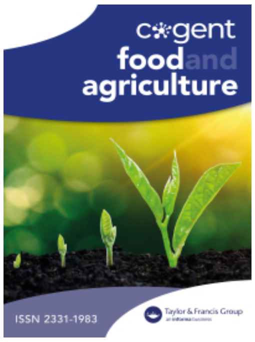

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Optimization of soaking conditions in parboiling using response surface methodology to enhance the properties of MR297 rice cultivar

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ABSTRACT
MR297 is known as a resistant cultivar to rustic disease but has a low head rice yield. The purpose of this study was to optimize the soaking conditions (temperature and time) for the enhancement of quality characteristics of long grain rice cultivar MR297 parboiled The experiment was done by optimizing the effects of soaking temperature (50–70 °C) and soaking time (2–4 h) for paddy using a central composite design of response surface methodology. The parboiling process then continued with steaming 100 °C for 20 min and drying 38 °C for 24 h). Besides analyzing the physical properties and milling properties of parboiled rice, the color and hardness properties of parboiled milled rice varieties were also investigated. We used design expert software to optimize the responses numerically. MR297 parboiled rice quality was significantly affected by the temperature and soaking time ($p < 0.05$). It was found that 54.75 °C and 2 h of soaking was the optimal temperature and time. The optimization was done to maximize the head rice yield, maximize the hardness, maximize the lightness, and also minimizing the browning index and total color change of the milled rice during parboiling, the proposed suggestion should be implemented.

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1. Introduction

Rice production worldwide is expected to reach 517 million metric tons in 2021, according to recent statistics. Nearly half of the world's population, or 3.9 billion people, rely on rice for carbohydrates. There are various varieties developed to meet the demand. MARDI released MR297, a new rice cultivar generated by the institute, during the 2014 off-season (MARDI, 2016). MR297 varieties had greater resistance to canker disease than previously published rice MR263, which benefited farmers. However, the milling yield of this variety is minimal, and the milling factories may place less value on it. Broken rice varieties may be repaired using the parboiling procedure. A technique of pre-treatment known as rice parboiling improves head rice yields (HRY) (Jaiboon et al., 2016). Parboiled rice accounts for 15–20% of the world's milled rice consumption (Jannasch & Wang, 2020). During the parboiling process, rice is soaked, steamed, and dehydrated before being milled (Bhattacharya, 2004). This process aims to improve rice's physical, functional, and nutritional properties (Chavan et al., 2017).

A hydrothermal treatment at the end of parboiling is an essential step that greatly impacts the quality of rice (Leethanapanich et al., 2016). The hydrothermal treatment of rice in parboiling can enhance its size, hardness, and color, among other physical properties. In paddy rice, the crystalline and amorphous forms of starch are irreversibly fused during the parboiling process, which results in a resistance structure during milling, which may increase yields (Fang et al., 2021) The soaking process is conducted at room temperature for 24–72 h, and at high temperature for 3 h

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(60–70 °C) (Taghinezhad et al., 2016). The soaking procedure results in complete hydration and partial gelatinization. After soaking, the steaming process is conducted for 15–20 min at atmospheric or high pressure (Balbinoti, Nicolin, et al., 2018). The entire process of rice gelatinization occurs during this steaming procedure. The drying procedure reduces the moisture content to 13–14%. Sun drying is the most traditional method; other methods include fluidized bed drying, microwave assistance, infrared drying, and superheated steam drying (Balbinoti, Nicolin, et al., 2018).

Rice soaking is critical to produce parboiled rice. Effective and efficient soaking will immediately impact the finished product's quality (Graham-Acquaah et al., 2015; Jagtap et al., 2008). The required soaking period is often pointed out as a challenge. A too-short soaking time can result in insufficient hydration, whereas a too-long soaking time develops off-flavors and intense color change (Ahmed et al., 2023; Mahfeli et al., 2022). Additionally, the color intensity of parboiled rice has been the subject of numerous studies (Ahmed et al., 2023; Saleh et al., 2018; Srichamnong & Lasukhang, 2022; Xi et al., 2016). Rice endures a color change during soaking (Da Fonseca et al., 2011). The color of cooked rice is golden yellow (Bootkote et al., 2016; Ojediran et al., 2020). Consumers disapprove of the golden-brown hue in some countries where parboiled rice is unfamiliar (Bairagi et al., 2021; Custodio et al., 2019). During the soaking process, technology plays a crucial role in overcoming obstacles that prevent parboiled rice from being produced efficiently.

However, there are limited scientific data regarding optimization of conventional soaking time and temperature for particular parboiled rice varieties MR297. Physical quality of the product can be compromised if processing conditions are not optimized, leading to quality inconsistencies. There are various quality parameters that are affected by this variation, including the physical and milling properties of the parboiled rice. It is important to consider the HRY, the hardness, and the lightness of the final product. To create commercial parboiled rice of MR297 that is competitive with imported rice, rice production must be optimized for consistency and quality. As well, developing an optimal parboiling method will facilitate commercialization and increased usage across the country. In turn, this enhances the market opportunities for cultivators of MR297 rice. The goal was to identify the optimal soaking conditions (temperature and time) during parboiling to enhance the quality of parboiled rice MR297.

2. Materials and methods

2.1. Raw material preparation

A local farmer in Tanjung Karang (Selangor, Malaysia) provided fresh paddy (MR297) for this study, which was taken in two harvesting seasons in June 2022 and November 2022. MR297 is a long-grain Malaysian rice with high resistance to rustic disease. The fresh paddy grain was selected randomly and stored in a tightly sealed container in a cold room at 10 °C until further analysis (Reddy & Chakraverty, 2004). Moisture content of the paddy was measured using a moisture analyzer (A&D MX50, USA). At the beginning, the paddy contained 19.5% moisture. During the cleaning process, sticks, stones, leaves, were other plant material was manually removed.

2.2. Set up of soaking treatment

Parboiling was done in three stages: soaking, steaming, and drying. To determine soaking time and temperature, response surface methodology was used. Parboiling of fresh paddy MR297 was conducted on a laboratory scale using hot soaking treatment. A 250 mL beaker glass containing 100 mL of water was heated in a water bath (Memmert. WNB22, Germany). The beaker was closed using aluminum foil to avoid excessive evaporation. When the temperature reached the required temperature, 100 g of paddy was added to the beaker glass water. The ratio of paddy to water 1:1 was done according to limited water soaking parboiling done by Jannasch and Wang (2020). A gentle mixing was done to make sure all the paddy was soaked. One, two, three, four, and five hours were the durations of soaking the paddy.

2.3. Steaming and drying for parboiled rice production

Afterward, the paddy was steamed for 20 min at 100 °C using a domestic steamer (TEFAL VC1401, FRANCE) (Balbinoti, Nicolin, et al., 2018). Balbinoti, Jorge, et al. (2018) stated that the most common condition for soaking was 100–110 for 10–20 min. The steaming temperature and condition were chosen by unpublished preliminary study. The steamed paddy was then tempered at room temperature (28 ± 2 °C) for 1 hr to ensure uniform moisture distribution and condition within the grain (Bootkote et al., 2016). To dry this paddy, it was placed inside an oven at 38 °C for 24 h (Memmert DO6836, Germany) (Roy et al., 2019; Tian et al., 2018; Villanova et al., 2017). The study did not consider steaming and drying because the operation was conducted at a single time and temperature. The dried paddy (moisture content 11–12%) for each treatment was used for physical properties determination, including the length, width, thickness, volume expansion, thousand kernel weight, and density.

A Satake THU-35 dehuller was used to remove the husk of the parboiled rice and a Satake TM05-C mill was used to polish it for 150 s (degree of milling 10 ± 1%). Head and broken rice kernels were separated using a laboratory width and length grader (TWL05C-T, SATAKE, Japan). HRY is the ratio of head parboiled rice mass to rough rice mass (paddy). The milled rice was then analyzed for the physical properties of hardness and color L, a, and b (FRU WR10, China).

