# Changes in physicochemical characteristics of germinated brown rice and brown rice during storage at various temperatures

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**Abstract:** The aim of this study was to investigate changes in physicochemical characteristics of brown rice (BR) and germinated brown rice (GBR) during storage at 4°C (low temperature) and 37°C (high temperature) for up to eight months. The higher storage temperature led to increase in b-value, hardness values and free fatty acid, but a decrease in whiteness index for both BR and GBR. Although the moisture contents of BR and GBR stored at 37°C decreased, adequate moisture content was retained for BR stored at 4°C for eight months. In contrast, the moisture content of GBR stored at the low temperature was found to increase. The γ-aminobutyric acid (GABA) contents in all rice samples decreased following storage at 4°C and 37°C for eight months. The low temperature helped maintain the water absorption and hardness of BR and GBR samples, whereas the higher storage temperature seemed to cause both parameters of the samples to rise. Compared to that of high temperature, low temperature led to a greater increase in free fatty acid with the aging of GBR. Based on the overall acceptability scores, the panelists preferred cooked GBR to cooked BR. Both cooked rice varieties nevertheless received lower scores in all sensory attributes after eight months of storage despite the fact that the cooked GBR received better scores in every sensory attributes. Storage at 37°C prompted the panelists to reject the aged BR due to low overall acceptability scores of less than five after eight months of storage. The study results indicate that short storage time at low temperature maintains the physical and chemical characteristics of brown rice and germinated brown rice.

**Keywords:** Germinated brown rice, Brown rice, GABA, Physicochemical properties

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## 1 Introduction

Rice (*Oryza sativa* L.) is a main staple food and a major source of nutrients of citizens in many parts of the world. Consumers today prefer to consume unpolished rice because of its nutritional excellence and thereby health benefits. Consequently, demand for brown rice is on a constant rise. Although brown rice has an advantage of high nutrients compared to white rice, it has some disadvantages such as slower absorption of liquid into the kernel, because the bran in brown rice contains fiber which leads to prolonged cooking time. Furthermore, oil in the bran shortens its shelf life as the bran becomes rancid. Hence, germinating brown rice is a process found to improve brown rice quality whereby brown rice is soaked in water until it begins to sprout by approximately 0.5 to 1.0 mm. The process is undertaken to increase GABA content and improve the flavor and texture of cooked brown rice (Kayahara et al., 2000).

Proteins and sugars broken down by enzymes produced during the sprouting process give a sweet flavor to the germinated brown rice. The outer bran layer becomes soft, thereby makes the rice easier to cook. In recent years, studies to demonstrate the enhancement of nutrients found in germinated brown rice are increasing (Watanabe et al., 2004; Varanyanond et al., 2005; Sasagawa et al., 2006; Kihara et al., 2007), and the major nutrient that increases is Gamma-aminobutyric acid

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(GABA). During water absorption, glutamate decarboxylase (GAD) in brown rice is activated and it then converts glutamic acid into GABA. Glutamic acid is an amino acid presents as stored proteins in brown rice and is changed into a transportation form of amide (Komatsuzaki et al., 2007). Soaking of brown rice in warm water at 20-40°C was found suitable for enhancing the GABA quantity (Shinmura et al., 2007).

Germinating brown rice can be applied to *indica* rice whose outer layer typically contains some bitter-tasting material; hence, Koa Dawk Mali105 variety is found suitable for germinated brown rice and is believed that its aroma can suppress the bitter taste. Although soaking brown rice under proper conditions could improve the GABA content in germinated brown rice product, literature on the storage conditions affecting germinated brown rice quality remains limited, especially with respect to the GABA content after storage. As such, a better understanding of changes in physicochemical characteristics of germinated brown rice is of great importance and further investigation is thereby recommended to create groundwork for future development of rice-related production technologies.

Changes in the physicochemical properties of germinated brown rice and brown rice induced during storage might be of desirable and undesirable nature, depending upon storage conditions, rice variety, and end user requirements. Storage temperature and duration time are the most influential factors affecting the chemical, physical and functional properties of germinated brown rice. However, evidence of the effects of temperature and storage duration on germinated brown rice quality is yet to be found and no research has been reported thus far. Many researchers reported changes in the physicochemical properties of rice during storage (Noomhorm et al., 1997; Zhou et al., 2002). The pasting properties, one of the most sensitive indices, change during rice storage (Zhou et al., 2003a) and this aging affects the rice cooking and eating qualities (Noomhorm et al., 1997; Teo et al., 2000; Zhou et al., 2003b). In addition, changes during aging have been attributed to starch-protein interaction (Juliano, 1985; Zhou et al., 2003a) and breakdown of lipids to free fatty acid (Navdeep et al., 2003). On the issue of storage, no evidence has been reported on the changes in the physicochemical properties of germinated brown rice during storage.

