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The Effect of Cooking Time on Physical, Cooking, and Textural Properties of Parboiled Rice MR297

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ABSTRACT

Parboiled rice is widely consumed across Asia for its enhanced nutritional retention and distinct texture, and cooking duration strongly affects its final eating quality. Cooking-time effects have mostly been studied for established varieties, however, and remain unexamined for the recently released Malaysian cultivar MR297. This study evaluated the effects of cooking time on the physical, cooking, and textural properties of parboiled MR297, benchmarked against unparboiled MR297 and commercially parboiled Malaysian rice. Samples were cooked for 4, 8, 12, 16, 20, and 24 minutes and analysed for physical dimensions, colour (L*, a*, b*), cooking properties (elongation ratio, moisture sorption, l/b ratio), and textural attributes (hardness, cohesiveness, chewiness, adhesiveness, springiness). Data were analysed by one-way ANOVA with Tukey's test ($p<0.05$), followed by principal component analysis (PCA). Cooking duration significantly affected textural, physical, colour, and cooking properties of all samples ($p<0.05$). Hardness in parboiled MR297 decreased markedly from 13.26 to 2.55 N, with parallel reductions in cohesiveness and chewiness, while springiness remained unchanged ($p>0.05$). L* rose from 55.43-57.80 to 64.47-65.02, elongation ratio rose to 1.34-1.46, and moisture sorption increased three- to four-fold ($p<0.05$); l/b ratio was unaffected ($p>0.05$). Textural properties largely plateaued by 16 min, whereas moisture sorption kept rising beyond this point, indicating ~16 min offers the best balance between softness and over-hydration for MR297. PCA showed PC1 distinguished samples by cooking duration, and PC2 separated unparboiled from parboiled rice. Overall, cooking time critically determines

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parboiled MR297 quality, with prolonged cooking yielding softer, more elongated, offering processors evidence-based cooking guidance for this cultivar.

Keywords: Cooking, cooking properties, MR297 rice, parboiling, physical properties, textural properties

INTRODUCTION

Rice (*Oryza sativa* L.) is a staple food for almost half of the global population. The International Rice Genebank at the International Rice Research Institute (IRRI) houses approximately 117,000 distinct rice varieties, encompassing both cultivated and wild types (Dutta & Mahanta, 2014). MARDI released MR297 in 2014. This Malaysian rice cultivar was bred locally to enhance disease resistance compared to the MR263 cultivar (Azmi, 2016). Still, the cooking and eating-quality traits are insufficiently characterised. This covers the behaviour under various cooking conditions. As a result, there are still high uncertainties about whether millers and consumers will accept it.

Nevertheless, the milling yield stands at 61.4%, and the head rice yield is just 67.8%, both of which fall below the corresponding values of MR 263, which are 65.5% and 88%, respectively. The economic value of the variety to milling factories may be negatively impacted as a consequence. Parboiling is the hydrothermal procedure used to pretreat raw paddy. To produce parboiled rice, the paddy (or brown rice) must undergo a process of soaking, cooking, and drying before it can be subjected to milling (Qin & Siebenmorgen, 2005). To obtain the highest possible amount of head rice and minimise breakage, which is a significant loss during processing, it is recommended to first parboil the paddy to gelatinise the starch (Buggenhout et al., 2014; Muchlisyiyah et al., 2024a). Parboiling is generally defined as mild steaming of rice, which alters its physical and chemical components, thus promoting digestibility, enhancing texture, increasing milling yield as well as lowering amylose loss during cooking (Dutta & Mahanta, 2012; Iqbal et al., 2021; Roy et al., 2019). Parboiling thus represents a feasible means to mitigate the milling liabilities of MR297, if it is able to balance quality and willingness to eat.

The modification of characteristics during parboiling would likewise result in distinct cooking properties. The texture of cooked rice is a vital element in assessing its quality and is frequently utilised as a gauge of consumer satisfaction and choice. The cooking process is associated with the capacity of water to moisturise the inner part of a rice grain while cooking (Karizaki, 2016). Upon cooking, rice starch absorbs water, hydrates and gelatinises while releasing amylose. The cooking time and temperature also largely influence the resulting physicochemical and textural properties (Chakkaravarthi et al., 2008; Meresa et al., 2020; Shinde et al., 2014). Processing or parboiling duration effects on texture and other physicochemical properties have been previously studied for different rice varieties, but not for black Sri Lankan rice. For example, Onmankhong et al. (2021) found that hardness and toughness were greatly affected by processing parameters in parboiled Thai rice. Similarly, for several germinated rice varieties, parboiling duration induced systematic changes in cooking, textural and pasting properties (Mudgal & Singh 2024). Although none of these studies investigated MR297. Nor is there any study that has compared parboiled samples of their respective paired raw and commercial parboiled reference for the full range of domestic cooking times utilised in food preparation. After all, this is the sort of comparison required in order to provide real-world, variety-specific guides to cooking.

In Malaysia, a wide range of imported rice types are available in the market, including jasmine, basmati, normal white, waxy, parboiled, and brown rice. These rice varieties from other countries (e.g., Thailand, Vietnam, India, Pakistan and the USA (Jamal et al., 2013), that any competitive local variety must be evaluated with respect to cooking and textural performance. The cooking-time behaviour of parboiled MR297 is also unknown at this time, as mentioned above. Since the effect of parboiling on starch structure is dependent on both variety and processing conditions (Dutta & Mahanta, 2012), one cannot simply assume that findings from other cultivars would extrapolate to these also. We postulate that the cooking time imparts systematic, measurable changes in the textural, physical, colour, and cooking attributes of parboiled mineral-rich 297 — changes which differentiate it from its raw and commercial equivalents. This profile serves two purposes. This provides millers and researchers with their first cooking-time reference for MR297. Second, it alleviates the problems regarding whether parboiling can offset the lower milling yield of this poorest quality rice cultivar with benefits for cooking. This work is novel in comparing MR297 over a full cooking-time range to an unparboiled sample and, at the same time, with a commercial parboiled benchmark. There has been no previous report comparing the three parameters. Consequently, this study examined the influence of cooking time (4-24 min) on certain physical properties (dimension and colour), cooking properties (elongation ratio, moisture sorption, l/b ratio) as well as textural properties (hardness, adhesiveness, cohesiveness, springiness and chewiness) in parboiled rice MR297 compared to both raw MR297 and its commercially processed parallel.

