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CHANGES IN RICE CHEMICAL COMPOSITION AND COOKING QUALITY BY RESPIRATION HEAT DURING STORAGE

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ABSTRACT

This study aims to determine the effect of the type of packaging and storage time on the chemical composition and rice cooking quality by utilizing the respiration generated heat of freshly harvested rice. “Siam Pandak” variety of freshly harvested rice stored in black plastic bag and tarpaulin with storage time of 0, 1, 2, 3, 4 and 5 days. The results showed that the accumulation of respiration heat of freshly harvested rice during storage is only capable of raising the temperature in the packaging up to 28–31 °C, slightly higher than room temperature ranging between 26–29 °C. Types of packaging and storage time could affect rice chemical composition, i.e. protein, crude fibre, fat, and carbohydrate contents. The highest protein content of 8.56% (an increase of 7.31% compared to control) was obtained by storage time of two days and the highest crude fibre content of 2.40% (an increase of 96.46% compared to control) was in the tarp packaging with storage time of five days. Fat and carbohydrate contents tended to decrease by storage time. Cooking quality was also affected by the packaging types and storage time as indicated by the increase of water absorption capacity to 298.27% (an increase of 27.74% compared to control), obtained in black plastic bag with storage time of one day.

Key Word: cooking quality, chemical composition, respiration heat, freshly harvested rice.

INTRODUCTION

Rice is one of the important cereals and staple food for more than half the world's population, especially in Asia (Wei et al., 2007), including Indonesia. Rice is used as the main source of carbohydrates and energy, which is generally consumed as a whole kernel of white rice obtained by milling (dehulling and polishing) rough rice (Payakapol et al., 2011) and then cooked into cooked rice.

Improving the quality of rice could naturally be done by storing dry grain/rice for several months. During storage of grain, aging process would occur spontaneously through a series of chemical and biochemical reactions that resulted in changes in the physicochemical and quality of rice. Grain would experience a physicochemical change and quality in the first 3–4 months in storage, especially when stored at temperatures above 15 ^{o}C (Houston, 1972; Faruq et al., 2003). The changes that occurred in the aging process during storage included the percentage of head rice, rice color, thermal characteristic and flour pasta and rice starch, cooking quality including water absorption, volume expansion, ratio of elongation and total dissolved solids, texture and aroma of cooked rice (Tananuwong and Malila, 2012; Zhou et al., 2015). Although quantitative changes in the rice chemical composition were small (Tulyathan and Leeharatanaluk, 2007; Zhou et al., 2002), but some qualitative changes in the composition occurred during storage (Thanathornvarakul et al., 2016). The rice that has undergone aging process when compared with freshly harvested rice showed different properties, such as chemical composition and physicochemical properties (Park et al., 2012).

The rate and magnitude of changes that occurred during storage were mainly influenced by grain moisture and storage temperature, higher moisture and temperatures would generate greater changes (Barber, 1972; Villareal et al., 1976; Dhaliwal et al., 1991). Storage conditions affecting the

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aging process were mainly time and temperature (Tananuwong and Malila, 2012; Zhou et al., 2015).

The aging of rice naturally takes approximately 4–6 months and also requires much more space for storage of paddy, so that requiring high operating cost, and are prone to insect and microorganism damages (Soponronnarit et al., 2008). Therefore, it was necessary to conduct acceleration process in order that the aging process could run faster by increasing the storage temperature and grain moisture.

Freshly harvested rice (FHR) is newly harvested grain and still wet, generally has water content between 20–27 % (Waries, 2006). Grain with high moisture when stored would generate heat as a result of respiration and microorganism activities. Dilhutany et al. (2000) stated that respiration was a metabolic process associated with grain as well as microbes, producing heat, water, and CO_2 originating from sugar oxidation. Heat and water as a result of respiration could accumulate that resulted in temperature and humidity in the packaging to improve, so it could be used for grain aging acceleration. This study aims to determine the effect of the type of packaging and storage time on the chemical composition changes and rice cooking quality by utilizing the respiration heat of dry harvest grain.

