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Chemical and Physical Characterizations of Cooked Rice Using Different Cooking Methods

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Abstract Various cooking methods: conventional (CV), rice cooker (RC), and steam (ST) were applied to Black rice, Brown rice, semi-organic white rice (Berlian sae), and organic white rice (Slyp super). The aim is to explore the effect of various cooking methods on different types of rice, including its eating quality. The uncooked and cooked rice were analyzed for chemical and physical characteristics including water, ash and nutrient content, morphology using Scanning Electron Microscopy, crystallinity using X-ray diffraction (XRD) analysis, and thermal property using simultaneous Thermogravimetry/Differential Thermal Analysis (TG/DTA) analysis. It was demonstrated that different results of organoleptic, nutrient and physical properties changes occurred when the rice is processed with the commonly used cooking methods. The results can be taken into consideration in choosing the method for particular rice varieties and the intended result. Cooked brown and black rice less likable in organoleptic than white rice. Brown rice is less preferred using conventional if the better texture wants to be achieved and can still be optimized with two other methods. For Berlian Sae, the steam method is less preferred for the two varieties if better taste wants to be achieved.

Keywords: rice, cooking methods, eating quality, nutrient content, crystallinity, thermal property

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1. Introduction

White, brown and black rice are widely consumed rice in Indonesia, with white rice is the most among all. Rice contains about 80% carbohydrates, 7–8% protein, 3% fat, and 3% fiber [1]. The composition depends on the variety and cooking method applied [2]. Brown and black rice contain pigments that can be distinguished by the kernel color due to the deposit of the compounds [3]. Rice variety can be classified based on the amylose content as very low content of amylose (<10%), low content of amylose (10-20%), intermediate content of amylose (20-24%) and a high content of amylose (>25%) [4]. Amylose, along with amylopectin, also has a major role in determining the characteristic of rice, especially the texture. Rice with low amylose content has a soft and sticky texture and vice versa [5]. Different rice varieties also have different physical properties. A study reported that non-organic white rice has a hardness value of 6.99 KgF, non-organic brown rice has a value of 6.74 KgF, and the hardness of non-organic black rice is 6.48 KgF [6].

To achieve the complete starch gelatinization and desirable texture, rice must be cooked properly. Also, cooking improves the bioavailability of the nutrients through inactivating the associated antinutritional factors [7]. Various ways of cooking, ranging from the very traditional to modern methods are applied, depending on the people's lifestyle and habits, as well as their knowledge. The method of cooking in which the gelatinization process is in general influenced by the temperature and addition of water will determine many factors: texture, taste, lifetime, and more importantly the nutrition content. Different types of rice might need a specific method of cooking to obtain the ideal condition of the cooked rice. The cooking method using a rice cooker, conventional/traditional, and steam (*Au Bain Marie*) are three methods commonly used in the Country. Rice cooker only need one step where water and rice were put into the apparatus then being heated until the device automatically turned off. The conventional method consists of boiling the rice until the water reduced before being moved to the rice steamer (*dandang*). Meanwhile, the *Au Bain Marie* method needs two steps with two different pans. This method requires more time since the rice does not touch boiling water directly [8,9]. This study aims to explore the effect of various cooking methods on different types of rice. The parameter includes chemical and physical changes as well as the effect on eating quality.

2. Materials and Methods

2.1. Materials

Four different varieties of rice (Black Rice, Brown Rice, Semi-organic White Rice (Berlian Sae), Organic White Rice (Slyp Super) were obtained from PT Karya Masyarakat Mandiri (Bogor, Indonesia).

2.2. Methods

2.2.1. Cooking Treatment

The cooking procedures applied are shown in Figure 1. The rice-water ratio and the cooking time of each different method and rice are also described [8,9].

2.2.2. Organoleptic Evaluation

The acceptance of respondents towards color, flavor, taste, and texture of the rice was evaluated by Hedonic Scale Test [10].