MATERIALS AND METHODS

Materials

A local farmer in Tanjung Karang, Selangor, Malaysia provided fresh paddy (MR297). The researchers randomly picked fresh paddy grain and transported it to the laboratory. The grain was then stored in a tightly sealed container at 10°C in a cold room until it was ready for further processing (Reddy & Chakraverty, 2004). The initial moisture content was 19.5%. Other plant parts and foreign materials were removed manually; the fresh paddy sample MR297 was sun-dried for two consecutive days until the moisture content (MC) decreased to 12.1%.

"Jati Rebus" brand parboiled rice was obtained from a local store in Malaysia and used as the commercially parboiled rice for comparison purposes.

Parboiling Process

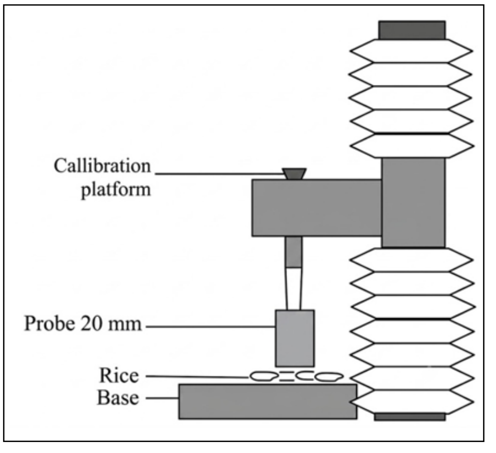
The parboiled MR297 was prepared by subjecting fresh MR297 paddy to a hot soaking method in a laboratory. A 100 mL amount of water was heated to 54.8 °C in a 250 mL beaker using a water bath (Memmert, WNB22, Germany) (Muchlisyiyah et al., 2025). Aluminium foil was used to completely seal the container in order to prevent excessive evaporation. Paddy (100 g) was added to the water in the glass beaker. The ratio of rice to water was 1:1 (Jannasch & Wang, 2020). A modest agitation was performed to guarantee thorough immersion of the paddy. The paddy was immersed for a period of 2 hours. The rice was then steamed for 20 minutes at a temperature of 100 °C using a domestic steamer (TEFAL VC1401, FRANCE). The rice was cooled at ambient temperature for a period of one hour (Bootkote et al., 2016). The paddy was then subjected to dehydration in an oven (Memmert DO6836, Germany) at 38 °C for 24 hours (Roy et al., 2019; Tian et al., 2018; Villanova et al., 2017). The hull removal process from dry parboiled rice was conducted with a Satake THU-35 dehusker (THU-35, Satake Corp., Japan), followed by a polishing time of 2.5 minutes using a TM05-C mill (Satake, Japan) (Liang et al., 2008).

Cooking Process

Three kernel types (unparboiled MR297, parboiled MR297, and commercial local Malaysian parboiled rice) were cooked in water (rice: water = 1:2 for unparboiled rice; rice: water = 1:2.5 for parboiled rice) at 100°C at selected cooking times (4, 8, 12, 16, 20, and 24 min) (Syafutri et al., 2016). Cooking times were chosen to cover the range of under- and fully-cooked, as well as slightly overcooked kernels, also covering the full softening-moisture uptake trajectory. A higher rice-to-water ratio was adopted for parboiled-plated (1:2.5) than for un-parboiled plated rice at the rate of 1:2. That is, the starch structure that results from parboiling in a gelatinised and hydrated yet more compact form needs a relatively larger amount of free water to achieve equivalent hydration/cooking in the same time and space. This bulk-cook method was applied to analyses of thickness, size and hue described below. For the elongation-ratio and moisture-sorption measurements, a different protocol (also detailed below) was used on a smaller scale here using assay conditions established from literature.

Textural Properties Determination

The texture profile analysis (TPA) was conducted promptly upon the cooked rice samples attaining ambient temperature, using the modified technique outlined by Chusak et al. (2019). Thirty kernels from each cooked rice sample were selected and placed at the bottom of the device. A TA.XT-Plus Texture Analyser, equipped with a 20 mm cylindrical probe attachment from Technologies Corp. and Stable Micro Systems Ltd., MA, was employed using a standard two-cycle compression method. The schematic diagram for the textural analysis can be seen in Figure 1a. The probe was permitted to fall at a rate of 1 mm/s, then ascend and then repeat the compression cycle. The compression was adjusted to a strain of 75%. Textural characteristics include hardness, adhesiveness, cohesion, springiness, gumminess, and chewiness.



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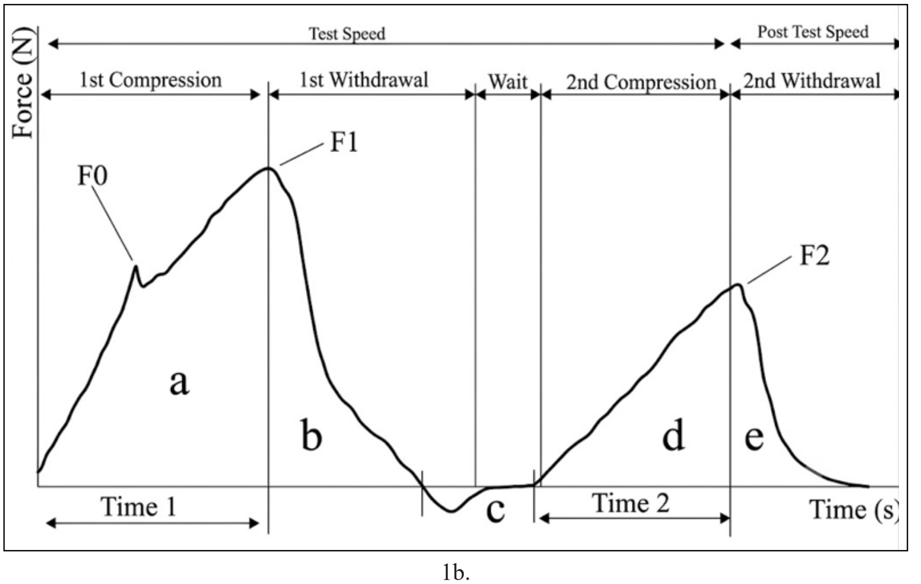

1b.

