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Effect of storage conditions on quality of organic brown rice

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Abstract

Organic brown rice production has grown up, especially in the SMEs business. However, the information on storage conditions for organic brown rice is still lacking. Therefore, the objective of this study was to evaluate the effects of packaging type, storage duration, and storage temperature on the storage quality attributes. Organic brown rice samples were packed using a gunny sack (GS, control), polypropylene woven (PP-woven) sack, low-density polyethylene (LDPE), and low-density polyethylene with vacuum-sealed (LDPE+vacuum). These samples then were stored at room temperature (RT) at 32±3 °C and freezer (FT) at -16±1 °C. During storage at both temperatures, lightness, fat content, and flavor likeness were evaluated monthly for five months. During 5 months of RT storage, the lightness of control sample were higher than that at FT storage with some variational changes. Storage temperature, packaging type, and storage duration were mainly and interactive significant effects ($P<0.05$) on the lightness changes of organic browning rice. At the end of storage regardless storage temperatures, the fat content showed fluctuations of increasing and decreasing. Also, the results reveal that packaging type did not affect fat content. Flavor likeness scores of cooked organic brown rice increased and were higher than initial storage. There was no interactive effects of storage temperature x storage duration on flavor likeness. In conclusion, the storage temperature, storage duration, and packaging type affect physiological qualities of organic brown rice. Therefore, the suitable method to be applied for storing organic brown rice should be considered according to practical factors such as facility availability as well as the managing cost in order to extend shelf life of organic brown rice with minor quality attribute changes.

Keywords

extend shelf life; organic brown rice; storage conditions; lightness; paddy

1. Introduction

Presently, the organic food trend has grown up worldwide. Furthermore, organic agriculture plays a crucial link as a pathway to achieve carbon neutrality. Organic agriculture is aimed to minimize chemical spray and production costs with healthy farmers. According to the most recent survey conducted during 2018-2020, the statistical annual reports show that organic agricultural areas have continued to grow in many areas such as Africa, Asia, Europe, Latin America, and Northern America [1]. Additionally, Thailand is the fourth country in Asia with the ten largest organic agricultural areas by 2020 [2]. Currently, Thai organic rice also has been spotted and the demand has grown up gradually [3].

Brown rice is manufactured by dehusking without removing bran layers. Brown rice is constituted of a pericarp, aleurone layer, germ, and a part of endosperm (starch). The aleurone layer of brown rice kernel that are rich in nutrients and includes minerals, vitamins, dietary fiber, fat, and some useful phytochemicals [4-8]. It has been reported that phytosterols presented in brown rice could effectively prevent cardiovascular disease [9]. Furthermore, phenolic compounds reportedly demonstrate antioxidant, anti- allergenic, anti-inflammatory, antimicrobial, cardioprotective, antiviral and anti- thrombotic [10-11].

Storage quality of brown rice is limited by lipids and nutritional components resulting in spoilage [7]. During storage enzyme lipase in rice bran hydrolyzes fat constituents into free fatty acids and glycerol, exceptionally high moisture grain [12]. Besides, moisture present during storage results in mold growing, consequently, accelerating further fat decomposition and generating stale flavor [12]. Additionally, moisture leads to off-odors and taste, and loss of nutrition [13].

Storage conditions such as environmental conditions and treatments applied to affect the quality of grain during storage [14]. Traditionally, storing rice using gunny sack (GS) or PP-woven bags kept in convenient warehouses is a standard method applying in developing countries. However, these storage conditions could subject to losses to pests, insects, mites, and high humidity in the warehouse and result in qualitative, quantitative, and nutritive depletions.

Hermetic storage of grains is an airtight condition in which mold growth and insect population are limited by the natural accumulation of carbon dioxide and deficient oxygen amount by grain and microorganism respirations [14]. LDPE, HDPE, and polyvinyl chloride (PVC) are used to manufacture plastic containers for grain storage [12]. Additionally, laminated plastic films for example oriented-polypropylene (Oriented-PP), aluminum, LLDPE and nylon, and LLDPE are used for packing organic milled rice, including fortified rice, organic rice, and fragrant rice [15-16].

Bag storage has the merits of cheaper storage cost and is suitable for handling, as well as could minimize the effects of humidity and temperature changes in comparison to bulk storage [12]. Nevertheless, bag storage has a limited storage period compared to bulk storage. Sealed packaging could minimize the moisture adsorption during storage resulting in a decline of existing insects and maintaining the grain quality [17]. A vacuum pack is a shallow oxygen pack that could minimize the growth of insects and pests resulting in maintaining organic rice quality [16].