Although previous studies have proposed the benefits of BR storage, few on the benefits of GBR storage exist. Therefore, an increased number of studies are necessary to provide consumers with more useful information. The main objective of this study is to evaluate the changes in physicochemical properties of germinated brown rice (GBR) stored at two different temperatures of 4°C and 37°C up to eight months. The observed changes in physicochemical properties of GBR are subsequently compared with those of brown rice (BR) stored under the same conditions.

## 2 Materials and methods

### 2.1 Preparation of rice samples

Koa Dawk Mali 105 Thai rice variety was obtained from the Pathum Thani Rice Research Center of Thailand. The rough rice samples were stored in a refrigerator (4±1°C) until use. Brown rice (BR) samples were prepared by shelling the husk using 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 germinated brown rice (GBR) samples, brown rice grains were soaked in water at 40°C for 4 h. Samples of soaked rice grains were removed and packed in filter cloth before putting in plastic boxes with lids. The thickness of the soaked rice grains placed in the boxes was 5±1 cm. The boxes were placed in an incubator at 40°C, 90% RH for 20 h. During incubation, the brown rice samples were washed with clean water every 4 h to prevent fermentation and formation of off flavor. The germinated brown rice (GBR) was put in wire netting (15 cm × 15 cm × 10 cm) and steamed in an autoclave (Model SA-300VL, Taiwan) at 100°C (~1 kg $cm^{-2}$) for 10 min. Afterward, all moist GBR samples were dried at 20±2°C and 60±5% RH until the final moisture content was at approximately 12±1% w.b. After drying, GBR samples were kept in airtight polyethylene bags for two weeks to achieve moisture equilibrium and hardness stabilization prior to storage at controlled temperatures.

## 2.2 Storage conditions

500 g sample each of BR and GBR was retained in a sealed polyethylene bag. Previous studies suggested that storage at 37°C accelerated the aging process, while storage at 4°C retarded the process. Thus, in the present study all sealed samples were placed in polyethylene buckets and stored in the dark at 4°C and 37°C in temperature controlled incubators for eight months. During storage, some samples were selected and analyzed for their physical and chemical parameters every two months throughout eight months. The physical and chemical properties were monitored for whole rice grains and flour.

## 2.3 Measurement of chemical parameters

For the free fatty acid analysis, rice samples (fresh and aging) withdrawn every one month were grounded using ultra centrifugal mill (Model ZM 100, Retsch, Germany) and passed through 100 mesh sieve screen. The obtained rice flour was then dried at 70°C overnight before extraction. The free fatty acid determination method was modified from Zhou et al. (2003c) and AOAC (1995). Approximately 3 g of dried rice flour were wrapped with filter paper, placed in a thimble using an analytical balance, and covered with fat-free cotton. Afterward, thimble was inserted into the thimble holder before going into the beaker, followed with addition of 150 mL petroleum ether and further extracted with soxtherm multistat (Model SX PC, Gerhardt, UK), which completed the automatic extraction process. After circulation of the finite extraction process, the solvent in the flask was evaporated to dryness and the sample was further dried in an oven at 105°C to constant weight. The increased weight after extraction was estimated and expressed in terms of the total lipid of sample as the percentage of the dry rice flour. Free fatty acid was then determined by titration method. Residue in extraction flash was dissolved with 50 mL of 0.04% alcohol-phenolphthalein solution and titrated with 0.0178 N potassium solution (KOH) using phenolphthalein as indicator until a faint pink color persisted for 1 min before calculating the percentage of free fatty acid as oleic acid by Equation (1):

$$Free\ fatty\ acis(\%) = \frac{KOH\ volume(\text{mL}) \times Normality\ of\ KOH(0.0178) \times 2.82}{weight\ of\ sample\ \text{of}\ oil(\text{g})} \quad (1)$$

The analysis of GABA content followed the method of Mustafa et al. (2007). All samples were pulverized by ultra centrifugal mill (Restch, model No. ZM 100, Hann, Germany). The flour samples of approximately 0.2 g were weighed in test tubes with screw caps. The samples were first subjected to alcohol extraction whereby ethanol (50% at 50°C) and internal standard l-norvaline (70 mg $mL^{-1}$ water) were added in volumes of 14 and 1 mL, respectively. The samples were mixed in a rotary mixer at 50°C for 20 min inside an incubator, after which the samples were subjected to centrifugation for 20 min at 1,350 g. An aliquot of 500 μL of the supernatant was subjected to solid phase extraction (SPE) and derivatization steps using the EZFaast technology and kit (Phenomenex, 2001). The extract solution was analyzed by *Gas Chromatograph* (GC).

