Effects of Storage Temperature on Physical and Chemical Properties of Brown Rice, Parboiled Brown Rice and Parboiled Paddy

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Abstract

Thai brown rice (BR), parboiled brown rice (PB) and parboiled paddy (PP) with Chainat1 variety were stored in polyethylene bag at different temperatures of 4°C, 25°C and 37°C for six months. The effects on the alteration of chemical and physical properties, namely, moisture content, b-value, hardness value, water absorption and morphological properties of starch were investigated every month. The cha[...] e (4°C) storage were retarded. The moisture content and the water abs[...] declining, while the b-value and the hardness were lightly rising. Tempe[...] orage provided significant affects on those properties. For stored rice sam[...] s (25°C and 37°C), the rate of quality change in BR, PB and PP samples [...] es were much more observed in the samples with longer aging. After 6 m[...] ructure changed when storage PB and PP grains at the high storage tempera[...] re unaltered under 4°C storage. These moisture and starch granule structure[...] xture of cooked rice. Short storage at below room temperature is suggested to maintain physical and chemical parboiled rice qualities whenever those parboiled rice is produced from brown rice or rough rice.

Keywords: brown rice, parboiled brown rice, parboiled paddy, physical property, storage rice

Introduction

Thailand is the leading rice exporter, in particular parboiled rice. Major markets mostly are in South Africa, Nigeria and various countries in Asia, Europe, the Mediterranean and the Middle East because of consumer's preference in textural characteristics. However, Japanese and Thai people in some countries prefer non-parboiled rice. Generally, the parboiled rice can be produced through the processes of presoaking, steaming and drying. Hence, parboiling certainly results in the alteration of cooked rice qualities. Not only providing darker yellowness, harder texture and lower cohesiveness, but also specific smell and taste were achieved from cooked parboiled rice (Bhattacharya, 1985; Kimura, 1991). However, parboiled rice requires longer time to cook. Since considerable time and heat energy is needed in parboiled rice production, its investment and price is then higher than non-parboiled rice production. However, the parboiling offers more benefits, such as the strengthening of kernel integrity, increase of milling recovery, the prevention of valuable nutrients loss during milling, the improvement of shelf life and the prevention of fungal and insect proliferation (Bhattacharya and Rao, 1966a, b; Rao and Juliano, 1970, Juliano et al., 1981; Marshall et al., 1993).

Generally, paddy grains have been used as raw materials in parboiling processes. However, it was found that, besides the increase of yellowness, these raw materials could lead to the creation of bad smell during soaking and to the slowness of the heat transfer to the grains because rice husk consists of silica, which results in the difficulty in surface wetting and water penetration into the inner kernel (Bhattacharya and Rao, 1966a, b). Consequently, brown rice has become an attractive alternative to be chosen for parboiled rice production. The brown rice parboiling was noted during the last 20 years (Bhattacharya, 2004). The use of brown rice has several advantages; faster hydration and lower weight and volume offered, which lead to faster parboiling (Soponronnarit et al., 2006) and cheaper processing (Kar et al., 1999). They reported that 40% of energy was saved, while better qualities were provided than parboiled paddy.

The changes during rice storage were attributed to starch-protein interaction (Juliano, 1985; Zhou et al, 2003a) and breakdown of lipids to free fatty acid (Sodhi, et al., 2003). The physical and chemical properties changes then affected rice's texture and appearance as it became harder (Villareal et al., 1976), less sensory preference (Shin et al., 1986; Piggott et al., 1991) and higher yellowness (Barber, 1972). The pasting property is one of the most sensitive indices that can change during storage (Perdon et al., 1997; Sowbhagya and Bhattacharya., 2001; Zhou et al., 2003b). These affected rice cooking and eating quality (Tsugita et al., 1983; Kongseree et al., 1992; Noomhorm et al., 1997; Teo et al., 2000; Zhou et al., 2003a). Even though the changes of parboiled paddy quality during aging have been well known, there is still very the limitation in available information on the alterations of physical and chemical properties of parboiled brown rice, especially in Thai rice varieties. Rice-aging usually results in numerous changes in chemical and physical properties (Villareal et al., 1976; Chrastil 1990a, b; Perdon et al., 1997; Noomhorm et al., 1997; Zhou et al., 2002). However, the changes depend on storage conditions (Sharp and Timme, 1986; Sodhi et al., 2003).

Therefore, the aim of this study was to investigate changes in physical and chemical properties of parboiled brown rice (PB) and parboiled paddy (PP) during 6 months storage at three different conditions of storage temperatures; refrigerator condition (4±1°C), room condition (25±2°C) and warehouse condition (37±1°C). The changing parameters were moisture content, color (b-value), morphology of starch, water absorption, and hardness. They were compared with those of brown rice (BR).