2.4. Optimization of experimental work using response surface methodology

Using Design Expert v13 (StatEase, Minneapolis, USA) software, the Central Composite Design (CCD) was used to determine how soaking time and temperature, as independent variables, influenced dried paddy lengths, widths, thicknesses, volume expansions, thousand kernel weights, and densities, as well as the hardness and color of milled rice. Based on Table 1, we can see the ranges and levels for the parameters examined. The temperature was chosen according to Balbinoti, Jorge, et al. (2018) and the most common temperature used for soaking was 60–70 °C. For optimization, only models with a non-significant lack of fit ($p > 0.05$) were considered. In the optimization process, specific constraints were applied to each variable, and a suitable combination was selected based on the highest desirability. Model validity was evaluated under optimal conditions predicted by the model. To determine the goodness of fit of the models, the average responses from the experiments were compared with the predicted values, and the residuals were calculated.

2.5. Physical properties determination

2.5.1. Length, width, thickness

Measurements for the length (L), width (W), and thickness (T) of the parboiled paddy were performed using a digital vernier caliper with a sensitivity of 0.01 mm. The results were done by displaying the means for 100 grains.

2.5.2. Bulk density (g/mm^3)

A bulk density measurement was performed by evaluating the mass between the mass and the bulk volume.

$$\rho_b = \frac{\textit{mass of grain}}{\textit{bulk volume}} \tag{1}$$

2.5.3. Thousand kernel weight (TKW)

Thousand kernel weight (TKW) measures grain yield and milling quality by measuring the weight in grams of 1000 seeds (Wu et al., 2018). The thousand kernel weight for milled head rice was determined by manually counting and weighing 100 grains using an electronic scale (ER-120A, AND, Japan) with a sensitivity of 0.0001 g. The results were then multiplied by 10 to determine the weight of one thousand kernels.

2.5.4. Density (g/mm^3)

The density was measured by evaluating the quotient between mass over the volume of the paddy. The mass was obtained by the average of single grain from TKW in Section 2.5.3. the volume was done by the average of calculated volume of single grain by equation in Section 2.5.5.

$$\rho_T = \frac{\text{mass of grain}}{\text{true volume}} \tag{2}$$

2.5.5. Volume expansion

The volume of rice grain represents the amount of space occupied by the whole grain. The volume of the paddy was presumed as uniform and calculated by using the relationship with the dimensions as follows (Bhat & Riar, 2016; Mir & Bosco, 2013; Nádvorníková et al., 2018):

$$V_c = \frac{\frac{\pi}{6} L(WT)^2}{4} \tag{3}$$

Table 1. Experimental range and levels of the independent variables for the design of the experiment.

Independent variables	Symbols	−α	Low	Medium	High	−α
Temperature (°C)	A	45.8579	50	60	70	74.1421
Time (h)	B	1.58579	2	3	4	4.41421

2.5.6. Color

In a petri dish, fifty (50) grams of each sample of milled rice grain was randomly chosen and placed then measured using a colorimeter (FRU WR10, China). Calibration was carried out using a whiteboard and a blackboard. The colorimeter was placed adjacent to the petri dish containing the samples and photographs were taken using a 40 mm diameter white blank paper background to determine the L^*, a^*, and b^* of the rice types (Kumar et al., 2022). The L^*, a^*, and b^* of the parboiled rice value were then used to calculate the total color change and browning index (BI).

$$\Delta E = \left[\left(L_0 - L^* \right)^2 + \left(a_0 - a^* \right)^2 + \left(b_0 - b^* \right)^2 \right]^{1/2}$$

$$BI^* = 100\left(x - 0.31 \right) / 0.17$$

Where,

$$x = \frac{a^* + 1.75\left(L^* \right)}{5.645\left(L^* \right) + a^* - 3.012\left(b^* \right)}$$

2.5.7. Hardness

Milled parboiled rice samples were measured for hardness. Hardness was determined as the peak force encountered during the initial compression. The hardness of the samples was assessed using the compression method, employing a Texture Analyzer (TA-XT2, Stable microsystems, UK) with a 30 kg load cell. A stainless steel probe with a diameter of 5 mm (P5) was utilized to compress individual rice grains along their thickness. Five samples of uncooked rice were used for measurements. The compression was carried out using a single force-*vs.*-time program, with a test speed of 2 mm/s and a post speed of 10 mm/s (Kumar & Prasad, 2018).

The cooked rice of optimum parboiled milled rice and milled raw rice were then analyzed for hardness, adhesiveness, and cohesiveness of cooked rice (modification of Chusak et al., 2019). Hardness (N) is the greatest force recorded during the initial compression. Adhesiveness is the integration of the curve up to the initial negative peak. Cohesiveness is determined by dividing the area under the second compression curve by the area under the first compression curve.

2.6. Milling properties determination

Milling properties represent rice quality after the milling process (Bao, 2019).

2.6.1. Milled rice recovery (MRR)

Milled rice recovery refers to the overall quantity of milled rice obtained from paddy. It is the weight percentage of milled rice (including broken) obtained from a paddy sample (Hapsari & Eun, 2016; Ojediran et al., 2020).

$$MRR = \frac{mass\ of\ milled\ rice}{mass\ of\ paddy} \times 100 \tag{4}$$

where *MRR* = *milled rice recovery* (%).

2.6.2. Head rice yield (HRY)

The head rice, obtained after the milling process, comprised rice grains that were at least three-quarters the length of the original kernel. A calculation was performed to calculate the amount of head rice recovered through milling (Hapsari & Eun, 2016; Ojediran et al., 2020).

$$HRY = \frac{mass\ of\ head\ rice}{mass\ of\ paddy} \times 100 \tag{5}$$

Where *HRY* = *head rice yield* (%).

2.7. Cooking properties determination

The assessment of cooking properties was done according to Ojediran et al. (2020) and Singh et al. (2005). The measured parameters were minimum cooking time, water uptake, and elongation ratios.

2.7.1. Cooking time

Two grams of head rice samples were extracted from each sample and cooked in a boiling bath with 20 ml of distilled water. The cooking time was determined by periodically extracting a few kernels during the cooking process and compressing them between two glass plates until no residual white core remained.

2.7.2. Water uptake ratio

Each cultivar's head rice samples, weighing 2 g each, were cooked in 20 mm of distilled water using a boiling water bath, ensuring the minimum required cooking time. The contents were depleted, and the surface water on the cooked rice was extracted by exerting pressure on the cooked samples using filter paper sheets. Precise measurements were taken of the cooked samples, and the water absorption ratio was computed.

2.7.3. Grain elongation

An elongation ratio was obtained by dividing the accumulated length of 10 cooked rice grains by the length of 10 uncooked raw grains.

2.7.4. L/W ratio

The dimensions of 100 randomly selected rice heads were assessed using a digital vernier caliper. The length (*L*) and width (*W*) were recorded, and the *L/W* ratio was computed by dividing the total length by the total width.

2.8. FTIR analysis determination

Two milligrams of raw and parboiled rice flour were meticulously blended with 50 mg of desiccated potassium bromide salt using a mortar and pestle. The combination was subjected to pelletization using the pelletizer machine (PCI, Analytical Pvt. Ltd.). The infrared absorption spectra of the pellet were examined using an FTIR spectrometer (IRPrestige21, Shimadzu, Tokyo, Japan). The spectrometer was calibrated using potassium bromide (KBr) and a deuterated triglycine sulfate (DTGS) monitor. The spectra were taken with a precision of 2 cm^{-1} and a range of intensity from 4000 to 400 cm^{-1} (Kumar & Prasad, 2018).

2.9. Morphological properties determination

The microstructural parameters of samples obtained at different processing stages were analyzed using a scanning electron microscope (FEI, Inspect-S50, USA). Utilizing double-sided conductive tape, every sample was positioned on separate aluminum stubs. Then, all samples underwent gold vacuum-coating and were scanned at different magnifications (130×, 400×, and 1000×) (Kumar & Prasad, 2018).

