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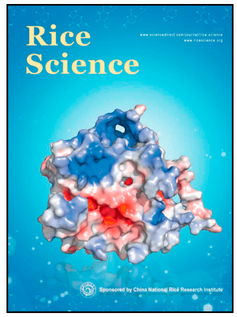

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Research Paper

Combined Insights from Leachate Structure and Microstructure Characteristics for Eating Quality of Convenience Rice Processed by Super-Heated and Pressurized Steam Technologies

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Abstract: Convenience rice has become widely popular due to its easy availability for cooking. This study investigated the starch structure and composition of leachate and the microstructure of reheated convenience rice using novel processing technologies: super-heated steaming (SHS), auto-electric cooking (AEC), and pressurized-steam cooking (PSC). Additionally, the effect of two different targeted water contents (58% and 63%) was also evaluated. The PSC_63% sample had the highest total solids and amylopectin amount in the leachate. The amylopectin amount in the leachate differed significantly based on the targeted water content. Morphological characterization revealed that the swelling of starch and the coated layer on the surface of rice grains were most pronounced in the PSC_63% sample due to the pressure processing. The textural hardness of the AEC_58% sample was much higher than that of the other samples. The PSC_63% sample had the highest textural adhesiveness value, which can be attributed to the highest amylopectin amount in the leachate. Sensory characterization showed that PSC_63% had the highest glossiness, whiteness, moistness, and overall acceptability. The principal component analysis score plots presented substantial differences in the leachate, textural, and sensory characteristics of reheated convenience rice among the different processing technologies.

Key words: reheated convenience rice; starch structure; leachate; multi-scale structure; eating quality; processing technology

Rice is widely consumed in South, East, and Southeast Asia as a staple food (Mohapatra and Bal, 2006). There are large variations in the amount of water added for cooking rice and the cooking methods used, such as cooking in a rice cooker, steaming, or parboiling, depending on the cultural background and consumer preference (Crowhurst and Creed, 2001; Champagne et al, 2010; Son et al, 2013; Yu et al, 2017). Rice is relatively simple to cook because it requires only water and heat for gelatinization. However, the general home cooking process takes more than 20 min (Yu et al, 2017). In recent years, the trend in rice consumption has shifted toward convenience rice due to changes in lifestyle and household size, such as the increasing number of single-person or small households (de Boer et al, 2004; Scholliers, 2015).

Convenience rice is a pre-reheated, pre-packaged alternative to raw rice that consumers can quickly and easily prepare at home for a convenient meal (Brown and McEnally, 1992). Convenience rice includes retorted, quick-cooking, or frozen rice (Yu et al, 2017). Convenience rice offers several other benefits, such as a long shelf life, consistent quality, and easy storage

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and transportation. The manufacture of convenience rice can be divided into three steps: pre-cooking, cooking, and post-cooking (Yu et al, 2017). The pre-cooking treatment includes washing and soaking raw rice before cooking, and the cooking stage includes the water-to-rice ratio, cooking time, cooking temperature, and cooking with pressure. Several previous studies have reported that the conditions of pre-cooking and cooking influence the quality and sensory characteristics of convenience rice (Srisawas and Jindal, 2007; Bett-Garber et al, 2011). The hydration and thermal properties of rice are mainly used to evaluate soaking quality before cooking, and the textural and sensory characteristics of convenience rice are crucial factors for the eating quality of convenience rice (Mohapatra and Bal, 2006; Bett-Garber et al, 2007; Tian et al, 2014). In light of the fact that raw rice components are an important determinant for the texture of convenience rice, the amylose and protein contents of raw rice are utilized to evaluate its palatability for Korean consumers (Kim et al, 2011; Park et al, 2016; Choi et al, 2021). However, this approach has limitations because rice is consumed after cooking, and the eating quality of convenience rice is affected by the leaching behavior of rice.

During rice cooking, starch begins to gelatinize, the structure of the rice grain is transformed by various factors, such as temperature and pressure, and materials are leached from the deformed granules to form a thin film on the surface of the rice kernel (Li et al, 2019; Ha et al, 2022). Previous studies have highlighted the importance of leachate compositions on the textural characteristics of cooked rice (Okuda et al, 2009; Li et al, 2017, 2018; Ha et al, 2022). Li et al (2019) reported that the total solids and the amount of amylopectin in the leachate are positively correlated with the stickiness of cooked rice, and higher stickiness are preferred by East Asian consumers. Ha et al (2022) also found that leachate characteristics affect the textural hardness and stickiness of rice cooked by different cooking methods. Convenience rice is generally cooked with excess water, and various cooking methods are applied in the continuous process (Yu et al, 2017). Selecting appropriate process technologies for rice manufacture can help maintain its eating quality. However, there is a lack of research on specific indicators that can evaluate the eating quality of convenience rice according to different processing technologies. Therefore, the objective of this study was to explore the starch structure and composition of leachate and the macrostructure of convenience rice manufactured by newly developed processing technologies used in the food industry for its eating quality assessment. Furthermore, the water content of convenience rice is also targeted at 58% and 63% to investigate the effect on the texture of convenience rice. The texture and sensory characteristics of convenience rice as well as their correlations with leachate characteristics, were investigated to explore the critical determinants affecting the eating quality of convenience rice. Our findings might provide useful information for estimating the quality of convenience rice and the development of processing technology by considering consumer preference.

RESULTS AND DISCUSSION

Compositional analysis of leachate

The leachate composition is an important determinant of the texture characteristics and consumer palatability of reheated convenience rice (Li et al, 2019; Ha et al, 2022). Previous studies have reported that cooking method can influence leachate composition (Tamura and Ogawa, 2012; Xu et al, 2020; Ha et al, 2022). Table 1 presents the leachate compositions of reheated convenience rice using three different processing technologies. The total solids in the leachate differed significantly according to the processing method and target water content. The PSC_63% treatment sample had the highest value (28.4 mg/g), indicating that the pressure treatment for sterilization before cooking led to the greatest material leaching. Yu et al (2017), Xu et al (2020), and Ha et al (2022) reported that pressure

Table 1. Composition of leachate obtained from convenience rice with different processing technologies.

