Available online at www.sciencedirect.com

ScienceDirect

Rice Science, 2015, 22(5): 227−236

Soaking Induced Changes in Chemical Composition, Glycemic Index and Starch Characteristics of Basmati Rice

S. J. KALE[1], S. K. JHA[1], G. K. JHA[2], J. P. SINHA[3], S. B. LAL[4]

([1]*Division of Food Science and Post Harvest Technology, Indian Agricultural Research Institute, New Delhi 110012, India;* [2]*Division of Agricultural Economics, Indian Agricultural Research Institute, New Delhi 110012, India;* [3]*Division of Agricultural Engineering, Indian Agricultural Research Institute, New Delhi 110012, India;* [4]*Division of Computer Applications, Indian Agricultural Research Institute, New Delhi 110012, India*)

Abstract: An attempt was made to determine the qualitative changes in basmati rice (Pusa Basmati 1121, PB1121) during soaking at 40 °C to 80 °C. Soaking temperature had significant effect (α = 0.01) on chemical composition, glycemic index and starch characteristics of rice. Starch content, apparent amylose content, crude protein content and crude fat content in un-soaked rice were found to be 73.24%, 27.26%, 8.79% and 2.56%, respectively, but differences in these traits were observed after soaking. Amylose to amylopectin ratio (Am/Ap) decreased from 0.59 to 0.52 (soaked at 80 °C). Crude fibre and crude ash contents increased after soaking. The mineral composition (K, P, S, Ca, Mg, Mn, Fe, Cu and Zn) in soaked rice was found to be 16.46% higher than un-soaked rice at the same degree of polishing. Glycemic index of un-soaked rice was found to be 58.41, but decreased to 54.31 after soaking at 80 °C. Pasting properties, scanning electron microscope images, and X-ray diffractograms suggested partial gelatinization of starch in the temperature range of 60 °C to 80 °C. Based on qualitative changes in rice (apparent amylose content, Am/Ap ratio and crystallinity rate), it was concluded that intermediate soaking temperatures (60 °C to 70 °C) would be useful for soaking of PB1121.

Key words: basmati rice; soaking; glycemic index; starch characteristic; temperature; chemical composition; crystallinity

Rice (*Oryza sativa* L.), providing carbohydrates, proteins, fats, fibres, minerals, vitamins etc. (Juliano, 1993), is considered as one of the major sources of nutrients due to its daily consumption (Heinemann et al, 2005). Rice undergoes different post harvest operations. Among them, parboiling is very common and has been applied to paddy produce in about half of Indian and one fourth of the world (Kar et al, 1999). Parboiling is aimed to induce the milling, nutritional and organoleptic improvements in rice. It is a hydrothermal process in which paddy is soaked in water followed by steaming and drying. Parboiling brings the spectrum of qualitative changes in rice. It affects the physical properties, nutritional composition, starch characteristics (pasting properties and crystallinity), cooking qualities etc. (Otegbayo et al, 2001; Heinemann et al, 2005; Manful et al, 2008; Patindol et al, 2008; Dutta and Mahanta, 2012; Mir and Bosco, 2013). Among three important steps of parboiling, soaking is the most critical step as it changes the gross composition and distribution of nutrients within grains (Otegbayo et al, 2001; Sareepuang et al, 2008; Mir and Bosco, 2013). Soaking is a hydration process in which water diffuses into rice grains, essential for the complete gelatinization of starch. Bhattacharya (1985) reported that 40%–45% moisture content is needed to attain the desired starch gelatinization.

Soaking causes the leaching of rice constituents in the soaking water (Otegbayo et al, 2001; Ibukun, 2008; Sareepuang et al, 2008). Starch is the primary component of rice which plays a vital role as a determinant of rice quality. When subjected to hot soaking, it undergoes gelatinization which alters its physical, chemical,

Received: 10 September 2014; **Accepted:** 23 April 2015

Corresponding author: S. J. KALE (sakha_yogesh@yahoo.co.in)

Peer review under responsibility of China National Rice Research Institute

http://dx.doi.org/10.1016/j.rsci.2015.09.002

nutritional, rheological and viscosity properties (Sareepuang et al, 2008; Mir and Bosco, 2013). Starch content of rice decreases due to leaching of starch granules (Sareepuang et al, 2008). Starch mainly consists of amylose (linear) and amylopectin (branched) molecules. Free and lipid-complexed amylose contents are the most important constituents of rice which decides gelatinization behaviour, pasting properties, cooking qualities, and glycemic index of rice (Juliano, 1985; Larsen et al, 2000; Frei et al, 2003; Lamberts et al, 2009), but soaking decreases the amylose content due to leaching thereby reducing rice quality. Starch crystallinity, an indicator of quality, also changes with severity of soaking as amylose, the major crystalline component, tends to degrade when rice is heat-treated (Manful et al, 2008). Apart from amylose, cooking quality of rice can also be influenced by components such as proteins, fats or amylopectin (Thomas et al, 2013). Proteins and fats are susceptible to hot soaking and their contents decrease (Otegbayo et al, 2001). Similarly, soaking changes fibre, ash and mineral compositions in rice. Minerals in paddy migrate with the soaking water, thereby changing their distribution in rice grains (Heinemann et al, 2005; Ibukun, 2008). Soaking also brings diffusion of color pigments, fat globules etc. from husk and bran layers into starchy endosperm (Otegbayo et al, 2001; Dutta and Mahanta, 2012).

Research on parboiling has mainly focussed on non-basmati rice varieties and information available on basmati varieties is scanty. This is despite the fact that the importance of basmati varieties is increasing enormously in terms of trade. Among the basmati varieties in India, Pusa Basmati 1121 (PB1121) has acquired more popularity. It has significant advantages over other basmati varieties, like shorter maturing period, less demand for water and fertilizer, higher cooked length, etc. (Anand, 2012). Though PB1121 gives better yield (≥ 4 t/hm^2), its milling yield is less due to extra length (≥ 8 mm of milled rice) leading to higher breakage. Such breakage can be reduced by parboiling the rice grain before milling. Parboiling of basmati rice is not desirable due to its adverse effect on aroma but increased head yield with improvement in nutritional content and cooking qualities can compensate such loss. Also, aroma has been found to be less important in case of PB1121 as compared to other traditional basmati varieties (Anand, 2012), which encourages its parboiling. Hence, an attempt was made to determine the effect of soaking conditions on chemical composition, glycemic index and starch characteristics of basmati rice PB1121. Mineral constituents in the rice fractions like husk, bran and polished rice were also estimated.