## 2.4 Measurement of physical parameters

The moisture content of rice samples in the wet basis (w.b.) was determined by drying them in an oven at 105°C to constant weight, according to AOAC (1995). The test was performed in triplicate. The color of whole grain BR and GBR samples was measured in triplicate by a Color Difference Meter (Model JC801, Tokyo, Japan). The color meter was calibrated with a standard white plate with L*, a* and b* values respectively of 98.11, -0.11 and -0.08, prior to testing. Moreover, the whiteness index (WI) was calculated by Equation (2):

$$WI = 100\text{-}[(100\text{-}L^*)^2 + a^{*2} + b^{*2}]^{0.5} \quad (2)$$

Cooked rice samples obtained from BR and GBR were prepared to evaluate water absorption and hardness. The optimal cooking time of each type of the rice samples was achieved following the method of translucent kernels evaluation suggested by Juliano (1982). Cooking time was determined in both conditions of water bath and cooker. The method of Sabularse et al. (1991) with modifications was used to determine water absorption in triplicate. Two grams of rice samples were added with 20 mL distilled water in test tubes which were then covered with a cotton plug. Afterward, the tubes were heated at 97-99°C in temperature controlled, covered water bath. The chosen optimal cooking time was 39 min for all rice samples. After all samples were cooked, their temperatures were reduced by cooling in cold water. The samples were then drained and placed upside down for 1 h. The weight of completely drained cooked rice was then carefully measured. The increase in weight was calculated and reported as grams of water per gram of rice.

Hardness of cooked rice by the calculated water method of Juliano (1985) and Banjong (1986) was measured using back extrusion tests with Texture Analyzer LLOYD model LRX plus. The back extrusion test proposed by Reyes and Jindal (1990) was applied by load cell of 500 N and 50 mm $min^{-1}$ compression rate was used. A stainless steel probe of cylinder shape with 1.55 $cm^2$ cross-sectional area, 15.5 mm inner diameter and 49.10 mm in height, together with a spherical-shaped stainless steel plunger of 12.4 mm diameter, was used for testing. Cooked rice sample of 4 g 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. The average bio-yield point value was expressed as the hardness of rice samples in Newton (N).

For sensory analysis, cooked rice samples were prepared using the calculated water method. The cooked rice samples were retained in a closed container until use, but no longer than 30 min at room temperature. The samples of approximately 5 g were placed in a plastic container, covered with foil lids, and presented to the panelists in random order as whole grains were labeled by codes. Water was provided to clean the palate between the samples. The sensory evaluation was performed by 30 semi-trained panelists. All sensory attributes were assessed using a 9-point hedonic scale (Jellinek, 1985) ranging from 1 = extreme dislike to 9 = extreme like. Each data point from sensory analysis was the mean value of thirty panelists' measurements. The panelists were required to compare their preferences in terms of flavor, appearance, taste, texture and overall acceptability. All data were analyzed with one-way analysis of variance using the Statistical Analysis System Software (SPSS).

### 2.5 Statistical analysis

The data were analyzed using the SPSS of version 11. One-way analysis of variance (ANOVA) and Duncan's Multiple Range test at 95% confidence level were applied to evaluate the significance of the changes in different quality attributes during the 8-month storage period.

## 3 Results and discussion

### 3.1 Moisture content

Table 1 shows the moisture contents of the rice samples up to eight months of storage at two different temperatures. The moisture content of BR sample slightly changed during storage at low temperature (4°C) for eight months, but decreased below 14.85±0.07% (to 11.81±0.19%) after eight months of storage at 37°C, consistent with the results of Park et al. (2012). In contrast, the moisture content of GBR stored at 4°C increased from 12.81±0.30% to 13.10±0.74% after one month. A gradual increase of moisture content was observed after storage at same temperature for eight months, due to the fact that they are in equilibrium with surrounding air temperature and relative humidity. However, the moisture content of 12-13% was found in GBR stored at high temperature (37°C). The changes in the moisture content during storage could cause the alteration of other properties, thereby resulted in poorer quality. To avoid the moisture loss, storage in polyethylene bag at low temperature (below room temperature) within short periods is therefore suggested.

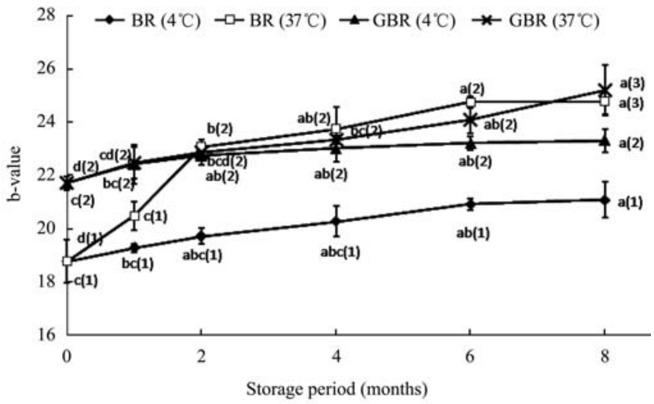
**Table1 Moisture content of brown rice (BR) and germinated brown rice (GBR) at different temperatures for eight months**