2.10. Statistical analysis

ANOVA and regression were utilized for statistical analysis to test the significance (*p*-value) of the models, interaction, and lack of fit of the tested responses ($p < 0.05$). The response values were reported as the mean value. The correlation between responses was assessed using the coefficient of determination (R^2), modified R^2, and adequate (Adeq) precision. An effective model will exhibit a high R^2 value together with high Adeq precision values, ideally more than 4. Design Expert 13.0 Trial version was used to conduct the statistical analysis.

3. Results and discussion

Before milling, the paddy parboiling process involves three steps: soaking, steaming, and drying rough rice. Parboiled rice offers enhanced head rice yield (HRY), higher nutritional content, and better protection against insect damage. Steaming and drying play a crucial role in paddy parboiling, but this study focuses explicitly on soaking temperature and time. As independent variables, these factors were examined for their impact on paddy's physical properties (length, width, thickness, bulk density, TKW, density, volume expansion), milling properties (recovery of milled rice, milling degree, and yield of head rice), color, and hardness of milled rice. Table 2 displays the ANOVA results of the fitted model for each plot. The response is plotted in the surface plot. The regression equations in Table 3 in coded form provide each variable's correlation coefficient (R^2), adjusted R^2, and adequate precision.

3.1. Effect of parboiling on physical properties

The dimensional characteristics of parboiled rice were characterized by the central axis (length), medium axis (width), and minor axis (thickness). The hydrothermal treatment of parboiled rice processing will affect the physical parameters of the paddy. The intensity of the physical change depends on the processing parameters applied. Table 4 shows the dimensions of parboiled rice after soaking at different temperatures and times. Rice grains enclosed in the husk will expand as water moves inward during soaking and steaming (Hu et al., 2021). And then, when subjected to drying, the rice grain will shrink. Due to the hydrothermal and dehydration processes, the starch structure is altered, and the dimension of parboiled rice is changed compared to raw rice. The measured dimensional parameters were taken after the drying process.

Table 4 represents the variations in the length of parboiled paddy as a function of temperature and time of soaking, which the effect was considered insignificant due to the significant lack of fit. The width of MR297 responses to the objected factors was suggested to be explained by using the quadratic model (R^2 = 0.7414) (Table 3). The thickness of the parboiled paddy in relation to soaking time and temperature, however, is well-fitted by a linear model (R^2 = 0.8589) (Table 4). As a consequence, it may be concluded that the change in dimensions of dried paddy after parboiling at different temperatures is more pronounced along the medium and minor axes

Table 2. ANOVA for dimensional change in physical and milling properties in parboiled rice in different soaking times and temperature.

Response	Suggested model	R^2	*p*-Value						
			Model	A-	B	AB	A^2	B^2	Lack of fit
Physical properties paddy									
Length	Linear	0.6095	0.0091*	0.0216*	0.0168*				0.0084*
Width	Quadratic	0.7414	0.0488*	0.3459	0.0211*	0.1442	0.9293	0.0289*	0.1708
Thickness	Linear	0.8589	<0.0001*	0.0003*	0.0002*				0.1954
Bulk density	Quadratic	0.9936	<0.0001*	0.0322*	0.4795	0.8729	<0.0001*	<0.0001*	0.2154
TKW	Quadratic	0.8365	0.0112*	0.0089*	0.0162*	0.1523	0.0570	0.0365*	0.2244
Density	Quadratic	0.9329	0.0006*	0.0152	0.0004*	0.7611	0.0592	0.0003*	0.9579
Volume expansion	Linear	0.6881	0.0029*	0.0226*	0.0032*				0.1145
Physical properties milled rice									
*L**	Quadratic	0.9418	0.0003*	0.0001*	0.0005*	0.2888	0.0062*	0.0986	0.0589
a-Color	Quadratic	0.8121	0.0176*	0.0428*	0.0141*	0.9205	0.3590	0.0081*	0.1491
b-Color	Linear	0.6603	0.0045*	0.0013*	0.7361				0.2829
BI	Quadratic	0.9515	0.0002	<0.0001	0.0069	0.5550	0.0369	0.0021	0.8986
ΔE	Quadratic	0.9396	0.0004	<0.0001	0.0431	0.1053	0.0956	0.0124	0.5627
Hardness	Linear	0.8265	0.0002*	0.0221*	<0.0001*				0.2348
Milling properties									
MRR	Quadratic	0.8034	0.0204*	0.3141	0.3267	0.0057*	0.0398*	0.1183	0.0881
HRY	Linear	0.7414	0.0012	0.0003	0.8582				0.7260

A: soaking temperature; B: soaking time.
*Significant at $p < 0.05$.

Table 3. Regression model for dimensional change in physical and milling properties in parboiled rice in different soaking times and temperature.

Response	Regression models	R^2	Adjusted R^2	*Adeq* precision (desire > 4)
Physical properties paddy				
Length	$L = 10.32 + 0.0291\,A + 0.03074\,B$	0.6095	0.5314	8.2205
Width	$W = 2.33 + 0.0052\,A + 0.0153\,B - 0.0120\,AB - 0.0005\,A^2 - 0.0152\,B^2$	0.7414	0.5567	5.8806
Thickness	$T = 2.0434 + 0.0144\,A + 0.0152\,B$	0.8589	0.8307	16.2367
Bulk density	Bulk density $= 4.24 - 0.0162\,A + 0.0045\,B - 0.0014\,AB + 0.2056\,A^2 + 0.0866\,B^2$	0.9936	0.9891	37.2006
Density	Density $= 0.8961 - 0.0107\,A - 0.0216\,B - 0.0015\,AB + 0.0081\,A^2 + 0.0237\,B^2$	0.9329	0.8849	12.4184
TKW	TKW $= 27.49 + 0.3946\,A + 0.3465\,B - 0.2500\,AB + 0.2686\,A^2 + 0.3045\,B^2$	0.8365	0.7197	7.172
Volume expansion	Volume expansion $= 1.756 + 0.0376\,A + 0.0537\,B$	0.6881	0.6258	9.6297
Physical properties milled rice				
L-color	*L*-color $= 65.26 - 1.35\,A - 1.08\,B + 0.2883AB + 0.7361\,A^2 + 0.3627\,B^2$	0.9418	0.9002	14.2612
a-Color	$a = 8.54 + 0.2605\,A + 0.3422\,B - 0.0154\,AB - 0.1110\,A^2 - 0.4130\,B^2$	0.8121	0.6779	7.1898
b-Color	$b = 38.0979 + 1.26\,A + 0.0993\,B$	0.6603	0.5924	9.1494
BI	$BI = 76.23 + 5.57A + 2.15\,B - 0.4976\,AB - 1.57\,A^2 - 2.89\,B^2$	0.9515	0.9168	15.9560
ΔE	$\Delta E = 11.26 + 1.88A + 0.4995\,B - 0.5327\,AB - 0.4182\,A^2 - 0.7260\,B^2$	0.9396	0.8965	15.0939
Hardness	$H = 3115.88 + 69.25\,A - 162.63\,B$	0.8265	0.7918	13.3292
Milling properties				
MRR	$MRR = 70.71 + 0.2375\,A - 0.2310\,B + 1.22\,AB + 0.5919\,A^2 - 0.4181\,B^2$	0.8034	0.6630	7.2301
HRY	$HRY = 66.93 + 1.08\,A - 0.0371$		0.6897	11.1410

A: soaking temperature; B: soaking time.

than along the major axes. The swelling of the paddy according to length is limited as the opening of the husk is more likely to affect the thickness and width. The change in dimension will affect the other physical characteristics of paddy, including the bulk density, density, weight of the thousand kernels, and volume expansion.

Table 4 displays the variations in density, bulk density, and thousand kernel weight resulting from parboiled paddy processing, which are influenced by varied soaking temperatures and times. The surface model effectively represented the three parameters and their corresponding responses. The recommended model was quadratic, and it exhibited a lack of fit that was not statistically significant, as indicated in Table 3. The coefficient of determination for bulk density, density, and thousand kernel weight in each model was 0.9936, 0.9329, and 0.8365, respectively. The ANOVA analysis revealed that the soaking temperature had a significant impact on the bulk density of paddy MR297 ($p < 0.05$), while the soaking time had a significant effect on the density ($p < 0.05$) (Table 2). Furthermore, both the soaking time and temperature had a significant influence on the

Table 4. Response for dimensional and physical change in dried parboiled paddy in different soaking time and temperature.