Chilled storage is being used for brown rice storage, especially in temperate and tropical countries, low temperature slows down chemical and biochemical reactions [12]. On the other hand, a cool storage system adds more expense to the system, even more on the operating cost for freezing storage. Storage at low temperature is usually advantageous in less insecticide application [14]. Storage at temperatures below 5 and 15 °C could prohibit mite and insect accumulations [12]. Otherwise, the temperature at 20 °C causes the occupation of insects and microorganisms including rapid deterioration of phytochemical constituents.

Temperature and time are the crucial parameters affecting storage quality [16]. Storing rice at high temperatures (approx. 30-40 °C) results in reductions in pH, turbidity, and solids content, but increases in hardness and fatty acidity in comparison to 4 °C storage [18-19]. Storage cereal at 10°C was reported to maintain quality, and it was suggested that cereal grains should not be stored at above 25°C to minimize the nutritional losses [20].

Farmers store rice in gunny sacks at ambient temperature that exert changes in quality attributes. Consequently, the poor storage practice results in diminishing the inherent constituents of organic brown rice. Organic rice farmers needed to be educated on the appropriate storage condition to maintain the organic brown rice quality. However, there is a limited amount of research related to organic brown rice storage. Hence, this research aims to investigate the effects of storage conditions on the quality attributes of organic brown rice.

2. Materials and Methods

2.1 Organic brown rice sample preparation

Organic brown rice paddy at commercial age about 500 kg was received from an organic rice farm located in Pimai sub-district, Nakhon Ratchasima province, Thailand. Pimai sub-district is well known as an abundant land for rice cultivation of this province such as organic rice, organic jasmine rice, in-organic jasmine rice and other types of rice. Thereafter, organic rice paddy was milled by a local rice mill plant and about 300 kg of milled rice was received. Then, they were kept in GS (29” width x 39” height) and transported to the Post-Harvest and Processing Engineering laboratory by vehicle at ambient temperature.

2.2 Storage conditions

LDPE (0.15 mm thickness, 8” width x 12” height), PP-woven sack (4” width x 6” height) and GS (4” width x 6” height) were purchased from local scientific suppliers. Sample bags of organic brown rice were prepared by weighing one kg of milled organic brown rice per bag type (LDPE, LDPE+vacuum and PP-woven sack). LDPE bags were sealed by heat, and the LDPE+vacuum condition was done using a vacuum packer (VP438, Ramon, Spain) vacuum scaled with heat sealed level 5. The PP-woven sack was sealed by hand-sawing (Traditional method). Samples were prepared for 2 sets and kept at 2 different temperatures (RT approx. 32±3 °C, FT -16±1 °C using a freezer (TCF65 WHC, Singer, Thailand) for five months. Control sample was set up by storing organic brown rice (one kg of milled rice per GS with hand-sawing) which stimulates the traditional storage. All treatments were withdrawn for further examinations at one-month intervals with three replicates (one bag represents one replicate).

2.3 Storage quality evaluations

Lightness changes of organic brown rice during storage were evaluated by using a portable spectrophotometer (CR 300, Minalta, Japan). This machine was set up at 10° observation with illuminant D65. The lightness changes during storage were assessed at three different points to obtain the average values of lightness. Fat content changes during storage were determined using AOAC, 32.1.14 [21] with three replicates.

The flavor likeness of organic brown rice of all treatments was examined from cooked organic brown rice using a rice cooker (Ot-cr-100t, OTTO, Thailand). For cooking conditions, organic brown rice of one standard cup (250 g) was added with 750 ml of distilled water. The cooked rice samples were analyzed for flavor quality by 30 untrained panelists. A 7 hedonic scale (7= like very much, 6= like moderately, 5=like slightly, 4=neither like nor dislike, 3=dislike slightly, 2=dislike moderately, and 1=dislike very much) ranking test was applied to evaluate panelist likeness among samples. Cooked samples (approx. 20 g) were prepared at room temperature (approx. 32-35 °C), and the panelists were asked to rinse their months with drinking water before testing each sample. Four samples were served in order to each panelist.

2.4 Data analysis

The statistical analyses were performed using the IBM SPSS Advanced Statistics: Local license for version 22.0. To statistically evaluate the quality attributes of organic brown rice when stored at different packaging materials, storage duration, and storage temperatures, the 3-factor factorial design was used to determine the main and interaction effects with a significance level of $P<0.05$. Analysis of variance (one-way ANOVA) was performed and the differences among means of 3 replicates were determined at 95% confidence level using Duncan's multiple-range tests.