| Storage period months | Moisture content/%* | | | |
|---|---|---|---|---|
| | Brown rice | | Germinated brow rice | |
| | Storage temp. /4°C | Storage temp. /37°C | Storage temp. /4°C | Storage temp. /37°C |
| 0 | 14.85±0.07a | 14.85±0.08a | 12.81±0.30c | 12.81±0.31a |
| 1 | 14.88±0.13a | 12.49±0.40b | 13.10±0.74bc | 12.47±0.38a |
| 2 | 14.77±0.17ab | 12.60±0.29b | 13.64±0.32abc | 12.47±0.05a |
| 4 | 14.17±0.61b | 12.28±0.01bc | 13.49±0.14abc | 12.31±0.78a |
| 6 | 14.18±0.37b | 12.10±0.34bc | 14.00±0.35ab | 12.34±0.58a |
| 8 | 14.54±0.37ab | 11.81±0.19c | 14.03±0.71a | 12.09±0.51a |

Note: *Values are expressed as means of three determinants. In any column in which means are followed by identical letter(s), the mean values are insignificantly different at $P$<0.05 by Duncan multiple range test.

### 3.2 Color (b-value) and whiteness index (WI)

The changes in color of whole grains of the BR and GBR samples from light yellowish to darker yellowish during eight months of storage were observed as the b-value slightly increased (Figure 1), especially at the high temperature (37°C). The b-value of BR grains was initially at 18.77±1.29 and slowly increased after four months of storage at 4°C, consistent with the results of Barber (1972). From the fifth month to the end of storage, the b-values rose steadily, but at a slower rate than the first four months and ended in the range of 21.07±0.68. Similar changes were also observed in the GBR samples stored at 4°C, but month-on-month their b-values were higher than those of BR grains. However, after eight months, the high storage temperature (37°C) caused the greater change in color as the b-value of BR samples rose approximately 32%, whereas those stored at 4°C had merely 12% rise in the b-value. Moreover, darker yellowish in the GBR grains was observed from initial (21.70±0.26) to eight months (25.17±0.95) of high storage temperature (37°C). The b-value of GBR stored at 4°C minimally changed (from 21.70±0.26 to 22.73±0.15) after two months and remained relatively constant (23.30±0.44) to the end of storage.

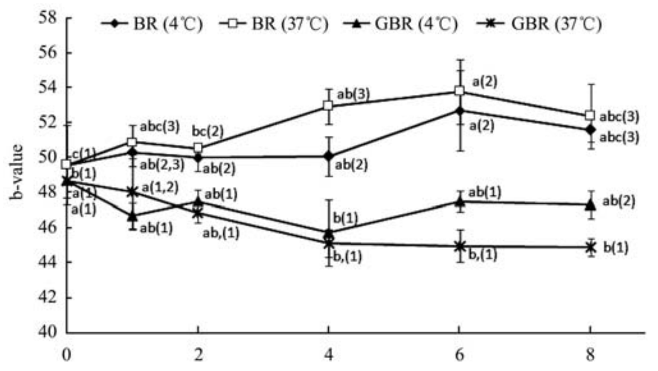



In any month in which the means are followed by the identical number, the mean values are insignificantly different ($p<0.05$) using Duncan's multiple range test.
In any treatment of which the means are followed by the identical number, the mean values are insignificantly different ($p<0.05$) using Duncan's multiple range test.

Figure 1 Changes in b-values of brown rice (BR) and germinated brown rice (GBR) during storage at different temperatures for eight months

Storage time, temperature, and type of rice influenced the degree of color change during storage (Barber, 1972, Sirisoontaralak and Noomhorm, 2007; Park et al., 2012). Moreover, heat treatment of germinated brown rice (GBR) during steaming process can improve yellowness of rice grain. Thus, at the initial stage of storage, GBR samples were typically higher in b-value than BR samples. The changes in color (b-value) during BR and GBR storage could be observed because of Maillard reaction (Villamiel et al., 2006). This reaction usually depends on the temperature, which was in line with the results in this study that the samples stored at 37°C had higher b-value than at 4°C. Nevertheless, b-value is influenced by not only storage temperature, but storage duration as well. As such, this study recommends that rice samples from brown rice and/or germinated brown rice be stored at low temperature (below room temperature) within short periods to prevent color change.

The degrees of whiteness index (WI) of GRB samples stored at 4°C and 37°C decreased as the storage period increased from initial to four months, after which the whiteness index remained constant ($P>0.05$) through the end of the eight-month period. Similar to this experiment, darkening of the GBR sample was accompanied by development of a prominent yellow color (Park et al., 2012). In contrast, the whiteness index values of BR storage at 4°C and 37°C increased during storage (Figure 2). No significant difference was observed in the whiteness index values of BR stored at 4°C for the first four months but the WI values slightly




In any month in which the means are followed by the identical number, the mean values are insignificantly different ($p<0.05$) using Duncan's multiple range test.
In any treatment of which the means are followed by the identical number, the mean values are insignificantly different ($p<0.05$) using Duncan's multiple range test.