Materials and Methods

Preparation of Rice Samples

Long grain rough rice variety (Chainat1) with 37.20% amylose content was purchased from Sisaket province, Thailand. The amylose content was an indicator for confirming the rice variety. The analysis of amylose in the rough rice samples was done by following the method of Juliano (1971). The rough rice samples were dried at 45°C to reduce the moisture content till was 12±1%w.b. All samples were stored in a refrigerator (4±1°C) until use. Brown rice (BR) samples were prepared by shelling the husk through a rubber roll sheller (Model THU 35A, Japan). Shelled samples were then graded by a Satake grader (Model TRG05B, Japan) to separate the broken kernels. In the preparation of parboiled brown rice (PB) samples, an approximately 4 kg of BR was soaked in hot water, at initial temperature at 80°C for 4 h. The soaked BR samples were held at an ambient temperature for 1 h and then continuously steamed at 100°C (~1 kg cm^{-2}) for 20 min in an autoclave (Model SA-300VL, Taiwan). Afterward, all moist PB samples were shade dried under room temperature (25±2°C and 60±5%RH) until the final moisture content reached approximately 12±1%w.b. (~2 days). Parboiled paddy (PP) samples were derived from parboiling of the rough rice samples. About 4 kg of rough rice was soaked in a water bath at 65±0.1°C for 6 h and then steamed at 100°C (~1 kg cm^{-2}) for 20 min in an autoclave (Model SA-300VL, Taiwan). The sample was shade dried through using the same conditions of PB shade drying. After shade drying, all PB and

PP samples were kept in airtight polyethylene bags and stored at room temperature (25±2°C and 60±5%RH) for two weeks to reach an equilibration of moisture content as well as hardness stabilization.

Storage Conditions

An approximately 500 g of each BR, PB and PP sample was kept in a sealed polyethylene bag. All sealed samples were placed in polyethylene buckets for storage at three conditions of temperature, namely, refrigerator (4±1°C), room condition (25±2°C) and ware house condition (37±1°C). All samples were stored in the dark without a humidity control. During storage, some samples were selected and analyzed physical and chemical parameters every month throughout six months. The physical and chemical properties were collected and analyzed for whole rice grains and flour. The experimental design of the study is shown in Figure 1.

Measurement of Chemical Parameter

The moisture content of the whole-grains BR, PB and PP samples was determined using the method of Mathew (1962). The test was done in triplicate.

Measurement of Physical Parameters

Dehusking of PP samples was conducted in a robber roll sheller (Model THU 35A, Japan). After that, polished rice grain (PB and PP) were prepared with a rice-polished machine (Satake Co., Model TM05, Japan) to remove the rice bran before used for determining all the parameters. While BR samples were used in whole grain to estimate changed in parameters with different durations. The color of BR, PB and PP samples was measured in triplicate by a Color Difference Meter (Model JC801, Tokyo, Japan) with whole-grains. Only the averaged yellowness (b-value) was considered to describe the color changes. The illumination source was provided with standard illuminant D65, and standard observer of 2°. The color meter was calibrated with a standard white plate having L*, a* and b* values of 98.11, -0.11 and -0.08, respectively, prior testing.

The changes in the morphological properties of starch were observed by using a Scanning Electron Microscope (SEM) Machine (Hitachi, Model S-2500). The BR, PB and PP kernel was manually broken along its cross-sectional axis, and was put on a bronze cylinder with glue. Afterward, it was coated with platinum-Palladium (Pt-Pd) by a spoutter-coater (Hitachi, Model; E-102, Japan) to prevent moisture loss during taking a picture. The magnification of microscope was 2000 times at the kernel surface (endosperm tissue) with an accelerator potential 15kV.

Cooked rice samples deriving from BR, PB and PP rice were prepared for testing of water absorption and hardness. The optimal cooking time for each type of rice samples was achieved following the method of translucent kernels evaluation that was suggested by Juliano (1982). Cooking time was determined in both conditions in water bath and cooker. The method of Sabularse et al. (1991) with modifications was used to determine water absorption in triplicate. Two grams of each milled rice sample was added 20 ml distilled water in test tube, which was then covered with a cotton plug. Afterward, the tube was heated at 97-99°C in covered thermostatically controlled water bath. The chosen optimal cooking time was 52, 31 and 37 min for milled BR, PB and PP samples, respectively. After all samples were cooked, their temperatures were reduced by cooling in cold water. Excess water was drained out and test tube was kept upside down for 1 h and carefully weighted. Water absorption was calculated based on increase in weight and expressed as gram of water per gram of rice (g water g^{-1} rice).