Actual value								
Temp	Time	L (mm)	W (mm)	T (mm)	Bulk density (g/mm^3)	TKW (g)	Density (g/mm^3)	Volume expansion
74.142	3	10.397	2.345	2.059	4.632	28.457	0.897	1.840
60	4.414	10.322	2.332	2.070	4.433	28.722	0.911	1.827
60	3	10.326	2.335	2.051	4.238	27.182	0.876	1.798
60	3	10.332	2.337	2.050	4.258	27.776	0.894	1.801
50	2	10.297	2.295	2.010	4.528	27.396	0.955	1.663
60	3	10.337	2.314	2.045	4.224	27.441	0.906	1.756
60	3	10.316	2.337	2.046	4.224	27.710	0.898	1.789
60	3	10.316	2.319	2.038	4.240	27.333	0.906	1.749
70	2	10.310	2.315	2.055	4.504	28.677	0.939	1.771
45.858	3	10.247	2.310	2.026	4.687	27.329	0.930	1.704
70	4	10.373	2.304	2.064	4.504	28.493	0.896	1.781
60	1.586	10.240	2.264	2.012	4.410	27.208	0.978	1.614
50	4	10.365	2.332	2.040	4.532	28.212	0.918	1.781

thousand kernel weight ($p < 0.05$). These three responses were closely linked to the movement of water into the kernel and the removal of substances during the hydrothermal treatment.

The increase in the volume of parboiled paddy compared to raw paddy was expressed in the volume expansion. The volume expansion of paddy, as well as the effects of the parboiling with different soaking times and temperatures, can be seen in Table 4. The response was plotted on a surface by using Design Expert 13.0 (Figure 1(g)) representing a linear model (R^2 = 0.6881). The more intense the process, the more grain swelling will result in the husk swelling that resembles splitting. A severe volume expansion would lead to husk splitting and endosperm flow-out. The process resulted in a grain defect called 'banana' grain (Da Fonseca et al., 2011). They also found that increasing high temperatures (65–72) and longer soaking times (2–7 h) will increase the percentage of defect grains.

The lightness (L*) of rice is a crucial parameter for evaluating the quality of the parboiling procedure. The relationship between soaking temperature and time is described using a quadratic response, which is seen as a surface plot in Figure 2(a). The table demonstrates that the duration of soaking, temperature, the interaction between these factors, and the quadratic relationship of soaking time have a substantial impact on the L* of parboiled rice (Table 5). The L* values were decreased by the combined effect of soaking time and temperature. The lowest value of L* (64.16) was recorded for the combination of a soaking temperature of 74.14 °C and a period of 3 h. The highest L* (69.19) was recorded under the least intense parboiling setting, with a soaking temperature of 45.87 °C and a period of 3 h. The regression equation for lightness, as obtained by the RSM, is displayed in Table 3. The L* diminished in proportion to the intensification of the parboiling procedure. The vibrant hue of the parboiled rice diminishes its consumer appeal and reduces its commercial worth. The cooking method used for parboiled rice directly impacts its color and weight. Increased temperatures and extended durations of soaking and steaming result in intensified tone of the parboiled rice (Graham-Acquaah et al., 2015). According to Lamberts et al. (2008), the change in color of white rice to a golden shade during the parboiling process is caused by the movement of pigments from the husk and bran, as well as, to a lesser degree, non-enzymatic Maillard and enzymatic browning.

Parboiled rice samples show a* readings ranging from 7.24 to 9.013 (Table 5). The interest of this parameter for rice would be to identify and quantify the color intensity of immature grains, whose results would be <0, indicating a tendency towards green. The a* scale explains the redness and greenness color range. The surface plot displayed in Figure 3(b) demonstrates that the temperature and time of soaking yielded an a* response that conformed to a quadratic model (R^2 = 0.8121). The a* color of parboiled rice was considerably influenced by both the temperature and time of soaking. Figure 2(b) displays the surface plot illustrating the impact of soaking time and temperature on the color of a*. The majority of previous research indicates that the a* color range of parboiled rice has a negative score, indicating a stronger greenish hue (Azuka et al., 2021; Zhang et al., 2022) and around 0–5 (Kumar & Prasad, 2018; Saleh et al., 2018; Wahengbam & Hazarika, 2019; Wiruch et al., 2019; Wu et al., 2021; Yamirudeng et al., 2022) which is less green. Our study was in the range of the study of Cheng et al. (2019), which ranges from 3.48 to 10.28.

Color is a crucial factor in determining customer acceptability. The interest of this parameter for rice would be to identify and quantify the color intensity of immature grains, whose results would be <0,

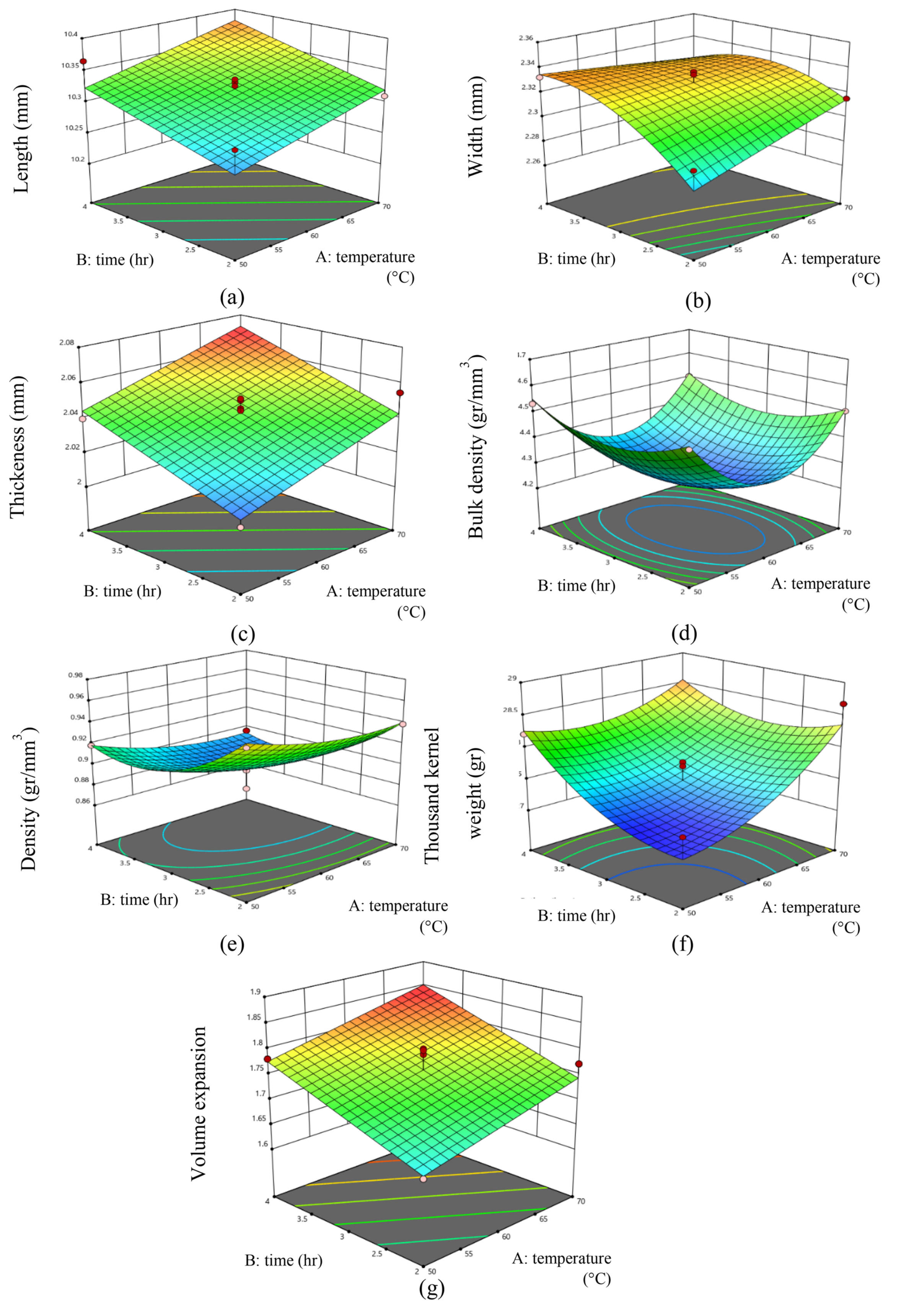

Figure 1. Response surface for dimensional (*L* (a), *W* (b), *T* (c)) and physical (bulk density (d), density (e), TKW (f), volume expansion (g)) change in dried parboiled paddy in different soaking time and temperature.