Reheated convenience rice	Total solid (mg/g)	Protein content (%)	Total starch (%)	Amylose content (%)	Amylopectin amount (mg/g)
SHS_58%	15.0 ± 1.9 c	4.9 ± 0.3 b	78.2 ± 0.3 c	17.0 ± 0.5 b	9.2 ± 0.0 e
SHS_63%	20.2 ± 0.5 b	5.1 ± 0.2 ab	78.9 ± 0.4 c	17.4 ± 0.5 ab	12.4 ± 0.1 d
AEC_58%	24.2 ± 0.9 ab	5.3 ± 0.2 a	80.6 ± 0.6 b	18.4 ± 0.2 a	15.1 ± 0.1 c
AEC_63%	27.7 ± 3.7 a	5.4 ± 0.2 a	81.5 ± 0.2 ab	18.6 ± 0.3 a	17.2 ± 0.0 b
PSC_63%	28.4 ± 1.1 a	5.4 ± 0.1 a	81.8 ± 1.4 a	18.5 ± 0.6 a	18.0 ± 0.3 a

SHS, Super-heated steaming; AEC, Auto-electric cooking; PSC, Pressurized-steam cooking.
Data are Mean ± SD (n = 3). Values followed by the different lowercase letters in the same column are significantly different at $P < 0.05$.

processing disrupted the inner structure of cooked rice and, creating fissures and holes in the kernel, which increased the amount of material leached from the grain. The SHS_63% and AEC_63% samples had higher total solids than their counterparts with lower target water content, respectively (Table 1). The amount of added water is a significant factors affecting the texture of reheated convenience rice due to differences in water diffusion during cooking process (Li and Gilbert, 2018; Chen et al, 2019). In addition, the extent of damage to the inner cell structure of rice grains increases with the amount of added water, providing a passage for water-soluble substances (Tamura and Ogawa, 2012; Zhu et al, 2020). Therefore, increasing the amount of added water for rice cooking may result in more leachate.

The protein content in the leachate from reheated convenience rice was not significantly different among the tested samples, except for SHS_58%, which had relatively low protein content (Table 1). Ha et al (2022) reported that the amount of leached protein is substantially affected by the ruptured gelatinized starch granules. During SHS cooking, rice is automatically transported through horizontal movement of a conveyor belt and cooked under superheated steam conditions. The water required for cooking is supplied by spraying superheated steam onto the surface of the sample, affecting the leachate composition. The protein content of SHS_58% was washed out to a relatively lower extent during cooking, resulting in significantly lower leachate materials in the reheated convenience rice using the SHS method compared with other processing methods.

The total starch content of the leachate differed significantly depending on the processing method (Table 1). However, previous studies reported that the total starch content of the leachate from cooked rice by different methods is not markedly different (Li et al, 2019; Ha et al, 2022). Unlike those previous studies, this study used unconventional processing methods for producing convenience rice, which could account for the different trend. Due to the washing-out effect during SHS processing, SHS_58% and SHS_63% samples showed the lowest total starch contents of the leachate, whereas that of PSC_63% was significantly high (81.8%). PSC has a high-pressure treatment for sterilization, which disrupts the internal structure of reheated convenience rice and breaks the bonds of the components, causing the highest total starch content of the leachate.

Significant differences were found in the amylose content and amylopectin amount of the leachate from reheated convenience rice by different processing methods (Table 1). SHS samples (58% and 63%) had the lowest amylose content and amylopectin amount in the leachate, whereas PSC_63% had the highest values. Meng et al (2018) and Ha et al (2022) reported that pressure conditions increase the stability of the amylose structure, limiting the amount of leached amylose. Interestingly, amylose leaching was significantly lower in the SHS processing method than under pressure conditions, indicating that SHS processing effectively reduced leached amylose by spraying superheated steam on samples and washing out the leachate material. The amylopectin amount was substantially increased when rice was reheated under pressure conditions, consistent with previous studies (Tian et al, 2014; Yu et al, 2017; Li et al, 2019). PSC_63% with pressure of 0.35 to 0.42 MPa could cause the degradation of the structure of branched amylopectin and easier elution compared with non-pressure conditions. In addition, because the water in reheated convenience rice could be used as a channel for flow of water-soluble substances, the amount of amylopectin was also greatly affected by the target water content.

Starch structural analysis of leachate

The normalized HPAEC-PAD (high performance anion exchange chromatography with pulsed amperometric detector) chromatograms of the amylopectin branch chain length distribution in leachate from reheated convenience rice are presented in Fig. S1. The HPAEC system used was sensitive in resolving glucans with a degree of polymerization (DP) $\leq$ 80. Although HPAEC results suffer from mass bias, which is difficult to correct (Wong and Jane, 1995), they could be compared as semi-quantitative results according to the processing technologies of convenience rice. The amylopectin chain length distribution in leachate from convenience rice with different processing technologies is presented in Table 2. The amylopectin chain length could be classified into four types based on the DP: DP 6–12 (A chain), DP 13–24 (B1 chain), DP 25–36 (B2 chain), and DP $\geq$ 37 (B3+ chain) (Hanashiro et al, 1996; Zhong et al, 2020). The debranched amylopectin chain length distribution in leachate varied slightly according to the processing methods. The PSC_63% sample had significantly higher proportions of A and B3+ chains, as well as an average chain length, than

Table 2. Amylopectin branch chain length distribution of leachate obtained from convenience rice using different processing technologies.