Hardness of cooked rice was measured with back extrusion test after cooking rice by the calculated water method of Juliano (1985) and Banjong (1986) using Texture Analyzer LLOYD model LRX plus. The back extrusion test proposed by Reyes and Jindal (1990) with a load cell of 500 N and 50 mm min^{-1} compression rate was used. Probe a stainless steel cylinder of 1.55 cm^2 cross-sectional areas, 15.5 mm inner diameter and 49.10 mm in length, with a spherical-shaped stainless steel plunger of 12.4 mm diameter was used for testing. A 25 g milled rice with 45 g distilled water in a 100 ml beaker was cooked by a cooker containing 400 ml water in the outer pot for 42, 29 and 26 min for BR, PB and PP samples, respectively. Cooked rice sample of 4 gram was selected and placed centrally into the test cylinder. The plunger was allowed to move down until it remained 1 mm above the cell base and then returned back. The hardness of cooked rice was determined from the maximum extrusion in term of Newton (N).
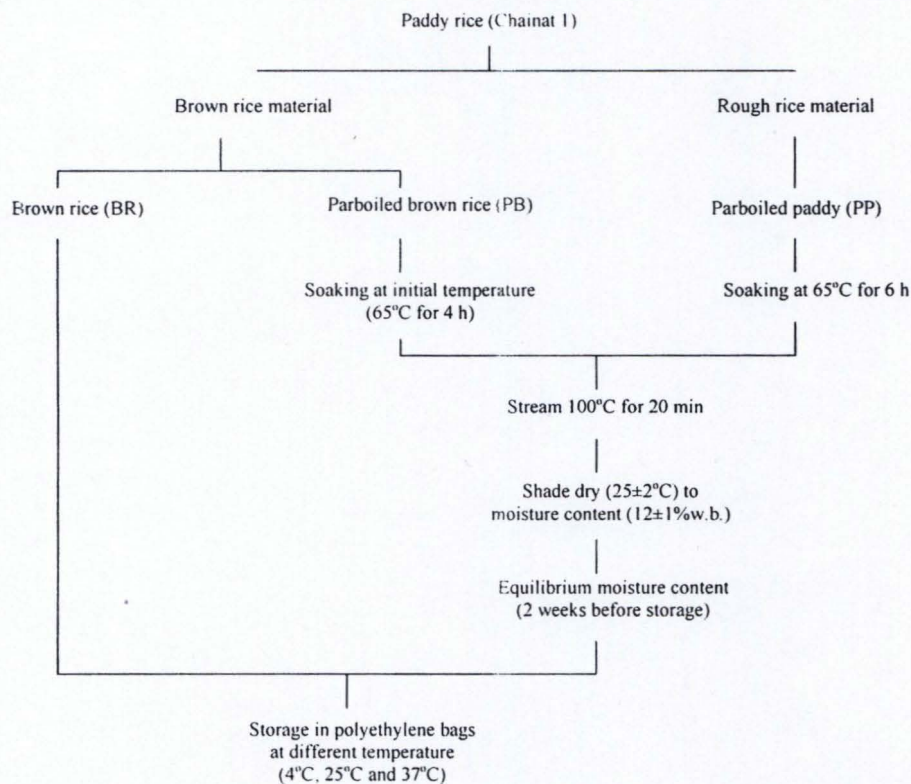
Paddy rice (Chainat 1)

Brown rice material   Rough rice material

Brown rice (BR)   Parboiled brown rice (PB)   Parboiled paddy (PP)

                         Soaking at initial temperature   Soaking at 65°C for 6 h
                         (65°C for 4 h)

                         Stream 100°C for 20 min

                         Shade dry (25±2°C) to
                         moisture content (12±1%w.b.)

                         Equilibrium moisture content
                         (2 weeks before storage)

Storage in polyethylene bags
at different temperature
(4°C, 25°C and 37°C)

Figure 1 Flowchart for sample preparation brown rice (BR), parboiled brown rice (PB) and parboiled paddy (PP) storage at different temperatures 4, 25 and 37°C for 6 months.

Statistical Analysis

The data were analyzed by using the SPSS (Statistical Analysis System Software) version-11. One-way analysis of variance (ANOVA) and Duncan's Multiple Range test at 95% confidence level was applied to evaluate the significance of the changes in different quality attributes during a 6 month storage period.

Results and Discussion

Moisture Content

Moisture in BR, PB and PP samples were almost unchanged during storage at low temperature (4°C) for 6 months (Figure 2). However, the moisture content of rice stored at 25°C significantly decreased after 1 month for BR samples, 3 months for PB samples and 4 months for PP samples. A gradual declination of moisture content was observed after storage at 25°C for 6 months, which was similar to the results of Zia-Ur-Rehaman (2006). The rapid reduction of moisture content was found in the 25°C for PP samples after 4 months whereas the 25°C for BR and 25°C for PB samples had a moisture loss with slower rate. As storage at 37°C, significant moisture losses could be occurred during 1 month, 2 months and 3 months for BR, PB and PP samples, respectively. Moreover, the moisture content rapidly decreased when the BR, PB and PP samples were stored for 4 month, 5 months and 3 months, respectively. The changes in the moisture content during storage could cause in the alteration of other properties resulting in poorer quality. To avoid the moisture loss, storage in polyethylene bag at low temperature (4°C) within short periods for 1-3 months is therefore suggested.

Rice Grain Color (b-value)

