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EFFECT OF DRYING AND MILLING MODES ON THE QUALITY OF WHITE RICE OF AN INDONESIAN LONG GRAIN RICE CULTIVAR

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ABSTRACT

Background. Many studies have revealed the susceptibility of long grain rice to breaking during milling, while others have demonstrated the variation in the yield of head rice due to different rough rice drying methods. Thus, this study aims to determine appropriate drying and milling methods to improve the head rice yield and nutritional quality of long grain rice.

Materials and methods. A series of drying experiments were performed on rough paddy rice employing shallow bed, oven and sun drying methods. Then, the dried rough rice grains were milled with various dehusking (H), separation (S) and polishing (P) configurations to obtain white rice. The resulting batches of white rice were analyzed and compared in terms of head rice yield, broken rice yield, brewer yield, whiteness and nutritional quality.

Results. Milling configurations strongly affected the total, head rice, broken rice and brewer yields. The configuration of one dehusking, one separation and one polishing (H – S – P) resulted in the highest milling and head rice yields. Although the whiteness of the rice samples was significantly affected by the milling configuration, their values fell within an acceptable range preferred by consumers in Southeast Asia (39–47). The milling of dried rough rice obtained from shallow bed and sun drying using a concrete floor and white tarpaulin resulted in a comparable total (65%) and head rice yield (51%). However, the milling of rough rice dried using an oven and sun drying on black tarpaulin resulted in a slightly lower total yield (64.50%) and head rice yield (50.50%). The moisture, ash, protein and lipid contents of the white rice were significantly lower than those of manually dehulled rice, whereas the carbohydrate and amylose contents of the white rice were significantly higher.

Conclusion. Application of shallow bed or sun drying on a concrete floor followed by milling with the H – S – P configuration produced the highest head rice yield with an acceptable whiteness and nutritional composition. These combined postharvest technologies are simple, efficient and economical for both small- and large-scale applications. Further research on consumer acceptance and on the nutritional and cooking qualities of the white rice obtained from these combined postharvest technologies is essential.

Keywords: drying mode, milling configuration, yield, whiteness, nutritional content

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INTRODUCTION

Rice (*Oryza sativa* L.) is one of the key food crops in the world, serving as a staple food and main economic contributor for the people of the Asian continent (Kamin and Janaun, 2017). Due to their fluffy texture, Situ Bagendit and Ciherang are the most popular long grain rice cultivars grown in Indonesia. However, long and tiny rice kernels are more vulnerable to breaking during the milling process when compared to wide, short rice kernels. The economic value of rice strongly depends on the milled rice yield (MRY), head rice yield (HRY) and its quality. Saeed and Mohammad (2013) observed that the quality of milled rice is affected by the moisture content (MC) of the grains during harvesting, drying, milling and storage. Siebenmorgen et al. (2009) found that the optimal harvest moisture content for long grain rice cultivars generally ranges from 18% to 22% wet basis (w.b.). Unfortunately, farmers in tropical countries commonly harvest their paddy rice at a MC between 20% and 28% (w.b.), which can lead to a loss of quality in the rice (Hung et al., 2019). Rough paddy grains have to be dried to a MC below 14% (w.b.) for safe storage, while the ideal MC of a paddy for milling exists between 13% and 14% (w.b.) (IRRI, 2013).

Since the drying process affects the milling yield and head rice quality, a proper drying method to lower the MC of rough rice to 12–14% (w.b.) is crucial (Poomsa-ad et al., 2005). During drying, the heat flow induces the development of moisture and temperature gradients and thermal stress inside the rice kernel, leading to the formation of fissures on the kernel. Usually, fissured kernels break easily during milling causing a serious reduction in the head rice yield, cooking qualities and market value (Zhang et al., 2005). In most parts of Southeast Asia, rice mill industries in rural areas prefer to use outdoor concrete floors for sun drying of rough paddy rice instead of modern mechanical dryers, while small rural farmers usually utilize tarpaulins or traditional mats made from bamboo or pandan tree fibers. The slow drying rate of rough paddy rice on a concrete floor favors a higher milling yield than drying on a mat (Imoudu and Olufayo, 2000). Xangsayasane et al. (2019) found that sun drying only in the morning with intermittent stirring results in a higher head rice yield when compared to drying for the whole day. Although sun drying is cheap, easy and efficient for large scale operations, it requires a spacious area, labor and high dependence on good weather conditions.