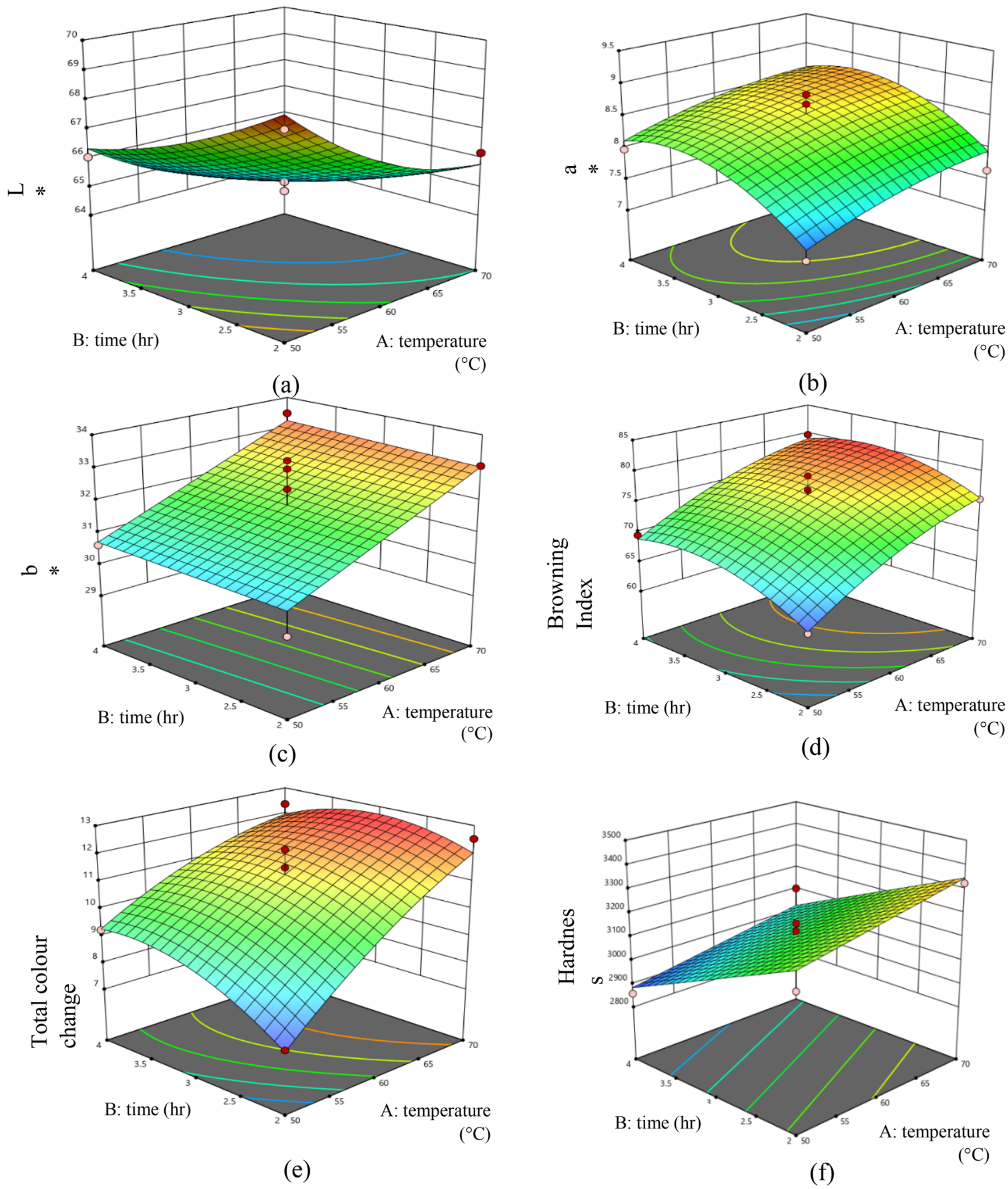

Figure 2. Response for physical properties (color (a–e)) and hardness (f) properties in parboiled milled rice in different soaking time and temperature.

indicating a tendency towards green (Da Fonseca et al., 2011). They also stated that the blueish and greenish color indicates the intensification of mold colonies. The variation in time and temperature of soaking in the MR297 parboiling procedure ranged from a *b** value of 29.783 to 33.477. This suggests that, based on the *b** scale, our samples lean towards the yellow end rather than the blue end. Table 3 represents that the suggested model is the quadratic model (R^2 = 0.6603), as shown by the surface plot in Figure 2(c). The temperature and second order of temperature of soaking time significantly affect the *b** value of parboiled rice ($p < 0.05$) (Table 2). Increasing the soaking temperature would raise the *b** value of parboiled rice. The time of soaking did not have a direct impact on the b value of parboiled rice. However, there was a significant interaction between the soaking time and temperature ($p < 0.05$). The results of our *b** value are higher than the previous study, which found ranges of 19–21

Table 5. Response for color and hardness properties in parboiled milled rice in different soaking times and temperatures.

Actual value							
Temp	Time	*L**	*a**	*b**	Browning index	Total color change (ΔE)	Hardness (g)
74.142	3	64.180	9.013	33.190	80.6722	12.535	3213.70
60	4.414	64.313	8.403	30.668	72.586	10.355	2869.51
60	3	65.177	8.330	32.357	75.879	11.196	3067.39
60	3	65.637	8.380	32.973	76.949	11.511	3020.76
50	2	68.643	7.240	29.783	63.270	7.272	3130.90
60	3	65.253	8.467	31.803	74.392	10.716	3060.29
60	3	65.370	8.837	31.800	74.644	10.726	3159.62
60	3	64.857	8.690	33.227	79.274	12.155	3125.83
70	2	66.193	7.643	33.067	75.490	11.254	3325.61
45.858	3	69.187	8.067	30.407	65.063	7.844	3132.94
70	4	64.743	8.320	33.477	79.739	12.365	3102.98
60	1.586	67.560	7.468	30.987	67.857	8.794	3439.00
50	4	66.040	7.978	30.618	69.510	9.232	2857.90

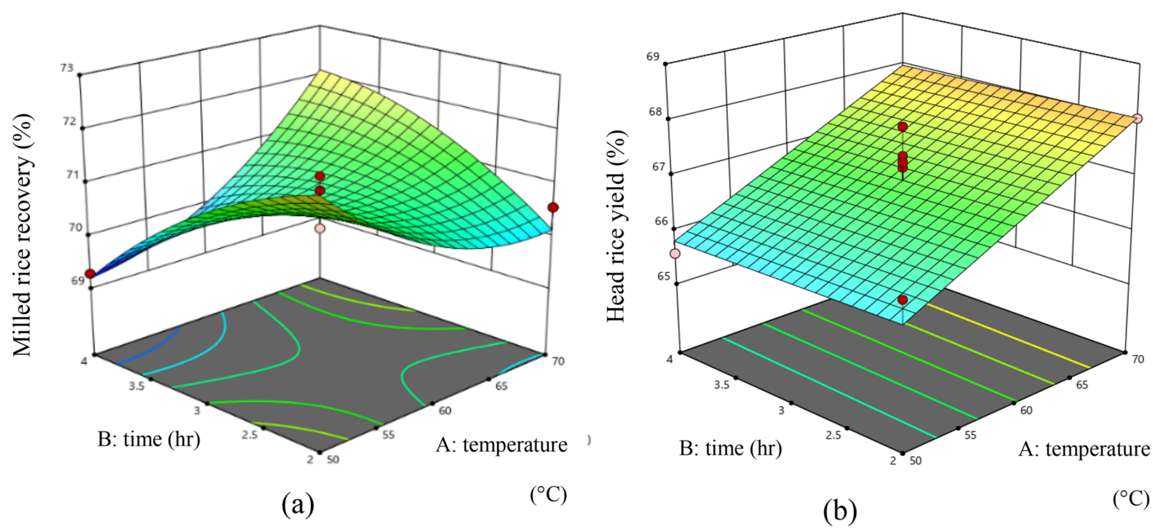

Figure 3. Response surface for milling properties (milled rice recovery (MRR) (a), and head rice yield (HRY) (b)) in parboiled milled rice in different soaking time and temperature.