MATERIALS AND METHOD

Several materials employed were FHR of “Siam Pandak” variety, ethanol, petroleum benzene, chloroform, ethanol, sodium hydroxide, hydrochloric acid, acetic acid, yod, amylose, glucose, soluble starch, sodium chloride, Whatman filter paper No. 1 and distilled water, thermometer, hygrometer, soxhlet, analytical balance, spectro-photometer, water bath, hotplate, vortex, turning cooler, oven, 4 mesh sieve, Erlenmeyer, beaker glass, test tubes and other glass tools.

The research used Completely Randomized Design (CRD) of two factors, namely the type of packaging and storage time. Packaging (K) consisted of two levels, namely black plastic bag (k1) and tarpaulin (k2), and storage time (P) consisting of five levels: 1 day (p1), 2 days (p2), 3 days (p3), 4 days (p4) and 5 days (p5), repeated two times so that there were 20 experimental units and one control unit. As a control, FHR was used, that was directly dried in the sun.

The study began with the weighing of FHR as much as 20 kg/package, then stored for aging process. After storage, the grain was subsequently dried by means of drying in the sun until the water content reached 13 ± 1 %, followed by grinding to produce milled rice.

Observations included chemical composition and rice cooking quality. The chemical composition of rice observed included protein, fat, crude fibre, mineral (expressed as ash content) and carbohydrate content (*By difference*). Cooking quality observed covered water absorption capacity, volume expansion, and dissolved solids. Measuring the conditions in the packaging every 6 hours, including measurement of temperature, relative humidity (RH) and grain moisture were conducted, as supporting data. The data were analyzed by analysis of variance (ANOVA) and if it showed real effect, the test would be followed by LSD test.

RESULT AND DISCUSSION

Change of Storage Condition

During storage of FHR being in two types of packaging, there occurred changes in temperature and RH in the packaging as shown in Figure 1 and Figure 2. In Figure 1 it can be seen that the temperatures inside the black plastic bag and the tarp were slightly higher than the storage room temperature. This was due to the respiration activity of the grain and microorganisms that produced heat and accumulated inside the packaging. According Dilhutany et al. (2000) respiration was a metabolic process associated with grain as well as microbes, producing heat, water, and CO_2 originating from the oxidation of sugar with the following reaction:

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + 677,2 \text{ kal}$$

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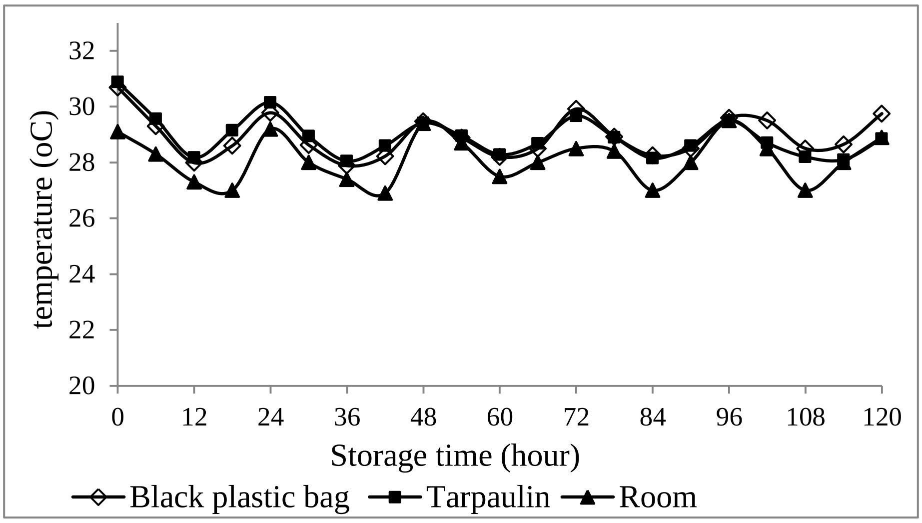