Reheated convenience rice	Average chain length	Amylopectin chain length distribution (%)			
		DP 6–12	DP 13–24	DP 25–36	DP ≥ 37
SHS_58%	19.3 ± 0.0 b	30.3 ± 0.0 b	48.8 ± 0.3 a	11.0 ± 0.0 a	9.9 ± 0.3 b
SHS_63%	19.4 ± 0.1 ab	30.4 ± 0.2 b	48.4 ± 0.1 b	11.0 ± 0.0 a	10.3 ± 0.1 ab
AEC_58%	19.4 ± 0.0 ab	30.3 ± 0.2 b	48.2 ± 0.1 b	11.1 ± 0.1 a	10.4 ± 0.1 a
AEC_63%	19.4 ± 0.0 ab	30.5 ± 0.2 ab	48.2 ± 0.1 b	11.0 ± 0.0 a	10.3 ± 0.1 ab
PSC_63%	19.5 ± 0.1 a	30.8 ± 0.4 a	48.5 ± 0.3 ab	10.4 ± 0.3 b	10.4 ± 0.3 a

SHS, Super-heated steaming; AEC, Auto-electric cooking; PSC, Pressurized-steam cooking; DP, Degree of polymerization. 58% and 63% refer to 58% and 63% targeted water contents, respectively.
Data are Mean ± SD (n = 3). Values followed by the different lowercase letters in the same column are significantly different at $P < 0.05$.

the other samples (Table 2). This could be ascribed to the severe destruction of cell structure in reheated convenience rice processed under high temperature and pressurized-steam conditions (130–150 ºC, 0.35–0.42 MPa), causing more short and long chains to leach onto the surface of the reheated convenience rice (Ha et al, 2022; Xu et al, 2020). On the contrary, the SHS_58% sample had significantly lower proportions of A and B3+ chains, and an average chain length than the other samples (Table 2). This phenomenon might be attributed to the formation of fewer holes and less disruption of the internal structure of reheated convenience rice by the SHS processing method, which has a low target water content compared with the other samples. For this reason, SHS_58% had a relatively firm internal structure, resulting in a low amount of leached amylopectin. This result suggests that the structural characteristics of amylopectin in leachate are highly dependent on the processing method of convenience rice of the same variety.

Textural properties of reheated convenience rice

The textural properties of reheated convenience rice, prepared using various processing methods, are presented in Table 3. The hardness of the reheated convenience rice differed significantly according to the processing method and the target water content. The AEC_58% sample exhibited the highest hardness value (3 242.2 g), whereas the AEC_63% sample had the lowest (2 160.0 g). As expected, the convenience rice with a 63% target water content showed a substantially lower hardness compared with that with a 58% target water content, irrespective of the processing method used. Yu et al (2017) and Li and Gilbert (2018) reported that the quantity of added water significantly influences the texture of cooked rice. Increased water content can provide more space for movement, potentially weakening the macrostructure and resulting in a decrease in hardness (Li et al, 2016; Zhu et al, 2019). Tamura et al (2014) also found that the hardness of cooked rice gradually decreased as water content increased.

In East Asia, a sticky texture in cooked rice is preferred, making adhesiveness an important factor affecting the eating quality of cooked rice (Mestres et al, 2019). The processing method significantly affected the adhesiveness of the reheated convenience rice (Table 3). The SHS_58% sample exhibited an extremely low adhesiveness (9.3 g·s), whereas the PSC_63% sample had the highest value (19.5 g·s) among the tested samples. Previous studies have reported that leached amylopectin is a crucial factor affecting the texture of reheated convenience rice, particularly its stickiness (Li et al, 2019; Tao et al, 2019; Zhang et al, 2023). The amylopectin amount in the leachate was highest in the PSC_63% sample and the lowest in the SHS_58% sample (Table 1), which greatly affected their respective adhesiveness values. Li et al (2022) described that leached amylopectin interacts with the probe of the texture analyzer, leading to high

Table 3. Textural properties of convenience rice using different processing technologies.

Reheated convenience rice	Hardness (g)	Adhesiveness (g·s)	Springiness	Cohesiveness	Chewiness (g)
SHS_58%	2 705.0 ± 10.1 c	9.3 ± 0.5 e	0.819 ± 0.015 b	0.624 ± 0.011 b	1 272.6 ± 15.2 c
SHS_63%	2 546.5 ± 37.0 d	10.5 ± 0.6 d	0.832 ± 0.022 b	0.624 ± 0.008 b	1 178.8 ± 22.0 d
AEC_58%	3 242.2 ± 13.3 a	13.0 ± 0.5 c	0.874 ± 0.008 a	0.659 ± 0.005 a	1 768.1 ± 25.6 a
AEC_63%	2 160.0 ± 19.3 e	16.9 ± 0.7 b	0.837 ± 0.031 b	0.613 ± 0.012 b	1 103.9 ± 9.0 e
PSC_63%	2 817.6 ± 39.3 b	19.5 ± 0.4 a	0.767 ± 0.028 c	0.598 ± 0.009 c	1 438.1 ± 38.7 b

SHS, Super-heated steaming; AEC, Auto-electric cooking; PSC, Pressurized-steam cooking. 58% and 63% refer to 58% and 63% targeted water contents, respectively.
Data are Mean ± SD (n = 3). Values followed by the different lowercase letters in the same column are significantly different at $P < 0.05$.

adhesiveness values in reheated convenience rice. Therefore, the greater amount of leached amylopectin adhering to the surface of the PSC_63% sample could require more force to detach the probe from the reheated convenience rice. Furthermore, the PSC_63% sample contained a significantly higher proportion of short A chains in the leachate than the other samples (Table 2), which could also account for its higher adhesiveness. Li et al (2016) and Li and Gilbert (2018) have also noted that the proportion of short chains in amylopectin (DP 6-12) is positively correlated with the stickiness of reheated convenience rice. Consequently, the length of the leached amylopectin chain could be a crucial factor affecting the adhesiveness of reheated convenience rice.