The color of whole grain deriving from the PB, and PP samples changed from light yellowish to darker yellowish during 6-months storage as the b-
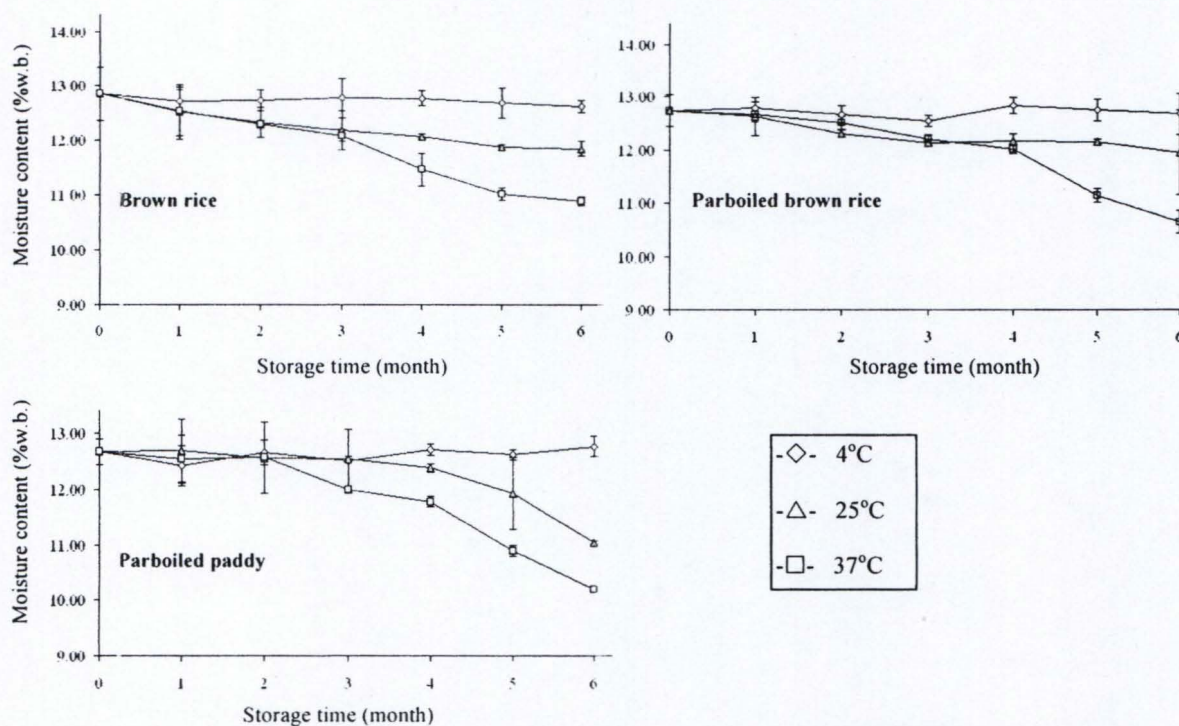
Figure 2 Change in moisture content of brown rice, parboiled brown rice and parboiled paddy during storage at different temperature for 6 months.

value were slightly increased especially at high temperature (37°C). This change was also observed in BR grains. The b-value of BR grains was 18.18±0.69 at the initial storage and then significantly increased (21.52±0.23; P<0.05) with slow rate after 3 months where the storage temperature was 4°C. Till the end of storage, the b-values were slightly changed as they were in range of 21-22 (Table 1). These trends of changes were also presented in the samples stored at 25°C, which has the similarity with the study of Barber (1972). However, high storage temperature (37°C) made the highest change in yellowish as the b-value raised about 46% whereas the storage at 4°C and 25°C provided only 25% and 37% escalation, respectively, after 6 months.

The initial b-value of the PB grains had the lowest value for 13.99±0.11 as compared with the BR and PP grains. The degree of color change during parboiling is affected by different processing parameters, such as the temperature and time of soaking and heating, and the drying temperature (Bhattacharya, 1966a, b; Pillaiyar and Mohandas,

1981). Moreover, husk and bran pigments can contribute to parboiled rice color. These resulted in darker yellowish in the PP grains than PB grains. During storage, the b-values of the PB grains rapidly increased with significant difference (P<0.05) at first two months of storage at 4°C. However, the b-values were continuously constant (P>0.05) throughout the four months left. This trend also occurred in the PB grains storage at 25°C, but their b-values were higher than that of grains stored at 4°C for over 6 months. Storage at 37°C caused the significant increase of b-values (P<0.05) in every month testing. The highest value showed at 6 months of storage (22.38±0.23), which increased 60% from the initial. As storage at lower temperatures (4°C and 25°C), total increasing percentages were approximately 35%. The changes in b-values of the PP samples could be explained that, with all three conditions of storage temperature, the b-value slightly increased throughout 6 months. Storage at 37°C provided the highest increase in b-value (79%) whereas smaller increases (39% and 49%) were found in the

Table 1 Changes in grain color (b-value) of brown rice (BR), parboiled brown rice (PB) and parboiled paddy (PP) following storage for 6 months at 4°C, 25°C and 37°C.

Treatment		Color (b-value)						
		Storage time (month)						
Sample	Temp. °C	0	1	2	3	4	5	6
BR	4	18.18±0.69[a]	19.04±0.51[a]	20.57±0.43[a]	21.52±0.23[a]	21.53±0.53[a]	22.56±0.19[a]	22.83±0.33[a]
	25	18.18±0.69[a]	19.40±0.47[a]	21.49±0.29[b]	22.63±0.61[b]	22.87±0.29[b]	24.28±0.29[b]	25.05±0.49[b]
	37	18.18±0.69[a]	19.24±0.08[a]	23.31±0.14[c]	24.32±0.39[c]	25.52±0.54[c]	25.11+0.25[c]	26.54±0.63[c]
	F-test	ns	ns	*	*	*	*	*
PB	4	13.99±0.11[a]	14.39±0.34[a]	18.34±0.43[a]	18.42±0.72[a]	18.68±0.18[a]	18.29±0.82[a]	18.76±0.55[a]
	25	13.99±0.11[a]	14.23±0.34[a]	18.38±0.47[a]	18.46±0.45[a]	18.61±0.27[a]	18.87±0.24[a]	19.34±0.57[a]
	37	13.99±0.11[a]	14.59±0.28[a]	19.37±0.48[b]	20.27±0.19[b]	21.65±0.17[b]	22.27±0.18[b]	22.38±0.23[b]
	F-test	ns	ns	*	*	*	*	*
PP	4	17.09±0.09[a]	17.40±0.41[a]	22.30±0.07[a]	21.93±0.69[a]	21.61±0.33[a]	22.64+0.35[a]	23.77±0.06[a]
	25	17.09±0.09[a]	17.62±0.49[a]	21.87±0.35[a]	22.57±0.80[a]	21.86±0.28[a]	23.37±0.86[a]	25.58±0.36[b]
	37	17.09±0.09[a]	18.47±0.30[b]	23.46±0.46[b]	25.29±0.22[b]	25.93±0.08[b]	29.31±0.22[b]	30.65±0.16[c]
	F-test	ns	*	*	*	*	*	*