(Da Fonseca et al., 2011), 10–14 (Yousaf et al., 2017), and 5–12 (Bhattacharya, 1996).

The browning index in parboiled rice reflects the changes in color that occur during the process of parboiling, which involves soaking and steaming the rice. The color changes are influenced by various factors, such as drying conditions, tempering, and enzyme reaction (Elbert et al., 2001). The soaking time and temperature in the MR297 parboiling resulted BI procedure ranged from 63.27 to 80.67, with a minimum and maximum value, respectively. Based on the BI scale, our samples demonstrate a predilection to brownish with the increasing of the soaking intensity. According to Table 2, the recommended model is the quadratic model, which is evident from the surface plot in Figure 2(d) and the corresponding coefficient of determination (R^2 = 0.9515). The temperature and duration of soaking time exert a substantial influence on the BI of parboiled rice ($p < 0.05$) (Table 2). Increasing both the soaking temperature and time would lead to a higher BI value of parboiled rice. However, a significant interaction was not seen between the time of soaking and the temperature ($p > 0.05$).

The primary cause of the color alteration in parboiled rice is predominantly attributed to non-enzymatic browning and the transportation of pigments in the husk and bran. An investigation was conducted to analyze the impact of processing parameters on the total color change of parboiled rice. The time and temperature of the soaking process in the MR297 parboiling method resulted in total color change varied between 7.27 and 12.54, representing the minimum and maximum values, respectively. According to the total color change scale, our samples show a preference for a higher total color change as the soaking intensity increases. Based on the data presented in Table 2, the quadratic model is the preferred model. This conclusion is supported by the surface plot shown in Figure 2(e) and the coefficient of determination (R^2 = 0.9396). The temperature and time of soaking have a significant impact on the total color change of parboiled rice, as indicated by statistical analysis ($p < 0.05$) (Table 2).

The results indicate that the linear model was proposed to demonstrate the impact of soaking temperature and time on the hardness of parboiled rice. The surface plot depicted in Figure 2(f) illustrates a positive correlation between the intensity of the procedure and the hardness of the milled rice. The color of parboiled rice can be intensified by the degree of soaking, as indicated by the L^*, a^*, and b^* measurements. The sugar produced during parboiling can catalyze a reaction between sugar and the amino acids present in the grain, leading to the discoloration of milled rice (Yousaf et al., 2017). The variability in the material's water absorption and leaching rates at various temperatures may explain the color change. Therefore, at higher soaking temperatures, maximal water absorption is achieved; consequently, a greater amount of material is leached, increasing the losses of constituents (yellow pigments present in the bran layer) that give the grain its yellow color (Da Fonseca et al., 2011).

3.2. Effect of soaking conditions on milling properties of parboiled rice

The milled rice recovery achieved in the parboiled rice varied between 69.28 and 72.28%, depending on the soaking times and temperatures. This range differed slightly from the result by Graham-Acquaah et al. (2015). Their total milling yield was 71–74.7%. Our study revealed that soaking temperature in the quadratic version significantly affects the milled rice recovery (MRR) of parboiled rice long grain MR297 ($p < 0.05$), as shown in Figure 3(a). The findings indicated that the soaking temperature did not have a significant impact on the MRR. However, there was a notable interaction between the soaking duration and temperature, which had an effect on the MRR ($p > 0.05$). The milled rice recovery increased with the soaking temperature. The highest milled rice recovery was 72.28%, obtained by the soaking temperature of 74.14 °C. Graham-Acquaah et al. (2015) stated that the increase in soaking temperature will increase the milled rice recovery. Kernels enlarge and occupy the husk during moisture treatment. After steaming, kernels gelatinize and slightly reduce after drying, pulling away from the husk when dried. The kernel is loose within the husk, making milling easier (Ayamdoo et al., 2013).

The head rice yield (HRY) held the utmost significance as a measure in determining the milling quality for rice factories. When calculating the MRR, take into account all the components of the rice, including both the broken parts and the intact grains, following the milling process. HRY specifically omits broken rice from the parameter. The HRY percentage is a crucial determinant of the market value of rice grains. The price of rice increases proportionally with better head rice output and lower broken rice percentage. The primary objective of parboiling is to seal any fissures in the rice grain and fortify the rice kernel, resulting in reduced breakage during milling and increased HRY (Graham-Acquaah et al., 2015). Consequently, subjecting rice to parboiling at the suitable temperatures increased the HRY of the parboiled rice. As a result, the starch experienced gelatinization and the proteins underwent denaturation as they moved into the intergranular area. The modification improves the milling process by increasing the binding effect (Taghinezhad et al., 2016).

The response surface plot reveals that the soaking time and temperature of parboiled rice MR297 significantly affect the HRY ($p < 0.05$), as shown in Figure 3(b). The HRY responses were well-fitted with the linear model (R^2 = 0.7414). The HRY range of the parboiled rice with the different soaking times and temperatures was 65.00–68.62% from the brown rice produced. The lowest HRY was obtained at 45.8 °C and 3 h of soaking, while the highest was obtained at 74.14 °C and 3 h. Interestingly, the HRY of the soaking at 70 °C and 4 h of soaking resulted in HRY of 67.38%, respectively, lower than the maximum HRY obtained in the study. Table 2 also represented that the soaking time significantly affects the head rice yield ($p < 0.05$). This decrease may be attributable to the longer time of soaking, which caused significant changes in the grain and the loss of a portion of the endosperm. Moisture absorption decreased milling yield. After grain breaks down, breakage and exposed endosperm likely decreased HRY value (Islam et al., 2004) (Table 6).

3.3. Optimization of soaking parameters in parboiling

The capability of RSM to optimize and forecast and characterize the effects of various factors on responses of variables is a significant advantage. According to CCD experimental designs, the soaking time and temperature significantly affect the responses. RSM was utilized to obtain accurate and dependable results by comparing the experimental

Table 6. Response for milling properties in parboiled milled rice in different soaking times and temperatures.

Actual value		Milled rice ratio (%)	Head rice yield (%)
Temp	Time		
74.142	3	72.280	65.000
60	4.414	69.840	67.380
60	3	70.480	68.040
60	3	71.150	65.900
50	2	72.950	66.300
60	3	70.880	68.620
60	3	70.160	65.570
60	3	70.880	67.160
70	2	70.560	67.900
45.858	3	71.000	67.370
70	4	71.760	66.910
60	1.586	69.400	67.260
50	4	69.280	66.660

values of parboiled rice to the estimated value predicted by Design-Expert 13. Appetizing parboiled rice requires a high color intensity (more light and less black) and a firm texture. The parboiling process also objected to an increase in the HRY of paddy. As the parboiling process intensifies, the texture's hardness increases, HRY increases, and lightness decreases. Based on the criteria, the hardness, HRY, and lightness of milled rice are selected as optimization factors. Table 7 depicts the desired outcome of the RSM. The optimal model for characterizing the responses was based on the model with the highest coefficient of determination and the significance of additional components. According to Table 7, the optimal conditions for the prepared parboiled rice quality were 54.752 °C and 2 h of soaking. The optimal treatment combination, as determined by the validation results (Table 7), produced parboiled rice with the desired characteristics.