The springiness and cohesiveness of reheated convenience rice were substantially dependent on the processing method (Table 3). Springiness and cohesiveness values spanned from 0.767 to 0.874 and 0.598 to 0.659, respectively. The AEC_58% sample presented the highest springiness and cohesiveness, whereas the PSC_63% sample showed the lowest values (Table 3). Springiness refers to degree of deformation the gel structure undergoes during initial compression and typically increases as the gel is fragmented into larger pieces (Huang et al, 2007; Tian et al, 2014). Cui et al (2022) defined cohesiveness as a measure of the structure's maintenance after a second deformation relative to the first. Gels with higher cohesiveness tend to preserve their integrity upon compression, inducing less deformation. On this basis, the low springiness and cohesiveness of the PSC_63% sample could be associated with extensive structural collapse inside the rice kernel due to the pressurized-steaming method, thereby breaking it into samller pieces. Similarly, Ha et al (2022) found cooked rice subjected to pressure conditions to have significantly reduced springiness and cohesiveness. Because chewiness is calculated as the product of hardness, springiness, and cohesiveness, the chewiness of reheated convenience rice followed a similar pattern to hardness, with the AEC_58% and AEC_63% samples showing the highest (1 768.1 g) and the lowest values (1 103.9 g), respectively (Table 3).

Sensory properties of reheated convenience rice

The sensory properties of reheated convenience rice for assessomg consumer acceptability are summarized in Table 4. The sensory attributes of reheated convenience rice differed substantially among the processing methods. For glossiness, the PSC_63% sample recorded the highest score (8.5), whereas the SHS_58% sample achieved the lowest score (4.6). Reheated convenience rice with a higher target water content generally presents a significantly higher glossiness score than that with a lower target water content. Kim and Kim (2007) observed that the glossiness of cooked rice increased as water content increased. Among the processing methods tested, the PSC_63% sample received the lowest score for whiteness, which could be attributed to the amount of leachate formed on the rice surface upon reheating Ha et al (2022) reported that cooked rice with the largest total solids in leachate had the lowest whiteness score. In the current study, PSC_63% had the highest leachate total solids, whereas SHS_58% had the lowest (Table 1), which could affect the whiteness of reheated convenience rice in sensory evaluation. AEC_58% and AEC_63% scored the highest for roasted flavor among all the convenience rice samples. This could be attributed to the different processing methods, because AEC involves direct transfer into the cooking pot, whereas the SHS and PSC samples are reheated by steaming process during moving along a conveyor belt. Bi et al (2023) also reported that volatile flavor compounds varied significantly with cooking methods, with steaming resulting in a few volatile substances. Furthermore, Ha et al (2022) found that rice cooked with pressurized steaming scored substantially less roasted flavor compared with rice cooked in a rice

Table 4. Sensory characteristics of reheated convenience rice using different processing technologies.

Reheated convenience rice	Glossiness	Whiteness	Roasted flavor	Hardness	Stickiness	Moistness	Overall acceptability
SHS_58%	4.6 ± 0.5 d	6.8 ± 0.4 a	4.7 ± 0.5 b	6.3 ± 0.5 b	3.4 ± 0.5 c	3.1 ± 0.3 d	5.3 ± 0.5 b
SHS_63%	5.3 ± 0.5 c	6.6 ± 0.5 a	4.4 ± 0.5 b	5.6 ± 0.5 c	5.3 ± 0.5 b	4.6 ± 0.5 c	4.4 ± 0.5 c
AEC_58%	5.4 ± 0.5 c	5.6 ± 0.5 b	6.6 ± 0.5 a	7.8 ± 0.9 a	5.7 ± 0.9 b	4.8 ± 0.4 c	5.9 ± 0.4 b
AEC_63%	6.5 ± 0.5 b	5.3 ± 0.5 b	6.5 ± 0.5 a	5.5 ± 0.6 c	6.5 ± 0.5 a	5.5 ± 0.5 b	5.5 ± 0.5 b
PSC_63%	8.5 ± 0.5 a	4.3 ± 0.9 c	4.3 ± 0.5 b	6.9 ± 0.9 b	5.4 ± 0.5 b	6.7 ± 0.8 a	6.8 ± 0.9 a

SHS, Super-heated steaming; AEC, Auto-electric cooking; PSC, Pressurized-steam cooking. 58% and 63% refer to 58% and 63% targeted water contents, respectively.

Data are Mean ± SD (n = 3). Values followed by the different lowercase letters in the same column are significantly different at $P < 0.05$.

cooker.

The acceptability of reheated convenience rice, concerning hardness, stickiness, moistness, and glossiness, is closely related to its texture (Park et al, 2019; Xu et al, 2019). Tao et al (2020) mentioned that hardness and stickiness, as determined by instrumental analysis, are positively correlated with sensory values by panelists. In this study, AEC_58% had the highest sensory and textural hardness scores. SHS_58% had the lowest stickiness score (3.4), while AEC_63% had the highest (5.7). The sensory scores for stickiness showed a similar trend to the textural adhesiveness, except for PSC_63%. Interestingly, PSC_63% had the highest textural adhesiveness, yet its sensory stickiness score was much lower than AEC. This result could be attributed to the high glossiness and moistness of PSC_63%, which might be perceived as relatively less stickiness. The moistness of reheated convenience rice was the lowest for SHS_58% and the highest for PSC_63%. For the same processing method, reheated convenience rice with a 63% target water content received a higher moistness score than that with a 58% target water content. The moistness also varied substantially depending on the processing method. This phenomenon might be attributed to the composition and amount of leachate. A larger amount of leached amylopectin could result in a higher moistness score as perceived by the panelists due to the sticky texture of amylopectin. For overall acceptability, PSC_63% had the highest score among the samples, possibly due to its higher textural adhesiveness, sensory glossiness, and sensory moistness.