Figure. 1a. Schematic diagram for rice textural analysis (Adapted and modified from Liu et al., 2019). 1b. Texture Profile Analysis (TPA) curve resulting from the testing of rice. The graph displays the Force (N) versus Time (s) profile from two compression cycles. Peak F1 represents the hardness of the first cycle, F2 represents the hardness of the second cycle, and Area 3 (the negative area) indicates adhesiveness

The hardness (N) corresponds to the maximum force observed during the initial compression. Adhesiveness (N · s) refers to the integral of the curve for the initial negative peak. Cohesiveness is calculated by dividing the area under the second compression curve by the area under the first compression curve. Springiness, expressed as a percentage, represents the ratio of a product's ability to regain its previous height after compression. Chewiness is defined by multiplying the values of Hardness, Cohesiveness, and Springiness.

The analysis for the textural parameters can be seen in Equations 1-5 and illustrated in Figure 1b:

$$Hardness = F1 \quad [1]$$

$$Adhesiveness = c \quad [2]$$

$$cohesiveness = \frac{(d+e)}{(a+b)} \quad [3]$$

$$springiness\ (\%) = \frac{Distance\ \ 2}{distance\ \ 1} \times 100 = \frac{Time\ \ 2}{Time\ \ 1} \times 100 \quad [4]$$

$$Chewiness\ (\%) = \frac{F1xDistance\ \ 2}{distance\ \ 1 \times \frac{(d+e)}{(a+b)}} \quad [5]$$

Colour Properties Determination

Milled rice grains were randomly picked and placed in a Petri dish. The colour reader (FRU WR10, China) was calibrated using a white and black whiteboard. L* (lightness), a* (green-red), and b* (blue-yellow) scale of the rice types were determined by placing the colour meter adjacent to the petri dish containing the samples and photographing it using a 40 mm diameter lens with a white blank paper background (Kumar et al., 2022).

Dimensional Properties

A digital vernier calliper with a precision of 0.01 mm was utilised to measure the dimensions of 100 randomly selected rice grain heads, namely their length (L) and width (W). The measured dimensional properties are displayed in Figure 2.

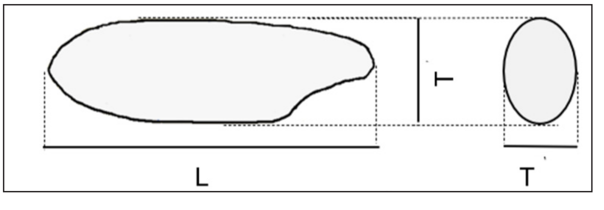

Figure 2. Dimensional characteristics of MR297 rice grain: length, L, width, W; thickness, T
Source: Muchlisyiyah et al. (2024b)

Cooking Properties Determination

The assessment of cooking properties was performed according to Ojediran et al. (2020) and Singh et al. (2005). The parameters measured were the l/b (length-to-breadth) ratio, moisture sorption, and elongation ratio. Head rice (25 grains) samples were randomly selected from milled rice grains and measured for length (L) and width (W) using a digital vernier calliper. The l/b ratio was then computed by dividing the total length by the total width (Equation 6).

$$ {}^{L}/_{b}\, ratio = \frac{total\ length\ of\ 25\ rice\ kernels}{total\ width\ of\ 25\ rice\ kernels} \quad [6] $$

5 g of head rice samples from each cultivar were cooked in 10 ml of distilled water in a boiling water bath. The rice was removed after 4, 8, 12, 16, 20, and 24 min. The surface water on the cooked rice was absorbed by pressing the cooked samples on filter paper sheets. Next, the cooked samples were precisely weighed, and the moisture sorption was determined (Equation 7).

$$ Moisture\ sorption = \frac{weight\ of\ cooked\ rice - weight\ of\ raw\ rice}{weight\ of\ raw\ rice} \quad [7] $$

The cumulative length of 10 cooked rice kernels was divided by the length of 10 uncooked raw kernels to calculate the elongation ratio (Equation 8).

$$ Elongation\ Ratio\ (ER\%) = \frac{Length\ of\ 25\ cooked\ rice\ kernels}{Length\ of\ 25\ raw\ rice\ kernels} \quad [8] $$

Statistical Analysis

Each experiment was performed in triplicate. Minitab (Version 19, LLC, USA) was used to conduct all statistical analyses, representing three independent parboiling/cooking batches processed and analysed separately. The results are expressed as the average standard deviation. The significance level for analysis of variance (ANOVA) differences was set at $p<0.05$. The principal component analysis (PCA) was also carried out using the Minitab Software (Version 19, LLC, USA).

RESULTS AND DISCUSSIONS

Textural Properties

Figure 3 shows the cooked rice grains at each cooking time interval, and Table 1 gives the corresponding hardness values. Hardness decreased with cooking time in all three samples. The decline was steeper at first and became more gradual thereafter. A similar pattern has

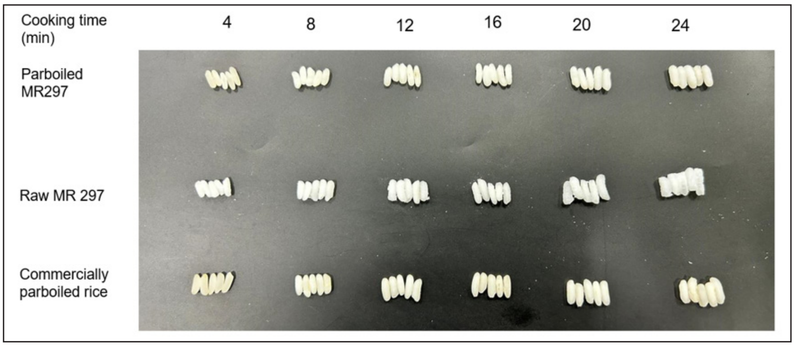

Figure 3. Cooked rice grains in different cooking times

been reported for other starchy foods during cooking (Beleia et al., 2004; Chusak et al., 2019; Gavahian et al., 2019; Saleh & Meullenet, 2013). This biphasic trend reflects the advance of the gelatinisation front through the kernel. Water and heat reach the outer layers first, disrupting the crystalline structure there and softening the surface relatively quickly. The denser core hydrates more slowly, so gelatinisation is completed there only later in cooking. Softening slows once the outer starch has gelatinised, having lost crystallinity, absorbed water, and swollen with continued amylose release (Li et al., 2016). The result is a more hydrated and looser matrix that resists compression less, which registers as the falling hardness values.