3. Results and discussions

3.1 Changes in lightness

During 5 months of RT storage the lightness of the control sample gradually increased whereas the lightness of the treated samples mostly increased (Table 1). After two month of RT storage, the lightness of the control sample increased continuously and showed significant high value (50.4) at the end of storage. The lightness of samples stored by PP-woven, LDPE and LDPE+vacuum showed similar increasing and decreasing trends during storage. Samples stored by LDPE also showed the increasing trend during the first three months of storage followed by reduced and then slightly increased. At the end of storage, samples kept in PP-woven showed the lowest lightness magnitude at 45.7. This result revealed by current study diverges from the previous report. It was found that there was a low correlation (0.604) between lightness and storage temperature (35°C) during storing brown rice [22].

During 5 months of FT storage the lightness of the control sample slightly increased while the lightness of the treated samples displayed fluctuations (Table 1). The lightness changes in the control sample at FT were smaller than that at RT (both within and between groups). Samples stored by PP-woven, LDPE and LDPE+vacuum illustrated similar increasing and decreasing trends during the first three months at FT. At the end of FT storage there were not significant different lightness changes of all samples.

After storage for 5 months, primarily, a slight change in lightness was observed in all samples stored by FT compares to RT. However, storage temperature, packaging type, and storage duration were mainly and interactive significant effects on the lightness of organic browning rice (Table 2).

Table 1 Changes of lightness of organic brown rice stored by different types of packaging during storage for 5 months at room and freezing temperatures.

Storage time (month)	Room storage at 32±3°C				Frozen storage at -16±1°C			
	Control	PP-woven	LDPE	LDPE+vac.	Control	PP-woven	LDPE	LDPE+vac.
Initial	44.8±1.2Aa	44.8±1.2Aa	44.8±1.2Aa	44.8±1.2Aa	44.8±1.2Aa	44.8±1.2Aa	44.8±1.2Aa	44.8±1.2Aa
1	45.7±0.9Aa	47.6±0.1Cb	49.9±0.1Cc	48.4±0.2Bb	45.8±1.8ABa	47.2±0.1Bb	48.2±0.1Cb	47.4±0.1Bb
2	47.5±1.3Ba	49.6±0.5Db	50.6±0.1Cb	50.6±0.4Cb	46.6±0.8ABa	47.7±0.3Ba	46.7±0.4Ba	47.7±0.2Ba
3	48.4±0.2Bb	49.8±0.9Dc	50.2±0.2Cc	50.3±0.5Cc	47.3±1.4Bb	47.3±0.1Bb	45.9±0.4ABa	45.6±1.0Aa
4	50.6±0.1Cd	46.9±0.3BCb	46.7±0.2Bab	49.8±0.7Cd	46.0±0.4ABa	45.9±0.4Aa	46.2±0.5Bab	48.1±0.7Bc
5	50.4±0.5Cc	45.7±0.9ABa	47.7±0.9Bb	47.8±0.3Bb	47.3±0.9Bb	48.1±0.9Bb	47.8±0.5Cb	47.3±0.4Bb

Data are presented as mean value (n=3) ± standard deviation. Significant level at $P<0.05$ are indicated by different capital letters for columns and lowercase letters for rows.

Table 2 Interaction effects of storage conditions on qualities of organic brown rice during storage for 5 months at room and freezing temperatures.

Sources/Quality parameters	Lightness	Fat content	Flavor likeness
Storage temperature	*	*	*
Packaging type	*	ns	*
Storage duration	*	*	*
Storage temperature x packaging type	*	*	*
Storage temperature x storage duration	*	*	ns
Packaging type x storage duration	*	*	*
Storage temperature x packaging type x storage duration	*	*	*
R-squared	0.879	0.942	0.248

ns, * non-significant or significant differences (factorial test) at $P<0.05$.

The observations found by this study are comparable results. Storing brown rice at 4°C could retard physical and chemical degradation at slower rate in comparison to store at higher temperatures (25 and 37°C) [19]. Additionally, super-low temperature (below freezing point) was reported to maintain physiological properties of rough rice [23]. However, the increase of lightness observed by this study was unlike with the result report by studies [19,24]. Changes in lightness of RT-storage organic brown rice samples could be influenced by attacking from moths. The organic brown rice is a chemical-free product; meaning that is nontoxic to moth as a result of rice kernel destruction. This study observed moths and white dust during storing for longer storage duration. This small white dust could influence the magnitude of lightness during measurement. However, FT could eliminate all insects [12,16], that could be the reason for the smaller change in lightness.