Morphological properties of reheated convenience rice

Scanning electron microscopy (SEM)

The morphological characteristics of reheated convenience rice, as influenced by the processing method, were analyzed using SEM at a 500× magnification (Fig. 1). Noticeable differences in the microstructure of the reheated convenience rice were evident based on processing technology and target water content. The cross-section of PSC_63% (Fig. 1-E1 and -E2) showed more severe disruption of the microstructure, with longitudinal chunks and adhesion, than did other reheated convenience rice samples. Yu et al (2017) and Xu et al (2019) have also reported that pressure cooking can disrupt the cell structure of rice. The external pressure applied during pressure cooking can lead to structural destruction by breaking the compact cell walls. Xu et al (2019) further noted greater disruption and porosity on the surface of rice cooked under higher-pressure conditions. Tamura et al (2014) and Zhu et al (2019) stated that the cell membranes of amyloplasts in rice become loose at temperatures between 50–70 ºC due to the gelatinization of the starch. At temperatures above 85 ºC, cracks and some

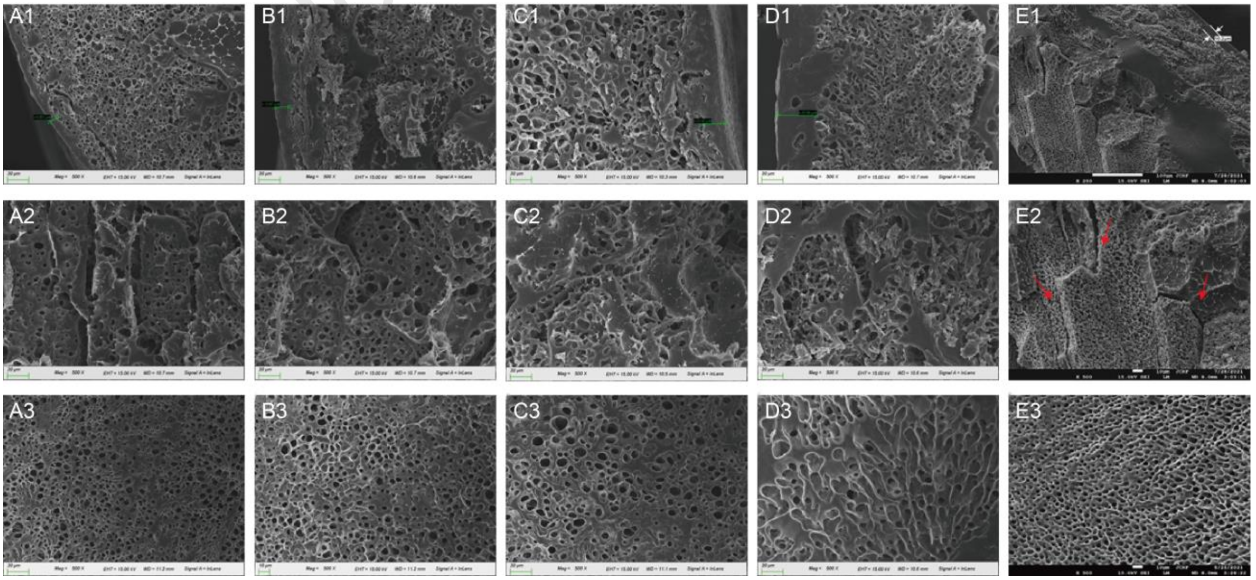

Fig. 1. Scanning electron microscopy images from cross sectional (A1–E2) and surface (A3–E3) of reheated convenience rice with different processing technologies (×500 magnification).

A1–**A3**, Super-heated steaming with 58% water content; **B1**–**B3**, Super-heated steaming with 63% water content; **C1**–**C3**, Auto-electric cooking with 58% water content; **D1**–**D3**, Auto-electric cooking with 63% water content; **E1**–**E3**, Pressurized-steam cooking with 63% water content.

holes appeared in the microstructure of rice, causing the leaching of starch and the disruption of the honeycomb structure of amyloplasts. In this study, the honeycomb structure was difficult to observe in the entirely gelatinized rice grains (Fig. 1-A1 to -E2), indicating that the temperature applied in the processing step was sufficient to destroy the amyloplasts. Unlike other samples, PSC_63% featured longitudinal chunks (marked as red arrows), which could be attributed to the combination of pressure and high-temperature conditions during the cooking process. Cooking at high temperatures combined with high pressure (0.35–0.42 MPa), might accelerate the leaching of amylose and amylopectin, resulting in the formation of large chunks due to the adhesion among adjacent granules. Interestingly, PSC_63% had regularly distributed pores and high porosity. This result could be associated with the evenly applied pressure during the sterilization of the rice grains as they moved along the conveyor belt during the cooking process.

The target water content greatly influenced the morphological changes of reheated convenience rice, particularly porosity. The SEM images of SHS_63%, AEC_63%, and PSC_63% featured substantially larger pores than that of reheated convenience rice with a target water content of 58% (Fig. 1). Tamura and Ogawa (2012) also reported that the destruction of the internal tissues in reheated convenience rice increased with the amount of added water during cooking. During the cooking process, water is absorbed into the peripheral region of the kernel and gradually penetrates the inner area with increased cooking time (Chen et al, 2019; Zhu et al, 2019).

