



Effects of Cooking Methods and Time on the Physical Properties of Cooked Glutinous Rice

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ABSTRACT

Glutinous rice is primarily grown in Southeast Asia, and it is highly diversified in uses. There is a limited study on the effects of different cooking methods on the physical properties and cooking time of glutinous rice. This study aims to evaluate the effects of different cooking methods on the physical properties and cooking time of glutinous rice. Before cooking, the glutinous rice obtained was stored for two months under 4°C and 28°C to represent chilled and ambient storage conditions. For the steaming method, 250 g of glutinous rice from the two conditions were soaked at room temperature for 3 hours, then cooked using an electric steamer. Meanwhile, the unsoaked glutinous rice was used for the boiling method in an electric rice cooker. This study uses soaked and unsoaked glutinous rice to represent the two common cooking methods consumers use. Based on the results, the cooked glutinous rice from storage condition B had the significantly ($p < 0.05$) highest increment in apparent density (2086.14 kg/m³) and cooking time (34.07 minutes). Also, they had the highest reduction in length (8.68 mm), equivalent diameter (2.95 mm), projected area (0.23), surface area (25.69 mm²), volume (13.45 mm³), and weight (0.0279 g) when compared to storage condition A. The size of cooked glutinous rice is greater than that of steamed glutinous rice, which shows more expansion.

Boiling produced greater swelling and water uptake, while steaming resulted in more compact grains with lower expansion. Hence, this study contributes to improving quality control in product development and guides on optimal cooking practices for consumers.

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INTRODUCTION

In many Southeast Asian countries, glutinous rice is the main foodstuff and is used in a variety of traditional and modern recipes. About 90% of Asia's global production and consumption was contributed by rice (Naomi & Lewis, 2019). Cooking is a key process for rice before eating. The whole cooking process involves water washing, pre-soaking, and cooking with the proper method. Pre-soaking is a traditional pretreatment before cooking. It would result in uniform cooking and less cooking time (Hu et al., 2020). Water soaking prior to cooking is common for cooking this rice form for better eating quality. Understanding the impact of the cooking method on the quality of these marketable rice varieties is beneficial to consumers (Krongworakul et al., 2020). In this study, the sample preparations were conducted prior to cooking (unsoaked and soaked processes based on the cooking methods). Generally, heating starchy meals can cause starch granules to gelatinise, losing their amylose and amylopectin crystallinity and creating a disordered structure that makes starch more prone to enzymatic hydrolysis (Ngo et al., 2023). Employing advanced processing and cooking technologies can enhance the quality and overall acceptability of glutinous rice (Ali & Hashim, 2024).

Grain dimensions are one of the crucial characteristics that need to be included in measuring the physical properties of rice (Bhattacharya, 2011). Measuring the grain dimensions is the first step to characterise the rice shape, and those values are also further used for several dimensional calculations (Nádvořníková et al., 2018). Physical properties such as dimensions, aspect ratio, projected area, surface area, volume, weight, and density are those properties that can be measured and observed without altering the material composition. Dimensions are an important property for designing the soaking system. Weight measurement is an external criterion that is mostly used for more valuable foods (Azman et al., 2020). Cooking time is essential for evaluating and interpreting how different cooking methods affect the physical properties of rice (Ojediran et al., 2020). Physical properties and cooking time are the most important aspects, which are the first expressions that will be observed by the consumers. Most of the previous studies investigated the physical properties of non-glutinous rice, including Díaz et al. (2015), Meena et al. (2010), Oli et al. (2016), Ravi et al. (2014), Smanalieva et al. (2015), Thakur & Gupta (2006), and Varnamkhasti et al. (2008). Most recent published studies on investigating nutritional, thermal, and pasting properties and potential products of glutinous rice. However, there is a limited study related to the effects of steaming and boiling methods on physical properties changes and cooking time of glutinous rice. Also, it has a lack of investigation into the effects of storage time on the cooking properties of glutinous rice. Most previous studies either focus on non-glutinous varieties or evaluate only selected physicochemical properties, leaving important gaps in understanding how direct versus indirect heating affects cooking properties. Moreover, this study contributes to improving quality control

in glutinous rice-based product development, supports standardisation in food preparation, and provides guidance on optimal cooking practices for consumers.

Therefore, this study aims to (1) evaluate the effects of cooking methods (steaming and boiling) on the physical properties and cooking time of glutinous rice, and (2) investigate the correlations between physical properties and cooking methods combined with storage conditions before cooking. Hence, this study provides knowledge and a theoretical basis for both home cooks and the food industry regarding the best practices for preparing glutinous rice.

MATERIALS AND METHODS

Materials Preparation

The local glutinous rice cultivar (Siding) was purchased from the local farm (Kuala Selangor, Selangor, Malaysia). Only head glutinous rice grains, free from any physical defects or insect infestations, were chosen for analysis. Once brought to the laboratory, the glutinous rice samples were stored under conditions A (4°C) and B (28°C) for 2 months, as shown in Figure 1. These two storage conditions were chosen to represent chilled and ambient storage conditions, which are commonly used in glutinous rice handling. The stored raw glutinous rice samples were taken from each condition to evaluate the changes in dimensions, aspect ratio, surface area, volume, weight, and cooking time of glutinous rice under different cooking methods for five replications.