Values are expressed as mean of three determinations. ns = non significant, * significant at P<0.05 probability level. In a column, means followed by the same letter are not significantly different at P<0.05 by Duncan multiple range test.

samples stored at 4°C and 25°C, respectively. The changes in color (b-value) during rice storage could be observed because of Maillard reaction (Villamiel et al., 2006). This reaction usually depends on the temperature, which were in line with the results in this study that the samples stored at 37°C had higher b-value than at 25°C and 4°C, respectively. Thus, not only storage duration influences on b-value, but also storage temperature. Moreover, this study recommended that parboiled rice even if it is produced either from brown rice or rough rice should be stored at low temperature (4°C and 25°C) within short periods (0-2 months) to prevent color change.

Morphological Property of Starch

After BR, PB and PP samples were stored at various temperatures of 4°C, 25°C, and 37°C for 6 months, the cross section of those rice grains were observed to study the changes on morphological property of starch through using -SEM. The changes during storage were compared with the morphology of unstored grains. The observation confirmed that parboiling resulted in the gelatinization of starch wherever the brown rice or rough rice was used in the process. Without storage, the polygonal starch granules and spherical protein bodies of milled BR grain were obviously perceived (Figure 3). The void spaces among the granules generally are filled with air and moisture. The gelatinization of starch and the disintegration of protein bodies in the endosperm (Rao and Juliano, 1970) through hydrothermal process of parboiling made the adjacent fusion of starch granules and leaded to the filling of the internal air spaces (Figures 4 and 5). Thus, the cracks and fissures in endosperm, which usually result in the breakages during milling, were sealed. Moreover, stronger cohesion between proteins and starches was created. The differences in morphological properties were notable in parboiled brown rice and parboiled paddy. Higher temperature of soaking and the absence of husk were important different parameters of brown rice parboiling process. As a result, brown rice parboiling generated grater morphological change in gelatinization and protein breakdown. There was no void space in the PB grain (Figure 4) whereas some void spaces and starch granules presented in the PP grain (Figure 5).

As storage at low temperature (4°C) for six months, the starch granules of the BR grain did not change in structure and other properties (Figure 3) whereas creaks were produced in the stored PB grain (Figure 4). The creaks were also found in the
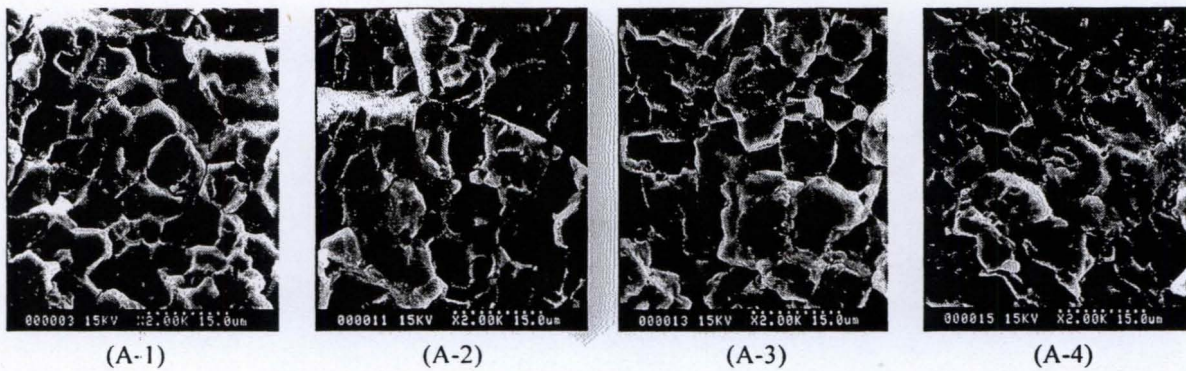
Figure 3 Scanning electron micrographs of brown rice at different temperature storage for 6 months (A-1): Brown rice at 0 month, (A-2): Brown rice at 6 month (4°C), (A-3): Brown rice at 6 month (25°C), (A-4): Brown rice at 6 month (37°C).
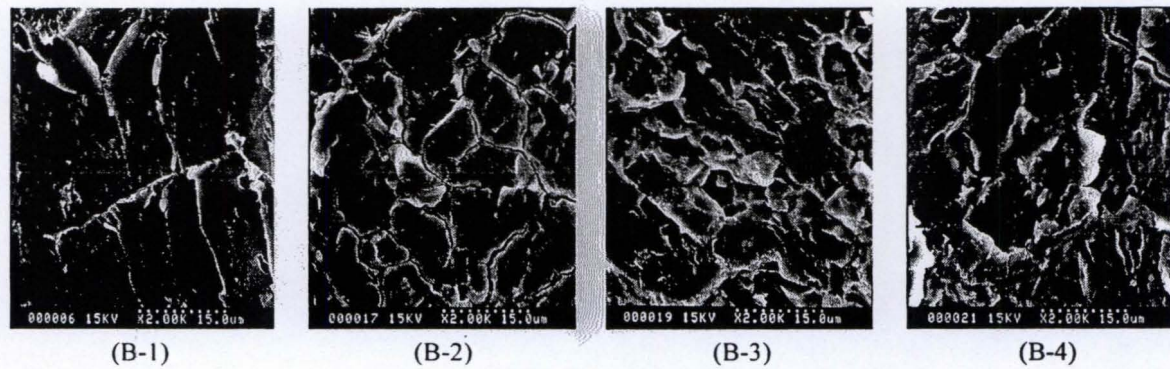