During this process, cracks develop across the ventral and dorsal surfaces of the rice kernel, and these cracks gradually widen as the temperature rises (Xu et al, 2019). The water absorbed during the cooking process uses these cracks as pathways for water diffusion (Concepcion et al, 2015; Zhu et al, 2019). Consequently, the reheated convenience rice with a higher target water content had larger cracks and voids, serving as channels for the migration of water and water-soluble substances. This finding is consistent with Prasert and Suwannaporn (2009), who reported numerous hollow structures inside instant jasmine rice with increasing water content. The large number of voids and loose structure of cooked rice with high water content might explain the increase in the total solids and amylopectin amount in the leachate (Ogawa et al, 2003; Rewthong et al, 2011; Bui et al, 2018). These morphological features of cracks and voids formed during different processing methods of rice could directly influence the textural and sensory attributes of convenience rice.

Confocal laser scanning microscopy (CLSM)

The morphological characteristics of starch and protein granules in the reheated convenience rice were determined using CLSM. Fluorescein-5-isothiocyanate (FITC) and rhodamine B were used to stain starch (green) and protein (red), respectively (Fig. 2-A1 to -E2). The CLSM images of the convenience rice

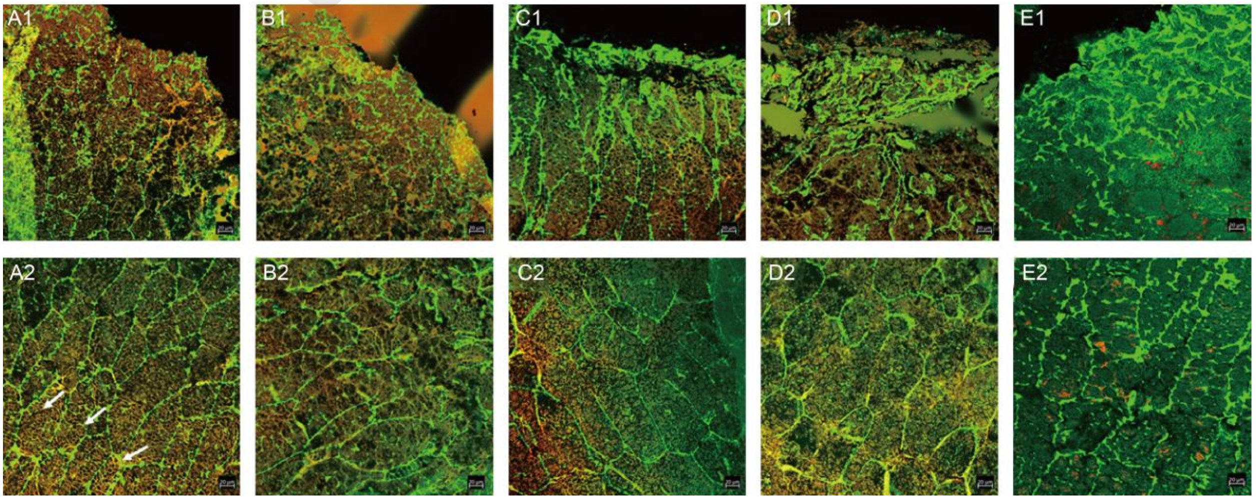

Fig. 2. Confocal laser scanning microscopy images in outer (A1–E1) and inner (A2–E2) regions of convenience rice with different processing technologies (×200 magnification).

A1 and **A2**, Super-heated steaming with 58% water content; **B1** and **B2**, Super-heated steaming with 63% water content; **C1** and **C2**, Auto-electric cooking with 58% water content; **D1** and **D2**, Auto-electric cooking with 63% water content; **E1** and **E2**, Pressurized-steam cooking with 63% water content.

differed substantially depending on the processing method. SHS_58% and SHS_63% relatively maintained the polygonal starch granules in both the inner and outer regions (Fig. 2-A1 and -A2, marked as white arrows). Starch granules gradually swell and expand during rice cooking (Chen et al, 2019; Zhu et al, 2020). Ha et al (2022) suggested that proteins are mainly located at the surface layers and cell walls of raw rice. Upon cooking, the proteins (red color) were substantially compressed by the leached and expanded starch granules, causing a substantial disappearance in the red coloration. Remarkably, SHS_58% and SHS_63% showed that the proteins (red color) in the outer regions were distributed with the starch granules. This could be associated with the SHS processing, which includes a step of superheated steam spraying onto the sample surface, potentially washing away a portion of the leachate from the rice kernel surface. Therefore, the coated layer on the SHS surface might be thinner, displaying even distribution of red color (protein). Conversely, a thicker layer of leached starch molecules (bright green color) was observed in the outer regions of AEC_58%, AEC_63%, and PSC_63% (Fig. 2-C1 to -E1). Tamura and Ogawa (2012) reported that the coated layer on the rice grain surface is related to the amount of cooking water, with a thicker coated layer formed as water content increases. In our study, AEC_63%, which contained higher total solids in the leachate, exhibited a thicker coated layer compared with AEC_58% (Table 1). The CLSM images of PSC_63% did not reveale starch granule cell walls, indicating severe disruption due to pressure conditions. Similarly, Xu et al (2020) and Ha et al (2022) observed a greatly increased coated layer on pressure-cooked rice grains. Ogawa et al (2003) and Briffaz et al (2012) stated that the structure of rice reheated convenience under non-pressure conditions is relatively undamaged, preserving the intact granule structure. Pressure cooking rice can compromise cell integrity, promoting material leaching from the inner region. Because the leachate is predominantly composed of starch, PSC_63%, with the highest total starch content in the leachate, appeared the brightest green color. The protein (red color) in the inner regions did not differ substantially according to the processing method, because the swollen starch granules compressed the protein during cooking.