2.2.3. Chemical Characterization

The macronutrient analysis such as protein (nitrogen total), crude fat and fatty acid, carbohydrate total, and starch content was done by Kjeldahl (Gerhardt, Germany), Soxhlet, Direct Acid Hydrolysis methods, respectively. Water and ash content were also evaluated using the gravimetric method. All chemical characterization methods, including amylose, amylopectin, and the micronutrient such as fiber, vitamin B1, were determined using the standard methods referred to the Indonesian National Standards [11,12].

2.2.4. Physical Characterization

Structural changes occurring during gelatinization was analyzed with the scanning electron microscope (Hitachi SU3500, Japan). The samples were fixed on a brass stub using double-sided tape and then gold coated in vacuum by a sputter coater. The pictures were taken using an acceleration voltage of 10 kV and at 5,000x magnification.

The X-ray diffraction analysis was performed using Bruker D8 Advance (Germany) with CuKα radiation to differentiate between starches and to detect changes in crystallinity brought about by the thermal application and water given during cooking. Dried rice samples were powdered using mortar and pestle. Powdered dried rice samples then placed inside the XRD sample holder and then placed inside the X-ray chamber to be observed.

Thermogravimetry (TG) and differential thermal analysis (DTA) were used to study the thermal dehydration and decomposition behavior of the starch granules in dried uncooked and cooked rice. TG and DTA curves were recorded using a simultaneous Hitachi STA 7200 (Japan) under a 10 mL min^{-1} of airflow and a heating rate of 20°C min^{-1}.
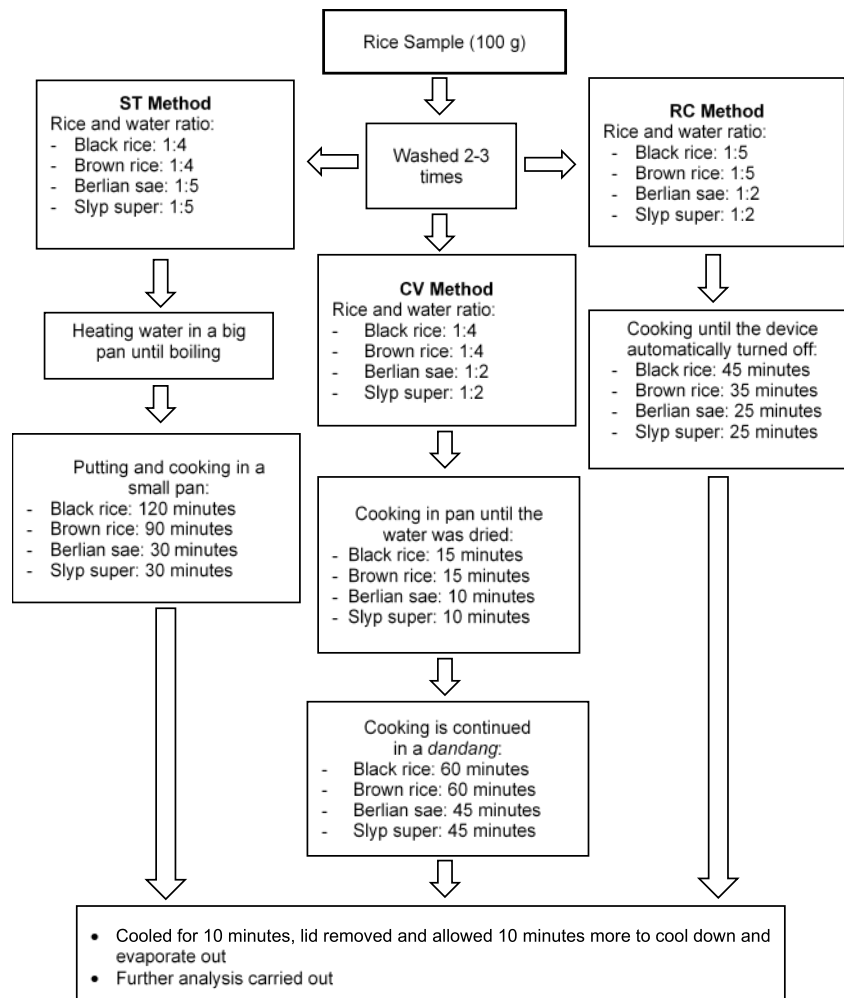

Figure 1. The diagram of cooking procedure applied to different types of rice. RC: Rice cooker, CV: Conventional, ST: Steam

3. Results and Discussion

3.1. Organoleptic Evaluation

Table 1 shows the result of the organoleptic evaluation. Berlian Sae processed with the conventional method of cooking was the most preferred among all processed rice based on color, flavor, and texture. Although, Slyp Super cooked with the steam method had a better score in terms of taste. Brown rice processed with steam and conventional method, respectively, were the least preferred in terms of color and texture. Black rice processed with steam cooking was found to be the least preferred in flavor and taste.

