Study of texture properties rejuvenation for aged rice kernel

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Abstract. Aged rice (stored > 3 months) undergoes significant texture changes, especially hardness and stickiness. Hardness increases, while stickiness decreases with aging. Rice grains were subjected to heat treatment using three different methods: hot air oven (HA), infrared (IR) and microwave (MW). The HA and IR applied heat at a temperature of 100°C, while the MW applied heat at a power of 800 watts. The heat treatment was applied for 3, 4, and 5 minutes. As a result, the hardness of aged rice treated with HA and IR was effectively reduced to 17.79±2.38 N and 17.73±1.26 N, respectively. In contrast, the MW exhibited a lesser reduction in hardness, reaching to 22.82±2.32 N. Regarding stickiness, no statistically significant differences were observed ($p < 0.05$). Furthermore, hardness exhibited a decreasing with increasing heating time. Additional parameters, Whiteness, transparency and Volume expansion, were also evaluated. Whiteness values were observed to exhibit an increase for all treatments, in contrast to transparency values, which demonstrated a decrease. Volume expansion values, on the other hand, displayed a stable trend, with the exception of MW treated samples, where a statistically significant increase ($p < 0.05$) was observed.

1 Introduction

Rice constitutes a fundamental source of dietary carbohydrates on a global scale for more than half of the world's population, particularly in Asia [1]. Consumer preferences for rice extend beyond basic sustenance, encompassing sensory attributes like aroma, grain separation, and textural characteristics [2]. However, it is the textural profile, specifically grain hardness and adhesiveness, that exerts the most pronounced influence on consumer rice selection [3]. Rice variety and storage duration are post-harvest factors significantly impacting rice texture. Aged rice (stored for over three months) exhibits consistent textural changes, characterized by increased hardness and decreased stickiness [4,5].

Storage-induced alterations extend beyond texture, affecting other quality attributes like aroma, color, gel viscosity, milling quality (HRY), electrical conductivity, and seed germination rate [6-11]. These changes are linked to fine structural modifications in starch granules, including chain length distribution, amylose size, and morphology [12-14]. Therefore, effective storage management practices, optimizing storage, condition and minimize air in packaging are crucial for rice aging [15,16]

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Despite numerous alterations induced by prolonged storage, cooking quality remains the primary concern, particularly the textural properties of cooked rice. Consequently, research has focused on two primary approaches: enhancing water uptake (water diffusion rate) within rice kernels [17] and adding enzymes to cooking water [18]. While both methods have demonstrated promising results, their application is limited to the cooking process. Consequently, alternative strategies for treating rice kernels were sought. The surface cracking of rice kernel accelerates desired substances including water into the rice kernel which gradually reduces rice hardness [19].

The formation of cracks in rice kernels arises not from pre-existing cracks, but from drying processing. Heating induces internal moisture loss, leading to the development of internal vapor pressure. With inefficient drying conditions, vapor pressure differential between the kernel's interior and exterior can exceed the mechanical strength of the rice grain, resulting in surface crack generation [20-21]. Currently, various heating methods are employed for rice drying, including hot air oven (HA), infrared (IR), and microwave (MW) heating, each yielding distinct outcomes [22,23]. This heating method is therefore well-suited for testing due to its extensive use in both small-scale and large-scale industrial applications.

Thus, this study aims to investigate the effects of heating sources on aged rice kernels properties. The impact on texture parameters, hardness and stickiness, as well as appearance surface cracking, whiteness, transparency, and volume expansion of the rice will be examined.

2 Materials and methods

2.1 Rice preparation

Aged paddy rice of Khao Hom Mali 105 variety, harvested in April 2023 and purchased from Surin Rice Research Centre, Rice Department, Thailand, was utilized in this experiment (approximately 12 months old at the time of testing). This aged rice was dehulled and polished using a huller (SATAKE HUSK TESTER model THU, Japan) and a rice polishing machine (SATAKE TM model 05, Japan) respectively. Subsequently, the rice was screened to obtain whole grains for the experiment using a grain size sorter (SATAKE model TWSB, Japan). Finally, the rice grains were packed in zip-lock bags for further experimentation.