Figure 2 Changes in whiteness index (WI) of brown rice (BR) and germinated brown rice (GBR) during storage at different temperatures for eight months increased afterward until the eighth month. A similar trend was detected for BR stored at 37°C during the 8-month storage period. Whiteness has been found to be an important factor affecting the quality of cooked rice and also used as a quality control measurement during milling process. In addition, the starch granules might be rearranged in endosperm during storage, especially in high temperature storage.

### 3.4 Hardness of cooked rice grains

The change in hardness of cooked rice is one of the most sensitive indices of the rice aging process because this textural property definitely relates to eating quality (Zhou et al., 2007). Table 2 shows that the hardness value of cooked GBR samples was lower than that of cooked BR samples at the initial storage. Previous research on germinated brown rice reported that as brown rice undergoes germination, its texture becomes soft to a certain extent owing to the physiological activity of brown rice itself and activities of various enzymes resulting in formation of a rice which is very easy to cook and has soft texture, compared with normal brown rice (Watanabe et al., 2004; Kim et al., 2007).

**Table 2 Changes of hardness and water absorption properties of brown rice and germinated brown rice during storage at different temperatures for eight months**

| properties | Type of rice | Storage temp. /°C | Storage period /Months | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | 0 | 1 | 2 | 4 | 6 | 8 |
| Hardness /N | BR | 4 | 20.39±0.47b$^{(1)}$ | 20.33±0.29b$^{(1)}$ | 22.23±0.34a$^{(2,3)}$ | 22.34±0.73a$^{(1,2)}$ | 22.62±0.60a$^{(1)}$ | 22.59±0.39a$^{(1)}$ |
| | | 37 | 20.39±0.47b$^{(1)}$ | 22.99±1.14a$^{(3)}$ | 23.17±1.03a$^{(1)}$ | 23.46±0.47a$^{(3)}$ | 23.47±0.45a$^{(2)}$ | 23.64±0.40a$^{(2)}$ |
| | GBR | 4 | 19.92±0.22d$^{(1)}$ | 20.17±0.41d$^{(1)}$ | 21.10±0.51c$^{(3)}$ | 21.86±0.91b$^{(1)}$ | 22.60±0.20a$^{(1)}$ | 22.68±0.13a$^{(1)}$ |
| | | 37 | 19.92±0.22c1$^{(1)}$ | 21.43±0.94b$^{(2)}$ | 22.05±0.81b$^{(1,2)}$ | 23.06±0.85a$^{(2,3)}$ | 23.39±0.80a$^{(2)}$ | 23.81±0.37a$^{(2)}$ |
| Water absorption /g water g$^{-1}$ rice | BR | 4 | 2.25±0.04a$^{(1)}$ | 2.21±0.01a$^{(1)}$ | 2.17±0.01a$^{(1)}$ | 2.19±0.05a$^{(1)}$ | 2.21±0.09a$^{(1)}$ | 2.22±0.05a$^{(1)}$ |
| | | 37 | 2.25±0.05c$^{(1)}$ | 2.33±0.05b$^{(2)}$ | 2.38±0.01ab$^{(3)}$ | 2.42±0.06a$^{(3)}$ | 2.41±0.02a$^{(3)}$ | 2.36±0.05ab$^{(2)}$ |
| | GBR | 4 | 2.13±0.10a$^{(1)}$ | 2.17±0.03a$^{(1)}$ | 2.15±0.04a$^{(1)}$ | 2.22±0.05a$^{(1)}$ | 2.23±0.02a$^{(1,2)}$ | 2.27±0.04a$^{(1)}$ |
| | | 37 | 2.13±0.11c$^{(1)}$ | 2.17±0.08bc$^{(1)}$ | 2.27±0.03ab$^{(1,2)}$ | 2.32±0.02a$^{(2)}$ | 2.31±0.04a$^{(2)}$ | 2.29±0.04a$^{(1,2)}$ |

Note: *Mean values ± standard deviation (*n*=3). Different numbers within the same column indicate significant difference ($p$<0.05) using Duncan's multiple range test. Different letters within the same row signify significant difference ($p$<0.05) using Duncan's multiple range test.

In addition, the results revealed that storage led to higher hardness in cooked rice of BR and GBR grains. Greater effect was achieved as the grains were stored at high temperature (37°C) in comparison with storage at lower temperature (4°C), which is similar to the findings of Park et al., (2012). The hardness of the cooked BR grains stored at 4°C slightly decreased ($P$>0.05) from initial to one month, and no significant difference ($P$>0.05) of the hardness values was observed to the end of storage. Meanwhile, the GBR grains stored at the same temperature, once cooked, showed a significant increase ($P$<0.05) in hardness values during storage. With the storage of BR and GBR grains for eight months, the highest increase in the hardness of cooked rice was found in the cooked rice from GBR grains stored at 37°C (from 19.92±0.22 N to 23.81±0.37 N), whereas the lowest change from 20.39±0.47 N to 22.59±0.39 N took place in the cooked rice from BR grains stored at 4°C. Moreover, it could be observed monthly that there was no significant difference in the hardness values ($P$>0.05) for BR and GBR stored at 4°C.