Table 1. Result of Cooked Rice Quality Assessment by Limited Panelist

Type of rice and cooking manner	Assesment value of cooked rice quality			
	Colour	Flavour	Taste	Texture
Black Rice				
Conventional	2.80[a]	2.80[a]	2.60[a]	3.10[b]
Rice coocker	2.67[a]	2.47[a]	2.50[a]	3.10[b]
Steam	2.87[a]	2.07[a]	1.80[a]	3.10[b]
Brown Rice				
Conventional	2.07[a]	2.60[a]	2.07[a]	2.77[a]
Rice coocker	3.07[a]	2.90[a]	2.28[a]	3.03[b]
Steam	1.9[a]	2.30[a]	2.03[a]	3.17[b]
Semi-organic White Rice (Berlian Sae)				
Conventional	4.37[b]	3.77[b]	3.30[b]	3.63[b]
Rice coocker	4.10[b]	3.50[b]	3.33[b]	3.23[b]
Steam	4.03[b]	2.93[b]	2.53[a]	3.33[b]
Organic White Rice (Slyp Super)				
Conventional	4.17[b]	3.33[b]	3.33[b]	3.63[b]
Rice coocker	4.03[b]	3.50[b]	3.30[b]	3.70[b]
Steam	4.07[b]	3.23[b]	**3.37[b]**	3.40[b]

1 = very dislike; 2 = dislike; 3 = average; 4= like; 5= very like.

3.2. Chemical Characteristics of Uncooked and Cooked Rice

The results of chemical characterization are shown in Table 2. Both white rice studied seem to have higher water and ash content. All cooking methods applied in this study result in an increase in water content and a decrease in ash content, as well as almost all other chemical constituents, compared to uncooked samples due to heat during the processes. The combination of lower hardness and water content of white rice might be the reason for the preference of them in the organoleptic test. In addition, the previous study suggested that rice with higher amylose and protein levels, as found in Black and Brown rice, need longer cooking time and more amount of water in cooking [13]. Black and Brown rice seems to have higher amylose and lower amylopectin. Total carbohydrate and amylopectin content are found larger in Brown rice than in Black rice. Both White rice can be categorized as low content of amylose (10-20%), and intermediate content of amylose (20-24%) for Black and Brown rice. The results can be used in assessing the methods giving the most and the least advantages to each variety in terms of minimizing

the nutrient loss, although the preference of which nutrient to be preserved may vary for each people. The results of ash analysis show the amount of mineral contained in the rice. The fact that all cooking processes applied in this study resulting in a decrease in the value indicate that this ingredient is partly lost during the washing and cooking. There is no significant difference in this measure in four rice analyzed both in uncooked and cooked state. For the preservation of particular nutrients, fiber is likely is the constituent that more preserved during cooking of black rice, as well as amylopectin in Berlian Sae. More preserved amylopectin was also achieved when Brown Rice is processed with a rice cooker. The increase in percentage indicates that the mass loss of the nutrient is lower than the others, resulting in an increase in its mass ratio in the cooked rice. The least total carbohydrate, starch, and amylopectin content among all uncooked rice were found in Black rice with 78.94%, 71.05%, and 47.88%. Although, both semi-organic and organic white rice reported having the lowest amylose content with 19.32% and 19.21%, respectively. On the other hand, black rice, and brown rice have the highest level of amylose, protein, fiber, and vitamin B1. There is no significant difference in the content of total fat and fatty acid found. The conventional method decreased the least carbohydrate total in black and brown rice. For Berlian sae and Slyp super, minimizing the loss of this nutrient can be achieved by using rice cooker. The steam process also reduced protein the most for Brown and Black rice, while the most protein loss for Berlian sae and Slyp super found in cooked rice by the conventional method and the rice cooker. A different method is needed if the aim is to maintain the protein level. The conventional method can be used to preserve the carbohydrate and protein levels in black rice. In fact, for this kind of rice, this method can be used to maintain the level of all other nutrients, except fat, which is preferred to be cooked using the steam method. For brown rice, Berlian sae, and Slyp super, the selected methods to maintain protein level are cooking with the rice cooker, conventional, and steam methods respectively. All analyzed nutrients except carbohydrates are better preserved in brown rice when cooked using the rice cooker. Preference of method with simultaneously preserving three nutrients (compared to the others) can also be used for both Berlian sae and Slyp super. The conventional method can be used on Berlian sae to preserve the content of protein, fiber, and vitamin B1. This pattern is similar to the application of the method to black rice. Steam method is the preferred way to preserve the protein, fat, and vitamin B1 in Slyp super, although the highest rate of fiber loss occurs.