For commercial applications, convective drying of rough paddy rice, either using hot air, steam, or flue gas is more feasible than sun drying. The flat bed dryer, recirculating batch columnar dryer and fluidized bed dryer are the most common drying equipment applied in Southeast Asia (Hung et al., 2019). In order to save energy, obtain high head rice yields and avoid rice yellowing, Jittanit et al. (2010) suggested that freshly harvested paddy rice should immediately be dried using hot air at 100–110°C to promote a rapid drying rate until the MC is 18–19% (w.b.). Then, the rough paddy rice is tempered for a specific period of time and dried further using ambient air to allow a slow drying rate to attain an MC of 12–14% (w.b.). Instead, rough paddy rice can be dried by solar drying at 45–55ºC as the allowable air-drying temperature for maximum head rice yield (Mehdizadeh and Zomorodian, 2009). However, mechanical drying methods are limited by their low drying and thermal efficiencies, and the tendency of a reduction in head rice yield and milled rice quality.

Paddy rice comprises a husk (18–28%) and caryopsis or brown rice (72–82%). The brown rice itself is composed of an external surface layer called bran (6–7%), the germen (2–3%) and the edible portion (89–94%) (Chen et al., 1998). Milling of dried paddy rice is performed to obtain the edible parts for consumption by removing the husk (dehusking), followed by some necessary bran removal steps (polishing). Milling yield is highly influenced by the quality of paddy rice, varieties used, type of milling equipment, milling cylinder speed, degree of milling, temperature and duration, cooling method, milling configuration, and head rice separation method (Schluterman and Siebenmorgen, 2007). For that reason, IRRI recommends a safe moisture content of paddy for milling ranging from 13% to 14% (w.b.), at which paddy can resist maximum compressive strength (IRRI, 2013). Instead of automatic rice mills, husky rice mills are more preferred by Indonesian rice mill unit owners. Hasbullah and Dewi (2012) found that the H – S – P (one dehusking, one separation and one polishing) milling configuration resulted in the highest milling yield and a considerably low milling loss in three

Indonesian long grain rice cultivars (Ciherang, Cibogo and Hidbrida). They also observed that the addition of a separator facilitates an increase in the milling yield of an average of 1.0%. During milling, brown rice is subjected to abrasive or friction pressure to remove bran layers resulting in high, medium or low degrees of milling (Chen et al., 1998). Because the bran layers, germ and outer layer of the caryopsis are rich in protein, lipid, fiber, vitamins and minerals, milling may cause significant loss of these nutrients (Chen et al., 1998). In addition, excessive milling also induces a loss in white rice yield (Laokuldilok et al., 2013). However, getting rid of rice bran layers also significantly enhances the appearance, cooking quality, and palatability of rice (Suwannaporn et al., 2007). Hence, the development of rice processing methods which obtain rice with the lowest breakage, preserved nutrients and more desirable cooking properties is important for rice processing enterprises.

Most of the studies conducted on paddy rice were done from an agronomical point of view, while only a few works focused on the aspects of postharvest processing. The objective of this study was to investigate the effects of drying modes (sun, oven and shallow bed) and milling configurations of rough paddy rice on the yield and nutritional quality of white rice.

MATERIALS AND METHOD

Materials

Freshly harvested paddy rice of Situbagendit cultivar was collected from rice farms in Karanganyar Regency, Central Java Province – Indonesia. Prior to drying and milling experiments, the rice straws, soils, and other impurities of the paddy rice were removed.

Shallow bed drying

The drying experiment began with a preheating of the drying air to 50°C at a flow rate of 5 m/s in a shallow bed dryer. The temperature and relative humidity of the air were confirmed by a digital anemometer (Amtast, AM-4836C, Indonesia). Once the desired drying air condition was established, the pre-weighed (5 kg) paddy rice was carefully placed in the drying chamber forming a 3–5 cm bed thickness. Every 10 min, the MC of the paddy rice was measured using a moisture meter (G-Won, GMK-303 RS Model, Korea) and was recorded. The experiment was stopped when the MC of the paddy rice was about 13% (w.b.). Each drying experiment was done in triplicate and the results were reported as the average of them.