Figure 1. Changes in temperature during storage

Based on data from Figure 1 it is known that the accumulation of respiration heat during storage could only increase the temperature of up to 28–30 ^{o}C that is lower than expected, i.e. 35–40 ^{o}C, because based on previous research it showed that curing at temperatures of 35–40 ^{o}C for 24 hours could improve the milling quality of rice significantly (Millati, 2009). Research by Trigo-Stockli and Pedersen (1994) indicated that the increase of temperature of rough rice can reach to 63 ^{o}C in 6 days when stored at 26 % moisture content, 50 ^{o}C in 17 days at 22 % moisture content, and 45 ^{o}C in 27 days at 18 % moisture content. Research results of Mejia-Martinez (1988) showed that grain stored with moisture of 22 %, the increase in grain temperature could reach 60°C, but during the first five days of storage temperature was still below 40 °C. In Figure 2 it can be seen that the RH in the packaging is much higher than the room RH. This was due to the activity of respiration and transpiration of grain that produced water vapor and stuck in the packaging, so that the RH in packaging increased. RH of tarpaulin packaging is a little higher than that of black plastic bag. This was presumably because the tarpaulin packaging is thicker than the black plastic bag so it is more impermeable to moisture. Tarpaulins are water-resistant (IEEE Global Spec., 2017).

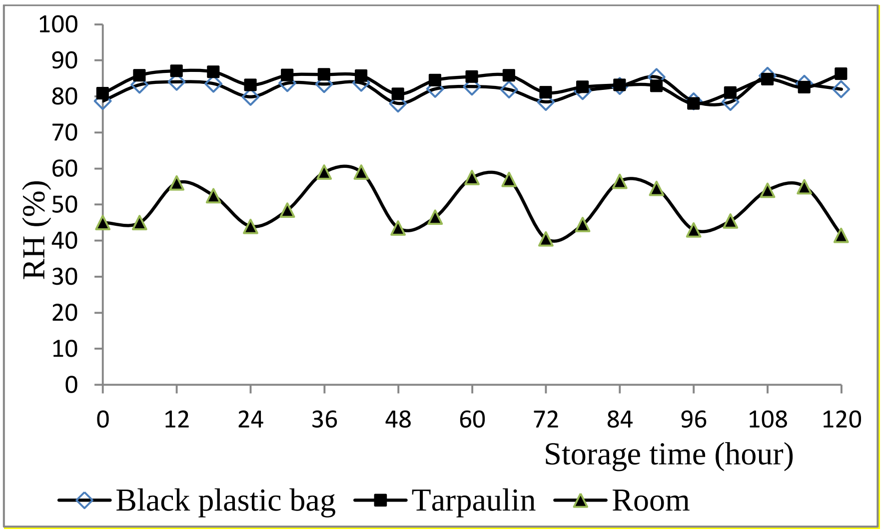

Figure 2. RH changes during storage

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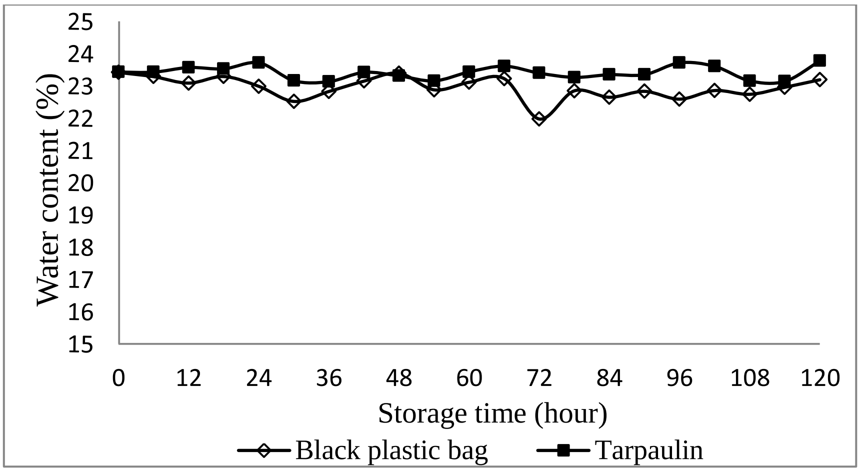

Figure 3. Grain water content changes during storage

During storage of FHR there are also occurred changes in grain moisture. The changes fluctuated as shown in Figure 3. The moisture of grain in the tarpaulin packaging is higher than that in the black plastic bag. This was because RH in the tarpaulin packaging is higher than that in the black plastic bag (Figure 2). One of tarpaulins properties is moisture-resistant (IEEE Global Spec., 2017) which caused the water vapor that accumulated inside the packaging might condense and furthermore be reabsorbed by the grain.