3.4. Comparison properties of parboiled and raw rice

3.4.1. Color

The L^*, a^*, and b^* values of white rice and parboiled rice were measured and observed to decrease from 70.91 ± 0.59 to 66.46 ± 1.15, increase from 6.53 ± 0.15 to 8.47 ± 0.32, and increase from 22.91 ± 0.26 to 35.04 ± 0.66, respectively (Table 8). A higher L^* value suggests a greater degree of whiteness, which was discovered to be higher in raw-milled rice. The a^*-value exhibited a higher value in parboiled rice (6.53 ± 0.15) and a lower value in white rice (8.47 ± 0.32). It is evident that during the process of parboiling, certain elements from the outer layer of the rice grain go to the inner part, known as the endosperm. When the rice is then polished, the outer bran layer is removed, resulting in white rice. A

Table 7. Optimization and validation of the soaking treatment.

Name	Target	Predicted	Observed	Desirability
A: temperature (C)	In range	54.752	54.800	0.633
B: time (h)	In range	2	2	
L	In range	10.2754	10.2748	
W	In range	2.2884	2.3117	
T	In range	2.0207	2.0306	
Bulk density	In range	4.3830	4.3532	
TKW	In range	27.1820	27.418	
***L*-color**	**Maximize (+3)**	**67.7664**	**67.9750**	
a	In range	7.6101	7.990	
b	In range	31.1131	31.7884	
Browning index	Minimize (+3)	76.2775	72.1900	
Total color change	Minimize (+3)	11.2608	10.57	
Density	In range	0.9484	0.9300	
Volume expansion	In range	1.6861	1.7195	
Texture	**Maximize (+3)**	**3242.16**	**3190.84**	
MR	In range	71.2002	70.50	
HRY	**Maximize (+3)**	**66.3240**	**65.3218**	

Bold values indicate the maximized parameter for optimization.

Table 8. Color properties of raw milled rice and milled parboiled rice.

	Color		
Rice sample	L^*	a^*	b^*
Raw milled rice	70.91 ± 0.59	6.53 ± 0.15	22.91 ± 0.26
Milled parboiled rice	66.46 ± 1.15	8.47 ± 0.32	35.04 ± 0.66

higher b^*-value signifies a greater degree of yellowness in the product. The b^*-value of parboiled rice under the given processing conditions is higher (11.27 ± 0.24) compared to white rice (35.04 ± 0.66). The parboiling process decreases the lightness of milled rice, as explained in Section 3.3. The lightness of milled rice is ranged from 51 to 60 (Cheng et al., 2019; Saleh et al., 2018; Srichamnong & Lasukhang, 2022; Wiruch et al., 2019; Yamirudeng et al., 2022; Zhang et al., 2005). Our research indicates that preserving the lightness of parboiled rice is possible.

3.4.2. Cooking properties analysis

Table 9 indicates an increase in the cooked rice elongation ratio, L/W ratio, and cooking time 1.268 ± 0.045 to 1.374 ± 0.074, 3.4321 ± 0.220 to 3.5549 ± 0.266, and 21.333 ± 0.577 to 24.333 ± 0.577, respectively. Parboiled rice takes longer to cook, but the grains are less sticky and fluffier (Soponronnarit et al., 2006). The hardness obtained after extensive parboiling can be attributable to well-parboiled rice cooking longer. This dense rice slowed water absorption and increased cooking time (Sivakamasundari et al., 2020). The water uptake ratio of parboiled rice (1.564 ± 0.042) is often more

Table 9. Cooking properties of raw milled rice and milled parboiled rice.

Rice samples	Elongation ratio	*L/W* ratio	Cooking time (min)	Water uptake ratio
Raw milled rice	1.268 ± 0.045	3.4321 ± 0.220	21.333 ± 0.577	1.538 ± 0.042
Milled parboiled rice	1.374 ± 0.074	3.5549 ± 0.266	24.333 ± 0.577	1.564 ± 0.042

Table 10. Textural properties of cooked raw milled rice and milled parboiled rice.

Rice samples	Hardness (g)	Cohesiveness (peak2/peak1) (%)	Adhesiveness (g.s)
Raw milled rice	444.440 ± 18.421	−14.996 ± 1.787	0.840 ± 0.118
Milled parboiled rice	304.264 ± 12.333	−2.226 ± 0.262	0.401 ± 0.085

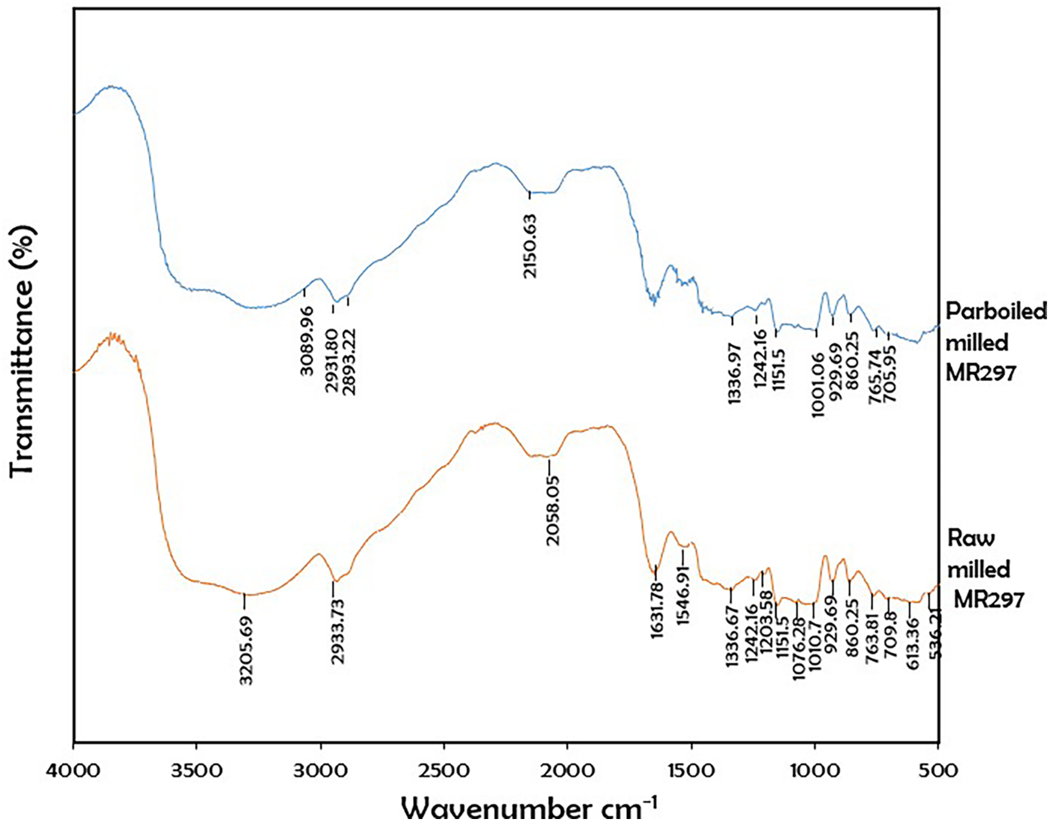

Figure 4. FTIR spectra of parboiled milled rice and raw milled rice.

significant than that of raw rice (1.538 ± 0.042) (Table 9). The irregular cellular arrangement of parboiled rice facilitated enhanced water absorption throughout the cooking process (Lisle et al., 2000). Parboiled rice has a higher water absorption capacity, potentially because of the elevated steam pressure during the parboiling process, which impacts the gelatinization of starch (Chavan et al., 2017). Rice with a greater water absorption capacity exhibited superior cooking quality (Kumar & Prasad, 2018).