Adhesiveness is the measure of the labour or force required to overcome the attraction forces between a product's surface and the surface of the substance it contacts. Adhesiveness is conventionally defined in the negative here. A larger negative value corresponds to greater stickiness, whereas a smaller (less negative) number corresponds to less stickiness, not to "less adhesiveness" in some absolute sense. After 24 min, cooking produced -0.01 N·s for parboiled MR297, -0.14 N·s for unparboiled MR297, and -0.03 N·s for commercially parboiled rice, placing the commercial sample between the two MR297 samples in stickiness (Table 1). The magnitude of tackiness decreased for parboiled MR297 from -0.06 to -0.01 N·s, approaching zero as cooking time increased, indicating that the grains became progressively less sticky. In contrast, unparboiled and commercially parboiled rice showed no significant variation in adhesive properties across cooking times ($p>0.05$). Parboiled MR297 and commercially parboiled rice were both significantly less sticky than unparboiled rice at all stages of cooking. This is compatible with the well-documented function of parboiling in reorganising starch into a compact matrix, which retains amylose within the granule rather than liberating it to the kernel surface (Islam et al., 2004), and ultimately limits the kernel's capacity to develop surface stickiness from freed amylopectin accumulating during cooking (Mohapatra & Bal, 2006). Unparboiled rice adhesiveness in the present study was similar to values reported for white rice cooked in an electric cooker (Chusak et al., 2019).

Table 1
The effects of cooking time on the textural properties of MR297 parboiled rice

Rice	CT	Hardness (N)	Adhesiveness (N.sec)	Cohesiveness (peak2/peak1)	Springiness	Chewiness (N)
Parboiled rice MR297	4	13.26 ± 1.66^{a}	-0.06 ± 0.01^{c}	0.83 ± 0.03^{a-c}	1.00 ± 0.00^{a}	9.99 ± 1.34^{a}
	8	10.90 ± 1.11^{b-c}	-0.05 ± 0.01^{b-c}	0.71 ± 0.06^{b-d}	1.00 ± 0.00^{a}	7.73 ± 1.15^{b}
	12	4.57 ± 0.88^{d-g}	-0.02 ± 0.01^{a-b}	0.67 ± 0.06^{b-d}	1.00 ± 0.00^{a}	2.40 ± 0.09^{d-g}
	16	2.94 ± 0.58^{e-g}	-0.02 ± 0.00^{a}	0.66 ± 0.03^{b-d}	1.00 ± 0.00^{a}	2.00 ± 0.27^{f-g}
	20	2.68 ± 0.18^{f-g}	-0.02 ± 0.00^{a}	0.63 ± 0.02^{c-d}	1.00 ± 0.00^{a}	1.15 ± 0.38^{e-g}
	24	2.55 ± 0.66^{g}	-0.01 ± 0.00^{a}	0.62 ± 0.04^{d}	1.00 ± 0.00^{a}	1.11 ± 0.25^{g}
Unparboiled Rice	4	9.65 ± 1.46^{c}	-0.15 ± 0.01^{d}	0.92 ± 0.02^{a}	1.00 ± 0.00^{a}	8.60 ± 0.79^{a-b}
	8	5.25 ± 0.32^{d-e}	-0.15 ± 0.00^{d}	0.81 ± 0.07^{a-d}	1.00 ± 0.00^{a}	3.80 ± 0.52^{d-e}
	12	4.71 ± 0.98^{d-g}	-0.15 ± 0.02^{d}	0.80 ± 0.06^{a-d}	1.00 ± 0.00^{a}	3.56 ± 0.90^{d-e}
	16	4.04 ± 0.28^{d-g}	-0.14 ± 0.01^{d}	0.78 ± 0.02^{a-d}	1.00 ± 0.00^{a}	3.42 ± 0.17^{d-e}
	20	4.36 ± 0.18^{d-g}	-0.15 ± 0.01^{d}	0.77 ± 0.10^{a-d}	1.00 ± 0.00^{a}	3.25 ± 0.02^{d-e}
	24	3.94 ± 0.32^{d-g}	-0.14 ± 0.02^{d}	0.74 ± 0.06^{a-d}	1.00 ± 0.00^{a}	3.01 ± 0.52^{d-f}
Commercially parboiled Malaysian rice	4	12.26 ± 0.68^{a-b}	-0.03 ± 0.00^{ab}	0.85 ± 0.07^{a-b}	1.00 ± 0.00^{a}	9.53 ± 0.43^{a-b}
	8	8.96 ± 0.47^{c}	-0.03 ± 0.01^{ab}	0.85 ± 0.07^{a-b}	1.00 ± 0.00^{a}	7.67 ± 0.25^{b}
	12	5.59 ± 0.13^{d}	-0.03 ± 0.01^{ab}	0.84 ± 0.07^{a-b}	1.00 ± 0.00^{a}	5.41 ± 0.23^{c}
	16	5.00 ± 0.64^{d-f}	-0.03 ± 0.00^{ab}	0.80 ± 0.11^{a-d}	1.00 ± 0.00^{a}	3.71 ± 0.13^{c-d}
	20	3.83 ± 0.39^{d-g}	-0.03 ± 0.00^{ab}	0.79 ± 0.12^{a-d}	1.00 ± 0.00^{a}	2.72 ± 0.16^{d-g}
	24	3.17 ± 0.45^{g}	-0.03 ± 0.00^{ab}	0.74 ± 0.04^{a-e}	1.00 ± 0.00^{a}	2.36 ± 0.30^{d-g}

Note. CT = cooking time (min). Data are expressed as mean ±SD; Different letters indicate statistically significant differences exist $p < 0.05$ for each column. Means that do not share a letter are significantly different. Tukey's test was applied with 95% simultaneous confidence intervals

All samples showed a gradual decrease in cohesiveness with increasing cooking time. Parboiled MR297 fell from 0.83 to 0.62, the unparboiled sample from 0.92 to 0.74, and commercial rice from 0.85 to 0.74. Cohesiveness was lower in parboiled than in unparboiled rice, and no significant difference was observed between unparboiled and commercial rice ($p>0.05$; Table 1). This decline shows that structure was reduced in a stepwise fashion over the course of cooking. As water diffuses in, starch gelatinises, and amylose leaches out, compromising the dense granule and protein network formed during parboiling (Islam et al., 2004) and decreasing structural recovery. These values are consistent with the 0.6 to 0.7 range reported by Chusak et al. (2019) and exceed the 0.55 reported by Bonto et al. (2018).