3.3. Physical Characteristics of Uncooked and Cooked Rice

SEM Images of uncooked and cooked rice samples with the steam method are shown in Figure 2. The uncooked samples have smoother textures, compared to all cooked rice. The individual uncooked granules are also can be distinguishable easily since they are not fused to each other, which is the common morphological feature of the cooked samples. The starch granules of the cooked samples also seem to be clump under the SEM images,

resulting to be larger in their size. Larger particles indicating the aggregation of the cooked granules are also observed under the SEM images. It confirms that gelatinizations and hydration processes have occurred in all cooked samples and resulting in the changes in the previous well-shaped granules. Heating and the water are given in three cooking methods led to partial disruption and swelling of the starch granules. The changes from the well-shaped granules of the uncooked rice indicate that the gelatinizations and hydration, which are the two main processes in rice cooking that change the rice become soft and more digestible have occurred. There is no distinguishable measure on the effect of three cooking methods on the disruption. However, the cooked samples of Berlian sae and Slyp super seems to still have a lot of small and unfused individual granules that the morphology still can be distinct from each other. The granules swelling is also fewer in these kinds of rice compared to two other samples. The images indicate that the two processes caused by the thermal application and the water given during cooking happened not as much as in the Black and Brown rice. The water uptake, which is needed in both the hydration and gelatinization process, is related to the grain surface area per unit weight [13]. The smaller surface area in that measure, indicated by larger granule size, the more water needed in its cooking. It is clearly shown that the grain size of Berlian sae and Slyp super are bigger than the others (Figure 2). Also, the two samples have lower amylose and protein content compared to Black and Brown rice.

Table 2. Result of chemical and physical characterizations of uncooked and cooked rice*