Figure 4 Scanning electron micrographs of parboiled brown rice at different temperature storage for 6 months (B-1): Parboiled brown rice at 0 month, (B-2): Parboiled brown rice at 6 month (4°C). (B-3): Parboiled brown rice at 6 month (25°C), (B-4): Parboiled brown rice at 6 month (37°C).
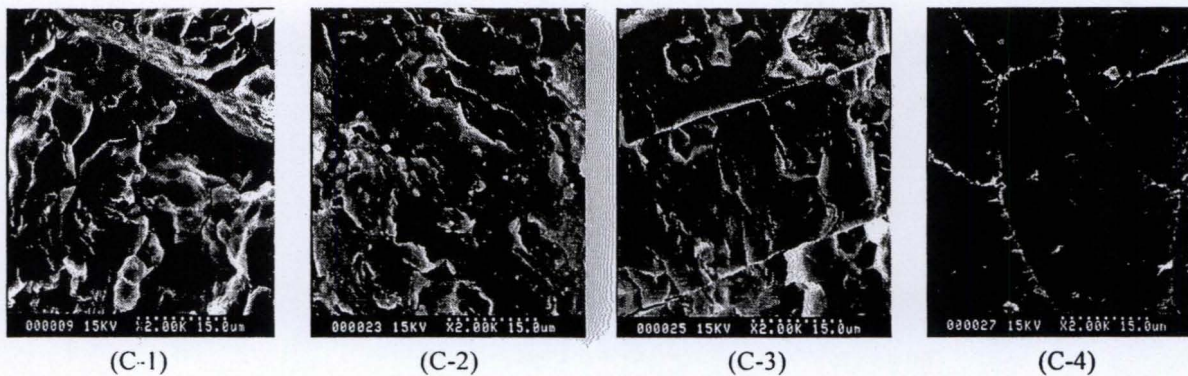

Figure 5 Scanning electron micrographs of parboiled paddy at different temperature storage for 6 months (C-1): Parboiled paddy at 0 month, (C-2): Parboiled paddy at 6 month (4°C), (C-3): Parboiled paddy at 6 month (25°C), (C-4): Parboiled paddy at 6 month (37°C).

stored PP grain. Moreover, more homogenous interior was found (Figure 5). At room temperature (25°C), some parts of starch granules in the BR grain were changed, but some parts still remained the polygonal shape (Figure 3). This change was the creaks occurring among starch granules, which certainly weakened the rice mechanical strength. The structure of endosperm tissue of the stored PB

grain was slightly damaged (Figure 4) because of the temperature and the re-association of starch granules. In general, the thermal stress and the shrinkage affected on the network structures between starch granules and protein (Dong et al., 2007). Since slight reduction of moisture content from 12.68% to 11.05% was detected in the stored PP grains, the creak and the shrinkage of gel matrix were then found (Figure 5). At 37°C of storage, almost of starch granules in the BR grain were completely changed in form by clustering that to creating the homogenous matrix and declining of the polygonal boundaries (Figure 3). The starch morphology of the stored PB and PP grains at 37°C show larger changes in creak creation than at 25°C because of higher temperature gradient. Moreover, the endosperm tissue could be subjected to torsion, compression and tension under the function of thermal stress, which leaded to the weakening of cell wall and the changes in starch structure (Dong et al., 2007). In addition, the moisture content of the stored PB grain decreased from 12.73% to 10.64%. The creaks could be then increasingly influenced by the moisture loss. This phenomenon showed higher effect on the PP grains than the PB grains because greater loss in moisture content was detected (from 12.68% to 10. 20%). Higher thermal stress and higher shrinkage extension could influence on the net work structure, which resulted in higher degree of syneresis and stronger gel matrix as presented in Figure 5 (Dong et al., 2007). Therefore, long time storage at high temperature (more than room temperature) can accelerate the rate of change in morphological properties, which can affect on the physical, cooking and eating qualities of BR, PB and PP grains.

Water Absorption of Cooked Rice Grains

Water absorption is an important parameter describing cooking qualities because it presents the capability of rice kernels to absorb water during cooking. Thus, hard or soft characteristic of cooked rice can be predicted. In every month testing during storage, water absorption values of cooked rice of BR, PB and PP samples stored at 4°C was higher than those stored at 25 and 37°C (Table 2). Moreover, with all storage temperature, the water absorption values significantly decreased (P<0.05) along the 6 months of storage.