MATERIALS AND METHODS

Sample preparation

Freshly harvested rice (PB1121) grains were obtained from Indian Agricultural Research Institute, New Delhi, India. Grains were cleaned and screened to get samples of uniform size (length = 12.70 mm, breadth = 2.36 mm and thickness = 1.85 mm). Grains used for the study were at average moisture content of 13.77%. The moisture content of samples was determined in triplicate by oven drying at 103 °C ± 2 °C until a constant weight (AACC, 2000).

Processing of rice grains

Rice grain samples of 200.0 ± 0.5 g were soaked in 500 mL distilled water at seven different temperatures 40 °C, 50 °C, 60 °C, 65 °C, 70 °C, 75 °C and 80 °C in a water bath (MAC, MSW-275, Micro Scientific Works (R), Delhi, India) with temperature control facility having an accuracy of ± 0.5 °C. Each sample was soaked till it achieved equilibrium moisture content, approximately 42% (Kale et al, 2013). The time required for attaining equilibrium moisture content at 40 °C, 50 °C, 60 °C, 65 °C, 70 °C, 75 °C and 80 °C was 810.0, 480.0, 390.0, 345.0, 232.5, 157.5 and 97.5 min, respectively. Soaked grains were then dried in shed under fan until the moisture content being 13.64%, and dehusked subsequently using a rubber roll sheller (Ambala Associates, Ambala, India) to get brown rice. Brown rice was polished using an abrasive polisher (Ambala Associates, Ambala, India) to get polished rice with a degree of milling as 8%. Brown rice and polished rice were used subsequently for further analysis.

Chemical composition of soaked and un-soaked rice grains

Proximate composition and mineral constituents of brown and polished rice were determined according to the standard methods. Starch content was determined by the anthrone reagent method as described by Clegg (1956). Apparent amylose content was determined based on the iodine-binding procedure as suggested by Juliano (1971). Apparent amylose to amylopectin ratio (Am/Ap) was calculated based on starch content and apparent amylose content [Am/Ap = Apparent amylose content / (Starch content – Apparent amylose content)]. Crude protein, crude fat, crude fibre and crude ash contents were determined using the standard methods (AACC, 2000). Crude protein content was calculated from nitrogen content, using the Kjeldahl method (Velp Scientifica, Italy) (Juliano, 1985). Crude fat was measured by extracting the ground rice samples with petroleum ether, using the Soxhlet apparatus (Buchi, Switzerland). Crude fibre was determined by extraction with hot acid and base, using a crude fibre extractor (Velp Scientifica, Italy). Crude ash content was determined by combustion of the sample at 550 °C in a muffle furnace.

Some nutritionally essential minerals (K, P, S, Ca, Mg, Mn, Fe, Cu and Zn) of soaked and un-soaked brown rice as well as polished rice were determined using the di-acid digestion method (Shabbir et al, 2008). P and S were quantified using the colorimetric method with a spectrophotometer (V-670, Jasco, USA), with K using an flame photometer 128 (Systronics India Limited, India), whereas remaining minerals were quantified using an atomic absorption spectrophotometer (AAS4141, Electronics Corporation of India Limited, India). Mineral compositions in polished rice, bran and husk of un-soaked and soaked (at 65 °C) rice were also determined.

Glycemic index (GI) of rice grains

GIs of un-soaked and soaked rice grains were determined using *in vitro* starch digestion method as suggested by Goni et al (1997) and Frei et al (2003). Cooked rice samples were digested for 3 h at incubating temperature 40 °C. Starch digestion was carried out using enzymes, pepsin from porcine gastrine mucosa (ref. 107195, Merck) and α-amylase from porcine pancreas (ref. A-3176, Sigma). During digestion, aliquots (1 mL) were taken from each sample after every 30 min from 0 to 3 h. Subsequently, the total reducing sugar content of aliquots was determined by the 3,5-dinitrosalicylic acid reagent method (Ghose, 1987). Maltose was used to prepare the standard curve. The rate of starch digestion was expressed as the percentage of starch hydrolysed at different time intervals (30, 60, 90, 120 and 180 min). The areas under hydrolysis curves (AUC, 0–180 min) were determined using the equation described by Goni et al (1997). The hydrolysis index (HI) was calculated as the ratio of AUC for a rice sample and a reference sample, white bread, and expressed as a percentage. Expected GI was then estimated using the following model (Frei et al, 2003).

$$GI = 39.71 + (0.549 \times HI)$$

Further, to make the GI values of PB1121 rice comparable with the GIs of different foods, it was converted into the GI based on glucose by multiplying it with 0.7 (Foster-Powell et al, 2002).

Determination of starch characteristics of soaked and un-soaked rice grains

Starch characteristics of soaked and un-soaked rice grains were evaluated in terms of their pasting properties, X-ray diffractograms, starch crystallinity and scanning electron microscopic images.

Pasting properties

A Rapid Visco-Analyser (RVA Starchmaster 2, Newport Scientific Instruments, Australia) was used to evaluate the pasting properties of rice flours (Dutta and Mahanta, 2012; Saikia et al, 2012). Rice flour suspensions of 10% (total weight: 28 g) were prepared and the Rice 1 profile of Newport Scientific instruments was used. The samples were initially held at 50 °C for 1 min, heated from 50 °C to 95 °C in 3.45 min, again held at 95 °C for 2.40 min and then cooled to 50 °C in 4.00 min and finally held at 50 °C for 1.00 min. Subsequently peak viscosity, breakdown viscosity, final viscosity and setback viscosity were observed.