Type of rice and cooking manner	Water (%)	Ash (%)	Carbohydrate (%)	Starch (%)	Amylose (%)	Amylopectin (%)	Protein (%)	Fat (%)	Fatty Acid (%)	Fiber (%)	Vitamin B1 (%)	Cristallinity (%)
Black Rice	1.75[a]	1.71[a]	78.94[b]	71.05[b]	23.17[c]	47.88[a]	7.85[c]	1.34[a]	0.10[a]	8.41[b]	0.37[b]	29.1
CV	6.65[a]	1.11[a]	75.83[a]	68.25[a]	21.64[c]	46.61[a]	6.62[c]	0.82[a]	0.10[a]	8.97[b]	0.24[b]	18.9
RC	5.53[a]	1.23[a]	76.06[a]	68.45[a]	22.21[c]	46.24[a]	6.97[c]	0.97[a]	0.11[a]	9.24[b]	0.28[b]	19.7
ST	6.77[a]	1.12[a]	75.47[a]	67.92[a]	20.63[c]	47.29[a]	6.51[c]	1.08[a]	0.10[a]	9.05[b]	0.22[a]	21.1
Brown Rice	1.67[a]	1.41[a]	80.82[c]	72.74[c]	21.58[c]	51.158[b]	6.78[c]	1.17[a]	0.10[a]	8.15[b]	0.31[b]	29.8
CV	7.15[a]	1.34[a]	76.30[a]	68.69[a]	20.27[c]	48.42[a]	6.02[c]	1.14[a]	0.11[a]	8.03[b]	0.21[a]	23.4
RC	7.81[a]	0.87[a]	77.17[a]	69.45[a]	18.11[b]	51.34[b]	5.41[b]	1.02[a]	0.10[a]	7.72[b]	0.20[a]	19.5
ST	8.17[a]	0.91[a]	76.91[a]	69.22[a]	18.72[b]	50.50[b]	5.38[b]	1.07[a]	0.10[a]	7.56[b]	0.20[a]	20.9
Semi-organic White Rice (Berlian Sae)	3.98[a]	2.57[a]	82.68[c]	75.19[c]	19.32[b]	55.87[d]	4.12[b]	1.77[a]	0.12[a]	4.02[b]	0.21[a]	28.5
CV	12.49[a]	1.51[a]	80.84[c]	72.76[c]	15.23[a]	57.53[d]	2.67[a]	0.34[a]	0.12[a]	2.15[a]	0.10[a]	27.0
RC	12.04[a]	1.47[a]	80.17[bc]	72.15[b]	15.49[a]	56.66[d]	3.65[a]	0.43[a]	0.14[a]	2.24[a]	0.19[a]	21.6
ST	12.31[a]	1.79[a]	79.88[b]	71.89[b]	14.08[a]	57.81[d]	3.41[a]	0.52[a]	0.11[a]	2.09[a]	0.18[a]	20.8
Organic White Rice (Slyp Super)	4.25[a]	2.41[a]	83.54[c]	75.34[c]	19.21[b]	55.85[d]	5.08[b]	1.75[a]	0.11[a]	4.05[b]	0.20[a]	20.8
CV	13.82[a]	1.13[a]	79.62[a]	71.66[b]	17.43[a]	54.23[c]	3.47[a]	0.35[a]	0.12[a]	1.61[a]	0.12[a]	21.1
RC	14.05[a]	1.02[a]	79.47[b]	71.52[b]	17.85[ab]	53.67[c]	3.41[a]	0.46[a]	0.11[a]	1.59[a]	0.11[a]	21.3
ST	14.99[a]	0.94[a]	78.75[b]	70.88[b]	16.86[ab]	54.02[c]	3.67[a]	0.59[a]	0.14[a]	1.06[a]	0.14[a]	23.9

*Means followed by different superscripts within the column are significantly different ($p < 0.05$).
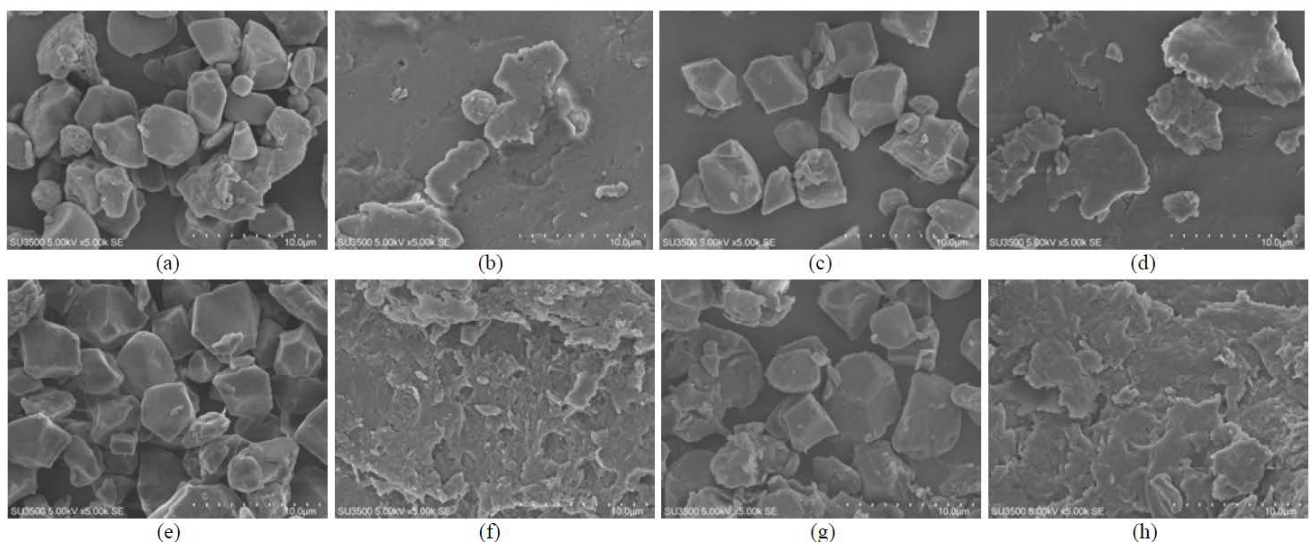**Significant difference of cristallinity loss due to different cooking method at 5%.