2.2 The process of heating rice grains

The milled aged rice was used for the experiment. One hundred grams of rice were portioned for each treatment and arranged as a single layer on a wire mesh for HA and IR heating methods. These samples were then placed within the designated heating devices: a Memmert model UF260 hot air oven (Germany) and an infrared heater (infrared heater was developed at the Department of Agricultural Engineering, KMITL, Thailand, by setting an adjustable infrared tube into a stainless-steel chamber.). Both HA and IR treatments were conducted at 100°C for 3, 4, and 5 minutes. For MW heating, the 800-watt microwave oven applied to one hundred grams of single layer of rice in a glass container for 3, 4, and 5 minutes.

2.3 Appearance surface cracking

Rice kernels were evaluated for surface crack formation using visual inspection and light microscopy (0.8x magnification, ZEISS Stemi 508). ImageJ software quantified the extent of cracking by measuring the crack area relative to the total kernel surface area, expressed as a percentage. This analysis was performed on three replicate measurements, and the data were subjected to determine average crack percentage and statistical analysis were performed to identify statistically significant differences between groups.

2.4 Whiteness and transparency measurement

In addition to the surface cracks induced by heat treatment, rice grains exhibited significant alterations in whiteness and transparency. These parameters were assessed using a rice whiteness meter (SATAKE, model MM1D, Japan), and the average values from each treatment were determined from three replicates.

2.5 Rice cooking, texture and volume expansion measurement

Rice cooking and subsequent texture analysis were conducted following ISO standards (ISO, 2012) for back extrusion testing. A weighed portion of 20 grams of rice was mixed with 38mL of stilled water in a 100 mL beaker to achieve a 4:7.6 rice-to-water ratio (w/w). The beaker was covered with a watch glass to minimize evaporation. The beaker was placed within a commercial rice steamer, avoiding submersion in boiling water. The cooking cycle was set for 20 minutes, followed by 10 minutes resting period within the steamer to facilitate even temperature distribution. The beaker was, then, removed from the steamer and inverted to facilitate the transfer of cooked rice to an airtight container. This container was, then, stored at a controlled temperature of 20-25°C for one hour to achieve uniform sample temperature. Subsequently, the cooked rice sample was evaluated for volume expansion by measuring its length and diameter.

Texture analysis was, then, performed on a 5 g subsample of the central rice core using a texture analyzer (TA.HD. plus, Stable Micro Systems, UK) equipped for back extrusion testing. This test yielded two textural parameters, hardness and stickiness. All measurements were performed in triplicate, and the average values were calculated for further analysis.

2.6 Statistical analysis

Average values of appearance surface cracking, whiteness, transparency, volume expansion, hardness and stickiness of rice from all treatments were subjected to statistical analysis using two-way ANOVA for hypothesis testing and least significant difference (LSD) for multiple comparisons. The two factors considered were heating time (3, 4, and 5 min) and heating method (untreated aged rice, HA, IR, and MW). Statistical analysis was performed using IBM SPSS Statistics V.29 (IBM, New York, USA).

3 Results and discussions

3.1 Whiteness and transparency of rice grain

Table 1 shows an average whiteness, transparency, hardness, stickiness and volume expansion of untreated aged rice. Table 2 presents data on the whiteness and transparency of untreated aged rice alongside rice subjected to three heating methods (HA, IR and MW) at varying durations (3, 4, and 5 minutes). A significant increase ($p < 0.05$) in whiteness was observed with increasing heating time for all heating methods employed compare with untreated aged rice. Conversely, transparency exhibited a significant decrease ($p < 0.05$) across all treatment groups. The HA treatment resulted in the most pronounced alterations in both whiteness and transparency. At the 5-minutes mark, HA rice displayed the highest whiteness value (84.84 ± 0.73%) and the lowest transparency value (1.32 ± 0.08%). In contrast, MW rice at 3 minutes exhibited the lowest whiteness (68.54 ± 0.40%), which was not statistically different ($p < 0.05$) from the untreated control. Similarly, MW rice at 3 minutes showed the highest transparency value (2.31 ± 0.06%). These observations can likely be attributed to heat-induced starch gelatinization, a well-established phenomenon impacting rice quality [24,25]. Starch, the primary constituent of rice grains (comprising approximately 80-90% by weight [24,25]), undergoes gelatinization at temperatures around 70-78°C for jasmine rice varieties like Khao Hom Mali 105 [26]. During gelatinization, the structural integrity of starch molecules is

disrupted, leading to increased light scattering and a consequent whiter, more opaque appearance due to partial starch cooking [26].

