increase in severity of parboiling, the sedimentation volume increased (Table 1). Very little difference was observed between raw and parboiled rice, in the sedimentation volume, indicating less gelatinization and less retrogradation in normal parboiled rice. In pressure parboiled rice, the sedimentation volume increased by about 5 ml, indicating higher degree of gelatinization. The sedimentation volume increased further in dry heat parboiled rice compared to parboiled rice, indicating still higher degree of starch gelatinization.

In puffed products, the dry heat parboiled rice was used for preparation, where the sedimentation volume further increased because of cooking followed by fast dehydration by HTST treatment. In different types of flakes, where flakes prepared in edge runner as well as in roller flaker, the sedimentation values were little higher than the dry roasted parboiled rice. Different types of impact forces might be responsible for the higher values of sedimentation volumes.

Degree of milling: The degree of milling for raw milled rice was 5.9%, for normal parboiled rice 6.9% and for dry roasted parboiled rice it was 5.8%. Pressure parboiled rice showed 6.4% as the degree of polish and roller flakes showed 7.1%. Higher the degree of milling more the whiteness was achieved in rice and it is also an indication of nutritional losses in rice. In roller flakes, the degree of milling or degree of polish was high, as it had undergone physical changes during dehulling and polishing as also starch degradation resulted while flaking in the roller (Mujoo and Ali 2000).

Table 3 The effect of sand: rice ratio on expansion ratio of rice samples

Material/Rice to sand ratio	Expansion ratio
Expanded rice	
1:10	7.0 ± 0.50
1:15	7.8 ± 0,25
1:20	7.7 ± 1.10
Popped rice	
1:10	13.7 ± 0.28
1:15	14.1 ± 0.13

Physical properties: Parboiled milled rice was slightly shorter and broader than milled raw rice in case of normal parboiled rice (Table 2), which may be due to steaming and drying process during the preparation. A significant increase in length of the pressure parboiled and dry heat parboiled rice grains compared to the raw milled or normal parboiled rice was noticed. The weight of the processed grains could be correlated to the loss of moisture content from the sample. The decrease in weight is probably due to the grains becoming lighter, because of processing, gelatinization, and retrogradation. Due to parboiling the grain colour became yellowish and more translucent.

Table 3 shows the effect of rice to sand ratio on the expansion of the puffed products. In expanded rice, it can be seen that between 1:15 and 1:20 ratio of rice to sand, much changes in the expansion ratio was not noticed, whereas there was a definite change in the expansion ratio between 1:10 and 1:20. This may be due to the high conductivity of heat from sand to the rice, which is due to high specific heat of the sand. In addition the conductivity increases because of the salt coating given to roasted parboiled rice while tempering the hot rice with saturated salt solution. Similarly, the expansion ratio in the popped rice was almost equal irrespective of the ratio of rice to sand used for popping. The expansion ratio was almost equal in more number of experiments conducted with 1:10 ratio of rice to sand and this was not significantly different from 1:15 ratio. The amount of un-popped grains observed in popped rice was also less. Hence, it can be concluded that 1:15 appears to be an ideal ratio of rice to sand for puffing purpose.

Starch content: Table 1 shows that raw rice contained highest amount of starch. However, it was very low in pressure parboiled, popped and expanded rice products as compared to dry roasted parboiled rice and both types of flakes. The variation in the starch content may be due to the formation of resistant starch during processing. But the products prepared from dry roasted parboiled rice i.e. flaked rice showed higher starch content. One possible explanation could be the methodology adopted for the estimation of the starch. In the polarimetric method, the starch was hydrolyzed by dilute HCl at nearly boiling temperature (98°C) and the proteins were precipitated out by the addition of appropriate salts.

The effect of decreasing starch content was reversed upon flaking, thus making part of the starch again available for estimation. The roller flakes showed more starch content since the polishing process takes place during formation of flakes, this also decreases the ash content, whereas in the edge runner process, there was increase in the ash content because less polishing takes place while processing. In the puffed products, specially in expanded rice, the starch content decreased which could be due to the HTST treatment. But in the popped rice, adhering bran and the resistant starch formed decreased the, starch content. The pressure parboiled rice had lower starch content due to the severe heating and probably due to the formation of resistant starch and also due to starch retrogradation and this was also the case with normal parboiled rice. The dry roasted parboiled rice had higher starch content than others as the retrogradation is prevented or reduced because of quick dehydration. In some cases, total starch could be estimated as starch undergoes thermal degradation (Richter et al. 1968, Casiraghi et al. 1993) which makes the system to undergo hydrolysis easily while hydrolyzing with HCl.