Therefore, the results of this research study indicate that increased storage temperature and duration increased rice hardness, consistent with the work of Perez and Juliano (1981). Ohno and Ohisa (2005) also reported that hardness increases during aging of rice due to polymerization of intermolecular disulfide linkages in the internal layer by oxidation during storage. These observations were in agreement with the work of Arai et al. (1993), who found that the denaturation of proteins was responsible for texture changes in cooked rice prepared from rice that has been stored. Furthermore, higher storage temperature could induce the organization of rice structure forms, resulting in the greater increase in hardness of cooked rice than at lower storage temperature (Zhou et al., 2007).

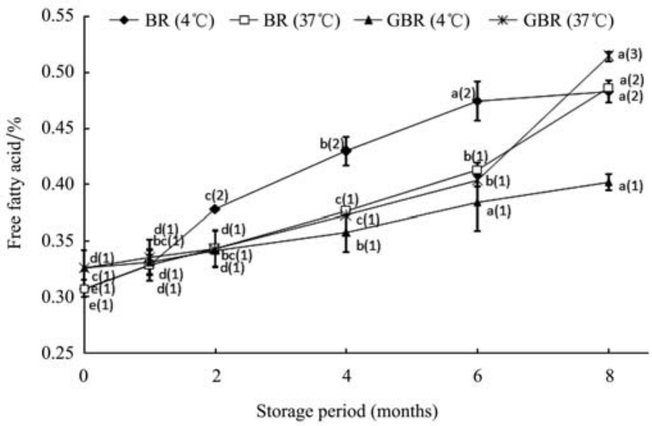
### 3.5 Water absorption of cooked rice grains

Water absorption is an important parameter of cooking quality because it indicates the capability of rice kernels to absorb water during cooking. Thus, hard or soft characteristic of cooked rice can be predicted. Higher temperature storage of BR and GBR resulted in significant decrease in water absorption value ($P$<0.05) compared to lower temperature storage (Table 2). In monthly testing during storage, water absorption values of cooked rice of BR and GBR samples stored at 4°C were lower than those stored at 37°C. This result related to Zhou et al. (2007) proposed that after cooking, rice stored at 4°C leached starch components interact with each other to form a homogeneous paste, in which the moisture is mainly involved in the starch hydration. In contrast, rice stored at 37°C the moisture is simply entrapped in the cooked grain because of greater volume expansion. Moreover, with low storage temperature (4°C), the water absorption values of BR and GBR samples measured monthly presented no significant difference ($P$<0.05) along the eight months of storage. As a result, the BR stored at low temperature (4°C) did not cause a marked change in water absorption and could retard the changes in physical properties, while high temperature (37°C) storage could accelerate aging process (Navdeep, 2003).

Water absorption of cooked GBR grains was 2.13±0.11 g $g^{-1}$ at the initial stage of storage. The value tended to significantly increase after four months of storage at 37°C, after which the absorption value slowly declined till the end of storage (eight months). These results were similar to those under the storage temperature of 37°C of BR samples. The same results imply that greater compact in starch structure during storage at high temperature could inhibit water penetration to the center of rice kernels, which was consistent with 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). Furthermore, 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).

### 3.6 Free fatty acid

Previous studies have reported that most of rice lipids are concentrated around the outer layer; thus, during storage these lipids make contact with lipases and thereby hydrolysis may take place to form free fatty acids (Piggott et al., 1991). Changes in free fatty acids of BR and GBR during storage at different temperatures are shown in Figure 3. During storage, free fatty acids of all rice samples were found varied and would increase under both low and high temperature conditions. The higher the temperature is, the greater the free fatty acid will be.




In any month in which the means are followed by the identical number, the mean values are insignificantly different (p<0.05) using Duncan's multiple range test. In any treatment of which the means are followed by the identical number, the mean values are insignificantly different (p<0.05) using Duncan's multiple range test.

Figure 3 Changes in free fatty acid of brown rice (BR) and germinated brown rice (GBR) during storage at different temperatures for eight months

The free fatty acids of BR and GBR were found initially at 0.308±0.007% and 0.326±0.016%, respectively. After one-month storage, free fatty acids of BR and GBR rose for all temperature conditions (4°C and 37°C). Observably, the increase in the case of BR was found greater than that of GBR, which may be due to the fact that GBR was gelatinized in steaming process, thus more resistant to disruption during storage. At 4°C for the first two months, GBR did not show a significant ($P$>0.05) change in free fatty acid, whereas a significant increase ($P$<0.05) was found with BR stored at the same temperature. The rapid increase in free fatty acid of GBR became significant after storage for two months at 37°C in contrast to a slight increase at 4°C. The results were consistent with the finding of Navdeep et al. (2003), who reported an increase in free fatty acid throughout the storage period.