Figure 2. SEM images of four uncooked and cooked samples with steam methods. : (a): Black Rice uncooked; (b): Black Rice with ST Method; (c): Brown rice uncooked; (d): Brown rice with ST Method; (e): Berlian sae uncooked; (f): Berlian sae with ST method; (g): Slyp Super uncooked; (h): Slyp Super with ST Method

The diffractograms of uncooked and cooked brown rice are shown in Figure 3. The uncooked rice shows a more structured diffraction pattern than the cooked samples. The overlapping of the diffractogram of amylose and amylopectin made it difficult to distinguish the corresponding peak related to them individually [14].
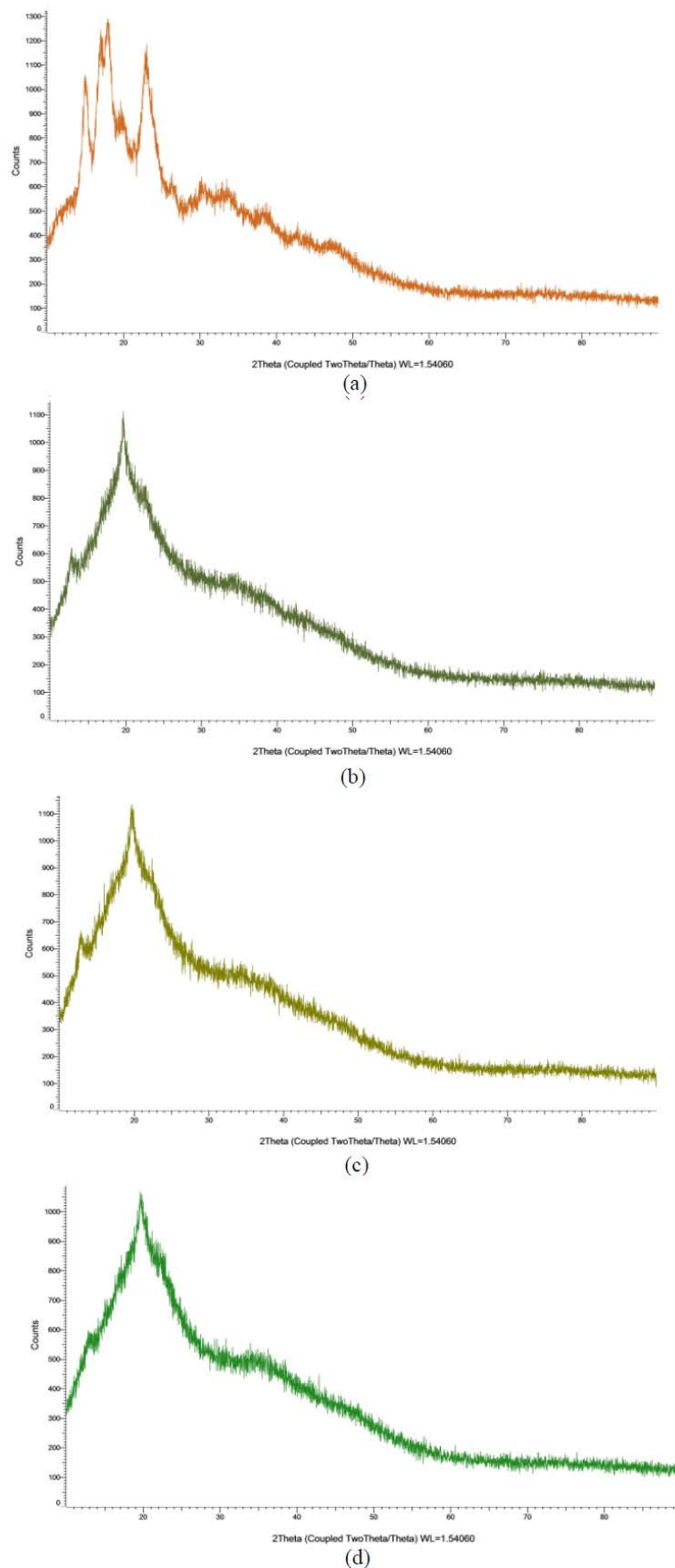