Chemical Composition

The chemical composition to be analyzed for the storaged rice included the contents of protein, fat, ash, fibre and carbohydrate.

Protein content

The research result showed that the protein content of rice ranged from 7.97 to 8.66 % (Table 1). The analysis of variance result showed that there was no interaction between the types of packaging with storage time against the protein content, and the protein content was only influenced by aging duration. Further LSD test result showed that aging duration that produced the highest protein content was storage for two days, which amounted to 8.6 % (an increase of 7.31 %) and did not differ from that of other aging duration, but in contrast to control. Research result of Ali et al. (2004) stated that the protein content of rice rose from 8.5 to 8.7 % after aging the grain at room temperature for six months. Zhou et al. (2002) stated that the rice protein content did not change during storage, but its solubility decreased. The similar thing was expressed by Kanlayakrit and Maweang (2013) that there were no changes in the protein content of rice and grain that were stored at low temperature (20±5 °C), at room temperature (30±5 °C) and in the warehouse (40±5 °C) for 10 months.

Table 1. Effect of storage time of FHR against the protein content

Storage time	Protein content (%, db)	Increase of protein content (%)
0 day	$7{,}97 \pm 0{,}11^{a}$	0,00
1 day	$8{,}44 \pm 0{,}16^{ab}$	5,88
2 days	$8{,}56 \pm 0{,}32^{b}$	7,31
3 days	$8{,}18 \pm 0{,}23^{ab}$	2,63
4 days	$8{,}27 \pm 0{,}26^{ab}$	3,77
5 days	$8{,}07 \pm 0{,}57^{ab}$	1,17

Description: Different letters behind the numbers indicate statistical significant difference

Increase of rice protein content in this study was probably because of the hardening of rice grain, resulting in reduced rice milling degree. Histologically, rice caryopsis consists of cuticlelayer, aleurone layer and endosperm layer. Cuticle layer and aleurone layer known as the bran and removed during the milling process and commercial milling (Wu et al., 2016).

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Protein, fat, vitamins and minerals are abundantly found in the kernel and outer layer of the endosperm is rich in starch, therefore the milling of grain could reduce the components (Monks et al., 2013).

Fat content

The fat content of rice as a result of aging ranged from 0.69 to 1.13% (Table 2). The analysis of variance result showed that the fat content of rice during aging was only affected by storage time, whereas the type of packaging and interaction of packaging type and storage time did not affect fat content. Further LSD test result showed that all aging durations were in contrast to control, but the storage time intervals (1, 2, 3, 4 and 5 days) did not show any differences.

Fat content during aging tended to decrease from 14.46 to 26.69%. The decline of the fat content occurred because the fat underwent hydrolysis by lipase producing fatty acids, monoglycerides, diglycerides and glycerol. Fatty acids, monoglycerides and diglycerides categorized as polar fats that will not be extracted by non-polar solvents such as hexane or petroleum ether are commonly used for fat analysis. In addition, polar fat could form amylose-lipid complexes which may alter the physicochemical properties of rice produced.

According to Park et al. (2012) during storage there occurred an increase in free fatty acids due to the presence of the hydrolysis of fats into free fatty acids and the free fatty acids could be oxidized into hydroperoxide and other secondary products or formed a complex with amylose.

Research result of Millati (1994) showed that during grain storage for six months, free lipid level decreased, and it decreased quickly in the first month of storage. Subsequently it dropped slowly and started to be stable in the forth month, whereas bound lipid level increased. This showed that during storage there was a formation of amylose-lipid complex.