X-ray diffraction analysis

X-ray diffractograms of flours of un-soaked and soaked rice grains were obtained using an Analytical Diffractometer (Pan Analytical, Phillips, Holland). The diffractograms were acquired over a 2θ (Bragg angle) ranging of 4–30° with a step size of 0.02° (Singh et al, 2011). Subsequently, the starch crystallinity (%) was calculated using the following equation as described by Manful et al (2008).

Crystallinity (%) = Total crystalline peak area / Total area of diffraction pattern 4–30° × 100

Microscopic images

Microstructures of soaked and un-soaked rice grains were studied using a scanning electron microscope (Zeiss EVOMA10) at 20 kV and 10 Pa. Dried grains were cut using sharp knife and specimens were mounted on aluminium studs (Li et al, 2008). Samples were coated with 24 nm thick coating of palladium and images were taken.

Statistical analysis

Duncan's multiple range tests were performed to evaluate the statistical differences in chemical properties, mineral composition, glycemic index, pasting properties and crystallinity as affected by soaking treatments. All possible pairs of treatment means were compared at 1% level of significance. SPSS statistical software version 16.0 (SPSS, INC., Chicago, USA) was used to conduct the tests.

RESULTS

Effects of soaking on head rice yield (HRY)

Soaked and un-soaked rice grains were de-husked and polished to get the head rice yield. Table 1 presents the HRY of PB1121 on paddy basis. It is evident that un-soaked rice grains had the lowest HRY (42.87%) but when soaked at temperature ranging from 40 °C–80 °C, HRY increased considerably. The highest HRY was observed at 80 °C. The first group (40 °C–60 °C) had HRY of 55.08%–56.33%; the second group (65 °C–70 °C) had about 59.00% whereas the third group (75 °C–80 °C) had HRY approximately 60.00%. The three groups of temperatures showed almost the same HRY within the group.

Table 1. Head rice yield of soaked and un-soaked rice grains. %

Treatment	Brown rice yield (paddy basis)	Polished rice yield (brown rice basis)	Head rice yield (paddy basis)
Un-soaked	48.64 a	88.14 a	42.87 a
40 °C	62.99 c	88.71 b	55.88 b
50 °C	63.01 c	89.39 c	56.33 b
60 °C	60.99 b	90.31 d	55.08 b
65 °C	63.74 e	92.50 e	58.96 c
70 °C	63.51 d	92.24 f	58.59 c
75 °C	64.35 g	92.99 g	59.84 c
80 °C	64.24 f	93.39 h	59.99 c

Values followed by the same letter in the same column are not significantly different at the 1% level.

Effects of soaking on chemical composition of rice (PB1121)

Starch content of un-soaked brown, un-soaked polished, soaked (at 65 °C) brown and soaked polished rice grains was determined as 73.24%, 74.84%, 68.74% and 71.14%, respectively (Table 2). Amount of starch in other basmati varieties like Bas 370 and HBC19 has been reported as 68.73% and 69.25%, respectively (Yadav et al, 2007). Starch content decreased significantly (by 3.74% to 11.06%) after soaking (Table 2). Apparent amylose content in un-soaked brown, un-soaked polished, soaked (at 65 °C) brown and soaked polished rice was determined as 27.26%, 27.79%, 25.46% and 25.67%, respectively (Table 2). Like starch content, apparent amylose content also decreased (by 6.2% to 13.5%) at different soaking temperatures significantly (Table 2). Am/Ap ratio was evaluated as 0.59 for both un-soaked brown and polished rice, which was significantly higher than the normal starch (reported for wheat, maize, potato and tapioca), which may be due to its high apparent amylose content. In normal starch, this ratio is around 0.25 (van Amelsvoort and Weststrate, 1992). Likewise, for soaked (at 65 °C) polished rice, it was found to be 0.57. Am/Ap ratio decreased to 0.57, 0.56 and 0.52, after soaking at temperatures 70 °C, 75 °C and 80 °C, respectively.

Soaking affected the crude protein content of PB1121 significantly (Table 2). Un-soaked brown and un-soaked polished rice had 8.79% and 7.87% crude protein content, respectively, whereas soaked (at 65 °C) brown and soaked polished rice had crude protein content as 8.31% and 7.22%, respectively. Table 2 shows that crude protein content decreased by 1.59% to 10.92% after soaking at different temperatures. The un-soaked brown and un-soaked polished rice had 2.56% and 0.74% crude fat content, respectively. Similarly, soaked (at 65 °C) brown and soaked polished rice had crude fat content as 2.58% and

Table 2. Proximate composition of un-soaked and soaked rice.

Rice	Treatment	Starch content (%)	Apparent amylose content (%)	Am/Ap	Crude protein content (%)	Crude fat content (%)	Crude fibre content (%)	Crude ash content (%)
Brown rice	Un-soaked	73.24 ± 1.92 de	27.26 ± 1.65 d	0.59 ± 0.03 b	8.79 ± 0.03 f	2.56 ± 0.00 c	1.52 ± 0.02 c	0.80 ± 0.01 d
	40 °C	65.14 ± 1.84 a	23.85 ± 0.01 ab	0.58 ± 0.03 ab	8.65 ± 0.03 ef	2.56 ± 0.01 c	1.51 ± 0.02 c	0.67 ± 0.01 a
	50 °C	66.02 ± 2.35 ab	24.43 ± 0.26 abc	0.59 ± 0.02 b	8.51 ± 0.03 de	2.59 ± 0.01 c	1.54 ± 0.01 cd	0.69 ± 0.03 abc
	60 °C	67.38 ± 0.59 abc	24.86 ± 0.26 abc	0.58 ± 0.02 ab	8.56 ± 0.03 e	2.59 ± 0.04 c	1.59 ± 0.01 de	0.76 ± 0.01 bcd
	65 °C	68.74 ± 2.52 abc	25.46 ± 0.03 c	0.59 ± 0.03 b	8.31 ± 0.02 cd	2.58 ± 0.01 c	1.62 ± 0.03 e	0.78 ± 0.01 cd
	70 °C	70.50 ± 1.10 bcd	25.57 ± 0.48 c	0.57 ± 0.03 ab	8.19 ± 0.02 c	2.56 ± 0.04 c	1.70 ± 0.01 f	0.83 ± 0.02 d
	75 °C	69.86 ± 1.67 bcd	24.95 ± 0.48 bc	0.56 ± 0.01 ab	7.91 ± 0.02 b	2.54 ± 0.01 c	1.74 ± 0.01 fg	0.94 ± 0.07 e
	80 °C	69.14 ± 3.93 abc	23.58 ± 0.24 a	0.52 ± 0.05 a	7.83 ± 0.02 b	2.53 ± 0.01 c	1.78 ± 0.03 g	0.99 ± 0.01 e
Polished rice	Un-soaked	74.84 ± 0.79 e	27.79 ± 0.91 d	0.59 ± 0.02 b	7.87 ± 0.26 b	0.74 ± 0.02 a	0.83 ± 0.05 a	0.64 ± 0.05 a
	65 °C	71.14 ± 0.82 cd	25.67 ± 0.54 c	0.57 ± 0.03 ab	7.22 ± 0.06 a	0.89 ± 0.24 b	0.93 ± 0.05 b	0.68 ± 0.08 ab