Figure 3. The diffractogram of rice samples: (a) Brown rice uncooked; (b) Brown rice CV method; (c) Brown rice with RC method; (d) Brown rice with ST Method
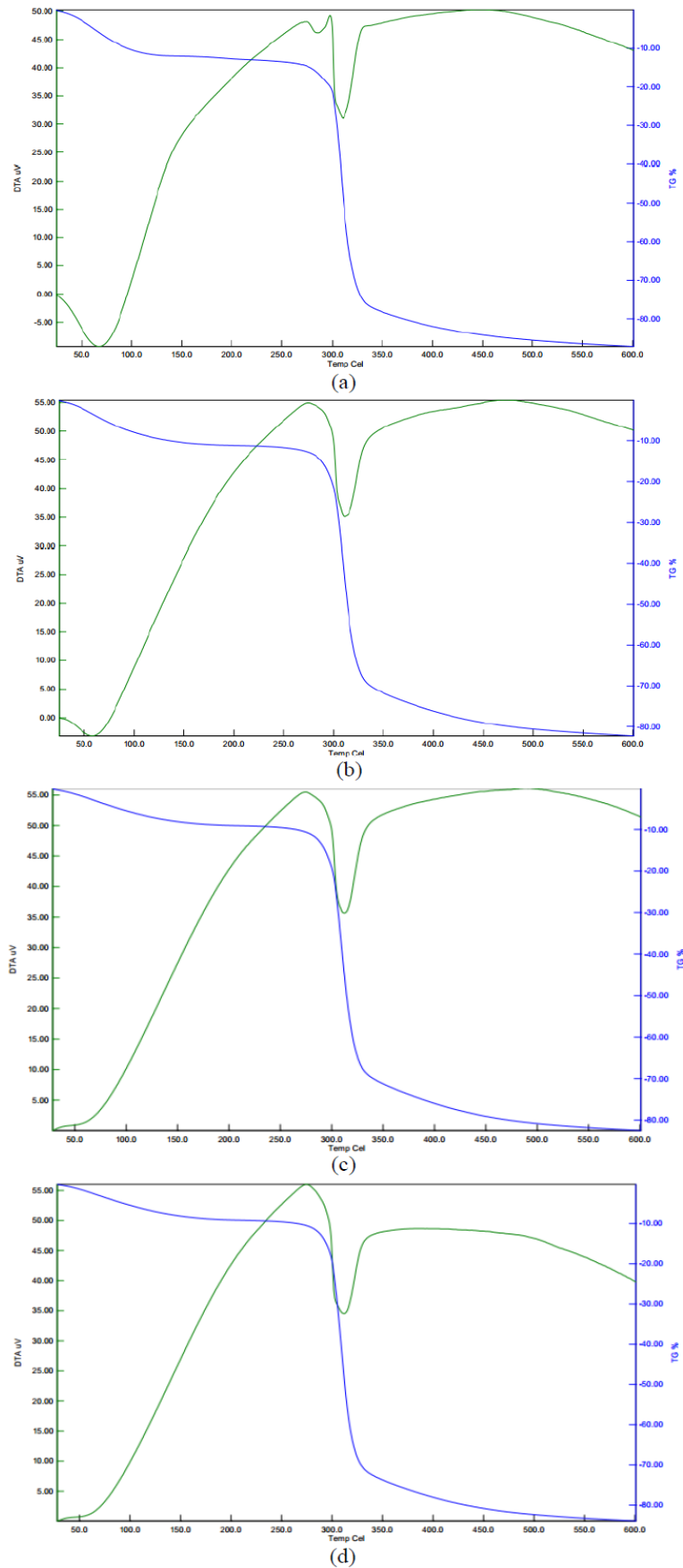
Figure 4. Simultaneous TG and DTA curves of: (a) Brown rice uncooked, m = 6.948 mg; (b) Brown rice with CV method, m = 6.217 mg; (c) Brown rice with RC method, m = 6.316 mg; and (d) Brown rice with ST Method, m = 6.037 mg