Table 1. The whiteness, transparency, hardness, stickiness and volume expansion of untreated aged rice

untreated aged rice	whiteness	transparency	hardness	stickiness	volume expansion
	69.02±0.31	2.42±0.05	25.78±1.98	-5.98±1.61	86.28±2.00

Table 2. The effect of heat source and heating duration on rice whiteness and on rice transparency.

Type of heating	**Time (minutes)**			
	3	**4**	**5**	**average**
Whiteness				
HA	77.26±2.97	82.82±1.10	84.84±0.73	81.64±3.75A
IR	74.36±0.87	75.64±1.05	75.96±0.38	75.32±1.04B
MW	68.54±0.40	70.44±0.64	74.62±1.17	71.20±2.73C
average	73.39±4.11b	76.30±5.33ab	78.47±4.76a	**69.02±0.31cD**
Transparency				
HA	1.80±0.12	1.42±0.25	1.32±0.08	1.51±0.26D
IR	1.67±0.09	1.74±0.18	1.67±0.11	1.69±0.13C
MW	2.31±0.06	2.08±0.10	1.80±0.04	2.06±0.22B
average	1.93±0.30b	1.75±0.33bc	1.60±0.22c	**2.42±0.05aA**

- Average ± SD is calculated from duplicate measurements.
- The bottom right corner of the table displays the desired properties of untreated aged rice.
- Values with different lower letters in the same row are significantly different with $p < 0.05$.
- Values with different uppercase letters in the same column are significantly different with $p < 0.05$.

3.2 Texture and volume expansion of cooked rice

Hardness and stickiness were investigated as texture parameters in this study. Two-way ANOVA analysis at a 95% confidence level revealed no significant interaction between heating method and heating time on either hardness or stickiness. The results are presented in Table 3.

As shown in Table 3, hardness demonstrated a statistically significant decrease ($p < 0.05$) from the untreated control upon heating, particularly at a 5 min of heating time. Conversely, stickiness was no statistically significant changes ($p < 0.05$). The greatest decrease occurred under HA and IR heating treatment. In contrast, no statistically significant changes ($p < 0.05$) were observed in stickiness.

The observed decrease in rice hardness with heating (Table 3) likely stems from two contributing factors. Additionally, heated rice displayed a rougher surface and increased incidence of burst/split grains (Figure 1), similar to rice treated with cellulase and pectinase enzymes known to degrade cell wall components [27,28]. These structural changes can contribute to reduced hardness. Rice stickiness is typically linked to protein-starch interactions during cooking [29]. Aged rice starch exhibits lower water solubility, potentially leading to decreased stickiness [29]. However, in this study, no significant changes in stickiness were observed (Table 3), likely because no modifications were made to starch water solubility during the heating process.

This study employed volume expansion measurements to assess the extent of whole-grain expansion after heating (Table 3). Generally, aged rice exhibits greater expansion compared to fresh rice due to a reduction in cooked grain cohesion, facilitating unrestricted swelling during cooking [30]. The statistical analysis revealed no significant differences ($p < 0.05$) in volume expansion between untreated aged rice and rice treated with HA or MW at heating times of 3 and 4 minutes. However, at 5 minutes, HA treatment resulted in a decrease in volume expansion, whereas MW treatment exhibited an increase compared to the control. These contrasting effects of HA and MW on volume expansion at a longer heating duration

warrant further investigation. In contrast to HA and MW, Infrared (IR) treatment did not induce significant changes in volume expansion compared to the control across all heating times ($p < 0.05$). This observation potentially reflects the previously reported association between volume expansion and stickiness [29]. As stickiness values remained unchanged, volume expansion in IR-treated rice likely remained consistent.

Table 3. The effect of heat source and heating duration on hardness, stickiness and volume expansion.