Preparation of Steamed and Cooked Glutinous Rice

The stored glutinous rice was cooked using both the steaming and boiling methods. Glutinous rice samples (1.5 kg) from two storage conditions, A (4°C) and B (28°C), were washed once with tap water before cooking to remove dirt and foreign objects. Two hundred and fifty grammes of washed samples from each storage condition were used for both the steaming and boiling methods. For the steaming method, the glutinous rice samples were soaked at room temperature for 3 hours with a glutinous rice-to-water ratio of 1:1.5 to ensure that the glutinous rice was completely immersed in the water and had uniform heat transfer and evaporation process. After soaking, the glutinous rice was cooked using an electric steamer. About seven hundred millilitres of water was used in the steamer, and the steaming temperature was $110.00 \pm 2.00^{\circ}\text{C}$. Meanwhile, the unsoaked glutinous rice was used for the boiling method in an electric rice cooker with a glutinous rice-to-water ratio of 1:1.5. This study uses soaked and unsoaked glutinous rice to represent the two common cooking methods consumers use, aiming to determine their influence on the physical properties of glutinous rice.

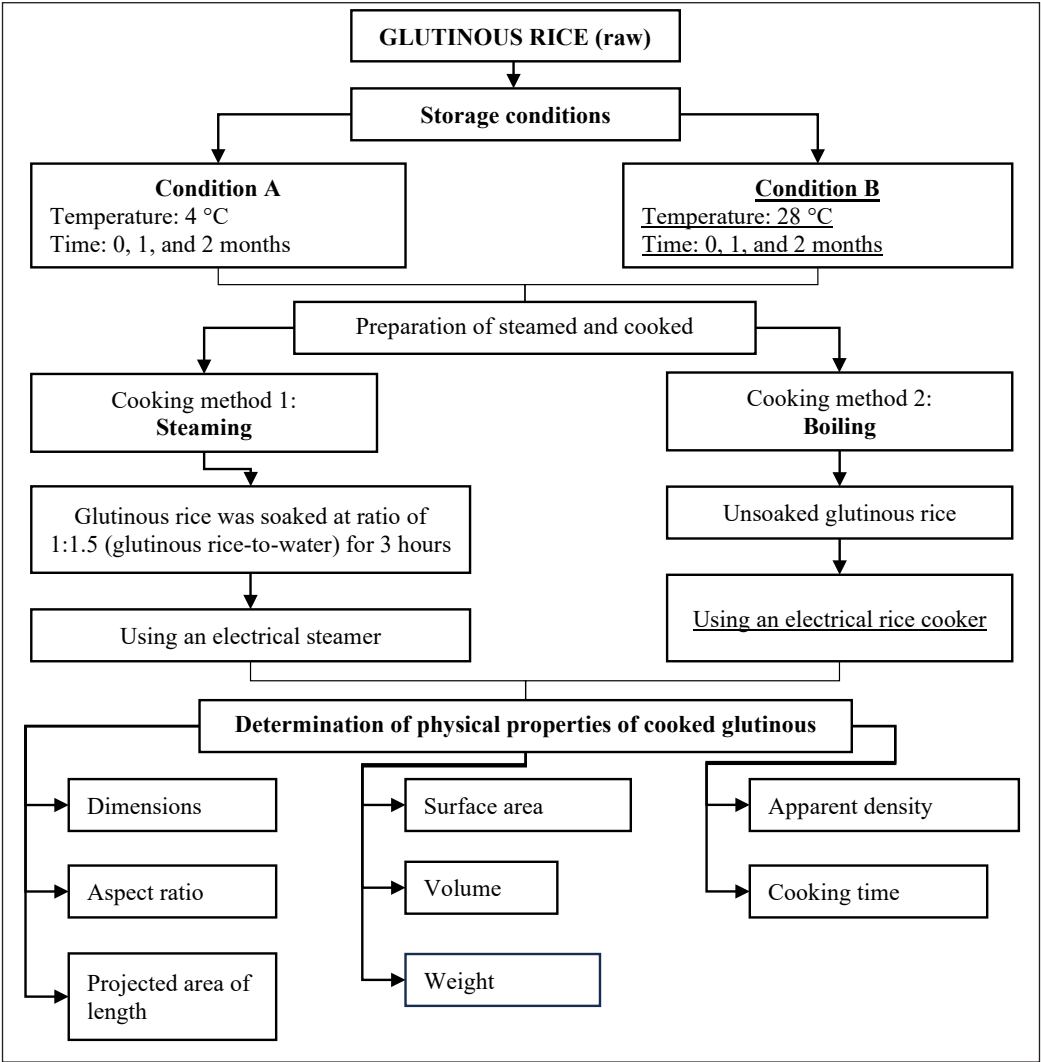


Figure 1. Flowchart for the preparation of steamed and cooked glutinous rice samples and determination of physical properties