Principal component analysis (PCA) correlations between processing methods and properties of reheated convenience rice

The PCA was used to investigate the correlations between processing technologies and the characteristics of reheated convenience rice, including leachate compositions, textural and sensory characteristics. As shown in Fig. 3-A, the PCA score plot was predominantly divided into three groups depending on the processing methods, indicating that processing technologies might greatly affect the characteristics of reheated convenience rice. The variation explained by principal component 1 (PC1) and principal component 2 (PC2) was 39.6% and 21.3%, respectively, which together accounted for 60.9% of the total variance. The PCA loading scatter plot, which illustrates the

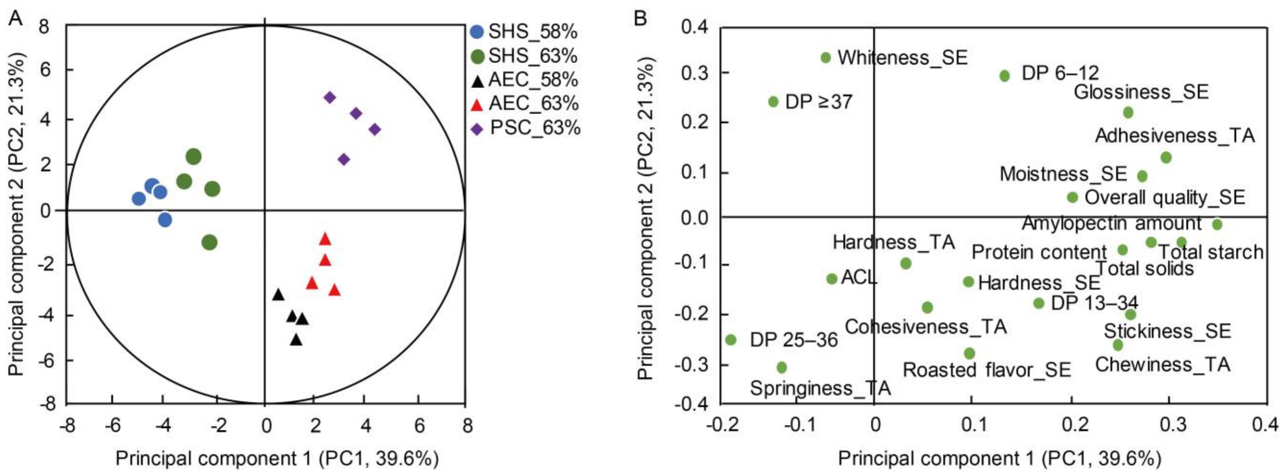

Fig. 3. Score (A) and loading (B) plots for principal component analysis (PCA) derived from leachate compositions, textural and sensory characteristics of convenience rice from different processing technologies.

SHS, Super-heated steaming; AEC, Auto-electric cooking; PSC, Pressurized-steam cooking; TA, Texture analysis; SE, Sensory evaluation; ACL, Average chain length.

factors influencing the grouping, is presented in Fig. 3-B. The amylopectin amount and total solids in the leachate, textural adhesiveness, and sensory scores for moistness and overall quality were located far to the right along PC1, suggesting that these factors played a substantial role in the grouping of SHS. This finding is consistent with the lowest values for amylopectin amount and total solids in the leachate (Table 1), textural adhesiveness (Table 3), and sensory scores for moistness and overall quality (Table S1) observed in SHS_58% and SHS_63% among the tested samples.

Furthermore, the textural hardness, cohesiveness, and chewiness, along with the sensory scores for roasted flavor and stickiness, were found towards the lower right in the PCA loading plot (negative PC2), indicating their significant influence on the grouping of AEC. This is in line with AEC_58% obtaining the highest sensory scores for roasted flavor, stickiness, textural hardness, cohesiveness, and chewiness, while AEC_63% exhibited the lowest textural chewiness and hardness and the highest roasted flavor score. The PCA results suggested that processing methods considerably affected the leachate compositions, textural properties, and sensory properties of reheated convenience rice.

Pearson correlations

Pearson's correlation coefficients for the relationships between the leachate compositions, textural, and sensory properties of reheated convenience rice are presented in Fig. 4. The total solids in the leachate showed positive correlations with total starch, amylopectin amount, roasted flavor, moistness, springiness, and chewiness. Since rice is mainly composed of starch, an increase in the total solids in the leachate corresponds to an increase in the total starch and amylopectin amount in the leachate. Patindol et al (2010) found that the leached amylopectin molecules were significantly smaller than that of native starch due to the restricted leaching of long amylopectin chains. This finding could explain the negative correlation between the total solids and DP ≥ 37 in the present study. The whiteness of reheated convenience rice was also negatively correlated with total solids in leachate. The leached materials formed a coated layer on the surface of reheated convenience rice, which could affect its perceived whiteness. In addition, the total solids were positively correlated with textural adhesiveness and sensory stickiness, which were consistent with the previous studies by Ha et al (2022) and Li et al (2019),