Ash content

Rice ash content as a result of aging varied between 0.62–0.80 % (Table 3) and this result agreed with the ash content of milled rice according to Champagne et al. (2004) ranging between 0.3–0.8 %. The analysis of variance result showed that there was no interaction effect between type of packaging and storage time, as well as the single factor of packaging type or the types of packaging. This showed that with FHR storage of up to five days, ash content was relatively stable, although if compared with control there was a slight increase

Table 2. Effect of storage time of FHR toward fat content.

Storage time	Fat content (%,db)	Fat content decrease (%)
0 day	$1,13 \pm 0,25^{b}$	0,00
1 day	$0,88 \pm 0,13^{ab}$	21,42
2 days	$0,96 \pm 0,17^{ab}$	14,46
3 days	$0,84 \pm 0,11^{a}$	25,80
4 days	$0,85 \pm 0,06^{a}$	24,53
5 days	$0,83 \pm 0,21^{a}$	26,69

Description: Different letters behind the numbers indicate statistical significant difference.

Table 3. Effect of packaging type and storage time of FHR toward ash content

Storage time	Ash content (%)	
	Black plastic	Tarpaulin
0 day	0,63 ± 0,10	0,63 ± 0,10
1 day	0,78 ± 0,06	0,72 ± 0,00
2 days	0,66 ± 0,07	0,73 ± 0,13
3 days	0,68 ± 0,08	0,80 ± 0,09
4 days	0,74 ± 0,15	0,72 ± 0,01
5 days	0,68 ± 0,16	0,62 ± 0,06

Crude fibre content

Crude fibre forms part of food fibre that has insoluble quality, consists of cellulose, hemicellulose and lignin. Fibre content of milled rice in this research ranged between 1.22-2.40 % (Table 4), while according to Champagne et al. (2004) fibre content of milled rice ranged between 0.7–2.3 %.

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Table 4. Effect of packaging type and storage time of FHR on crude fibre content

Storage time	Crude fibre content (%)		Changes in crude fibre content (%)	
	Black plastic	Tarpaulin	Black plastic	Tarpaulin
0 day	1,22 ± 0,10^{abc}	1,22 ± 0,10^{abc}	0,00	0,00
1 day	1,27 ± 0,24^{abc}	1,04 ± 0,00^{a}	3,99	-14,79
2 days	1,67 ± 0,17^{def}	1,46 ± 0,00^{bcd}	37,11	19,27
3 days	1,87 ± 0,18^{ef}	1,16 ± 0,00^{ab}	53,48	-5,33
4 days	1,56 ± 0,24^{de}	1,55 ± 0,31^{cde}	27,86	26,62
5 days	1,63 ± 0,28^{de}	2,40 ± 0,34^{f}	33,69	96,46

Description: Different letters behind the numbers indicate statistical significant difference

The analysis of variance result showed that interaction between packaging type and storage time, and single factor of storage time had an effect on the fibre content. Then LSD test was conducted, the result of which can be seen in Table 7.

The result of LSD test showed that the highest crude fibre content was obtained from tarpaulin packaging with storage time of five days (2.40%) but did not significantly differ from black plastic bag packaging with storage time of 2 and 3 days, whereas the lowest being of control (1.22%). This showed that there was an increase in fibre content during storage. The percentage of increase of fibre content of each treatment varied between 3.99–96.56 %. This increase of crude fibre content was presumed to have related with the decrease of rice milling level by the longer storage because of the hardening of rice kernel, so during milling aleurone layer was much left in the rice kernel surface. During storage there was an increase in the number cell wall remainder on the rice that strengthened the rice structure (Zhou et al., 2016). Cell wall consists of cellulose and hemicellulose that forms part of crude fibre component.