Sun drying and oven drying experiments

The sun drying operation was conducted at 7.00 a.m. – 12.00 p.m. by evenly spreading 5 kg of rough paddy rice onto a concrete floor or tarpaulin (white and black in color) while keeping the rice layer thickness to about 2–5 cm. The temperature, relative humidity and velocity of the ambient air during the experiments were 35.9 ±1.65°C, 41.5 ±3.15% and 3.47 ±0.41 m/s, respectively. The rough rice was then exposed to direct sunlight, wind and other atmospheric conditions. During the drying process, the MC of the rough paddy rice was measured at 30 min intervals using a moisture meter, followed by a manual stirring of the rough paddy rice to ensure even drying. Once the targeted MC of 13% (w.b.) was reached, the dried paddy was collected, packed into sealed plastic bags and stored in ambient conditions for further analysis.

Oven drying was carried out by evenly spreading 5 kg of paddy rice onto aluminum pans with a 2–5 cm layer thickness and placing the pans in an electric oven at 50°C. The subsequent drying procedures were the same as those employed for sun drying. In both drying methods, the drying process was done in triplicate and the reported data were the average of them.

Milling process

Prior to the milling test, triplicate samples of rough paddy rice were re-cleaned using a small cleaner just one night after the drying process. Two hundred grams of dried rough paddy rice from each sample was dehusked using a rubber roller dehusker (Satake Rice Machine, Type-THU-35, Satake Eng. Co. Ltd., Japan). Then, the dehusked rice samples were further polished using an abrasive type rice polisher (Satake TM-05, Satake Eng. Co. Ltd., Japan) for 2 min at 1,450 RPM. Milling processes with the configurations presented in Table 1 were performed in triplicate and the reported data were the average of them.

Quality analysis

The head rice, broken rice and brewers were separated using a rotating sieve (Test Rice Grader, TRG058

Model, Satake Eng. Co. Ltd., Japan). A kernel with 75% or more intact was considered to be head rice. Head rice, broken kernels and brewer yield are defined as the ratio of the head-rice, broken rice and brewer mass to the original paddy mass (IRRI, 2013).

Whiteness. The whiteness of milled rice samples was judged with a commercial whiteness meter (Model MM1-B, Satake Engineering Co., Tokyo, Japan). This apparatus reports the whiteness index (WI) linearly from 0 (perfect black surface) to 100 (whiteness of magnesium oxide fumes). The apparatus was calibrated against a ceramic plate with a WI of 85.2.

Nutritional composition. The moisture content of the rice was determined by weighing the grains before and after the drying process in an oven at 105 ±3°C with natural air circulation for 24 hours. The ash content was examined by the AACC method 08-01 (AACC, 2000), while the protein content was measured using an automatic Kjeldahl apparatus following the AACC method 46-13 (AACC, 2000). The crude fat content was analyzed by Soxhlet extraction according to the AACC method 30–20 (AACC, 2000). The carbohydrate content was then calculated by difference. The amylose content was determined by spectrophotometry assay, as suggested by Avaro et al. (2011). All measurements were performed in triplicate.

Statistical analysis

All experiments were done in triplicate and the data were analyzed statistically using Statistica 10 software (StatSoft Inc., USA). For multiple comparisons, one-way analysis of variance (ANOVA) was performed. The significance of differences between means was judged based on Tukey's test at the significance $\alpha = 0.05$.

RESULTS AND DISCUSSION

The effects of drying mode and milling configuration on milling yield

The total, head rice, broken rice and brewer yields of white rice obtained from the milling of dried rough paddy rice are presented in Table 1. The total milling yields achieved in this study ranged from 60% to 67%, and were within the range of the average milling yield of Indonesian rice mill industries (Tjahjohutomo et al., 2004). It can also be observed that polishing reduces the total and head rice yield of white rice (Laokuldilok et al., 2013). Although the inclusion of a separation step between dehulling and polishing slightly reduces the total yield, it significantly enhances the head rice yield. Milling of dried rough paddy rice using the H – P configuration resulted in the highest total yield of white rice, but a lower value of head rice yield. Similar to Hasbullah and Dewi (2012), the highest head rice yield was obtained from milling dried rough paddy rice using the H – S – P configuration. In addition, the total yield of white rice of this milling configuration is still comparable to that produced when using the H – P configuration. Using the H – S – P milling configuration, the broken rice yields for rough rice dried using a shallow fluidized bed dryer, sun drying, and oven drying were all about 26%, which were within 20–30% as reported by Arora et al. (1973).