Type of heating	Time (minutes)			average
	3	4	5	
Hardness				
HA	19.05±0.76	17.70±1.50	16.61±3.92	17.79±2.38C
IR	17.87±0.51	18.55±1.90	16.77±0.11	17.73±1.26C
MW	24.33±0.75	24.26±1.20	19.88±0.28	22.82±2.32B
average	20.42±3.04b	20.17±3.37b	17.75±2.53b	**25.78±1.98aA**
Stickiness				
HA	-6.12±1.21	-5.64±0.97	-4.25±1.40	-5.34±1.34ns
IR	-4.29±1.00	-5.35±1.70	-4.88±0.63	-4.84±1.13ns
MW	-5.57±1.39	-5.42±1.24	-4.59±1.14	-5.19±1.18ns
average	-5.33±1.33ns	-5.47±1.16ns	-4.57±0.99ns	**-5.98±1.61ns**
Volume expansion				
HA	88.48±1.28	86.70±0.55	81.53±1.33	85.57±3.26B
IR	84.63±2.89	86.06±3.24	85.80±1.99	85.49±2.48B
MW	89.64±0.44	89.47±1.59	89.88±0.27	89.66±0.85A
average	87.58±2.78ns	87.41±2.41ns	85.74±3.81ns	**86.28±2.00nsB**

- Average ± SD is calculated from duplicate measurements.
- The bottom right corner of the table displays the desired property of untreated aged rice.
- Values with different uppercase letters in the same column are significantly different with $p < 0.05$.
- ns: nonsignificant different in the same row.

Fig. 1 Effect of heating on cooked aged rice A) untreated aged rice B) HA 5 minutes C) IR 5 minutes D) MW 5 minutes

3.3 Appearance surface cracking

Appearance surface cracking and the surface cracking after passing image processed for calculating percentage of surface cracking are illustrated in Figure 2 and Figure 3. A two-way ANOVA was conducted to assess the effects of the heating method and time on the appearance surface cracking at a 95% confidence level was presented in Table 4. A significant interaction between heating method and duration was observed ($p < 0.05$), indicating that fissure development was differentially affected by these factors. Specifically, an increase in heating duration led to a corresponding increase in surface cracking extent across all heating methods, with HA and IR treatments inducing greater crack formation compared to MW treatment representing by the LSD comparisons in Table 2. This phenomenon is attributed to elevated internal rice grain pressures during heating, resulting in expansion of the central layer [20]. The consequent mechanical stress exerted on the grain exceeds its plasticity and elasticity, leading to the formation of fissures, fractures, or even breakage [31]. Prolonged exposure to these stresses exacerbates surface cracking development.

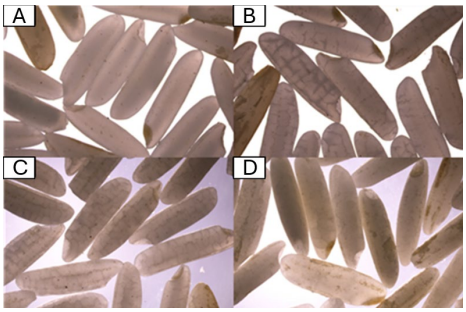

Fig. 2 Effect of heating on aged rice grains A) untreated aged rice B) HA 5 minutes C) IR 5 minutes D) MW 5 minutes

Fig. 3 Example of surface cracking on rice kernel after image processing. (IR 5 minutes).

Table 4. Appearance surface cracking (%) of rice treated with HA, IR and MW for 3, 4 and 5 minutes

Type of heating	Time (minutes)		
	3	4	5
HA	4.94±0.82bB	5.33±0.80bB	11.33±2.39aA
IR	5.621±0.50cA	7.82±0.94bA	10.26±1.02aA
MW	0.53±0.19bC	5.88±1.61aB	7.42±0.66aB

- Average ± SD is calculated from duplicate measurements.
- Values with different lowercase letters in the same row are significantly different with $p < 0.05$.
- Values with different uppercase letters in the same column are significantly different with $p < 0.05$.

4 Conclusions

The experimental results revealed that heating rice grains could only rejuvenate the texture properties of rice with respect to hardness. The trend of hardness decrease was consistent across all three treatments, with increasing heating time leading to a greater decrease in hardness values. However, heating was unable to enhance stickiness regardless of heating time. In addition, heating induced appearance surface cracking, increased whiteness and decreased transparency. When considering the texture results, a primary parameter of this study, it was found that both HA and IR heating methods yielded comparable and statistically insignificant results. Therefore, both HA and IR methods are recommended for further investigation in future studies. However, the observed increase in whiteness and decrease in transparency negatively impact the appearance of the rice, imparting a chalky-like appearance, and compromise grain strength, making the rice more susceptible to breakage

than usual. Nevertheless, if cracks could be induced on rice grains without the need for heat treatment, it could potentially mitigate these drawbacks.

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