3.4.3. Textural properties of cooked rice

Table 9 indicates the instrumental textural properties of raw milled rice and milled parboiled rice MR297. Raw milled rice has a higher hardness than parboiled rice. This might be due to the higher moisture uptake of parboiled rice in comparison with milled rice. This is supported by Jagtap et al. (2008) that stated higher moisture content will lead to a lower hardness of cooked rice. The main difference between parboiled rice and raw rice can be seen in the cohesiveness and adhesiveness. Raw milled rice is more sticky than parboiled rice. Table 10 shows that cooked raw milled rice is more cohesive than cooked parboiled rice. Also, the adhesiveness of raw

3.4.4. FTIR analysis

The infrared (IR) absorption spectra of milled raw and parboiled rice have discernible peaks that correspond to various functional groups, such as alcohol, ketones, aldehydes, esters, and so on. Figure 4 depicts the FTIR spectra of milled raw and parboiled rice, respectively. The presence of bands in the fingerprint region between 850–1000 cm^{-1} in milled raw and parboiled rice suggests the presence of α-linkages in the starch molecule (Kumar & Prasad, 2018). However, the peak in 1010.7 and 1076.28 in raw rice is changed into a minor peak in parboiled rice. The peak can be represented by asymmetric stretching of S=O, confirming the attachment of sulfonyl groups to polysaccharides (Hong et al., 2021). The shifting band of the 1203.58 cm^{-1} peak of raw rice into minor peaks in parboiled rice resulted in the higher intensity of surrounding peaks 1151.5, 1241.46,

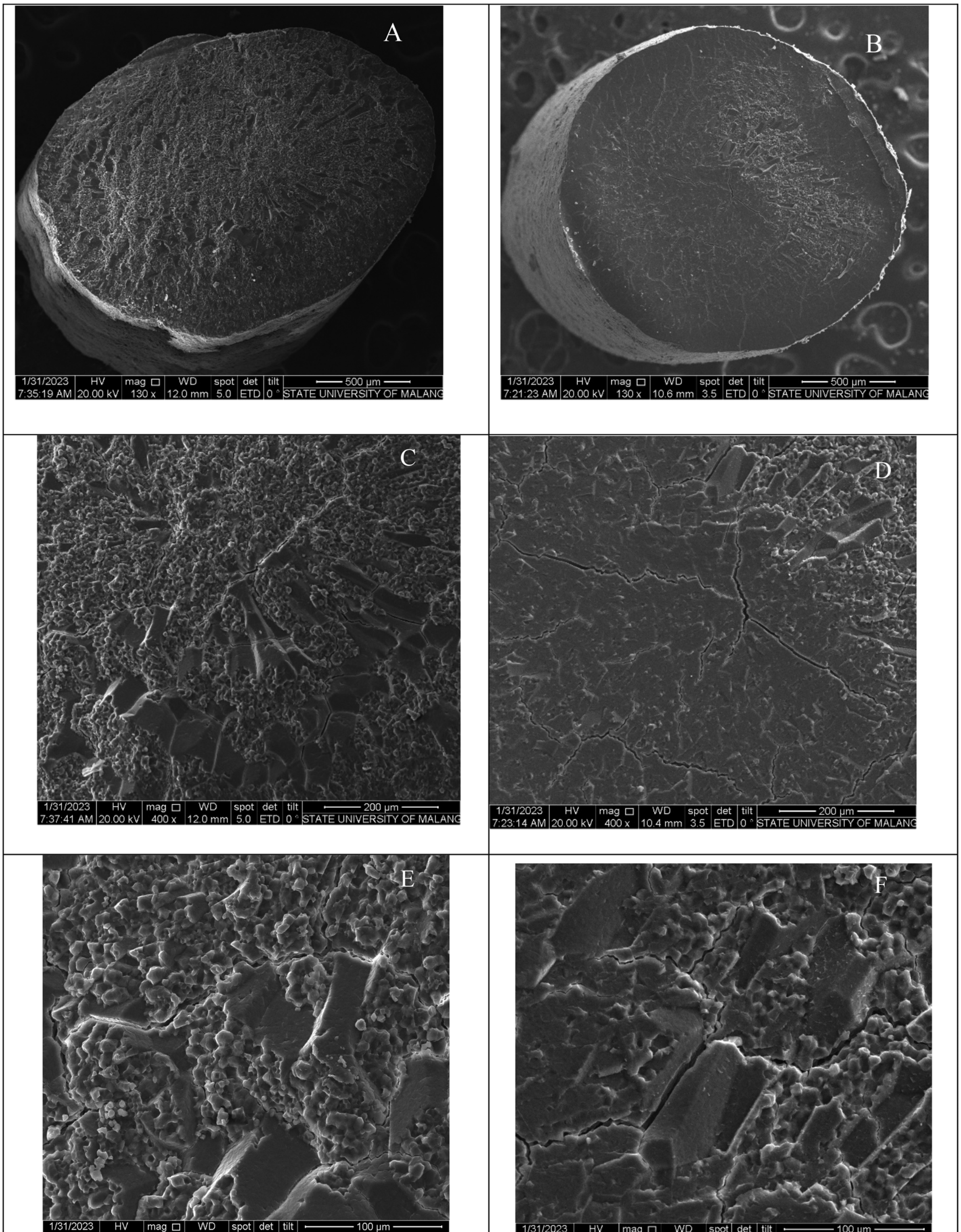

Figure 5. Scanning electron micrograph of parboiled milled rice in ×130 (A), ×400 (C), and ×1000 € and raw milled rice ×130 (B), ×400 (D), and ×1000 (F).

and 1336.67 cm^{-1} that appear both in raw and parboiled rice. Another notable shifting towards infrared spectra of raw rice in 1546.91, 1631.78, and 3205.69 which can be utilized to interpret amide band of protein, amide I of β-pleated sheet structures of protein, and N–H stretching amide of proteins, respectively (Davis & Mauer, 2010). These peaks were minor in parboiled rice but resulted in an intense peak of 2893.32, representing CH stretching of amino acids (Davis & Mauer, 2010). All the characteristic bands of FTIR spectra of parboiled rice compared to raw rice showed some degree of modification of rice starch especially in starch and protein structure.

3.4.5. Scanning electron microscope (SEM) analysis

Figure 5 illustrates the results obtained by using scanning electron microscopy (SEM) to analyze the morphological characteristics of parboiled milled rice and raw milled rice. The figure depicts many unique and hexagonal starch granules seen in parboiled rice. The granules have a smooth surface texture and include rounded and polygonal forms. During parboiling, rice grains absorb water, undergo gelatinization, and cook while still in the paddy. Throughout this process, the inherent configuration of the starch molecule undergoes alteration, resulting in the reorganization of individual starch molecules, commonly referred to as fusion (Figure 5). Rice grains exhibit many morphologies. Both parboiled milled rice and raw milled rice exhibit splits in the endosperm, however, non-parboiled rice possesses a more consistent bulk with a reduced number of cellular divisions (Rockembach et al., 2019). Paiva et al. (2016) say that the change is due to gelatinization during the parboiling process. Our optimization showed that 2 h is enough to soak the parboiled rice MR297. Previous study of three Brazilian rice cultivars also showed that the duration of the parboiled rice procedure should not exceed 3 h, as the desired results (gelatinization and removal of voids) are both permanent and occur within the initial 3-h period (Balbinoti, Jorge, et al., 2018). Increasing the duration of the parboiling process or raising the temperature of hydration will result in greater energy consumption.

4. Conclusion

This study focused on developing parboiled rice with good quality characteristics especially high yield and hardness, while retaining the lightness of the milled rice by different soaking conditions. The optimum soaking time was 54.75 °C for 2 h, cooled to room temperature, then steamed for 20 min, and dried at 38 °C until moisture content was 13%. Parboiled rice with good quality characteristics can be created. The optimization successfully produced parboiled rice with the maximum head rice yield, maximum hardness, maximum lightness, minimum browning index, and total color change and lightness of parboiled rice MR297. Treatment combinations (soaking time and temperature) should be carefully selected to enhance the quality parameters of the parboiled rice. Physical characteristics of paddy, such as changes in physical properties (dimensions, thousand kernel weight, and volume expansion of paddy; color and hardness of rice) and milling properties (HRY and milled rice recovery,) are also affected by different parboiling techniques. This is the first research focusing on soaking parameters in increasing the head rice yield of long-grain rice MR297 using a conventional parboiling process.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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Data availability statement

Data will be made available on request.

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