The reduction of water absorption of cooked BR grains were not significantly (P>0.05) for the BR grains stored at 4°C for 4 months. This trend was also observed in the storage which done under higher temperatures (25°C and 37°C). The significant difference (P<0.05) in water absorption was induced after storing for 4 months at 4°C and for 5 months at 25°C and 37°C. The lowest water absorption (2.06 g/g) was investigated in the BR samples stored at 37°C. The BR storage at low temperature did not cause a marked change in water absorption. The lower water uptake occurred when increasing in aging duration which corresponded to Sharp and Timme (1986) and Sodhi et al. (2003).

Water absorption of cooked PB grains was 3.16 g g^{-1} at the initial of storage. The value tended to significantly decrease after 6 months of storage at 4°C, 25°C and 37°C. The initial water absorption of cooked PP grains was 3.91 g g^{-1}, which was higher than that of cooked BR and PB grains, respectively. Water absorption of cooked rice deriving from the stored PP grains at 4°C slightly decreased (approximately 13%) with significant difference (P<0.05) after 1 month, and then remained constant for 3 months before continuously declined till the end of storage (6 months). These results were dissimilar to the results of under the storage temperatures of 25°C and 37°C, which the reduction of the water absorption values occurred throughout the storage period. These results could be implied that greater compact in starch structure during storage at high temperature could inhibit water penetration to the center of rice kernels at the same of cooking time, which was similar to the study of Yalendur et al. (1978) who reported that at low temperature storage, the water absorption values remained constant, but the values decreased rapidly after longer storage at high temperature storage (37°C). The causes of the decrease in water absorption could be the rearrangement of starch granules and the combination of starch and other substances in rice bran (Inprasit, 2001).

Hardness of Cooked Rice Grains

The change in hardness of cooked rice is one of the most sensitive indices of the aging rice process because this textural property definitely relates to eating quality. The hardness value of cooked PB samples was lower than that of cooked PP samples

Table 2 Changes in water absorption of brown rice (BR), parboiled brown rice (PB) and parboiled paddy (PP) following storage for 6 months at 4°C, 25°C and 37°C.

Treatment		Water absorption (g water g^{-1} rice)						
		Storage time (month)						
Sample	Temp. °C	0	1	2	3	4	5	6
BR	4	2.83 ± 0.08^a	2.79 ± 0.06^b	2.76 ± 0.09^a	2.65 ± 0.06^a	2.72 ± 0.04^b	2.49 ± 0.08^a	2.32 ± 0.12^b
	25	2.83 ± 0.08^a	2.71 ± 0.02^b	2.74 ± 0.03^a	2.81 ± 0.05^b	2.67 ± 0.06^b	2.55 ± 0.05^a	2.28 ± 0.19^b
	37	2.83 ± 0.08^a	2.61 ± 0.04^a	2.73 ± 0.13^a	2.71 ± 0.03^{ab}	2.51 ± 0.07^a	2.47 ± 0.07^a	2.06 ± 0.00^a
	F-test	ns	*	ns	*	*	ns	*
PB	4	3.16 ± 0.11^a	2.38 ± 0.02^c	2.46 ± 0.19^a	2.42 ± 0.04^b	2.33 ± 0.01^c	2.29 ± 0.03^b	2.09 ± 0.05^b
	25	3.16 ± 0.11^a	2.31 ± 0.02^b	2.28 ± 0.08^a	2.28 ± 0.05^{ab}	2.16 ± 0.03^b	2.11 ± 0.04^a	2.01 ± 0.08^b
	37	3.16 ± 0.11^a	2.26 ± 0.03^a	2.34 ± 0.12^a	2.23 ± 0.13^a	2.08 ± 0.03^a	2.02 ± 0.07^a	1.77 ± 0.03^a
	F-test	ns	*	ns	*	*	*	*
PP	4	3.91 ± 0.05^a	3.40 ± 0.12^a	3.13 ± 0.07^a	3.17 ± 0.12^a	3.26 ± 0.06^c	3.02 ± 0.08^b	2.60 ± 0.03^b
	25	3.91 ± 0.05^a	3.28 ± 0.03^a	3.05 ± 0.06^a	3.05 ± 0.06^a	3.15 ± 0.01^b	2.98 ± 0.04^b	2.54 ± 0.07^b
	37	3.91 ± 0.05^a	3.25 ± 0.04^a	2.90 ± 0.18^a	3.01 ± 0.07^a	2.65 ± 0.05^a	2.49 ± 0.04^a	2.28 ± 0.02^a
	F-test	ns	ns	ns	ns	*	*	*

Values are expressed as mean of three determinations. ns = non significant, * significant at $P<0.05$ probability level. In a column, means followed by the same letter are not significantly different at $P<0.05$ by Duncan multiple range test.