Chewiness is defined as the energy needed to chew a semi-solid food until it can be swallowed (Li et al., 2023). As shown in Table 1, it ranged from 9.99 to 1.11 N for parboiled MR297, from 8.60 to 3.01 N for unparboiled MR297, and from 9.53 to 2.36 N for commercially parboiled rice, with no statistically significant difference between samples after 20 min of cooking. As previously noted, the reduction in hardness and cohesiveness contributes to the decline in chewiness, since chewiness is a function of both acting together.

This decrease therefore reflects a general loosening of the grain structure as the kernel softens. Gumminess was calculated as an intermediate step and is not reported separately.

Springiness was evaluated as the ratio of recovery height after the second compression to that after the first (Tao et al., 2020). A value of 1.00 ± 0.00 was recorded in all samples at every cooking time and treatment ($p>0.05$; Table 1). This uniformity likely reflects a real characteristic of cooked rice, namely near-complete elastic height recovery under the 75% strain regime applied here, consistent with springiness values reported elsewhere for cooked rice as being close to 1.0. Because springiness did not change significantly between treatments, it was removed from the PCA (see Section Principal Component Analysis).

Dimensional Properties

During cooking, rice grains grow in all three dimensions (Febina et al., 2023; Table 2). Water moves progressively into the starchy endosperm, and as the starch granules take it up and swell, they push outward against the cell wall and protein matrix surrounding them; because that matrix is only semi-rigid, it yields, and the kernel stretches along its length,

Table 2
The effects of cooking time on the dimensional properties of MR297 parboiled rice

Rice	CT	Length (mm)	Width (mm)	Thickness (mm)
Parboiled rice MR297	4	8.10 ± 0.43^{f-g}	2.19 ± 0.15^{g}	1.92 ± 0.14^{g-h}
	8	8.69 ± 0.52^{d-e}	2.43 ± 0.12^{f}	2.03 ± 0.07^{e-g}
	12	9.04 ± 0.54^{c-e}	2.44 ± 0.16^{e-f}	2.08 ± 0.12^{d-f}
	16	9.53 ± 0.53^{b}	2.48 ± 0.13^{d-f}	2.15 ± 0.11^{c-e}
	20	9.53 ± 0.50^{b}	2.53 ± 0.16^{c-f}	2.15 ± 0.11^{c-e}
	24	10.12 ± 0.68^{a}	2.69 ± 0.15^{a-b}	2.35 ± 0.14^{a-b}
Unparboiled Rice	4	7.51 ± 0.44^{h}	2.20 ± 0.16^{g}	1.85 ± 0.13^{h}
	8	8.06 ± 0.52^{g}	2.44 ± 0.19^{e-f}	1.99 ± 0.14^{f-g}
	12	8.95 ± 0.57^{c-e}	2.60 ± 0.15^{a-e}	2.17 ± 0.24^{c-d}
	16	9.14 ± 0.66^{b-d}	2.63 ± 0.15^{a-d}	2.23 ± 0.14^{b-c}
	20	9.22 ± 0.59^{b-c}	2.64 ± 0.19^{a-c}	2.31 ± 0.17^{a-b}
	24	9.28 ± 0.68^{b-c}	2.70 ± 0.23^{a-b}	2.41 ± 0.22^{a}
Commercially parboiled Malaysian rice	4	8.10 ± 0.30^{f-g}	2.18 ± 0.12^{g}	1.93 ± 0.06^{g-h}
	8	8.57 ± 0.27^{e-f}	2.39 ± 0.17^{f}	2.04 ± 0.07^{d-g}
	12	9.03 ± 0.31^{c-e}	2.43 ± 0.12^{f}	2.09 ± 0.07^{d-f}
	16	9.53 ± 0.25^{b}	2.48 ± 0.16^{d-f}	2.15 ± 0.09^{c-e}
	20	9.54 ± 0.27^{b}	2.54 ± 0.18^{b-f}	2.15 ± 0.09^{c-e}
	24	10.12 ± 0.35^{a}	2.71 ± 0.17^{a}	2.35 ± 0.11a-b

Note. CT = cooking time (min). Data are expressed as mean ±SD; Different letters indicate statistically significant differences exist $p < 0.05$ for each column. Means that do not share a letter are significantly different. Tukey's test was applied with 95% simultaneous confidence intervals width, and thickness. Expansion measured at a given cooking time is therefore a proxy for how deeply the hydration front has penetrated. Across the 4-24 min range, grain length rose significantly ($p<0.05$) in all samples: 8.10 to 10.12 mm in parboiled MR297, 7.51 to 9.28 mm in unparboiled rice, and 8.10 to 10.12 mm in the commercial rice, the parboiled and commercial samples converging on the same final value.

Width showed the same trend. It rose from 2.19 to 2.69 mm in parboiled MR297, 2.20 to 2.70 mm in the unparboiled rice, and from 2.18 to 2.71 mm in the commercial sample ($p<0.05$). All three reached a comparable width by the end of the cooking range. Thickness increased in parallel: 1.92 to 2.35 mm in parboiled MR297, 1.85 to 2.41 mm in the unparboiled rice, and 1.93 to 2.35 mm in the commercial sample ($p<0.05$). Together, the three dimensions point to the same conclusion. Temperature was held at 100°C throughout, so heat input cannot explain the differences in expansion. Cumulative water uptake is therefore the governing factor, consistent with a hydration-driven swelling mechanism.

Colour Properties

Prior research has demonstrated that a decrease in the intensity of colour in cooked rice improves consumer satisfaction and increases its market worth (Tian et al., 2014). The rice's L* increased from 56.92 ± 2.04 to 64.74 ± 0.30 after being cooked for 24 minutes, which was comparable to the L* of the commercially parboiled rice samples. Nevertheless, the extended duration required to fully cook the unparboiled rice MR297 resulted in an elevation in the rice's L*, reaching 57.80 ± 0.0.10 and 65.02 ± 0.68 after 0 to 24 minutes of cooking time, respectively. Unparboiled MR297 rose from 57.80 ± 0.10 to 65.02 ± 0.68 over the same 4-24 min range ($p<0.05$). L* increased in all samples. As water penetrates the kernel, the crystalline structure of the starch granules breaks down, and the pigmented surface layers are diluted. The result is a lighter grain than the raw kernel.