Sun drying of rough paddy rice using a concrete floor resulted in the highest total yield of white rice and a lower percentage of broken grains than drying on a mat. Similar findings were reported by Imoudu and Olufayo (2000). This was probably because the paddy dried on a concrete floor took a longer time to attain the desired moisture content than did that dried on a mat. A lower rate of drying of rough paddy rice should result in a higher milling yield (Zhang et al., 2005). It is also clear that drying using shallow bed and sun drying using a white tarpaulin produced similar values of total and head rice yields. Similarly, the values of total and head rice yields of rough rice dried using sun drying on a black tarpaulin surface and an electric oven are close to each other. Broken and brewer rice produced during milling is the result of large moisture and temperature gradients in the grain occurring during rapid drying. This causes the development of compressive stresses at the grain surface and tensile stresses at the centre. When the compressive stresses exceed the tensile stresses of grain at its centre, grain cracking develops, leading to less mechanical resistance during milling (Poomsa-ad et al., 2005). Poor air ventilation and excessive heat adsorbed by black tarpaulin may be related to the susceptibility of fissured grain to be broken at the time of milling. Thus, it appears that the harsher drying conditions of black tarpaulin over concrete and white tarpaulin sun drying

Table 1. Milling yield and whiteness of rice from various drying and milling modes

Milling configurations	Yield, %				Whiteness
	total	head rice	broken rice	brewers	
Configurations for milling of dried paddy rice from shallow fluidized bed drying					
H – P	67.29 ±0.23^{a}	43.50 ±0.23^{a}	30.21 ±0.11^{a}	26.30 ±0.40^{a}	40.90 ±0.20^{a}
H – 2P	66.70 ±0.27^{b}	41.65 ±0.22^{b}	28.86 ±0.27^{b}	29.50 ±0.15^{b}	42.10 ±0.15^{b}
2H – P	62.48 ±0.30^{c}	40.88 ±0.29^{c}	30.48 ±0.17^{a}	28.64 ±0.16^{c}	41.50 ±0.02^{c}
2H – 2P	61.47 ±0.10^{d}	40.20 ±0.07^{d}	29.81 ±0.40^{a}	29.99 ±0.10^{d}	42.45 ±0.34^{b}
H – S – P	65.19 ±0.23^{e}	51.29 ±0.34^{e}	25.74 ±0.29^{c}	22.97 ±0.27^{e}	41.30 ±0.04^{d}
H – S – 2P	64.73 ±0.20^{e}	49.87 ±0.41^{f}	26.56 ±0.07^{d}	23.57 ±0.11^{f}	42.40 ±0.03^{b}
2H – S – P	60.53 ±0.06^{f}	47.80 ±0.50^{g}	28.04 ±0.38^{bc}	24.17 ±0.19^{g}	41.60 ±0.14^{c}
2H – S – 2P	59.72 ±0.30^{g}	46.34 ±0.05^{h}	28.34 ±0.31^{bc}	25.32 ±0.35^{h}	42.80 ±0.13^{b}
H – S – P configuration for milling of dried paddy rice from other drying methods					
Concrete	65.40 ±0.04^{e}	51.21 ±0.22^{e}	25.24 ±0.22^{c}	23.55 ±0.32^{i}	41.53 ±0.10^{ef}
White Tarpaulin	65.15 ±0.19^{e}	51.39 ±0.03^{e}	25.06 ±0.38^{c}	23.55 ±0.06^{f}	41.39 ±0.12^{dfg}
Black Tarpaulin	64.49 ±0.22^{h}	50.56 ±0.18^{f}	26.57 ±0.16^{d}	22.87 ±0.30^{e}	41.36 ±0.09^{dfg}
Electric Oven	64.51 ±0.06^{e}	51.70 ±0.20^{e}	25.86 ±0.22^{c}	22.45 ±0.07^{e}	41.50 ±0.03^{fg}

All reported values in the table are means ±standard deviation.
Means with the same letter are not significantly different from each other (Turkey test, $P < 0.05$).

and fluidized bed drying induced more fissured grains to be broken during milling (Xangsayasane et al., 2019). However, tarpaulin offers operational flexibility because it can be folded to prevent the grain from being exposed to sudden rainfall.