Carbohydrate content

Carbohydrate is the biggest component in rice whose main composer is starch. In this research crude fibre was not included in the carbohydrate component but rather analysed separately. Carbohydrate content of rice as a result of FHR storage ranged between 76.92–78.62 % (Table 5). The analysis of variance result showed that interaction between packaging type and storage time affected carbohydrate content. Then LSD test was conducted whose result can be seen in Table 8

Table 5. Effect of packaging type and storage time of FHR toward carbohydrate content

Storage time	Carbohydrate content (%)		Change in carbohydrate content (%)	
	Black plastic	Tarpaulin	Black plastic	Tarpaulin
0 day	78,31 ± 0,30^{cd}	78,31 ± 0,30^{cd}	0	0
1 day	78,10 ± 0,18^{cd}	78,36 ± 0,33^{cd}	0,27	-0,06
2 days	77,93 ± 0,45^{bcd}	77,40 ± 0,80^{ab}	0,49	1,17
3 days	77,71 ± 0,19^{abc}	78,62 ± 0,23^{d}	0,77	-0,40
4 days	77,87 ± 0,21^{bcd}	77,83 ± 0,53^{bcd}	0,57	0,62
5 days	78,06 ± 0,62^{bcd}	76,92 ± 1,04^{a}	0,33	1,78

Description: Different letters behind the numbers indicate statistical significant difference

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Rice that has the highest carbohydrate content was that of tarpaulin packaging, stored for three days (78.62 %), but it did not differ significantly from control or other treatments. Carbohydrate content during storage tended to slightly decrease, with the percentage of carbohydrate content decrease ranged between 0.27–1.78 %. The decrease of rice carbohydrate was caused by the rise of other chemical components, such as protein and crude fibre, so it would directly decrease the carbohydrate content.

The main carbohydrate in rice is starch, and starch is an inert compound so the change in rice starch content during storage was not significant (Zhou et al., 2015). During storage there was a change in starch structure as a result of endogenic starch activity, that resulted in the decrease in long chain percentage and the increase in short chain of amylopectin during storage, especially at higher temperature and in longer time (Huang and Lai, 2014).

Cooking Quality

Cooking quality of rice was mainly determined by water absorption capacity, volume expansion and dissolved solid in the cooking water. The research result showed that changes in water absorption capacity, volume expansion and dissolved solid were relatively small and did not influenced by packaging type and storage time, except for water absorption capacity. This was presumably because the temperature difference between that inside the packaging and the small room temperature ranged 1–2 ^{o}C (see Figure 1), so it did not significantly affect reaction speed occurred in the rice. Changes would be greated if the temperature was higher (Barber, 1972; Millati, 1994; Villareal et al., 1976; Zhou et al., 2007).

Water absorption capacity

Water absorption capacity and volume expansion are physicochemical properties that were expected to increase during storage. The increase of volume expansion and water absorption ran parallelly (Barber, 1972). In this research, water absorption capacity during rice cooking ranged between 235.34–298.27 %. The analysis of variance result showed that interaction between packaging type and storage time, as well as single factor of storage time duration significantly influenced water absorption capacity. Subsequently LSD test was conducted whose result can be seen in Table 6.

The highest water absorption capacity was obtained from black plastic bag packaging after three days of storage time, i.e. 289.59 % and differed significantly from other treatments except from black plastic bag packaging after two days of storage time. In tarpaulin packaging, the highest water absorption was obtained after three days of storage, i.e. 272.11 %, but it did not differ from that of four and five days of storage time of the same packaging and of two days of plastic bag packaging. The result showed that water absorption capacity of rice stored in black plastic bag packaging was higher than that in tarpaulin packaging.

Amylopectin chain termination by rice amylase resulted in higher formation of amylopectin of shorter chain, leading to wider surface area that could absorb water, so the granule could expand larger (Huang and Lai, 2014). Higher water absorption was allegedly because of the fragmentation of starch and protein so the area that could bind the water was larger. Whereas Soponronnarit et al. (2008) stated that increase in water absorption capacity and rice volume expansion were because rice cell wall became stronger, due to the gelatinated starch being able to maintain hexagonal shape, that facilitated higher water absorption. According to Sabularse et al. (1991), there was a decrease in water absorption after three months of storage, but other researchers stated that there was an increase in water absorption after 12 months of storage. The level of hydration and volume expansion of aged rice decreased and starch granule was more resistant to damage due to cooking (Zhou et al., 2016).