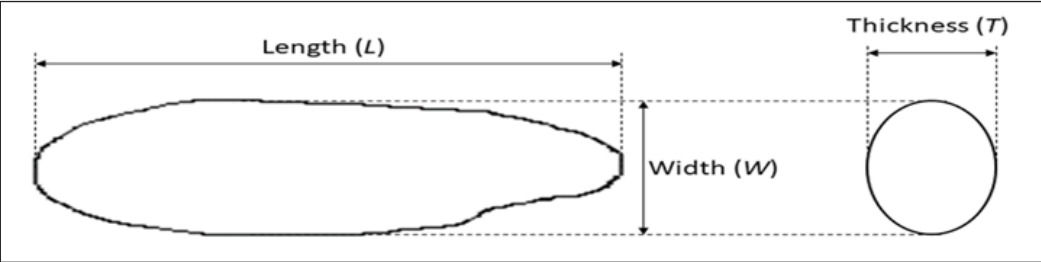


Figure 2. Dimensions of glutinous rice grain

Determination of Dimensions

As shown in Figure 2, the length (L), width (W), and thickness (T) of the steamed and cooked glutinous rice grains were measured using a digital vernier calliper (Series 500, Mitutoyo, Japan) with an accuracy of 0.01 mm. For each condition, glutinous rice grains were randomly selected, and their dimensions were measured and recorded 10 times to ensure accuracy (Hoque et al., 2022).

The equivalent diameter (De) of the steamed and cooked glutinous rice was determined as Equation 1 based on the measured length, width, and thickness (Hoque et al., 2022; Othman & Oma, 2017):

$$De \text{ (mm)} = \left(\frac{L(W+T)^2}{4} \right)^{\frac{1}{3}} \quad [1]$$

Determination Aspect Ratio

The Equation 2 used to calculate the aspect ratio (R_a) of the steamed and cooked glutinous rice is as follows (Hoque et al., 2022):

$$R_a = \frac{W}{L} \quad [2]$$

Determination of the Projected Area of Length

Projected area of length (PA_L) is defined as the projected area of steamed and cooked glutinous rice in a perpendicular direction to the length. An Equation 3 was used to calculate the projected area of the length (Azman et al., 2025).

$$PA_L = \left(\frac{\pi WL}{4} \right) \quad [3]$$

Determination of Surface Area

The surface area (SA) was calculated by using the measurements of length, width, and thickness of the steamed and cooked glutinous rice. The calculation followed the Equation 4 as follows (Hoque et al., 2022; Othman & Oma, 2017):

$$SA \text{ (mm}^2\text{)} = \frac{\pi \times B \times L^2}{2L - B} \quad [4]$$

$$\text{Where } B = (W \times T)^{\frac{1}{2}}$$

Determination of Volume

The volume (V) of the steamed and cooked glutinous rice was determined by Equation 5 (Hoque et al., 2022; Zainal & Shamsudin, 2021):

$$V \text{ (mm}^3\text{)} = 0.25 \times [(\pi/6) \times L \times (W + T)^2] \quad [5]$$

Determination of Weight

The 100 glutinous rice grain weight was obtained for a sample of individual grains from each condition, which were selected randomly and weighed on a digital electronic scale (JA203P, Xingyun, China) with a precision of 0.001 g, and the result was expressed in grammes.

Determination of Apparent Density

The apparent density (ρ_{app}) The density of a grain is defined as the ratio of the mass of a grain to its volume. The apparent density of a grain was calculated using Equation 6:

$$\rho_{app} = \frac{M_i}{V_i} \quad [6]$$

Determination of Cooking Time

Head rice (250 g) samples were put into some aluminium cups from each storage condition and steamed in the electric steamer. Cooking time was assessed by taking out a few grains during various time intervals of cooking and pressing them until no white core was left. The steps were repeated for the boiling methods of glutinous rice five times

Statistical Analysis

Data analyses were done using the Minitab Statistic 16 Edition to conduct a Tukey's test to differentiate and determine the significant difference between the means. Both mean and standard deviation were reported from data of five replications for each analysis. The limits of confidence were taken as 95% ($p < 0.05$). Pearson correlation coefficient analysis for the relationships between different cooking methods in some storage times and the dimensions, aspect ratio, surface area, volume, weight, and cooking time of glutinous rice.