Regarding the a* value, as depicted in Table 3, it can be noticed that the a* value of rice grain decreased with cooking time from -0.30 to -0.61, from -0.59 to -1.51, and from 1.11 to -1.39 ($p<0.05$) for parboiled rice MR297, unparboiled MR297, and commercially parboiled rice MR297, respectively. At a 24-minute cooking time, the a* value of commercially parboiled rice was not significantly different from that of parboiled rice MR297 and unparboiled rice MR297. Meanwhile, the a* value of unparboiled MR297 is significantly different from that of parboiled rice MR297 at the final cooking time. The shift toward green is most likely a dilution effect. Parboiling and husk removal leave a brownish pigmentation on the grain surface. As the kernel takes up water and lightens, that pigmentation is progressively masked, which fits the rise in L* described above. The pigment composition itself does not appear to change.

Table 3
The effects of cooking time on the colour properties of MR297 parboiled rice

Rice	CT	**L***	a*	b*
Parboiled rice MR297	4	56.92 ± 2.04g-h	-0.30 ± 0.19b	12.24 ± 0.06^{c}
	8	59.14 ± 1.07^{e-g}	-0.30 ± 0.12^{b}	10.17 ± 0.28^{d}
	12	59.97 ± 0.20^{d-g}	-0.45 ± 0.36^{b-d}	8.63 ± 0.26^{d-e}
	16	61.54 ± 0.81^{b-e}	-0.37 ± 0.08^{b-c}	7.63 ± 1.40^{e-f}
	20	63.01 ± 0.52^{a-d}	-0.45 ± 0.05^{b-d}	6.48 ± 1.27^{f-g}
	24	64.74 ± 0.30^{ab}	-0.61 ± 0.14^{b-e}	5.50 ± 0.52^{g}
Unparboiled Rice	4	57.80 ± 0.10^{f-h}	-0.59 ± 0.05^{b-e}	5.96 ± 0.64^{f-g}
	8	59.91 ± 0.40^{d-g}	-0.71 ± 0.01^{b-f}	3.23 ± 0.42h
	12	60.89 ± 0.17^{d-f}	-0.92 ± 0.05^{b-f}	2.32 ± 0.50^{h-i}
	16	61.15 ± 0.15^{c-e}	-1.17 ± 0.02^{c-f}	1.67 ± 0.10^{h-i}
	20	62.78 ± 2.90^{a-d}	-1.22 ± 0.02^{d-f}	1.26 ± 0.06^{h-i}
	24	65.02 ± 0.68^{a}	-1.51 ± 0.07^{f}	1.17 ± 0.47^{i}
Commercially parboiled Malaysian rice	4	55.43 ± 1.63^{h}	1.11 ± 0.88^{a}	19.16 ± 0.42^{a}
	8	56.87 ± 0.71^{g-h}	0.59 ± 0.42^{a}	16.87 ± 0.83^{b}
	12	60.59 ± 1.21^{d-f}	-0.79 ± 0.26^{b-f}	15.32 ± 0.85^{b}
	16	64.29 ± 0.09^{a-c}	-1.14 ± 0.04^{c-f}	10.43 ± 0.22^{c-d}
	20	64.29 ± 0.09^{a-c}	-1.28 ± 0.19^{e-f}	9.04 ± 0.45^{d-e}
	24	64.47 ± 0.21^{ab}	-1.39 ± 0.16^{e-f}	7.68 ± 0.92^{m}

Note. CT = cooking time (min). Data are expressed as mean ±SD; Different letters indicate statistically significant differences exist $p < 0.05$ for each column. Means that do not share a letter are significantly different. Tukey's test was applied with 95% simultaneous confidence intervals

Yellowness (b*) fell significantly in all three samples as cooking time increased ($p<0.05$). Parboiled MR297 dropped from 12.24 to 5.50, unparboiled MR297 from 5.96 to 1.17, and the commercial parboiled rice from 19.16 to 7.68. By 24 min, parboiled MR297 did not differ significantly from the commercial sample. The pattern follows what was seen for L* and a*, and the same explanation applies. Water uptake dilutes or masks the surface pigments, so the loss of yellowness reflects hydration rather than a separate colour-forming reaction. This runs opposite to several other starchy foods. In those products, extended heating causes darkening as free amino acids react with reducing sugars in Maillard-type browning (Sovia et al., 2026). The direction of colour change under heat may therefore depend on a food's amino acid and reducing sugar content rather than on starch gelatinisation alone.

Cooking Properties

Table 4 displays the variations in the grain size of various rice samples throughout the cooking process. The elongation ratio increased from 1.16 to 1.44 for parboiled rice MR297, from 1.08 to 1.34 for unparboiled MR297, and from 1.17 to 1.46 for commercially parboiled rice MR297. Elongation reflects preferential water uptake and swelling along the length axis of the kernel. Starch granules face the least constraint from the surrounding cell-wall structure in that direction. Unparboiled rice showed slightly higher elongation in the early stages. This fits its faster initial moisture uptake relative to parboiled rice (see Section Moisture sorption), since the denser granule packing produced by parboiling slows water penetration at first. The elongation ratio change seen in this study is less than that of rice types cultivated in India (1.5-1.8) (Febina et al., 2023).

Table 4
The effects of cooking time on the cooking properties of MR297 parboiled rice

Rice	CT	Elongation Ratio	Moisture Sorption	l/b Ratio
Parboiled rice MR297	4	1.16 ± 0.06[g]	0.43 ± 0.06[i]	3.71 ± 0.24[a-d]
	8	1.24 ± 0.07[e]	0.65 ± 0.03[g-h]	3.58 ± 0.32[a-e]
	12	1.29 ± 0.08[d-e]	0.95 ± 0.10[e-f]	3.70 ± 0.35[a-d]
	16	1.36 ± 0.08[b-c]	1.12 ± 0.03[c-e]	3.85 ± 0.29[a]
	20	1.36 ± 0.07[b-c]	1.28 ± 0.06[b-c]	3.78 ± 0.30[a]
	24	1.44 ± 0.10[a]	1.63 ± 0.07[a]	3.76 ± 0.32[a-b]
Unparboiled Rice	4	1.08 ± 0.06[h]	0.48 ± 0.04[h-i]	3.41 ± 0.36[e]
	8	1.16 ± 0.08[g]	0.82 ± 0.01[f-g]	3.30 ± 0.27[d-e]
	12	1.29 ± 0.08[d-e]	1.32 ± 0.04[b]	3.45 ± 0.27[c-e]
	16	1.31 ± 0.09[b-d]	1.55 ± 0.03[a]	3.48 ± 0.31[b-e]
	20	1.33 ± 0.09[b-d]	1.57 ± 0.02[a]	3.49 ± 0.29[b-e]
	24	1.34 ± 0.10[b-d]	1.57 ± 0.03[a]	3.44 ± 0.36[c-e]
Commercially parboiled Malaysian rice	4	1.17 ± 0.04[f-g]	0.40 ± 0.03[i]	3.72 ± 0.21[a-c]
	8	1.23 ± 0.04[e-f]	0.50 ± 0.13[h-i]	3.59 ± 0.22[a-e]
	12	1.30 ± 0.04[c-e]	0.79 ± 0.07[f-g]	3.71 ± 0.24[a-c]
	16	1.37 ± 0.04[b]	1.07 ± 0.06[d-e]	3.84 ± 0.30[a]
	20	1.37 ± 0.04[b]	1.26 ± 0.08[b-d]	3.75 ± 0.26[a-b]
	24	1.46 ± 0.05[a]	1.57 ± 0.10[a]	3.73 ± 0.27[a-b]