p ISSN: 2354-5844
e ISSN: 2477-5223

Table 6. Effect of packaging type and storage time of FHR toward water absorption capacity

Storage time	Plastic	Tarpaulin
0 day	241.63 ± 4.63[bc]	241.63 ± 4.63[bc]
1 day	256.60 ± 13.02[cde]	244.79 ± 7.19[cd]
2 days	277.55 ± 14.95[fg]	240.58 ± 14.04[bc]
3 days	289.59 ± 7.69[g]	272.11 ± 8.47[ef]
4 days	225.91 ± 11.39[ab]	259.77 ± 11.24[de]
5 days	220.87 ± 2.15[a]	271.69 ± 3.24[ef]

Description: Different letters behind the numbers indicate statistical significant difference

Volume expansion

During cooking of raw rice into cooked rice there was a volume expansion of rice. Rice volume expansion of this research result ranged between 252–287 % (Tabel 7). The analysis of variance result showed that there was no interaction effect between packaging type and storage time, as well as single factor of packaging type and storage time duration, even though there was a tendency of volume expansion value to increase until the third day of storage, and then dropped back though still higher than that of control.

Table 7. Effect of packaging type and storage time of FHR toward volume expansion

Storage time	Volume expansion (%)	
	Black plastic	Tarpaulin
0 day	261 ± 36	261 ± 36
1 day	281 ± 28	274 ± 14
2 days	287 ± 27	277 ± 19
3 days	286 ± 35	287 ± 29
4 days	263 ± 18	282 ± 36
5 days	280 ± 16	252 ± 28

Increase of rice volume expansion during cooking was relatively small that was allegedly because during storage there was a formation of amylose-lipid complex that would hamper volume expansion. Expansion behavior of cereal starch was mainly influenced by amylopectin content, whereas amylose hindered the expansion mainly due the presence of fat.

Dissolved solid

Dissolved solid is starch that escaped from starch granule during cooking process. Dissolved solid could be used as cooking quality indicator, because dissolved solid would influence the appearance of cooked rice. When dissolved solid content was high, the cooked rice tended to become porridge, the rice kernel was broken and sticked to each other, conversely when dissolved solid content was low it would produce unbroken rice kernel and not sticked to each other.

Table 8. Effect of packaging type and storage time of FHR toward dissolved solid

Storage time	Dissolved solid (%)	
	Black Plastic	Tarpaulin
0 day	3,06 ± 0,12	3,06 ± 0,12
1 day	2,67 ± 0,17	3,75 ± 0,15
2 days	2,96 ± 0,05	4,24 ± 0,39
3 days	2,89 ± 0,40	4,38 ± 0,02
4 days	3,68 ± 0,27	3,38 ± 0,27
5 days	2,75 ± 0,32	3,56 ± 0,26

Rice dissolved solid of the research result ranged between 2.67–4.38 % (Table 8). The analysis of variance result showed that there was no interaction effect between packaging type and storage time, as well as single factor of packaging type and storage time toward dissolved solid. Although it was not influenced by the packaging type and storage time, but there was a tendency the dissolved solid in the tarpaulin packaging to be higher than that in the black plastic bag. This was related to RH and grain moisture, where in the tarpaulin packaging they were higher than that in the black plastic bag. So in the tarpaulin packaging, the starch digesting enzyme would probably be higher, and compound with shorter chain readily solved in water was higher.

p ISSN: 2354-5844
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CONCLUSIONS

Accumulation of respiration heat of FHR during storage was only able to increase the temperature in the packaging of up to 28–31 ^{o}C, slightly higher than the room temperature that ranged 26–29 ^{o}C. Packaging type and storage time used in the utilization of respiration heat could increase water absorption capacity, protein and crude fibre content, and decrease fat and carbohydrate content. The highest increase of water absorption capacity was produced by black plastic bag packaging with storage time of three days, i.e. 289.59 % (increased by 27.74 % compared to control), the highest protein content was of two days storage with protein content of 8.56 % (increased by 7.31 % compared with control), fibre content by the tarpaulin packaging with storage time of five days, i.e. 2.40 % (increased by 96.46 % compared with control).

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