RESULTS AND DISCUSSION

Dimensions

The dimensions (length, width, thickness, and equivalent diameter) of cooked glutinous rice grains, prepared using steaming and boiling methods from various storage conditions

(4 °C and 28 °C) for 0, 1, and 2 months, are presented in Table 1. The shape and size of glutinous rice grains are important physical properties. Glutinous rice exhibits significant variation across storage conditions and cooking methods. It was steamed in an electrical steamer at 110.00 ± 2.00 °C. After 2 months of storage in conditions A and B, the glutinous rice was steamed, and the length was significantly ($p < 0.05$) decreased from 9.39 ± 0.10 mm to 8.43 ± 0.30 mm. The steamed glutinous rice was insignificantly decreased from 1.92 ± 0.09 mm to 1.87 ± 0.08 mm in width, and 1.67 ± 0.08 mm to 1.61 ± 0.03 mm in thickness for the first- and second-month storage, respectively. Meanwhile, the cooked glutinous rice dimensions using a rice cooker were significantly decreased at $p < 0.05$, from 9.46 ± 0.30 mm to 8.68 ± 0.09 mm in length, and 1.93 ± 0.07 mm to 2.10 ± 0.09 mm in width for 2 months storage conditions A and B. However, the cooked glutinous rice had insignificantly decreased from 1.52 ± 0.08 mm to 1.46 ± 0.05 mm in thickness, for the first- and second-months storage, respectively.

According to Table 1, the length, width, and thickness of steamed glutinous rice for the 2-month storage condition B were the highest compared to other conditions. The cooked glutinous rice of 2 months storage condition B had the greatest change in length, width, and thickness compared to other conditions. Furthermore, the results showed that the equivalent diameters of steamed and cooked glutinous rice varied from 3.12 ± 0.06 mm to 2.94 ± 0.05 mm and from 3.04 ± 0.07 mm to 2.95 ± 0.04 mm, respectively.

During gelatinisation of cooking, the cell structure of glutinous rice started to rupture, which caused amylopectin to be leached. Moreover, the utilisation of heat and water during cooking breaks down the double helical and crystalline structures within starch granules, as it allows water to diffuse more easily into glutinous rice, and it expands in size (Liang et al., 2025). Generally, the dimensions of cooked glutinous rice will be increased due to gelatinisation of starch. However, this study revealed different results due to the effects of storage conditions prior to cooking and different cooking methods used. Therefore, this study shows that the cooked glutinous rice using an electric rice cooker has the greatest change in length, width, and equivalent compared to the steamed glutinous rice using a steamer.

This is due to direct contact with water during cooking compared to the steaming method, which uses vapour contact on the glutinous rice.

Projected Area of Length

The projected area of steamed glutinous rice under storage conditions A and B decreased from 14.16 ± 0.64 to 12.67 ± 0.76 and 14.16 ± 0.64 to 12.38 ± 0.65 when the length and width decreased. A similar trend was indicated for the projected area of cooked glutinous rice under storage conditions A and B, with the values from 14.34 ± 0.52 to 13.75 ± 0.75 and 14.34 ± 0.52 to 13.50 ± 0.39 , respectively.

Table 1
Dimensions of each 100 steamed and cooked glutinous rice

Storage Condition	Storage Time (Months)	Cooking Method	L (mm)	W (mm)	T (mm)	De (mm)	PA _L	Ra	SA (mm ²)
A	0	Steaming	9.39 ±0.10 ^a	1.92 ±0.09 ^a	1.67 ±0.08 ^a	3.12 ±0.06 ^a	14.16 ±0.64 ^a	0.20 ±0.01 ^b	29.17 ±0.88 ^a
	1		8.57 ±0.54 ^b	1.92 ±0.09 ^a	1.64 ±0.05 ^a	3.00 ±0.09 ^b	12.93 ±1.04 ^b	0.22 ±0.02 ^a	26.64 ±1.61 ^b
	2		8.49 ±0.43 ^b	1.90 ±0.07 ^a	1.63 ±0.05 ^a	2.98 ±0.06 ^b	12.67 ±0.76 ^b	0.22 ±0.01 ^a	26.17 ±1.16 ^b
B	0	Steaming	9.39 ±0.10 ^a	1.92 ±0.09 ^a	1.67 ±0.08 ^a	3.12 ±0.06 ^a	14.16 ±0.64 ^a	0.20 ±0.01 ^b	29.17 ±0.88 ^a
	1		8.48 ±0.41 ^b	1.92 ±0.09 ^a	1.62 ±0.04 ^a	2.98 ±0.06 ^b	12.79 ±0.84 ^b	0.23 ±0.02 ^a	26.20 ±1.17 ^b
	2		8.43 ±0.30 ^b	1.87 ±0.08 ^a	1.61 ±0.03 ^a	2.94 ±0.05 ^b	12.38 ±0.65 ^b	0.22 ±0.01 ^a	25.61 ±0.90 ^b
A	0	Boiling	9.46 ±0.08 ^a	1.93 ±0.07 ^b	1.52 ±0.08 ^a	3.04 ±0.07 ^{ab}	14.34 ±0.52 ^{ab}	0.20 ±0.01 ^b	27.98 ±1.09 ^a
	1		8.98 ±0.09 ^b	2.10 ±0.09 ^a	1.49 ±0.06 ^a	3.07 ±0.05 ^a	14.81 ±0.72 ^a	0.23 ±0.01 ^a	27.66 ±0.71 ^a
	2		8.71 ±0.10 ^c	2.01 ±0.11 ^{ab}	1.48 ±0.08 ^a	2.98 ±0.05 ^b	13.75 ±0.75 ^b	0.23 ±0.01 ^a	26.16 ±0.64 ^b
B	0	Boiling	9.46 ±0.08 ^a	1.93 ±0.07 ^a	1.52 ±0.08 ^a	3.04 ±0.07 ^a	14.34 ±0.52 ^a	0.20 ±0.01 ^b	27.98 ±1.09 ^a
	1		8.91 ±0.06 ^b	1.99 ±0.06 ^a	1.51 ±0.07 ^a	3.01 ±0.07 ^{ab}	13.93 ±0.44 ^{ab}	0.22 ±0.01 ^a	26.87 ±0.96 ^b
	2		8.68 ±0.09 ^c	1.98 ±0.06 ^a	1.46 ±0.05 ^a	2.95 ±0.04 ^b	13.50 ±0.39 ^b	0.23 ±0.01 ^a	25.69 ±0.50 ^c