Note. CT = cooking time (min). Data are expressed as mean ±SD; Different letters indicate statistically significant differences exist $p < 0.05$ for each column. Means that do not share a letter are significantly different. Tukey's test was applied with 95% simultaneous confidence intervals.

Moisture sorption increased from 0.430 to 1.633 for parboiled rice MR297, from 0.48 to 1.57 for unparboiled MR297, and from 0.40 to 1.58 for commercially parboiled rice MR297. Table 4 illustrates that the moisture sorption of the unparboiled sample shows a slower rate of increase after reaching 16 minutes of cooking. Conversely, the absorption rate of moisture in parboiled rice MR297 was slower than in unparboiled rice MR297. Parboiled rice absorbed more moisture than unparboiled rice by the end of cooking.

Continued heating disrupts the crystalline structure and hydrogen bonding of the starch granules, allowing water uptake to progress alongside gelatinisation (Gavahian et al., 2019). The slower uptake seen early on in parboiled rice fits its denser pre-gelatinised granule structure (Islam et al., 2004), which takes longer for water to penetrate. Once this structure starts breaking down under continued cooking, though, that same denser matrix may end up retaining more absorbed water at equilibrium, which would explain its higher sorption by 24 min.

Weight gain is a representation of the water that is absorbed by the starch of the grain that is capable of keeping water in the granules. This weight gain is estimated as hydration rates for various types of rice, including cultivars and ages. The increase in moisture sorption with increasing cooking time ($p < 0.05$) can be seen in Table 4. As noted above, unparboiled rice absorbed moisture more rapidly at the start of cooking, while parboiled MR297 and commercial parboiled rice absorbed moisture more gradually, yet parboiled rice ultimately absorbed more water than unparboiled rice by the final cooking time. The results indicated that the parboiling technique altered the starch properties in the grain, resulting in a delayed hydration and gelatinisation process compared to unparboiled rice.

Rice grains are measured in terms of their compared to their width, which is referred to as the L/B ratio. Among the three kinds of rice that were cooked, the L/B ratio ranged from 3.3 to 3.8. The l/b ratio does not exhibit a discernible trend as cooking time increases. This result indicates that length and width expand roughly proportionally during cooking rather than one dimension outpacing the other. However, the table shows that there were significant difference of l/b ratio between the three samples. The results indicated that the l/b ratio of unparboiled rice MR297 is smaller than the l/b ratio of both MR297 and the commercial parboiled rice ($p < 0.05$). The change in dimensions observed upon parboiling indicates a small shift in the l/b ratio of the cooked rice, rather than in cooking time itself.

Principal Component Analysis

PCA helped identify which variables best capture how cooked-rice quality shifts over cooking time (Figure 4). Springiness was excluded from the analysis. Its value stayed nearly constant across all treatments ($p > 0.05$; Table 1), so it added no meaningful variance to correlate against the other variables. The first two components together accounted for 87.4% of the total variance (PC1: 64.1%, PC2: 23.3%; Table 5). PC1 loaded most heavily on length, width, thickness, elongation, moisture sorption, and lightness (L*), with loadings between 0.32 and 0.33. Hardness and chewiness loaded negatively (-0.32 and -0.32; Table 6). PC1 therefore captures the overall cooking-time trajectory. As cooking progresses, the dimensional, moisture, and colour variables rise together while hardness and chewiness fall. PC2 was most strongly tied to l/b ratio (-0.53) and adhesiveness (-0.57), the two variables that most clearly distinguish unparboiled from parboiled samples (Table 6). PC3 explained only 5.2% of the variance and is not discussed further. Processing duration is

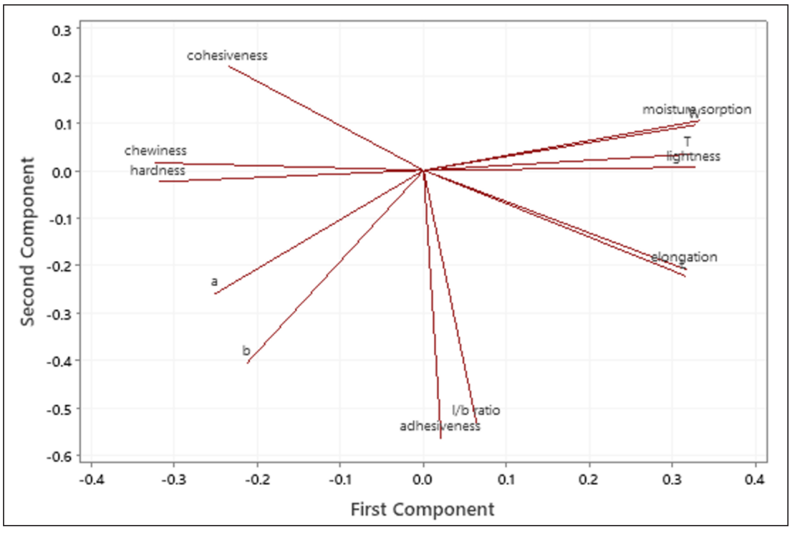

Figure 4. First and second component plots on the x and y axes for the (physical, textural, and cooking properties)