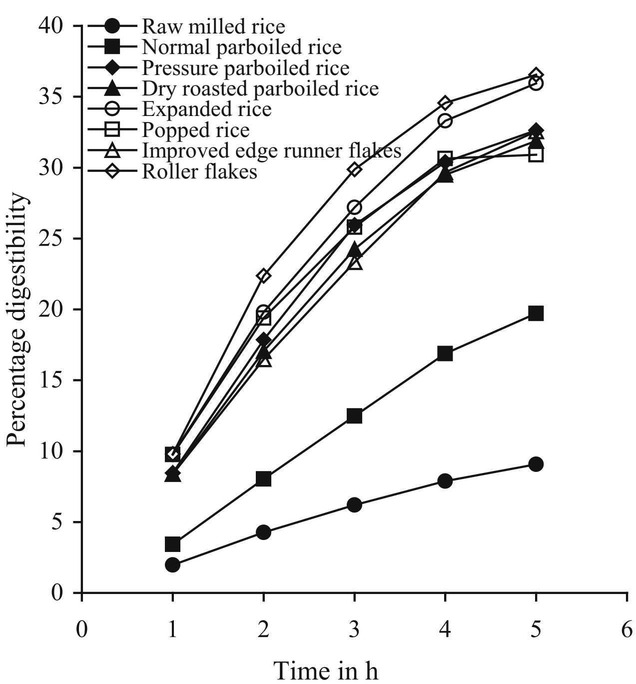

Fig. 1 Starch digestibility for raw and parboiled rice, puffed and flaked rice

In vitro starch digestibility: The digestibility rate was less than 8% in raw and parboiled rice at 1 h (Fig. 1). Maximum digestibility was at 5 h, which was lowest for raw rice than parboiled rice. This may be due to the native structure of the starch which is semi-crystalline in nature. In normal parboiled rice, the digestion was more compared to raw rice. With increase in degree of parboiling, the digestion rate also increased. At 1 h, around 8.5% digestibility took place in pressure parboiled and dry heat parboiled rice. This increase in digestibility could be due to gelatinization followed by retrogradation. The digestion was less in raw rice, increased by 74% in normal parboiled rice, by 334% in pressure parboiled rice and by 327% in dry heat parboiled rice at the end of 1 h. At 5 h, the increase in digestion compared to normal milled rice was 106% in normal parboiled rice, 259% in pressure parboiled rice and 251% in dry heat parboiled rice. Irrespective of type of heat (wet or dry) applied while parboiling, the digestion pattern was almost same. With dry heat treatment the digestion was less compared to wet heat treatment of parboiling.

In puffed products, the initial material used was dry heat parboiled rice. In dry heat parboiled rice the digestion at 1 h was around 8.4%, in expanded rice it was 9.76%, hence the percentage digestibility was ~16% higher than that of dry heat parboiled rice. Almost similar observation was seen in the case of popped rice. In edge runner flakes the digestibility was almost same as in dry heat parboiled rice. However in roller flakes the percentage of digestion was almost equal to that of expanded rice.

At 5 h digestion, expanded rice showed around 13% higher digestion compared to dry heat parboiled rice, indicating the treatment given to parboiled rice i.e salt treatment and expansion in sand, had increased the digestion, or the digestion was less, probably because of resistant starch formation in the expanded rice. In the case of popped rice, the digestion was ~3% less than that of dry heat parboiled rice, which may be due to resistance starch formation in the popped rice. In the case of edge runner flakes, the digestion was 2% higher than that of dry heat parboiled rice. However, in roller flaker flakes, the digestion was more by ~15%. It was observed that among the products studied, roller flaker flakes showed highest digestibility, which may be due to shearing action between the rollers. Reason for lesser digestibility shown by puffed products appears to be due to resistance starch formation.

Conclusion

Paddy variety 'IR – 64' was parboiled by different methods. Dry heat parboiled rice was used for the preparation of various products like expanded, flaked rice and raw paddy was used for preparing popped rice. Moisture contents in pre-gelatinized materials were comparatively less. EMC was high in parboiled rice products because of gelatinization and retrogradation. Sedimentation volume increased with severity of parboiling. Starch content was low in puffed rice products, which may be due to resistant starch formation. *In vitro* digestibility was almost same in pressure as well as dry heat parboiled rice, and in popped rice. Because of shearing mechanism, the *in vitro* digestibility was high for roller flaker flakes. Puffed products showed lesser digestibility, and because of this property they may find use in the preparation of diabetic foods.

Acknowledgement

Authors thank Prakash V, Director, CFTRI, Mysore, India, for his support and encouragement shown in carrying out the above work.