Note. Data are expressed as mean ±SD; L, length (mm); W, width (mm); T, thickness (mm); De, equivalent diameter (mm); PA_L, projected area of length; Ra, aspect ratio; SA, surface area (mm²); A, storage of glutinous rice at 4°C before cooking; B, storage of glutinous rice at 28°C before cooking. Different letters indicate statistically significant differences exist, *p*<0.05 for each column within each condition. Means that those that do not share a letter are significantly different. The Tukey test was applied with 95% simultaneous confidence intervals

Based on the results in Table 1, the steamed glutinous rice under storage condition B had the greatest change in projected area of length when compared to other conditions. The relationship between projected area and length was shown significantly.

Aspect Ratio

The aspect ratio of steamed and cooked glutinous rice varied from 0.20 ± 0.01 to 0.23 ± 0.02 for 2 months storage conditions A and B. As can be seen, they were increased when compared to the cooked glutinous rice without storage. As indicated, the aspect ratio of steamed and cooked glutinous rice was affected by the storage conditions A and B in 2 months. Thus, storage condition B has the most impact on the aspect ratio increment of cooked glutinous rice.

Surface Area

The surface area of steamed glutinous rice has decreased gradually, with the values of $26.64 \pm 1.61 \text{ mm}^2$ and $26.17 \pm 1.16 \text{ mm}^2$ for the first and second months after storage conditions A, respectively. Meanwhile, it was also decreased gradually from $26.20 \pm 1.17 \text{ mm}^2$ to $25.61 \pm 0.90 \text{ mm}^2$ for the first and second months after storage condition B. The surface area of cooked glutinous rice attained on the first and second months of storage condition A was $27.66 \pm 0.71 \text{ mm}^2$ and $26.16 \pm 0.64 \text{ mm}^2$. For storage condition B, the surface area values of cooked glutinous rice were $26.87 \pm 0.96 \text{ mm}^2$ and $25.60 \pm 0.50 \text{ mm}^2$ for the first and second months, respectively. Therefore, the surface area of cooked glutinous rice using an electric rice cooker was higher when stored in condition A.

Volume

The mean volume values of steamed glutinous rice were varied from $13.85 \pm 0.85 \text{ mm}^3$ to $15.85 \pm 0.90 \text{ mm}^3$ (storage condition A) and $13.37 \pm 0.70 \text{ mm}^3$ to $15.85 \pm 0.90 \text{ mm}^3$ (storage condition B). The volume values of cooked glutinous rice ranged from $13.89 \pm 0.72 \text{ mm}^3$ to $15.16 \pm 0.76 \text{ mm}^3$ and $13.45 \pm 0.48 \text{ mm}^3$ to $14.75 \pm 0.97 \text{ mm}^3$ after 2 months of storage conditions A and B, respectively. As indicated, the volume of steamed and cooked glutinous rice was affected by the storage conditions A and B in 2 months. The volume is directly proportional to the dimensions of glutinous rice, as the volume is reduced when the dimensions decrease. Thus, storage condition B has the most impact on volume reductions of steamed and cooked glutinous rice.

Weight

The weight of glutinous rice was determined for all steamed and cooked glutinous rice after 2 months of storage conditions A and B. The weight of a steamed glutinous rice

Cooking Time

As can be seen in Table 1, the cooking methods (steaming or boiling) affect the cooking time significantly at $p < 0.05$. For steamed glutinous rice, the cooking time increased from 25.21 ± 0.03 mins to 26.17 ± 0.06 mins and 25.21 ± 0.03 mins to 29.16 ± 0.08 mins, respectively, for conditions A and B. It has the same trend as the cooked glutinous rice, which increased until reaching 33.23 ± 0.05 mins and 36.19 ± 0.03 mins for conditions A and B, respectively. As indicated, the cooking time of steamed and cooked glutinous rice was affected by the storage conditions A and B in 2 months. The glutinous rice stored in condition B and then cooked using the boiling method showed that it required a longer time to cook when compared to the steaming method. This is due to the boiling method of using an electric rice cooker, which involves a more gradual cooking process compared to steaming, where the glutinous rice is soaked first before being cooked, resulting in faster gelatinisation and cooking. According to the previous study of Thomas et al. (2013), the glutinous rice from Thailand had a minimum cooking time of 22.67 ± 0.00 mins. Patria et al. (2020) stated that the cooking time of Japonica Rice ranged from 3.00 to 10.33 mins. These previous studies showed the difference in their determination of cooking time because there is no storage condition prior to cooking included, and the laboratory procedure cooking methods used, rather than replicating the common cooking methods used by consumers.