at the initial storage. However, the cooked PB samples were harder than cooked BR samples. These results indicated that using BR grains as raw materials for parboiling process provided softer texture and lower cooking time, which were similar to the research of Kar et al. (1999). In addition, the results revealed that storage leaded to higher hardness in cooked rice derived from BR, PB and PP grains. Moreover, more effect was achieved as the grains were stored at high temperature (37°C). There were significant rapid ($P<0.05$) rapid increases in hardness value after 3 months. The hardness of the cooked BR grains slightly increased ($P>0.05$) from 3 months to 6 months. With the storage of BR, PB and PP grains for 6 months, the highest increase in the hardness of cooked rice was found in the cooked rice deriving from PB grains stored at 37°C (from 34.33 N to 64.61 N) whereas the lowest change from 32.26 N to 49.93 N was occurred in the cooked rice deriving from BR grains stored at 4°C. However, there were no significant differences of the hardness ($P>0.05$) in all storage temperatures (4, 25 and 37°C) during first four months of PB grains storage. When the PB grains were stored for 5 months and 6 months, their cooked rice provided the significant increase ($P<0.05$) in hardness values whenever the grains

were stored at 25°C or 37°C, but no significant difference was observed under the 4°C storage (Table 3). These phenomena were in line with the cooked rice deriving from PP grains stored at the same period. In addition, the changes in hardness were in the opposite site to that in water absorption.

Therefore, the change in hardness of cooked rice samples of the stored BR, PB and PP grains depends on the duration and the temperature of that the storage. Villareal et al. (1976) also reported the effects of these two factors n rice storage. Arai et al., (1993) suggested that the denaturation of proteins was responsible for textural changes in cooked rice that was prepared from stored rice grains. Moreover, the changes in moisture content during storage for 6 months caused the packing of gel matrix, which leaded to lower water absorption and higher hardness of cooked rice (Ohno and Ohisa (2005). The packaging (a polyethylene bag) allowed heat and mass transfer during storage, which created an easier oxidation reaction. Ohno and Ohisa (2005) indicated that hardness increased during rice aging because of the polymerization with intermolecular disulfide linkages in the internal layer through oxidation process. Furthermore, higher storage temperature could induce the organization of rice structure forms

Table 3 Changes in cooked rice hardness of brown rice (BR), parboiled brown rice (PB) and parboiled paddy (PP) following storage for 6 months at 4°C, 25°C and 37°C.

Treatment		Hardness value (N)						
		Storage time (month)						
Sample	Temp. °C	0	1	2	3	4	5	6
BR	4	32.26 ± 3.12^a	40.72 ± 4.31^a	45.03 ± 6.35^a	47.52 ± 5.21^a	50.25 ± 4.46^a	50.31 ± 2.07^a	49.93 ± 1.75^a
	25	32.26 ± 3.12^a	46.12 ± 2.60^b	48.39 ± 3.97^{ab}	52.66 ± 6.02^a	52.53 ± 7.29^a	53.13 ± 2.68^a	48.35 ± 8.19^b
	37	32.26 ± 3.12^a	48.87 ± 4.35^b	53.72 ± 5.33^b	52.57 ± 8.91^a	53.12 ± 4.13^a	54.30 ± 3.73^a	59.76 ± 3.72^c
	F-test	ns	*	*	ns	ns	ns	*
PB	4	34.33 ± 1.07^a	44.34 ± 2.39^a	46.19 ± 4.13^a	48.15 ± 5.26^a	49.99 ± 6.72^a	53.21 ± 2.01^a	56.18 ± 1.95^a
	25	34.33 ± 1.07^a	47.01 ± 4.92^a	49.75 ± 5.74^a	51.21 ± 4.03^a	53.12 ± 6.32^a	54.21 ± 3.58^{ab}	61.09 ± 2.04^{ab}
	37	34.33 ± 1.07^a	50.05 ± 4.59^a	52.68 ± 7.77^a	53.44 ± 2.75^a	55.28 ± 3.85^a	57.20 ± 2.28^b	64.61 ± 5.53^b
	F-test	ns	ns	ns	ns	ns	*	*
PP	4	41.56 ± 1.54^a	47.18 ± 1.04^a	49.36 ± 2.53^a	48.19 ± 1.57^a	51.13 ± 5.08^a	53.81 ± 4.26^a	59.02 ± 3.05^a
	25	41.56 ± 1.54^a	49.11 ± 1.64^a	51.94 ± 3.75^a	51.84 ± 6.05^{ab}	54.96 ± 2.85^{ab}	55.61 ± 0.97^a	60.29 ± 4.53^a
	37	41.56 ± 1.54^a	51.50 ± 1.54^b	54.47 ± 7.69^a	53.97 ± 2.95^b	57.71 ± 4.79^b	58.30 ± 3.77^a	62.06 ± 3.65^a
	F-test	ns	*	ns	*	*	ns	ns

Values are expressed as mean of three determinations. ns = non significant, * significant at P<0.05 probability level. In a column, means followed by the same letter are not significantly different at P<0.05 by Duncan multiple range test.

resulting in the increase of hardness of cooked rice more than lower storage temperature (Zhou et al., 2007).

Conclusions

These results suggested storage of BR, PB and PP samples at different temperatures of 4°C, 25°C and 37°C proved the changes in chemical and physical properties, such as moisture content, b-value, starch morphology, water absorption and hardness. The changes were influenced by storage temperature and storage time. Declining changes were observed for moisture content and water absorption, while increasing changes were of b-value and hardness values. Moisture loss and the alteration in microstructures of starch granule affected the cooking and textural property of brown rice and parboiled rice. Type of rice also influenced the changes in those properties during aging. These results support the storage of BR, PB and PP grains should be done under the low temperature (4°C) and short time to avoid the creation of undesirable phenomena that lead to the achievement of poorer brown rice and parboiled rice qualities.

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