3.2 Fat content during storage

During 5 months of storage at 2 different temperatures, the fat content showed fluctuations of increasing and decreasing trends (Table 3). Interestingly, small changes were observed in samples stored by LDPE+vacuum (within treatment) at RT. The maximum fat content (3.7 %w/w) was found in samples stored by LDPE at FT after 4 months. After 5 months, storing control samples at RT was observed inconsistent changes of fat content which were similar to those found by samples stored in PP- woven and LDPE at FT with different magnitudes. It was observed that during FT storage for 5 months, the fat content alteration of control sample slightly increased and then stable. PP-woven (at RT storage) and LDPE+ vacuum (at both temperatures) displayed increasing followed by decreasing fat content at the end of storage. This study reveals that storage temperature and storage duration affected fat content but not packaging type. Additionally, there were interactive effects of storage temperature x packaging type x and storage duration on fat content of organic browning rice (Table 2).

Table 3 Alterations of fat content (%w/w) of organic brown rice stored by different types of packaging during storage for 5 months at room and freezing temperatures.

Storage time (month)	Room storage at 32±3°C				Frozen storage at -16±1°C			
	Control	PP-woven	LDPE	LDPE+vac.	Control	PP-woven	LDPE	LDPE+vac.
Initial	3.32 ±0.01Ba	3.32 ±0.01Ba	3.32 ±0.01Ba	3.32 ±0.01Aa	3.3 2±0.01Aa	3.32 ±0.01Aa	3.32 ±0.01ABa	3.32 ±0.01Aa
1	3.41 ±0.01Ccd	3.43 ±0.01CDd	3.40 ±0.01Cbcd	3.34 ±0.09Aabc	3.46 ±0.03Bd	3.29 ±0.01Aa	3.33 ±0.02Bab	3.35 ±0.01Aabc
2	3.58 ±0.03Ad	3.48 ±0.01Dc	3.54 ±0.01Ed	3.29 ±0.03Aa	3.46 ±0.02Bc	3.58 ±0.03BCd	3.42 ±0.01Cb	3.41 ±0.01Bb
3	3.27 ±0.01Da	3.49 ±0.06Dd	3.27 ±0.01Aa	3.27 ±0.02Aa	3.50 ±0.01BCd	3.36 ±0.03Ab	3.45 ±0.04Ccd	3.42 ±0.03Bc
4	3.45 ±0.03Cbc	3.37 ±0.07BCb	3.29 ±0.01ABa	3.53 ±0.04Bcd	3.52 ±0.02Cc	3.61 ±0.09Cde	3.71 ±0.01Df	3.64 ±0.02Cef
5	3.28 ±0.03ABb	3.01 ±0.03Aa	3.46 ±0.03Dcd	3.29 ±0.04Ab	3.48 ±0.01Bcd	3.51 ±0.01Bd	3.29 ±0.03Ab	3.45 ±0.03Bc

Data are presented as mean value (n=3) ± standard deviation. Significant level at P<0.05 are indicated by different capital letters for columns and lowercase letters for rows.

Changes in fat content during brown rice storage could be affected by high temperature storage. It was found that there was a low correlation (0.604) between fat acidity and storage temperature (35 °C) during storing brown rice [22]. Also, high ambient temperature with high relative humidity could reduce grain quality during storage period that influences milled rice quality [17]. High humidity is reported to significantly increase the accumulation of the unsaturated fatty acids during storage [25]. Hence, this could be the reason of increasing of fat content observed from samples stored by FT storage due to high humidity level in the freezer.

A sample stored in LDPE+vacuum tends to have a consistent change in fat content in comparison to other treatments at RT and FT storage for 4 months. This could be due to low temperature accompany by vacuum packaging which was reported to retard changes in physicochemical qualities of organic hulled rice stored at ambient temperature and 15 °C [16].

Also, it was reported that under controlled atmosphere storage had a lower rate of fatty acid value change in brown rice in comparison to conventional storage at high temperature [26]. This study found a similar observation that the fat content of LDPE+vauum at RT sample was quite stable.

Furthermore, storing brown rice at 15°C using LLDPE could minimize the volatile lipid oxidation and maintain the desirable odorants [15]. However, storing brown rice in LLDPE and nylon resulted in a greater extent and higher rate of undesirable changes in volatile compounds when stored at ambient temperature [15]. Increasing the fat content of all samples after RT storing for 2 months could be impacted by the higher storage temperature resulting in an increase of free fatty acid which is reported in brown rice sample [24,27], milled rice [19], and germinated parboiled rice [28].

3.3 Flavor likeness of cooked organic brown rice

Flavor likeness of cooked organic brown rice displays difference over traditional storage (Control) at RT (Table 4). The overall trends of all treatments either within or between groups illustrates decreases and increases repeatedly.