Correlations for Physical Properties of Glutinous Rice After Cooking using the Steaming and Boiling Methods

Table 3 indicates a significant ($p < 0.05$) correlation analysis of some physical properties of glutinous rice that are affected by storage conditions (A and B) combined with the selected cooking methods (steaming and boiling). For storage condition A and steaming method, length was highly positively correlated with the equivalent diameter ($r = 0.999$, $p < 0.05$) and surface area ($r = 0.998$, $p < 0.05$). The correlation coefficients between thickness and volume and weight were highly positive, with the values of 0.998 ($p < 0.05$) and 1.000 ($p < 0.001$), respectively. The equivalent diameter was highly positively correlated with surface area ($r = 1.000$, $p < 0.05$) and volume ($r = 0.999$, $p < 0.05$). The correlation coefficient between surface area and volume was highly positive with the value of 1.000 ($p < 0.05$), while the volume was highly positively correlated with weight ($r = 0.998$, $p < 0.05$). Under storage condition B and steaming method, the thickness was highly positively correlated with the equivalent diameter ($r = 0.998$, $p < 0.05$), surface area ($r = 1.000$, $p < 0.001$), volume ($r = 0.999$, $p < 0.05$), and weight ($r = 0.999$, $p < 0.05$). The correlation coefficients between equivalent diameter and surface area, volume, and weight were highly positive with the values 0.998 ($p < 0.05$), 1.000 ($p < 0.05$), and 1.000 ($p < 0.05$), respectively. The surface area was highly positively correlated with the volume and weight ($r = 0.999$, $p < 0.05$), while the

correlation coefficient between volume and weight was highly positive with the value of 1.000 ($p<0.05$).

As shown in Table 3, the length of cooked glutinous rice under storage condition A and boiling method was highly positively correlated with the weight ($r=1.000$, $p<0.05$). Meanwhile, the correlation coefficient between equivalent diameter and volume was 1.000 ($p<0.05$). However, the length of cooked glutinous rice under storage B and the boiling method was highly negatively correlated with aspect ratio ($r=-0.999$, $p<0.05$). The correlation coefficient between equivalent diameter and volume was highly positive, with a value of 1.000 ($p<0.05$). Thus, the results showed that the storage conditions combined with the cooking methods using steaming and boiling have different trends of correlations with some physical properties of steamed and cooked glutinous rice.

Principal Component Analysis for Physical Properties of Steamed and Cooked Glutinous Rice

Principal component analysis (PCA) was performed to determine the clustering length, width, thickness, equivalent diameter, aspect ratio, surface area, volume, and weight within the cooking methods (steaming and boiling). According to Figure 3, PC1 explained the total variance of length, width, thickness, equivalent diameter, aspect ratio, surface area, volume, and weight. In PCA, PC1 was dominant when compared to PC2. Figure 3 shows the PCA score plot used to illustrate the PCA results. They specified a clear and scattered separation between the two cooking methods based on the length, width, thickness, equivalent diameter, aspect ratio, surface area, volume, and weight of steamed and cooked glutinous rice. Theoretically, the PCA results illustrated that storage conditions prior to cooking and cooking methods influenced these physical properties. Hence, their changes were verified by classifying the two cooking methods and four storage conditions.

The PCA loading plot of length, width, thickness, equivalent diameter, aspect ratio, surface area, volume, and weight is illustrated in the Figure 4. The correlations among these physical properties and cooking methods, combined with storage conditions, can be seen in the loading plot. Based on Figure 4 the thickness and surface were loaded positively on PC1 and PC2. Meanwhile, width and aspect ratio were loaded negatively on PC1 and PC2.