The uncooked sample exhibited a common A-type pattern, which is common for cereal starches [15]. The diffraction region may be used to calculate the percentage of crystallinity and amorphous using its area under the curve. The percentage of crystallinity comparison between the uncooked and cooked samples summarized from the

diffraction pattern is shown in Table 2. The results indicate that all samples are dominated by amorphous particles. Cooking methods applied tended to reduce crystallinity that is correlated with the gelatinization during the cooking process. This reduction is necessary since the nutrient will become digestible due to more access by the digestive enzymes. The Slyp super, which is the sample with the biggest granule size based on SEM observation somehow showed a minor increase in its crystallinity of all cooked samples. On the other hand, the conventional method is the method of giving the largest advantages when applied to brown rice. The highest crystallinity reduction occurred in Brown rice processed by the conventional method, with the percentage reduced from 29.8% to 19.5%. Lower crystallinity loss in both white rice samples, together with their larger grain size, indicates that the varieties need more time, water, or heat to complete the gelatinization even that the two samples already had the largest increase in water content after cooking. Although, with these common procedures these varieties have the most preference based on the organoleptic test. In addition, an opposite result was obtained for the Slyp super. The results of all cooking methods applied somehow increased the percentage of crystallinity slightly.

The simultaneous TG and DTA curves of brown rice samples are shown in Figure 4. All measured samples show mass losses in three steps and thermal events corresponding to these losses [16]. Dehydration and decomposition are the main two processes associated with the degradation mechanisms of starches [17]. The thermal treatment of starches normally leads to their degradation after the applied temperature exceeds 300°C. The process itself considered being the total oxidation of the partially decomposed organic material [18]. Based on the obtained TG/DTA data, the first mass losses, attributed to the dehydration occurs from the beginning of the heating until about 100°C in uncooked and about 150°C in cooked samples, with corresponding to the endothermic peak at 60°C. All anhydrous samples are stable up to about 300°C before the decomposition occurs in two consecutive steps in 300 to 340°C, that is attributed to the thermal decomposition with corresponding to the endothermic peak at 320°C, and above that temperature to 600°C, that is attributed to the total oxidation of the organic matter with corresponding to the endothermic peak at (about 450 for the uncooked and 480 for the cooked). It is demonstrated that the uncooked sample has an endothermic peak before it undergoes the decomposition that is probably related to the disruption of the crystal structure or decomposition of non-starch compounds that are not present anymore in the cooked samples.

The simultaneous TG and DTA curves show that the amount of water released is similar at around 10% both in uncooked and cooked samples of Brown rice based on the corresponding mass loss process during dehydration. However, the uncooked, followed by the cooked rice with the conventional method, seemed to require more energy during that process as indicated by a deep endothermic peak at the DTA curve between 50 to 100°C. The results indicate that the higher crystallinity level play role in dehydration due to undisrupted granule structure, as observed using SEM (Figure 2).

4. Conclusions

Different results of organoleptic, nutrient, and physical properties changes occurred when the rice is processed with the commonly used cooking methods. The results can be taken into consideration in choosing the method for particular rice varieties and the intended result. Cooked Brown and Black rice less likable in organoleptic than white rice. Brown rice is less preferred using conventional if the better texture wants to be achieved and can still be optimized with two other methods. For Berlian Sae, the steam method is less preferred for the two varieties if better taste wants to be achieved.

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Competing Interests

None of the authors have any competing interest.

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