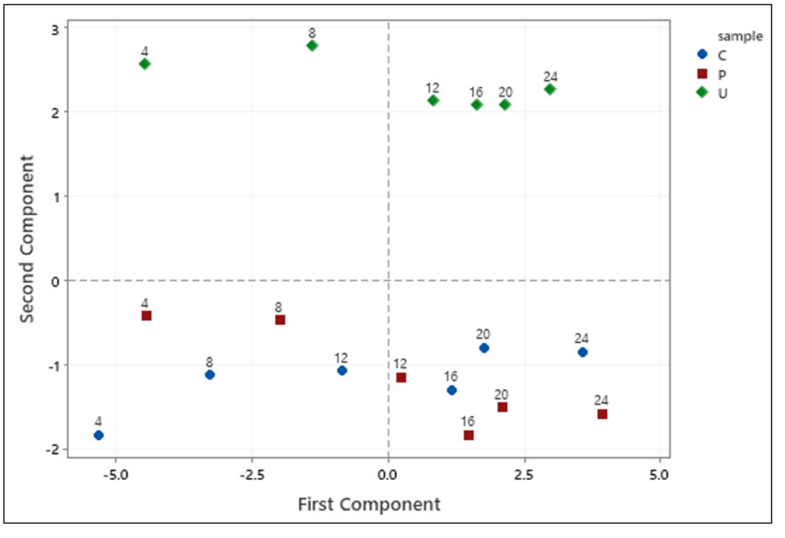

Figure 5. Score plot of cooked rice at different cooking times for the first and second principal components

similarly recognised as a critical determinant of physicochemical outcomes across other food matrices (Istrada et al., 2026).

The score plot (Figure 5) shows clear separation along both axes. Samples moved rightward along PC1 as cooking time increased, confirming it as the dominant cooking-time axis. Unparboiled rice samples clustered more tightly after 12 min. Both parboiled samples only began clustering from 16 min onward. Quality changes therefore appear to

Table 5
Eigen analysis of the Correlation Matrix

	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9	PC10	PC11	PC12	PC13
Eigenvalue	8.339	3.030	0.674	0.428	0.289	0.123	0.059	0.031	0.013	0.009	0.004	0.000	0.0000
Proportion	0.641	0.233	0.052	0.033	0.022	0.009	0.005	0.002	0.001	0.001	0.000	0.000	0.000
Cumulative	0.641	0.875	0.926	0.959	0.982	0.991	0.996	0.998	0.999	1.000	1.000	1.000	1.000

Table 6
Eigenvectors

Variable	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9	PC10	PC11	PC12	PC13
Length	0.315	-0.222	-0.127	0.131	0.021	-0.036	0.214	0.215	0.250	-0.017	0.023	-0.069	0.810
Width	0.328	0.095	-0.040	0.360	-0.105	0.298	0.252	0.238	0.167	0.173	-0.013	0.632	-0.273
Thickness	0.320	0.033	-0.135	0.509	0.074	-0.057	-0.284	-0.640	0.048	-0.240	-0.245	-0.025	0.007
elongation	0.316	-0.209	-0.172	0.145	-0.025	-0.043	0.194	0.238	0.230	0.056	-0.021	-0.656	-0.471
l/b ratio	0.064	-0.533	-0.170	-0.272	0.224	-0.559	0.017	-0.139	0.195	0.125	-0.046	0.374	-0.176
moisture sorption	0.332	0.104	-0.017	0.189	0.033	-0.440	0.068	0.179	-0.742	0.024	0.246	0.017	0.004
Lightness (L*)	0.327	0.006	-0.229	-0.221	0.151	0.213	-0.780	0.296	0.021	0.104	0.124	0.034	0.003
a*	-0.251	-0.260	0.431	0.445	-0.352	-0.293	-0.392	0.315	0.144	-0.029	-0.027	0.028	-0.003
b*	-0.214	-0.407	-0.308	0.188	-0.289	0.271	-0.035	-0.281	-0.226	0.521	0.302	-0.060	0.063
hardness	-0.318	-0.024	-0.114	0.298	0.595	0.056	-0.010	0.236	-0.177	0.306	-0.504	-0.048	0.049
adhesiveness	0.021	-0.566	0.003	-0.074	-0.031	0.377	0.053	0.122	-0.365	-0.572	-0.204	0.087	-0.066
cohesiveness	-0.235	0.219	-0.702	-0.011	-0.440	-0.220	-0.027	0.193	-0.005	-0.195	-0.285	0.073	0.012
chewiness	-0.323	0.016	-0.258	0.295	0.391	-0.001	0.018	0.082	0.174	-0.389	0.627	0.051	-0.071

taper off earlier in unparboiled rice than in parboiled rice. Unparboiled MR297 sat in the upper part of the plot, while parboiled MR297 and commercial parboiled rice occupied the lower part. This confirms PC2 (l/b ratio, adhesiveness) as the axis separating parboiled from unparboiled samples. The convergence of parboiled samples along PC1 from 16 min onward matches the plateau in hardness and chewiness seen in Table 1 over the same window. Together, these support 16-20 min as the point past which further cooking produces only diminishing changes to most quality parameters, a useful benchmark for recommending a practical cooking time.

CONCLUSION

Cooking time significantly shaped the textural, physical, colour, and cooking properties of parboiled MR297 rice relative to its unparboiled and commercially parboiled counterparts. Extending cooking time consistently softened the grain and reduced its cohesiveness and chewiness. Grain dimensions, lightness, elongation, and moisture uptake all increased over the same range. Springiness and the l/b ratio remained stable regardless of cooking duration. Parboiled MR297 was consistently less sticky and less cohesive than unparboiled rice. It also reached a final size and brightness comparable to the commercial parboiled benchmark. Principal component analysis confirmed cooking duration as the dominant source of variation among samples. Parboiling status formed a secondary but consistent distinction based on l/b ratio and adhesiveness.

These findings provide the first cooking-time profile for parboiled MR297. Appropriately timed cooking brings its texture and appearance in line with an established commercial parboiled rice despite the lower milling yield of MR297. Textural softening plateaus while moisture uptake continues beyond this point. A cooking time of approximately 16 to 20 min is therefore recommended for parboiled MR297.

This study relied on instrumental and physicochemical measures only. Sensory and consumer acceptance were not assessed, so eating-quality conclusions are instrumentally inferred rather than taster-confirmed. Findings are based on a single paddy batch and one commercial benchmark, so they may not capture broader seasonal or supplier variability.

Future work should incorporate sensory evaluation to validate the recommended cooking time. Direct examination of compositional changes such as amylose and amylopectin ratio and starch crystallinity would confirm the structural mechanisms proposed here. Testing across multiple paddy batches and harvest seasons would also strengthen the generalisability of these findings.

COMPETING INTERESTS

The authors declare that they have no conflict of interest.

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