References

Anon (2007) Agricultural statistics. http://faostat.fao.org (8 October)

Ali SZ, Bhattarcharya KR (1982) Studies on pressure parboiling of rice. J Food Sci Technol 19:233–240

Ananthachar TK, Narasimha HV, Shankara R, Gopal MS, Desikachar HSR (1982) Improvement of the traditional process for rice flakes. J Food Sci Technol 19:47–50

Arya SS (1990) Grain based snack and convenience foods. Indian Food Packer 44:17–38

Bhattacharya KR, Ali SZ (1976) A sedimentation test for pre gelatinized rice products. Lebensm Wiss Technol 9:36–37

Bhattacharya KR, Ali SZ (1985) Changes in rice during parboiling and properties of parboiled rice. In: Advances in Cereal Science and Technology, Vol 8, Pomeranz Y (ed), AACC, St. Paul, Minn, p 105–67

Casiraghi MC, Brighenti F, Pellegrini N, Leopardi, Testolin G (1993) Effect of processing on rice starch digestibility evaluated by *in vivo* and *in vitro* methods. J Cereal Sci 17:147–156

Chinnaswamy R, Bhattacharya KR (1986) Pressure parboiled rice-A new base for making expanded rice. J Food Sci Technol 23:1–6

Ekanayaka S, Narasimha H V (1997) Comparative properties of rice flakes prepared using edge runner and roller flaker. J Food Sci Technol 34:291–295

Ghose RLM, Ghatge MB, Subramanyan V (1960) Rice in India. Rev edn, Indian Council of Agricultural Research, New Delhi

Hsieh F, Bor SL (1991) Breakfast rice cereals and baby foods - Rice snack foods. In: Rice utilization, 2nd edn, Bor SL (ed). Van Nostrand Rienhold, New York, Vol 2, p 177-194, 225-249

Holm J, Bjorck, I, Asp NG, Sjoberg LB, Lundquist I (1985) Starch availability *in vitro* and *in vivo* after flaking, steam-cooking and popping of wheat. J Cereal Sci 3:193–206

Indudharaswamy YM, Ali SZ, Bhattacharya KR (1971) Hydration of raw and parboiled rice and paddy at room temperature. J Food Sci Technol 8:20–22

Jorgen H, Barbro H, Inger B, Ann-Charlotte, Ingmar (1987) The effect of various thermal processing on the glycemic response to whole grain wheat in human and rats. J Nutr 119: 1631–1638

Juliano BO, Sakuria J 1985. Miscellaneous rice products. In: Rice chemistry and technology, Juliano BO (ed), AACL, St. Paul, MN

Meera MS, Manisha Guha, Vasudeva Singh 2004. Studies on physico-chemical properties of different degree milled rice. 16th Indian Convention of Food Science and Technology, AFST (I), CFTRI Campus, Mysore, 9–10 December

Mujoo R, Chandrashekar A, Ali SZ (1998) Rice protein aggregation during the flaking process. J Cereal Sci 28: 187–195

Mujoo R, Ali SZ (2000) Changes in physico-chemical and rheological properties of rice during flaking. Int J Food Properties 3:117–135

Murgeshan G, Bhattacharya KR (1986) Studies on puffed rice. I. Effect of processing conditions. J Food Sci Technol 23: 197–202

Narasimha HV (1995) Value addition to food grains through food processing: A CFTRI approach. CFTRI Annual Report, p 68–72

Narayanaswami CK (1956) The rice we eat. All India Khadi and Village Industries Board, Bombay, India

Richter M, Augustat S, Schierbaum F (1968) Polarimetric HCl method for the determination of starch. In :Selected methods in starch chemistry (in German) Wissenshaftliche Verlagsgesellscahft mbH, Stuttguart, Germany, p 72–76

Rosario S, Jayashree A (2000) Effect of domestic processing methods on the starch, non-starch polysaccharide and *in vitro* starch and protein digestibility of three varieties of rice with varying level of amylose. Food Chem 70:107–111

Shashikala IS, Vasudeva Singh, Ali SZ (2005) Changes in physicochemical properties of Basmati paddy upon parboiling. Tr Carbohydr Chem 9:53–59

Vasudeva Singh, Ali SZ (2006) *In vitro* hydrolysis of starches by alpha amylase in Comparison to that by acid. Am Food Technol 1:43–51

Vasudeva Singh, Jayadeep A, Lakshimshree R, Ashwathnarayana KN (2004) Status of micronutrients in different degree milled rice before and after parboiling. 16th Indian Convention of Food Science and Technology, AFST (I), CFTRI Campus, Mysore, 9–10 December