CONCLUSION

The study revealed that both steaming and boiling methods affect the dimensions, projected area, aspect ratio, surface area, volume, weight, apparent density, and cooking time of glutinous rice. In this study, the glutinous rice Siding cultivar was used in storage, steaming, and boiling methods. The effects of different cooking methods on the physical properties and cooking time of glutinous rice were investigated. Due to storage conditions (before

Table 3
Correlation matrix for some physical properties of glutinous rice after cooking using the steaming and boiling methods

Condition A (Steaming method)												Condition B (Steaming method)											
	L	W	T	De	Ra	SA	V	L	W	T	De	Ra	SA	V		L	W	T	De	Ra	SA	V	
W	0.568*							0.540*								0.540*							
T	0.987*	0.693*						0.994*	0.629*							0.994*	0.629*						
De	0.999**	0.610*	0.994*					0.986*	0.672*	0.998**						0.986*	0.672*	0.998**					
Ra	-0.997*	-0.500*	-0.971*	-0.991*				-0.929*	-0.189*	-0.882*	-0.854*					-0.929*	-0.189*	-0.882*	-0.854*				
SA	0.998**	0.621*	0.995*	1.000**	-0.989*			0.994*	0.628*	1.000***	0.998**	-0.883*				0.994*	0.628*	1.000***	0.998**	-0.883*			
V	0.996*	0.643*	0.998**	0.999**	-0.985*	1.000**		0.987*	0.668*	0.999**	1.000**	-0.857*	0.999**			0.987*	0.668*	0.999**	1.000**	-0.857*	0.999**		
Weight	0.987*	0.693*	1.000***	0.994*	-0.971*	0.995*	0.998**	0.990*	0.655*	0.999**	1.000**	-0.866*	0.999**	1.000**		0.990*	0.655*	0.999**	1.000**	-0.866*	0.999**	1.000**	

Condition A (Boiling method)												Condition B (Boiling method)											
	L	W	T	De	Ra	SA	V	L	W	T	De	Ra	SA	V		L	W	T	De	Ra	SA	V	
W	-0.605*							-0.902*								-0.902*							
T	0.993*	-0.697*						0.825*	-0.500*							0.825*	-0.500*						
De	0.526*	0.359*	0.419*					0.912*	-0.645*	0.984*						0.912*	-0.645*	0.984*					
Ra	-0.935*	0.849*	-0.971*	-0.189*				-0.999**	0.882*	-0.849*	-0.929*					-0.999**	0.882*	-0.849*	-0.929*				
SA	0.869*	-0.131*	0.803*	0.878*	-0.636*			0.969*	-0.767*	0.939*	0.985*	-0.978*				0.969*	-0.767*	0.939*	0.985*	-0.978*			
V	0.536*	0.348*	0.430*	1.000**	-0.200*	0.884*		0.918*	-0.656*	0.982*	1.000**	-0.934*	0.988*			0.918*	-0.656*	0.982*	1.000**	-0.934*	0.988*		

Note. Data are expressed as L, length; W, width; T, thickness; De, equivalent diameter; Ra, aspect ratio; SA, surface area; V, volume
*Not significant, **Significant at $p<0.05$, ***Significant at $p<0.001$

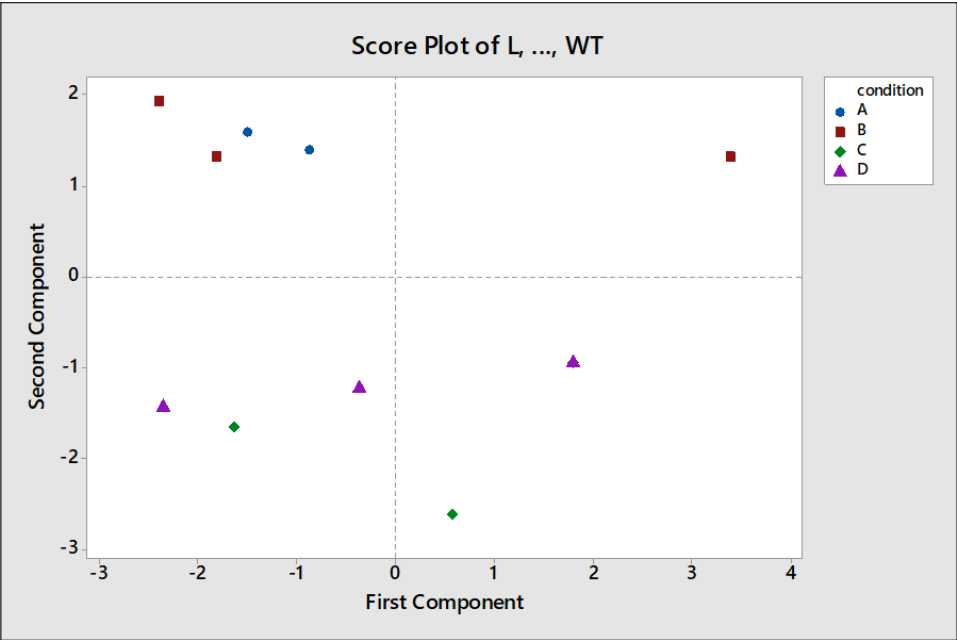


Figure 3. The score plot of the physical properties of steamed and cooked glutinous rice. The yellow circle shows the steaming method, while the blue circle shows the boiling method. Storage conditions are labelled as A: 4 °C storage before steaming, B: 28 °C storage before steaming, C: 4 °C before boiling, and D: 28 °C before boiling of glutinous rice