Values followed by the same letter in the same column are not significantly different at the 1% level.
Am/Ap, Apparent amylose to amylopectin ratio.

Table 3. Mineral composition of un-soaked and soaked rice (PB1121). mg/kg

Rice	Treatment	P	K	Ca	Mg	Mn	Fe	Zn	Cu	S	Σ
Brown rice	Un-soaked	1 729.0 j	2 048.4 d	32.6 i	568.5 i	5.5 h	94.4 g	431.8 i	1.5 d	345.9 j	4 869.0 j
	40 °C	1 693.1 i	1 862.2 c	27.9 h	551.0 h	2.9 c	91.5 f	310.7 a	1.5 d	322.9 e	4 584.1 i
	50 °C	1 667.7 h	1 862.2 c	26.7 f	513.5 d	5.2 g	88.4 d	401.5 f	1.4 cd	340.4 i	4 545.7 h
	60 °C	1 394.0 c	1 862.2 c	26.0 d	519.3 e	4.2 e	71.7 a	325.9 b	1.4 cd	316.2 b	4 227.6 d
	65 °C	1 457.3 d	1 862.2 c	26.3 e	546.0 g	5.1 fg	91.6 f	430.8 h	1.3 bc	325.6 f	4 358.5 f
	70 °C	1 535.1 f	1 676.0 b	25.6 c	506.4 b	3.6 d	88.3 d	356.1 c	1.8 e	338.4 h	4 210.7 c
	75 °C	1 606.8 g	1 862.2 c	27.2 g	538.7 g	5.0 f	89.9 e	416.7 g	1.1 a	286.4 a	4 459.0 g
	80 °C	1 506.7 e	1 862.2 c	25.6 c	524.0 f	3.6 d	77.8 b	371.3 d	1.1 a	317.5 c	4 355.7 e
Polished rice	Un-soaked	917.4 a	1 303.5 a	16.3 a	509.3 c	1.3 a	71.7 a	386.4 e	1.2 ab	326.3 g	3 185.6 a
	65 °C	1 101.5 b	1 676.0 b	20.9 b	462.7 a	1.7 b	83.8 c	446.9 j	1.5 d	321.6 d	3 709.8 b

Values followed by the same letter in the same column are not significantly different at the 1% level.

0.89%, respectively (Table 2). For brown rice, soaking temperature had no significant effect on crude fat content. Soaking significantly affected crude fibre content and crude ash content in PB1121 (Table 2). Crude fibre content, an important nutritional parameter, of un-soaked brown and un-soaked polished rice was estimated as 1.52% and 0.83%, respectively, whereas soaked (at 65 °C) brown and soaked polished rice had the values of 1.62% and 0.93%, respectively. Crude ash content of un-soaked brown and un-soaked polished rice was found as 0.80% and 0.64%, respectively, and that of soaked (at 65 °C) brown and soaked polished rice was found as 0.78% and 0.68%, respectively.

Study showed that P, K, Mg and S were the major constituents (96.36% of total composition as in case of un-soaked brown rice) of mineral composition of PB1121. Soaking temperature affected the mineral composition of soaked rice (Table 3). With some exceptions, almost all the minerals estimated showed decreasing trend (up to 19.37% in P, 18.18% in K, 21.47% in Ca, 10.92% in Mg, 23.64% in Mn, 24.05% in Fe, 28.01% in Zn, 36.36% in Cu and 17.20% in S) with increase in soaking temperatures. The total estimated mineral was the highest in un-soaked rice (4 869.0 mg/kg) whereas it decreased during soaking at all temperatures. Brown rice after polished had only 3 185.6 mg/kg minerals, whereas after soaked (at 65 °C) and polished, the total mineral content was found to be 3 709.8 mg/kg (16.46% higher). Table 4 presents the amount of mineral constituents in the different rice fractions. Mineral composition of un-soaked rice husk was more (by 41.73%) than that of husk from rice grains soaked at 65 °C.

Effects of soaking on GI of PB1121

GIs of PB1121 was determined using bread and glucose as reference samples. When bread was a reference sample, GIs of un-soaked PB1121 and that soaked at 40 °C, 60 °C and 80 °C were determined as 83.44, 82.80, 78.11 and 77.59, respectively, whereas when glucose was as a reference sample, the values were found to be 58.41, 57.96, 54.67 and 54.31, respectively (Table 5). Soaking at ≥ 60 °C decreased GI of PB1121 making it low GI (≤ 55) food (Table 5). Such decrease in GI with increase in soaking temperature might be attributed to the formation of additional amylose-lipid complexes and partial gelatinization of starch at ≥ 60 °C.

Table 4. Mineral composition in polished rice, bran and husk of un-soaked and soaked (at 65 °C) rice. mg/kg

Rice fraction	Un-soaked rice	Soaked rice
Polished rice	3 185.6 a	3 709.8 b
Bran	12 617.2 c	13 293.5 c
Husk	4 797.7 b	3 385.0 a

Values followed by the same letter in the same column are not significantly different at the 1% level.

Table 5. Estimated glycemic index (GI) of un-soaked and soaked rice samples.