Table 1 shows that intensive polishing processes improve the whiteness of the rice grain. This phenomenon is confirmed by the significant whiteness difference ($P < 0.05$) between white rice obtained from one and two polishing processes. This increase is related to the removal of fat-soluble nutrients and minerals from the bran layers and outer endosperm during the milling process, which are responsible for the yellowish color of brown rice (Monks et al., 2013). Obviously, sun drying and oven drying resulted in slightly higher whiteness levels of milled rice than shallow bed drying (Wongpornchai et al., 2004). Although an increase in the degree of milling may reduce the nutritional value of the rice, milled rice appears to fulfill consumer sensory demands. The Latin Americans prefer a whiter and more translucent product (Monks et al., 2013). Coincidentally, South Asian consumers prefer rice that has great appearance and taste attributes.

The effects of drying mode and milling configuration on the nutritional composition of white rice

Nutritional compositions, which include the protein, lipid, carbohydrate and amylose contents, are usually used as a basis for predicting the uses of a rice lot. In this study, some of the dried rough paddy rice samples were manually dehulled, while the rest of the samples were subjected to several milling configuration steps. The nutritional compositions of the milled rice obtained are presented in Table 2.

Table 2 shows that drying methods and milling configurations affect the moisture content of the white rice. In most cases, the moisture of the white rice decreased significantly ($P < 0.05$) due to the milling process. During milling, the heat generated by intensive friction between the rice kernels and the roller machine increases the thermal stress on the grains (Reddy et al., 2017). As a result, the rice grain temperature increases and induces the diffusion and vaporization of moisture from the inner part to the outer part of the rice kernel.

Generally, the bran layers of the rice caryopsis contain high levels of minerals, which corresponds to an ash content of about 61.0% (Reddy et al., 2017; Lamberts et al., 2007). Table 2 presents an obvious reduction of ash content in white rice due to different milling configurations compared to that obtained from manual dehulling. The ash content reduction varied from 55–76%. These results also proved that polishing removes the outer bran layer of brown rice, which finally reduces the ash content of the white rice. However, in general, the milling configurations did not significantly ($P < 0.05$) affect the ash content of white rice. This result is also in good agreement with Paiva et al. (2014), who found an ash content reduction in polished rice when compared to husked rice.