At 37°C and after eight-month storage, free fatty acids soared to 0.487±0.001% and 0.514±0.004% for BR and GBR, respectively. The free fatty acid of GBR mostly changed at higher temperature. In addition, Sharp and Timme (1986) reported that free fatty acid rose during rice storage, especially at high temperature. Moreover, the deterioration of BR during storage was dramatic because of the existence of a great deal of lipids and lipolytic enzyme in the bran.

### 3.7 GABA content

The GABA contents in BR and GBR stored at different temperatures and lengths of time are presented in Figure 4. The GABA contents of BR and GBR at the initial stage of storage were respectively 4.67 mg (100 g)$^{-1}$ and 5.47 mg (100 g)$^{-1}$, showing that the GABA content of GBR was not much higher than that of untreated sample (BR). Many research studies reported that the GABA content in germinated brown rice increased three times as much as that of milled rice (Kayahara and Tsukahara, 2000, Shoichi and Yukihiro, 2004). The results of this study however were different possibly because the moist GBR samples were dried before storage, which affected the GABA content. However, it is difficult to compare the GABA contents of the present and previous studies due to different rice varieties and processing.

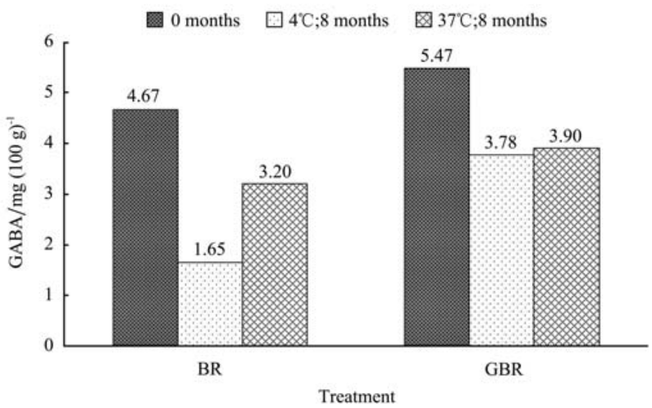



Figure 4 Changes in GABA contents of brown rice (BR) and germinated brown rice (GBR) during storage at different temperatures for eight months

The GABA content decreased from 4.67 to 1.65 mg (100 g)$^{-1}$ for brown rice stored at low temperature (4°C) and to 3.2 mg (100 g)$^{-1}$ for reference high temperature (37°C). For GRB stored at high temperature (37°C), the GABA content decreased with longer storage time (Figure 4) from 5.47 to 3.90 mg (100 g)$^{-1}$ after eight months of storage. Similarly, GBR stored at 4°C had a lower GABA content when stored for a long time (eight months), decreasing from 5.47 to 3.78 mg (100 g)$^{-1}$. Decrease of GABA content in GBR was nonetheless less than that in BR probably because the rice structure of GBR was gelatinized before storage and thereby rice grains were more resistant to disruption during storage. Since the GABA content in the aging rice was affected by storage temperature, duration and type of rice; rice grains should hence be stored under low temperature and for short storage time to retard the aging process.

### 3.8 Sensory qualities

Flavor, appearance, taste, texture, and overall acceptability scores for BR and GBR were significantly affected (*P*<0.05) by storage temperature and duration (Table 3). At the initial stage of storage, the panelists preferred GBR to BR and GBR had higher scores in all sensory qualities. After two-month storage, a slight decrease in all sensory qualities was observed with no significant difference (*P*>0.05) in overall acceptability for all BR and GBR stored at 4°C and 37°C. A significant difference (*P*<0.05) was reported in flavor, appearance, taste, and texture at the same storage temperature of BR and GBR after four-month storage. Moreover, the lower scores of all sensory qualities were evaluated when storing BR at the higher temperature (37°C). The panelists reported differences (*P*<0.05) in sensory values between GBR stored at 4°C and 37°C for the first four months and gradual decreases (*P*>0.05) in sensory values afterward.

The attributes of flavor, appearance, taste, texture, and overall acceptability of BR were observably inferior after eight months of storage. Brown rice stored at 37°C was given the lowest scores for all sensory qualities, but that stored at low temperature (4°C) received higher scores for all sensory qualities, meaning that the panelists rejected BR at higher storage temperature. For GBR stored for eight months, change of flavor was detected by the panelists, but differences (*P*>0.05) in taste, texture, and overall acceptability between low and high storage temperatures were not reported. Reduction in scores of overall acceptability was observed in all rice samples, especially for BR stored at high temperature (37°C). The overall acceptability of BR was reduced from an initial 7.07 to 4.47 at the end of storage, while GBR stored at low temperature (4°C) was evaluated with the highest score of overall acceptability.