Treatment	GI (bread = 100)	GI (glucose = 100)
Un-soaked	83.44 d	58.41 d
40 °C	82.80 c	57.96 c
60 °C	78.11 b	54.67 b
80 °C	77.59 a	54.31 a

Values followed by the same letter in the same column are not significantly different at the 1% level.

Table 6. Pasting properties of flour slurries from un-soaked and soaked rice (PB1121). cP

Treatment	Peak viscosity	Final viscosity	Breakdown	Setback
Un-soaked	1 302 d	3 995 d	-4 d	2 693 d
40 °C	1 075 c	3 577 c	-7 b	2 502 c
60 °C	677 b	2 309 b	-14 a	1 632 b
80 °C	526 a	1 505 a	-6 c	979 a

Values followed by the same letter in the same column are not significantly different at the 1% level.

Table 7. Comparison between crystallinity of un-soaked and soaked rice.

Sample	Total area	Peak				Total peak	Crystallinity rate (%)
		1	2	3	4		
Un-soaked	2 116.53	62.57	301.01	31.80	207.71	603.09	28.49 d
40 °C	3 225.66	74.34	284.59	32.90	278.21	670.04	20.77 c
60 °C	2 778.37	53.41	210.16	61.34	203.93	528.84	19.03 b
80 °C	2 872.47	55.45	171.94	63.58	113.35	404.32	14.08 a

Values followed by the same letter in the same column are not significantly different at the 1% level.

Effects of soaking on pasting properties of PB1121

Results (Table 6) revealed that un-soaked rice flour had higher values of peak viscosity (1 302 cP), final viscosity (3 995 cP) and setback viscosity (2 693 cP) compared to the soaked rice flours. Increase in soaking temperature from 40 °C to 80 °C decreased the peak viscosity, final viscosity and setback viscosity significantly. In all rice flour samples, breakdown viscosity had negative values.

X-ray diffraction

X-ray diffraction patterns of rice samples soaked at different temperatures showed the typical A-shaped pattern as also reported by Singh et al (2011) and Dutta and Mahanta (2012) for different basmati and non-basmati rice varieties. Both un-soaked and soaked rice showed strong reflections at 2θ = ~15.5°, ~17.3°, ~18.0° and ~23.5°. Also, all the samples showed an additional peak at 2θ = ~20.0°. The crystallinity rate, calculated from X-ray diffraction plots reduced with the severity of soaking treatment (Table 7). It was observed that un-soaked PB1121 starch had 28.49% crystallinity rate whereas the soaked samples at 40 °C, 60 °C and 80 °C had 20.77%, 19.03% and 14.08%, respectively. Manful et al (2008) and Dutta and Mahanta (2012) reported the crystallinity rate of different un-soaked rice (non-basmati) samples as 24.6% (TOX3108) and 27.1% (Bhogali bora). Decrease in crystallinity rate (from 24.6% to 5.5%) with increase in severity of parboiling has also been reported by Manful et al (2008).

Scanning electron microscopy

Fig. 1 showed that un-soaked grain and grain soaked at 40 °C had distinct polyhedral starch granules. No swelling of starch was observed in case of grain soaked at 40 °C. But grains soaked at 60 °C and 80 °C showed swelling of starch granules.

DISCUSSION

It is well documented that parboiling brings numerous changes in rice grains. Soaking, a hydrothermal treatment, during parboiling involves diffusion of water into grains. At the same time, some of the grain constituents leach out to the soaking water. Present study revealed that soaking temperature, one of the most important parameter of parboiling, affected HRY. Increase in soaking temperature was associated with increase in HRY. Such increase in HRY might be attributed to partial gelatinization of starch and thereby increase in grain hardness (Mir and Bosco, 2013).

Soaking induced changes in chemical composition of PB1121

Chemical compositions of any grains are utmost important as it determines grain's nutritional value, storage life, digestibility etc. Soaking had significant effect on chemical compositions of rice grains. There were significant differences in starch content of soaked and un-soaked brown rice and polished rice. Such difference might be due to the loss of other constituents with the bran and outer layers of endosperm during polishing (Juliano, 1971). Soaking treatment decreased the starch content of PB1121. Sareepuang et al (2008) also reported loss in starch content of aromatic rice (KDML105) from 64.52% (un-soaked rice) to 63.88%, 63.58% and 64.13% for rice grains soaked at 40 °C, 50 °C and 60 °C, respectively. Decrease in starch content after soaking might be due to leaching of amylose during heating in water (Singh et al, 2006).

Apparent amylose content of PB1121 was about 27.0%, indicating that this variety is a high amylose variety. Husaini et al (2009) and Singh et al (2011) have also reported the amylose content of the same variety as 29.42%, and 20.9% to 21.9%, respectively. Such variation in amylose content of the same variety might be due to number of factors such as location of the field, planting season, time and rate of nitrogen fertilizer application, solar radiation during grain development, application of herbicides etc. (Otegbayo et al, 2001). In the present study, apparent amylose content decreased after soaking. The decrease was