Consideringly, the trends of flavor likeness of samples stored by LDPE and LDPE+vacuum at RT were comparable. The flavor likeness of samples stored by PP- woven regardless of storage temperature presented the similar trends both within and between treatments. Interestingly, at the end of storage the score of flavor likeness increased which was higher than initial storage except those of control. During 5 months of RT storage, mean values of flavor likeness of control seem to be lower than the rest of samples. The highest flavor likeness score (3.7) was found from a sample stored by LDPE+vacuum at RT.

Since the first month of FT storage, the flavor likeness score of samples stored by PP-woven, LDPE and LDPE+vacuum presented comparative scores (between treatment interaction). The flavor likeness of control samples increased with some fluctuations during storage for 2 to 5 months. This study revealed that the storage temperature, packaging type, and storage duration were the main influences on flavor likeness of cooked organic brown rice. Additionally, there were some interactive effects between storage temperature x packaging type, packaging type x storage duration, and storage temperature x storage duration x packaging type on the flavor likeness of cooked organic brown rice. But there was no interactive impact of storage temperature x storage duration on flavor likeness (Table 2).

Considering changes in fat content of LDPE+vacuum treatment, it was revealed small changes in both storage temperatures. Accordingly, it is possible to report that LDPE+vacuum could maintain the flavor of organic brown rice samples at FT which is similar to the previous studies. More acceptable samples stored at lower temperature were reported [18,19,24]. Moreover, the oxygen level during storage could affect the cooking quality as well as the phytochemicals of brown rice during storage at high temperature (37°C) [29]. Also, freezing storage was reported to maintain eating quality of rough rice [23].

Table 4 Flavor likeness of organic brown rice stored by different types of packaging during 5 months at room and freezing temperatures.

Storage time (month)	Room storage at 32±3°C				Frozen storage at -16±1°C			
	Control	PP-woven	LDPE	LDPE+vac.	Control	PP-woven	LDPE	LDPE+vac.
0	2.6±0.5Ca	2.6±0.8ABa	2.6±0.5ABa	2.6±0.5Aa	2.6±0.5ABa	2.6±0.5Aa	2.6±0.5Ba	2.6±0.5ABa
1	1.5±0.5ABa	2.3±0.8Aabc	2.3±0.8Aabc	2.3±0.8Abc	3.2±1.5BCc	2.5±1.2Aabc	1.8±1.0Aab	2.0±0.7Aab
2	1.7±0.7ABa	3.1±0.6ABb	3.0±0.9ABb	3.1±1.5ABb	3.4±0.9Cb	2.4±0.5Aab	3.2±1.0BCb	3.3±1.1Bb
3	2.0±0.8Ba	3.3±1.0Bb	2.9±0.9ABb	3.1±0.9ABb	3.4±0.8Cb	3.4±0.6Bb	3.5±1.1Cb	3.0±1.1Bb
4	2.3±0.8Ca	2.8±0.9ABb	3.0±0.8ABb	2.9±1.0ABb	2.3±0.6Aa	2.9±0.8ABb	3.0±1.0BCb	3.1±1.1Bb
5	1.2±0.6Aa	3.3±1.6Bb	3.4±1.4Bb	3.7±1.5Bb	3.3±0.6BCb	2.8±0.9ABb	3.2±0.8BCb	3.3±0.8Bb

Data are presented as mean value (n=3) ± standard deviation. Significant level at P<0.05 are indicated by different capital letters for columns and lowercase letters for rows.

The overall cooking quality of cooked milled brown rice stored at 15 °C was higher than 35 °C [22]. Furthermore, cooking quality of cooked rice that was stored for a long time was less acceptable [16,30].

4. Conclusions

The storage conditions (Types of packaging, storage duration, and storage temperature) have significant impacts on the physicochemical properties and cooking quality of organic brown rice (P<0.05). At the end of RT storage, the lightness of control sample gradually increased while the lightness of the treated samples mostly increased follow by decreased. The smaller changes of lightness were observed from samples stored at FT. The fat content showed an uncertainty change of increasing and decreasing during 5 months of storage regardless of packaging types. At the end of storage, the scores of the flavor likeness of treated sample were similar and higher than scores of controls regardless the interactive effects of storage temperature x storage duration. Interestingly, at the end of storage the score of flavor likeness increased and were higher than initial storage. Hence, storing organic brown rice at low temperature would be better to minimize the physiological quality changes and deterioration. Cost related to RT or FT application should be concerned as it plays an important role in the system management. The outcome of this study could provide useful information for small farmers to extend organic brown rice physicochemical properties and cooking quality for a broader market.

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