Table 2 reveals that milling configurations significantly ($P < 0.05$) reduced the lipid contents of rice. Barber (1972) found that a thin bran layer at approximately a 5% degree of milling (DOM) possesses the highest lipid content. The lipid content decreases as the bran layers are further removed. The lipid content continues to decrease during the milling of short and long grain rice varieties until a DOM of 12% is reached (Monks et al., 2013). Lipids may form complexes with amylose and amylopectin, which restrict the swelling of starch granules and the leaching of amylose into water. Therefore, this condition results in a firmer kernel texture (Suwannaporn et al., 2007). Table 2 also shows a significant difference ($P < 0.05$) in the lipid contents of rice obtained from the milling of paddy rice samples dried using sun and oven drying. The rough paddy rice samples obtained from sun drying on a black tarpaulin were more brittle because their moisture content was not uniform due to excessive exposure to heat, which leads to an extremely rapid drying rate. Therefore, the rice kernel has a higher tendency to break during milling and leads to a reduced removal of the bran layers during polishing. However, a milder condition was observed for rough paddy rice samples obtained from sun drying on a white tarpaulin and concrete floor due to a slower drying rate. As expected, the rough paddy rice samples obtained from oven drying had a more uniform moisture content, exhibited lower breakage tendency during milling and led to a higher removal of the bran layers during polishing. This basic advantage of the artificial dryer would be due to the controlled use of heat and the avoiding of excessive heat generated in the early afternoon during sun drying. The rice samples obtained from the H – S – P milling sequence of paddy rice samples after sun drying on a concrete and black tarpaulin have comparable lipid levels to rice samples obtained from the H – P milling sequence of paddy rice dried using shallow fluidized bed drying. The separation stage functions to remove dry matter, including the rice husk and the lipid rich rice bran, from the rice grain kernel. Therefore, although the H – P milling sequence results in a lower head rice yield, it retains more lipids in the rice kernel. On the other hand, the H – S – P milling sequence results in a higher head rice yield but also a higher loss of lipid rich rice bran from the rice grain kernel. It is also obvious that the rice samples obtained from the H – S – P milling sequence and shallow fluidized bed drying have significantly greater losses of lipids. Because of their similar size, the separation of whole and broken rice husks and the rice kernel obtained from one dehusking stage (H) is more difficult than that of two dehusking stages (2H), which requires a longer time. Therefore, the lowest value of lipid content in rice kernels obtained from the H – S – P milling sequence may be due to the oxidation of lipids because the lipids in rice grains are mostly unsaturated, which makes them susceptible to oxidation by atmospheric oxygen during this long separation stage. In addition, re-adsorption of lipids to the rice husk particles may also occur during this long separation stage.

The protein contents of white rice obtained from milling processes employing one and two polishing are significantly different ($P < 0.05$). In general, the two polishing removes more of the outer bran layer resulting in a lower value of protein contents. However, there is a contradiction of the protein content of rice samples obtained from the H – S – P and H – S – 2P milling sequences of paddy rice dried using shallow fluidized drying. These results might be due to irregular milling processes that are prone to occur in the laboratory scale milling apparatus, which is triggered by the relatively lower hardness of the rice kernels due to their higher temperatures and moisture contents.

Table 2. Nutritional content of rice from various drying and milling modes

Milling configurations	Nutritional quality parameters, %					
	moisture	ash	lipid	protein	carbohydrate	amylose
Manually dehulled	17.70 ±0.29	1.01 ±0.02	2.64 ±0.04	6.93 ±0.18	71.72 ±0.27	21.58 ±0.13
Configurations for milling of dried paddy rice from shallow fluidized bed drying						
H – P	10.79 ±0.01^{a}	0.34 ±0.04^{a}	1.36 ±0.14^{a}	7.10 ±0.30^{a}	80.41 ±0.03^{a}	26.29 ±0.31^{a}
H – 2P	10.47 ±0.02^{b}	0.32 ±0.03^{a}	0.44 ±0.04^{b}	6.28 ±0.17^{b}	82.49 ±0.04^{b}	26.36 ±0.21^{a}
2H – P	10.55 ±0.03^{c}	0.35 ±0.04^{a}	0.79 ±0.04^{c}	6.39 ±0.09^{b}	81.92 ±0.12^{c}	27.02 ±0.44^{ac}
2H – 2P	10.39 ±0.02^{d}	0.29 ±0.01^{a}	0.43 ±0.02^{b}	6.08 ±0.11^{b}	82.81 ±0.17^{b}	24.99 ±0.32^{b}
H – S – P	10.62 ±0.01^{e}	0.49 ±0.02^{b}	0.42 ±0.03^{b}	5.72 ±0.11^{c}	82.75 ±0.16^{b}	25.82 ±0.11^{a}
H – S – 2P	10.46 ±0.04^{b}	0.30 ±0.02^{a}	0.64 ±0.01^{d}	6.80 ±0.12^{a}	81.80 ±0.13^{c}	27.79 ±0.23^{ac}
2H – S – P	10.56 ±0.02^{c}	0.31 ±0.02^{a}	0.50 ±0.06^{b}	7.61 ±0.03^{d}	81.02 ±0.06^{d}	27.77 ±0.16^{cd}
2H – S – 2P	10.54 ±0.02^{c}	0.24 ±0.03^{c}	0.79 ±0.04^{c}	6.78 ±0.09^{a}	81.65 ±0.11^{c}	27.56 ±0.02^{cd}
H – S – P configuration for milling of dried paddy rice from other drying methods						
Concrete	10.42 ±0.02^{f}	0.45 ±0.04^{be}	1.37 ±0.05^{a}	7.12 ±0.15^{a}	80.61 ±0.09^{e}	27.76 ±0.29^{e}
White Tarpaulin	10.22 ±0.03^{g}	0.40 ±0.02^{cf}	0.66 ±0.02^{d}	7.77 ±0.21^{e}	80.85 ±0.17^{e}	24.45 ±0.15^{b}
Black Tarpaulin	10.60 ±0.02^{h}	0.35 ±0.03^{df}	1.35 ±0.06^{a}	6.41 ±0.16^{f}	81.29 ±0.31^{d}	25.80 ±0.36^{af}
Electric Oven	10.44 ±0.01^{i}	0.39 ±0.03^{ef}	0.61 ±0.03^{d}	6.45 ±0.07^{f}	82.11 ±0.14^{b}	25.37 ±0.16^{f}