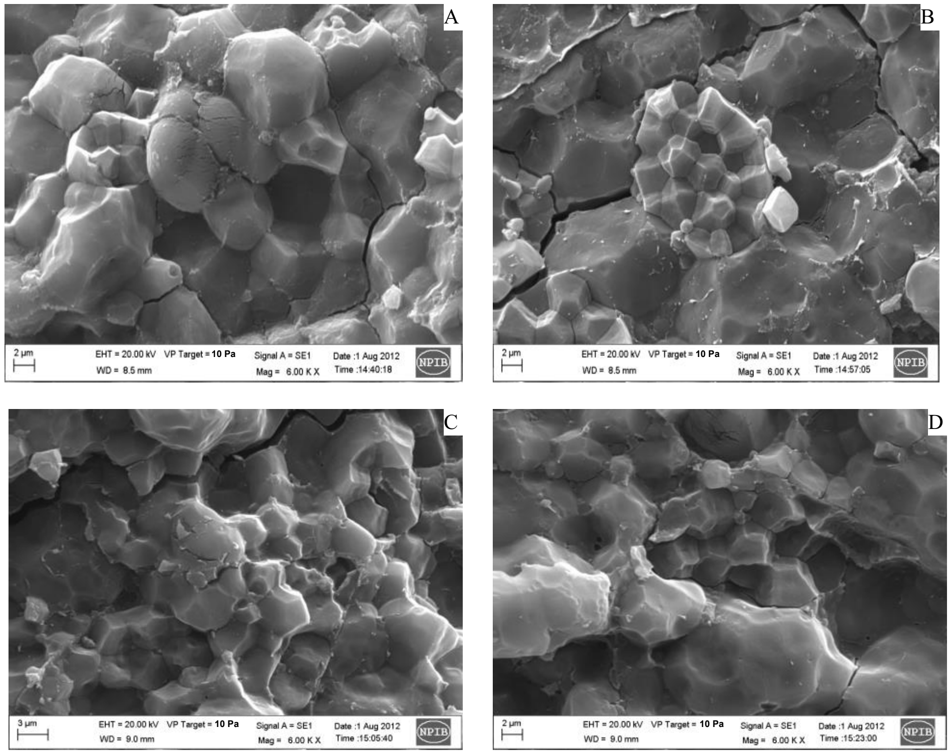

Fig. 1. Structure of transversely fractured un-soaked and soaked rice observed by scanning electron microscopy.
A, Un-soaked rice; B, Soaked at 40 °C; C, Soaked at 60 °C; D, Soaked at 80 °C.

found to be more at extreme soaking temperatures (40 °C, 50 °C, 75 °C and 80 °C) compared to the intermediate temperature range (60 °C to 70 °C). The reduction might be the net effect of soaking time and temperature on leaching and formation of amylose-lipid complexes (Derycke et al, 2005), which was more at extreme soaking conditions. Thus, soaking at intermediate temperatures could be beneficial.

Am/Ap ratio is one of the most important factors affecting the rate and extent of starch digestion and hence the glycemic response of the food (Denardin et al, 2007). van Amelsvoort and Weststrate (1992) reported that postprandial glucose and insulin concentrations depend on Am/Ap ratio of food. Frei et al (2003) have also reported that rice varieties with higher amylose content are associated with lower blood glucose levels and slower emptying of the gastrointestinal tract compared to those with lower levels of amylose content. Hence, Am/Ap ratio is relevant in the formulation of diets for diabetics. The Am/Ap ratio of rice flour also plays an important role in determining different viscosity parameters of rice flour (Dutta and Mahanta, 2014). In the present study, Am/Ap ratio decreased after soaking. This decrease might be due to decrease in apparent amylose content during soaking and formation of amylose-lipid complexes at higher temperatures (Derycke et al, 2005). It may also be observed that the change in Am/Ap ratio was minimal at intermediate temperatures (60 °C–70 °C). Further, even though Am/Ap ratio decreased after soaking, it was still higher than the normal value (0.25) and thus could be considered good for diabetic people.

Crude protein content of PB1121 decreased after soaking. The highest decrease (10.92%) was found at 80 °C, possibly due to leaching of proteins during soaking (Ibukun, 2008). Rao and Juliano (1970) also reported decrease (0.05% to 0.37%) in crude protein content during parboiling, due to the leaching out of non-protein nitrogen and albumin. Similar results have been reported by Otegbayo et al (2001) for non-basmati variety Offada, and Alaso-osun and Heinemann et al (2005) for indica subspecies of rice. It has also been noted that during soaking, the protein bodies sink into the compact starchy endosperm which makes proteins less extractable and thus lowers estimated value (Otegbayo et al, 2001). Unlike crude protein content, a slight reduction in crude fat content occurred at higher temperatures, which might be attributed to leaching and rupturing of the fat globules as also reported by Otegbayo et al (2001). However, Sareepuang et al (2008) reported significant decrease in crude fat content of aromatic rice (KDML105) with increase in soaking temperature up to 60 °C. Difference in crude fat content of brown and polished rice revealed that the maximum amount of fats is located in bran layer. Soaked polished rice had 20.27% higher crude fat content than un-soaked polished rice, indicating the diffusion of fat globules into the starchy endosperm during soaking. Study also revealed that soaked brown and soaked polished rice had higher (1.32%–17.11%) amount of crude fibre content than un-soaked brown and un-soaked polished rice, indicating the higher nutritional value of soaked rice. Like crude fibre content, crude ash content also increased by 3.75%–23.75% after soaking. Increase in temperature caused the increase in both, possibly due to leaching of other constituents of rice. Ash content of un-soaked PB1121 has also been reported by Singh et al (2011) in the range of 0.66%–0.99%.

Changes in mineral composition of PB1121

Mineral composition is one of the most important indicators of nutritional value of food. Decrease in minerals after soaking was observed in the present study, which might be due to leaching loss during soaking. Decreases (up to 13.30% in Ca, 16.66% in Fe, 5.76% in Na and 2.31% in K) in mineral composition of non-basmati rice with increase in severity of parboiling have also been reported by Ibukun (2008). It might be due to leaching of minerals from the husk and bran into the starchy endosperm during soaking process. Rice husk contains large amount of mineral composition. A significant difference between mineral composition of un-soaked rice husk and soaked (at 65 °C) rice husk was observed, which might be attributed to the displacement of minerals from the husk during soaking. Thus, minerals moved in both inward and outward directions during soaking. Minerals leached into the soaking water and also diffused into the endosperm of rice, and therefore, caused the decrease in the mineral content of husk and corresponding increase in that of the bran and polished rice. Polished rice and bran of soaked rice had higher amount of minerals (16.46% and 5.36%, respectively) than that of un-soaked rice, and thus underscored the importance of parboiling of PB1121.

Changes in glycemic index of PB1121

GI is one of the most important quality characteristics of rice. Rice with high GI is not suitable for diabetic people. It is considered that rice with high amylose content has lower GI. GI of basmati rice (Mahatma brand, Sydney, Australia) was reported as 83 and 58 when reference samples were white bread and glucose, respectively (Foster-Powell et al, 2002). The present study revealed that un-soaked PB1121 rice was a medium GI (56–69) food due to its high apparent amylose content (27.26%) and presence of stable amylose-lipid complex as also observed from the X-ray diffractograms. Investigations on the effect of amylose-lipid complexes on the starch digestibility also suggested that amylose-lipid complex II, a type of amylose-lipid complex having melting temperature above 100 °C and well defined crystallites, contributed in the slower degradation of starch during its digestion (Larsen et al, 2000).