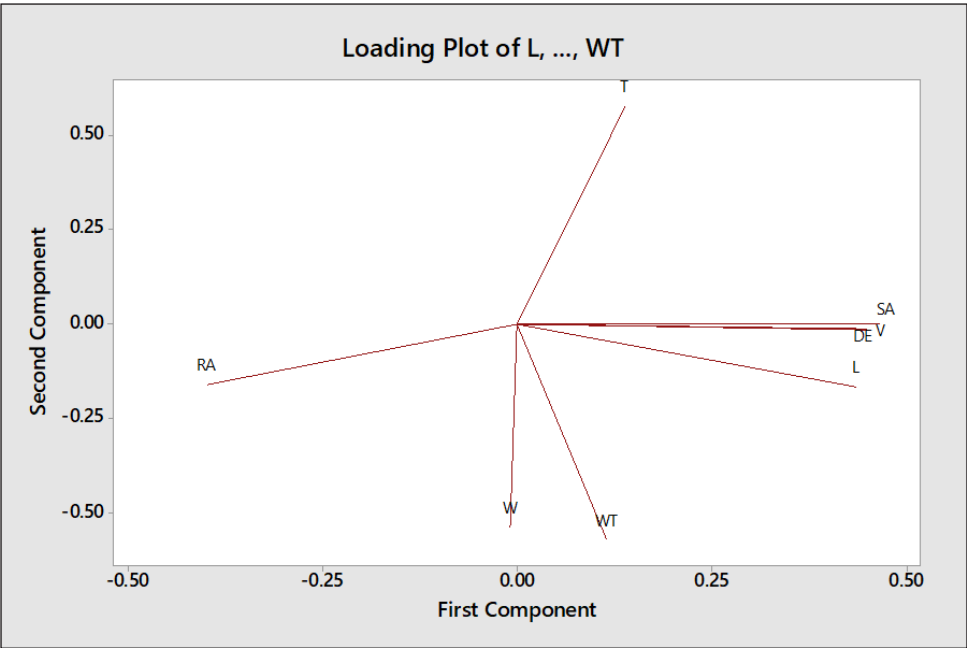


Figure 4. The loading plot of the physical properties of steamed and cooked glutinous rice

cooking) and cooking methods, significant changes in the physical properties of glutinous rice were observed. A reduction in length, equivalent diameter, projected area, surface area, volume, and weight of the steamed glutinous rice was determined, along with a notable increase in aspect ratio, apparent density, and cooking time. For the steaming method, the steamed glutinous rice from storage condition A had the highest increment in apparent density ($1792.30 \pm 49.28 \text{ kg/m}^3$), while the steamed glutinous rice from storage condition B had the highest in cooking time ($29.16 \pm 0.08 \text{ mins}$). The steamed glutinous rice from storage condition B had reduced in length ($8.43 \pm 0.30 \text{ mm}$), equivalent diameter ($2.94 \pm 0.05 \text{ mm}$), projected area (12.38 ± 0.65), surface area ($25.61 \pm 0.90 \text{ mm}^2$), volume ($13.37 \pm 0.70 \text{ mm}^3$), and weight ($0.0239 \pm 5.50 \times 10^{-5} \text{ g}$) when compared to storage condition A. In the boiling method, the cooked glutinous rice also led to a reduction in length, equivalent diameter, projected area, surface area, volume, and weight. However, it had an increase in aspect ratio, apparent density, and cooking time. For the boiling method, the cooked glutinous rice from storage condition B had the highest increment in apparent density ($2086.14 \pm 43.85 \text{ kg/m}^3$) and cooking time ($36.19 \pm 0.03 \text{ mins}$). Also, they had the highest reduction in length ($8.68 \pm 0.09 \text{ mm}$), equivalent diameter ($2.95 \pm 0.04 \text{ mm}$), projected area (0.23 ± 0.01), surface area ($25.69 \pm 0.50 \text{ mm}^2$), volume ($13.45 \pm 0.48 \text{ mm}^3$), and weight ($0.0279 \pm 5.50 \times 10^{-5} \text{ g}$) when compared to storage condition A. The size of cooked glutinous rice is greater than that of steamed glutinous rice, which shows more expansion. Nevertheless, steamed glutinous rice is generally preferred over the cooked glutinous rice using the boiling method, which tends to result in glutinous rice that is slightly soggy and more prone to sticking together compared to steaming. This is due to the direct water absorption during cooking using the boiling method. Overall, the findings highlight that storage conditions (A and B) together with the selected cooking methods (steaming and boiling) significantly influence the physical properties and cooking behaviour of glutinous rice. Hence, this study provides knowledge and a theoretical basis for both home cooks and the food industry regarding the best practices for preparing glutinous rice. It provides meaningful insights for both consumers and food processors by evaluating cooking approaches that optimise the desired quality attributes of glutinous rice. Based on this study's findings, some key areas for future research that can be identified include the determination of the longer-term storage effects' influence on physical and functional changes of glutinous rice, evaluation of cooking methods' effect on the chemical properties, microstructural analysis, and investigation of sensory perception and consumer acceptability.

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