All reported values in the table are means ± standard deviation.
Means with the same letter are not significantly different from each other (Turkey test, $P < 0.05$).

Removal of heat from rice kernels caused by friction and abrasion in the laboratory (small) scale milling apparatus is minimal. For brown rice with higher kernel temperatures and moisture contents, it is difficult to achieve an effective milling process with a homogeneous surface of milled rice. Therefore, commercial rice mill enterprises operate industrial milling equipment to reduce mechanical stresses and heat buildup in the grain, to minimise grain breakage and produce more uniformly polished grain (Kalpanadevi et al., 2018). A previous study by Paiva et al. (2016) revealed the protein contents in the bran (15.8%) and the outer endosperm (12.8%), and that the highest protein content is located in the endosperm (57.0%). Protein plays an important role in the texture of cooked rice because the protein forms a complex with starch that hinders starch granule swelling. Therefore, white rice with a high protein content is less sticky and exhibits a harder texture (Suwannaporn et al., 2007). Rice with a higher degree of polishing offers better cooking quality because of textural changes, which is due to the removal of dietary fiber and a reduction of protein contents (Park et al., 2001).

According to Lamberts et al. (2007), the starch content is highest in the core endosperm. The two polishing removes more outer bran layer, aleurone and germ portions leaving behind the starchy endosperm resulting in a higher value of carbohydrate contents (Reddy et al., 2017). There are significant differences ($P < 0.05$) between the carbohydrate contents of white rice obtained from milling processes employing one and two polishing. However, there is a contradiction of the carbohydrate content of rice samples obtained from the H – S – P and H – S – 2P milling sequences of paddy rice dried using shallow fluidized drying. In this study, the carbohydrate contents were calculated by difference. Therefore, their values varied following the changes in other nutrient constituents. In addition, the susceptibility of the laboratory scale milling apparatus to irregular milling processes is likely to be the main cause of this phenomenon, which is similar to what happens to the protein content. (Kalpanadevi et al., 2018).

The manually dehulled rice contains a medium amylose content (21–25%). The milling process removes the bran layers adhering to the endosperm, which contain moisture, protein, ash, fiber and lipid. As a consequence, the amylose content of the white rice increases by approximately 13–29% resulting in white rice with a high amylose content (25–33%) (Suwannaporn et al., 2007). Fortunately, increased amylose content due to milling offers better cooking quality. Milling configurations do not significantly ($P < 0.05$) affect the amylose content of white rice obtained from rough paddy rice dried using shallow bed drying. In contrast, drying modes significantly influence ($P < 0.05$) the amylose content of white rice.

CONCLUSION

It was proven that the drying of rough paddy rice using a shallow fluidized bed dryer or sunlight on a concrete floor followed by milling with the H – S – P configuration results in the highest head rice yield with an acceptable whiteness and nutritional composition. Since sun drying of rough paddy rice will continue to be widely practiced by small rural farmers in developing countries, for the best results it is suggested that the paddy is dried to an MC of 12–14% on a concrete floor in the morning. The moisture, ash, protein and lipid contents of the white rice were lower than those of manually dehulled rice, whereas the carbohydrate and amylose contents were significantly higher. This information is useful for feasible white rice production by small farmers and large enterprises.

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