Changes in starch characteristics of PB1121

Pasting properties of rice starch represents the quality of starch and can be related with the cooking and textural properties of cooked rice. Rice with lower viscosity values, when cooked, gives non sticky, firmer grain with reduced gruel loss and improved texture (Patindol et al, 2008). Peak viscosity, a rapid increase in viscosity due to swelling of starch granules, indicates the ability of starch granules to swell; setback viscosity indicates the hardness of gel paste upon cooling, which in turn provides the indirect measurement of retrogradation of starches; and breakdown viscosity indicates the ease, with which the swollen granules can be disintegrated (Mir and Bosco, 2013). Decreased peak viscosity (from 1 075 to 526 cP) with increase in soaking temperature was due to decreased swelling ability and water-binding capacity of starch granules, which further indicated the partial gelatinization of starch during soaking at higher temperatures (Soponronnarit et al, 2006; Mir and Bosco, 2013). Similar results were observed for final viscosity, breakdown viscosity and setback viscosity. Decrease in setback viscosity of soaked rice flours after soaking indicated the decrease in their tendency to retrograde upon cooling. Decrease in viscosity with increase in severity of parboiling has also been reported by Patindol et al (2008). Negative values of breakdown viscosity showed that there was no distinct peak viscosity for all the flour samples (Table 6) and viscosity increased with the time. It also indicated the lack of complete pasting and swelling of starch granules (Dutta and Mahanta, 2012).

Amylose is the major crystalline component and crystallinity rate measures the levels of crystalline amylose in rice (Manful et al, 2008). The four peaks exhibited typical crystalline nature of PB1121. An additional peak at 2θ = ~20° showed by all the samples reflected the presence of crystalline amylose-lipid complexes (V_h-type crystallites) in PB1121 (Lamberts et al, 2009; Singh et al, 2011). However, soaked samples showed higher intensity of reflections at 2θ = ~20° than un-soaked sample, which indicated the formation of additional amylose-lipid complexes after soaking and thus reduce in the apparent amylose content. Results also revealed that, though X-ray diffractogram pattern was not disturbed, peak intensity decreased with increase in soaking temperature, indicating the partial gelatinization of starch. The difference in crystallinity of un-soaked and soaked samples might be attributed to the difference in proportions of amylose and amylose-lipid complexes (Singh et al, 2011). Also, the decrease in crystallinity with increase in soaking temperature suggested swelling and partial gelatinization of rice. The study suggested that loss in crystallinity was relatively less at intermediate soaking temperatures.

Scanning electron microscpic images of transversely cut rice grains show an arrangement of starch granuels within the grain. In the present study, starch grauels of soaked (at ≥ 60 °C) rice grains were appeared to be swelled. This swelling was more prominent at 80 °C, which might be attributed to the partial gelatinization of starch.

CONCLUSIONS

Basmati rice (PB1121) was found to be a high amylose variety with high Am/Ap ratio (0.59) and medium GI (58.41), indicating its importance in diets of diabetics. Soaking reduced the apparent amylose content (up to 23.58%) and Am/Ap ratio (up to 11.8%), but their values remained much higher than the normal. Soaking significantly affected the chemical composition, pasting properties and crystallinity rate of PB1121. It caused the reduction in starch content, crude protein content and crude fat content of the grains. In contrast, crude fibre content and crude ash content of rice increased after soaking. All minerals (K, P, S, Ca, Mg, Mn, Fe, Cu and Zn) showed a decreasing trend with increase in soaking temperature. Crude fibre content and mineral composition of polished soaked rice were found higher (by 12.05% and 16.46%, respectively) than those of polished un-soaked rice, underscoring the importance of parboiling of PB1121. Soaking reduced GI of PB1121 at ≥ 60 °C. Soaking reduced the viscosities of starch slurries and starch crystallinity. Pasting properties, scanning electron microscpic images, X-ray diffractograms, and crystallinity rate revealed that partial gelatinization of starch occurred at 60 °C–80 °C. Severity of soaking, either higher temperature-short duration or lower temperature-longer duration caused higher degree of changes in rice quality characteristics (apparent amylose content, Am/Ap ratio, glycemic index and crystallinity rate). It was inferred that intermediate soaking temperatures (60 °C to 70 °C) would be suitable for soaking of PB1121.

ACKNOWLEDGEMENTS

The authors duly acknowledge the financial support and facilities provided by Post Graduate School, Indian Agriculture Research Institute, New Delhi, India, and the Council of Scientific and Industrial Research, New Delhi, India.

REFERENCES

AACC International. 2000. Approved Methods of the American Association of Cereal Chemists. 10th ed. Methods 14-50 and 44-15A. St. Paul, Minnesota, USA: The Association.

Anand R. 2012. Indian basmati rice industry. *In*: Anand R. Horizon Research. New Delhi, India: 1–14.

Bhattacharya K R. 1985. Parboiling of rice. *In*: Juliano B O. Rice Science and Technology. St. Paul, Minnesota, USA: AACC International: 289–348.

Clegg K M. 1956. The application of the anthrone reagent to the estimation of starch in cereals. *J Sci Food Agric*, **7**(1): 40–44.

Denardin C C, Walter M, da Silva L P, Souto G D, Fagundes C A A. 2007. Effect of amylose content of rice varieties on glycemic metabolism and biological responses in rats. *Food Chem*, **105**: 1474–1479.

Derycke V, Vandeputte G E, Vermeylen R, de Man W, Goderis B, Koch M H J, Delcour J A. 2005. Starch gelatinization and amylose-lipid interactions during rice parboiling investigated by temperature resolved wide angle X-ray scattering and differential scanning calorimetry. *J Cereal Sci*, **42**(3): 334–343.