**Table 3 Sensory properties of cooked brown rice and cooked germinated brown rice during storage at different temperatures**

| Sensory quality | Quality score (initial) | |
|---|---|---|
| | BR | GBR |
| Flavor | 7.30 | 7.53 |
| Appearance | 7.03 | 7.63 |
| Taste | 6.77 | 7.57 |
| Texture | 6.93 | 7.60 |
| Overall Acceptability | 7.07 | 7.27 |

| Sensory quality | Quality score (two months) | | | |
|---|---|---|---|---|
| | BR (4°C) | BR (37°C) | GBR (4°C) | GBR (37°C) |
| Flavor | $7.10^b$ | $6.70^c$ | $7.13^b$ | $7.50^a$ |
| Appearance | $6.63^b$ | $6.03^d$ | $7.33^a$ | $6.93^c$ |
| Taste | $6.37^b$ | $5.87^c$ | $7.17^a$ | $6.67^b$ |
| Texture | $6.63^b$ | $6.23^c$ | $7.30^a$ | $6.90^b$ |
| Overall Acceptability | $6.97^a$ | $6.77^a$ | $7.17^a$ | $6.87^a$ |

| Sensory quality | Quality score (four months) | | | |
|---|---|---|---|---|
| | BR (4°C) | BR (37°C) | GBR (4°C) | GBR (37°C) |
| Flavor | $6.80^{ab}$ | $6.50^c$ | $7.13^a$ | $7.30^b$ |
| Appearance | $6.43^c$ | $5.93^c$ | $7.13^a$ | $6.83^b$ |
| Taste | $6.07^c$ | $5.77^c$ | $7.07^a$ | $6.47^b$ |
| Texture | $6.53^b$ | $6.03^c$ | $7.10^a$ | $6.80^b$ |
| Overall Acceptability | $6.67^a$ | $6.57^a$ | $7.07^a$ | $6.77^a$ |

| Sensory quality | Quality score (six months) | | | |
|---|---|---|---|---|
| | BR (4°C) | BR (37°C) | GBR (4°C) | GBR (37°C) |
| Flavor | $6.50^b$ | $5.40^c$ | $6.63^b$ | $6.80^a$ |
| Appearance | $6.03^b$ | $4.63^c$ | $6.53^a$ | $6.33^a$ |
| Taste | $5.57^b$ | $5.03^c$ | $6.67^a$ | $6.07^a$ |
| Texture | $6.13^b$ | $5.13^c$ | $6.70^a$ | $6.30^a$ |
| Overall Acceptability | $6.17^a$ | $5.47^b$ | $6.57^a$ | $6.37^a$ |

| Sensory quality | Quality score (eight months) | | | |
|---|---|---|---|---|
| | BR (4°C) | BR (37°C) | GBR (4°C) | GBR (37°C) |
| Flavor | $5.50^b$ | $4.40^c$ | $5.63^b$ | $5.80^a$ |
| Appearance | $5.03^b$ | $3.63^c$ | $5.53^a$ | $5.33^a$ |
| Taste | $4.57^b$ | $4.03^c$ | $5.67^a$ | $5.07^a$ |
| Texture | $5.13^b$ | $4.13^c$ | $5.70^a$ | $5.30^a$ |
| Overall Acceptability | $5.17^a$ | $4.47^b$ | $5.57^a$ | $5.37^a$ |

Note: Means in the same row with different superscripts are significantly different ($p<0.05$). Sensory quality is defined by scores ranging from 1 to 9 (i.e., "extreme dislike" to "extreme like").

The poor quality of cooked BR stored at high temperature was due to the release of free fatty acids which led to quality change, such as generation of stale flavors (Lee et al., 1991). It was found that temperature during aging had the most influence on the acceptability of the panelists. Thus, storage below room temperature is recommended to maintain rice quality.

## 4 Conclusions

The results of storage of BR and GBR samples at different temperatures of 4°C and 37°C proved the changes in their chemical and physical properties. The changes in physicochemical properties were influenced by storage temperature and storage time. The moisture content of GBR stored at 37°C and GABA content of all rice samples decreased, while b-value, hardness values, and free fatty acid increased. Moisture loss and the alteration in microstructures of starch granule affected the cooking and textural property of BR and GBR. In this study, water absorption of rice samples stored at high temperature increased at initial period of storage and slightly decreased for longer storage period. Regarding sensory evaluation, the preference of the panelists was for rice samples stored at low temperature and shortened storage time. Changes in flavor, appearance, taste, and texture induced by time and temperature during storage mainly contributed to the declining overall acceptability of both cooked BR and GBR. Type of rice also influenced the changes in those properties during aging. These results support the fact that the storage of BR and GBR grains under the low temperature and short time can avoid the creation of undesirable phenomena that lead to poorer rice quality.

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