Dutta H, Mahanta C L. 2012. Effect of hydrothermal treatment varying in time and pressure on the properties of the parboiled rices with different amylose content. *Food Res Int*, **49**: 655–663.

Dutta H, Mahanta C L. 2014. Traditional parboiled rice-based products revisited: Current status and future research challenges. *Rice Sci*, **21**(4): 187−200.

Foster-Powell K, Holt S H A, Brand-Miller J C. 2002. International table of glycemic index and glycemic load values: 2002. *Am J*

Clin Nutr, **76**(1): 5–56.

Frei M, Siddhuraju P, Becker K. 2003. Studies on the *in vitro* starch digestibility and the glycemic index of six different indigenous rice cultivars from the Philippines. *Food Chem*, **83**: 395–402.

Ghose T K. 1987. Measurement of cellulase activities. *Pure Appl Chem*, **59**(2): 257–268.

Goni I, Garcia-Alonso A, Saura-Calixto F. 1997. A starch hydrolysis procedure to estimate glycemic index. *Nutr Res*, **17**(3): 427–437.

Heinemann R J B, Fagundes P L, Pinto E A, Penteado M V C, Lanfer-Marquez U M. 2005. Comparative study of nutrient composition of commercial brown, parboiled and milled rice from Brazil. *J Food Comp Anal*, **18**: 287–296.

Husaini A M, Parray G A, Rather A G, Sanghera G S. 2009. Performance of elite basmati rice varieties of subtropical India under temperate valley conditions of Kashmir. *Int Rice Res Note*, (1): 1–3.

Ibukun E O. 2008. Effect of prolonged parboiling duration on proximate composition of rice. *Sci Res Essay*, **3**(7): 323–325.

Juliano B O. 1971. A simplified assay for milled rice amylose. *Cereal Sci Today*, **16**: 334–338.

Juliano B O. 1985. Rice: Chemistry and Technology. 2nd ed. St. Paul, Minnesota, USA: American Association of Cereal Chemists.

Juliano B O. 1993. Rice in Human Nutrition. Rome, Italy: Food and Agriculture Organization: 162.

Kale S J, Jha S K, Jha G K, Samuel D V K. 2013. Evaluation and modelling of water absorption characteristics of paddy. *J Agric Eng*, **50**(3): 29–38.

Kar N, Jain R K, Srivastav P P. 1999. Parboiling of dehusked rice. *J Food Engin*, **39**(1): 17–22.

Lamberts L, Gomand S V, Derycke V, Delcour J A. 2009. Presence of amylose crystallites in parboiled rice. *J Agric Food Chem*, **57**(8): 3210–3216.

Larsen H N, Rasmussen O W, Rasmussen P H, Alstrup K K, Biswas S K, Tetens I, Thilsted S H, Hermansen K. 2000. Glycaemic index of parboiled rice depends on the severity of processing: Study in type 2 diabetic subjects. *Eur J Clin Nutr*, **54**(5): 380–385.

Li X, Huang K, Zhu B Z, Liang Z H, Wei L, Luo Y W. 2008. Comparative physicochemical properties and structure of rice containing the *sck* + *cryIAc* genes and its nontransgenic counterpart. *J Food Sci*, **73**(1): 64–69.

Manful J T, Grimm C C, Gayin J, Coker R D. 2008. Effect of variable parboiling on crystallinity of rice samples. *Cereal Chem*, **85**(l): 92–95.

Mir S A, Bosco S J D. 2013. Effect of soaking temperature on physical and functional properties of parboiled rice cultivars grown in temperate region of India. *Food Nutr Sci*, 4: 282–288.

Otegbayo B O, Osamuel F, Fashakin J B. 2001. Effect of parboiling on physico-chemical qualities of two local rice varieties in Nigeria. *J Food Technol Afr*, **6**(4): 130–132.

Patindol J, Newton J, Wang Y J. 2008. Functional properties as affected by laboratory-scale parboiling of rough rice and brown rice. *J Food Sci*, **73**(8): 370–377.

Rao S N R, Juliano B O. 1970. Effect of parboiling on some physicochemical properties of rice. *J Agric Food Chem*, **18**(2): 289–294.

Saikia S, Dutta H, Saikia D, Mahanta C L. 2012. Quality characterisation and estimation of phytochemicals content and antioxidant capacity of aromatic pigmented and non-pigmented rice varieties. *Food Res Int*, **46**(1): 334–340.

Sareepuang K, Siriamornpun S, Wiset L, Meeso N. 2008. Effect of soaking temperature on physical, chemical and cooking properties of parboiled fragrant rice. *World J Agric Sci*, **4**(4): 409–415.

Shabbir M A, Anjum F M, Zahoor T, Nawaz H. 2008. Mineral and pasting characterization of Indica rice varieties with different milling fractions. *Int J Agric Biol*, **10**(5): 556–560.

Singh N, Kaur L, Sandhu K S, Kaur J, Nishinari K. 2006. Relationships between physicochemical, morphological, thermal, rheological properties of rice starches. *Food Hydrocoll*, **20**: 532–542.

Singh N, Pal N, Mahajan G, Singh S, Shevkani K. 2011. Rice grain and starch properties: Effects of nitrogen fertilizer application. *Carbohydr Polym*, **86**(1): 219–225.

Soponronnarit S, Nathakaranakule A, Jirajindalert A, Taechapaorij C. 2006. Parboiling brown rice using super heated steam fluidization technique. *J Food Engin*, **75**(3): 423–432.

Thomas R, Wan-Nadiah W A, Bhat R. 2013. Physicochemical properties, proximate composition, and cooking qualities of locally grown and imported rice varieties marketed in Penang, Malaysia. *Int Food Res J*, **20**(3): 1345–1351.

van Amelsvoort J M, Weststrate J A. 1992. Amylose-amylopectin ratio in a meal affects postprandial variables in male volunteers. *Am J Clin Nutr*, **55**(3): 712–718.

Yadav R B, Khatkar B S, Yadav B S. 2007. Morphological, physicochemical and cooking properties of some Indian rice (*Oryza sativa* L.) cultivars. *J Agric Technol*, **3**(2): 203–210.