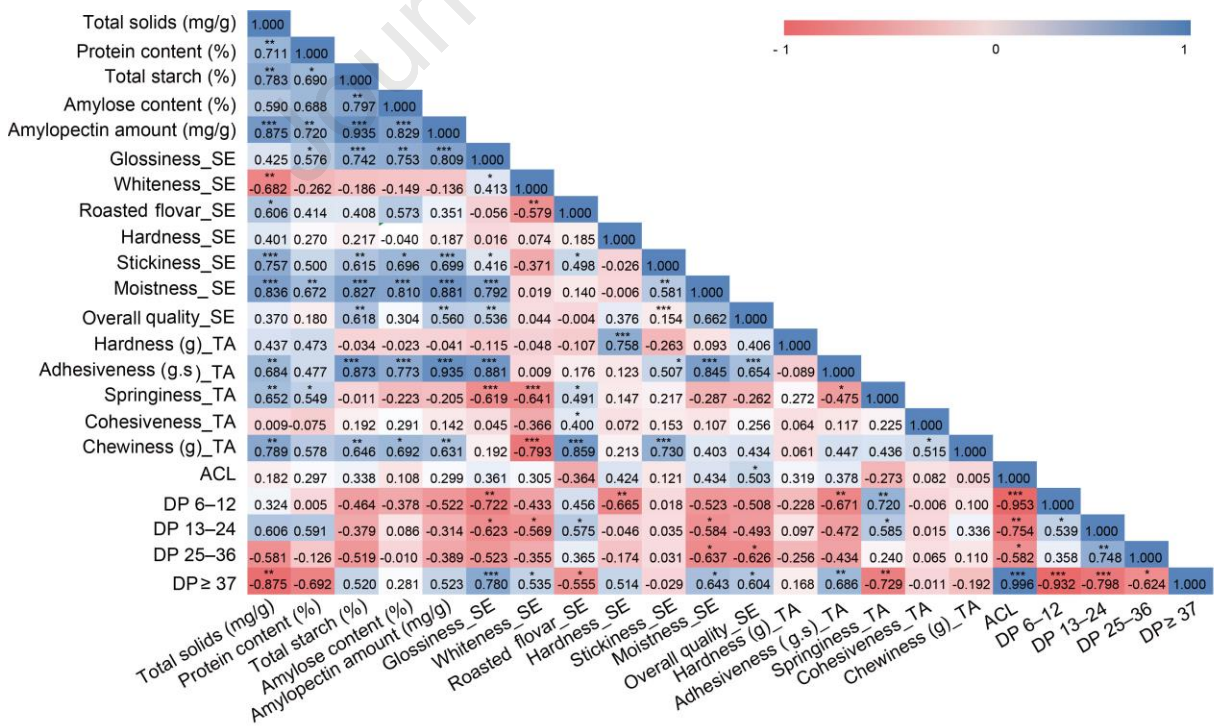

Fig. 4. Pearson correlation coefficients for the relationship between compositions of leachate, texture properties and sensory characteristics of reheated convenience rice from different processing technologies.

*, **, and *** mean that the correlations are significant at $P \leq 0.05$, $P \leq 0.01$, and $P \leq 0.001$, respectively.

who reported a positive correlation between total solids and stickiness of cooked rice. Consequently, the high adhesiveness of PSC_63% could be highly associated with its notable amounts of total solids in leachate, which could be used as an important indicator for predicting the eating quality of reheated convenience rice.

The protein content in the leachate had a positive correlation with the total solids, total starch, and amylopectin amount (Fig. 4). The protein content in the leachate did not differ significantly among the processing methods, except for SHS (Table 1). The leaching of protein could be related to the leaching of gelatinized starch molecules, which account for the significant correlation between the measured parameters and starch molecules in the leachate.

The amylopectin amount in the leachate was positively correlated with sensory glossiness, stickiness, and moistness. Li and colleagues (Li and Gilbert, 2018; Li et al, 2019) also found that leached amylopectin was positively correlated with the stickiness of cooked rice. Ha et al (2022) reported that cooked rice with higher sensory glossiness had more amylopectin in the leachate. Mar et al (2013) suggested that the low amylose content of raw rice decreased the glossiness of cooked rice. Unlike amylose, amylopectin interacts well with water, thus easily leaching out during cooking (Li and Gilbert, 2018). Leached amylopectin forms a thin film on the surface of reheated convenience rice, leading to a sticky texture. This feature could explain the positive correlation between amylopectin amount and stickiness. The amylopectin amount had a positive correlation with overall quality, suggesting that the leached amylopectin amount might be a crucial factor affecting the palatability of reheated convenience rice.

The sensory hardness of reheated convenience rice had a negative correlation with DP 6–12, but a positive correlation with textural hardness. Deng et al (2021) stated that the hardness of cooked rice was closely associated with the long amylopectin chains, not the short chains (DP 6–12). Similarly, Pematilleke et al (2022) reported that instrumental and sensory hardness showed a significant positive correlation.

Adhesiveness is regarded as an important factor affecting the eating quality and palatability of reheated convenience rice (Li and Gilbert, 2018; Li et al, 2019). The textural adhesiveness was positively correlated with glossiness, moistness, stickiness and DP $\geq$ 37, but negatively correlated with springiness and DP 6–12. Pematilleke et al (2022) also found a significant positive correlation between instrumental and sensory stickiness. Li et al (2019) observed an increase in the adhesiveness of reheated convenience rice with the increasing amylopectin amount and proportion of short chains in the leachate. Interestingly, in the present study, short amylopectin chains in the leachate had a negative correlation with adhesiveness, whereas the long chains showed a positive correlation with adhesiveness. This result suggested that the amylopectin amount in the leachate might be an important determinant of the sensory stickiness of reheated convenience rice. These findings could provide valuable insights for assessing the eating quality of convenience rice depending on the processing technologies.

CONCLUSIONS

This study investigated the impact of different processing technologies on the leachate and morphological properties of reheated convenience rice, as well as the relationship between textural and sensory characteristics and leachate properties. The total solids and amylopectin amount in the leachate from pressure-convenience rice and high target water content (PSC_63%) were higher compared with cooking under non-pressure conditions and low target water content (58%). This resulted in higher textural adhesiveness and sensory stickiness. The pressure-reheated convenience rice had high porosity and extensive disruption of the microstructure, producing a notable amount of leachate that formed a thick coated layer on the outer regions of the grains. These features of the leachate led to high sensory glossiness, moistness, and overall acceptability. The PCA plot of the leachate characteristics and textural properties revealed three distinct groups based on the processing methods. The adhesiveness was highly correlated with the total solids and amylopectin amount of the leachate from the reheated convenience rice. In summary, the reheated convenience rice with high porosity in its structure, which induced a higher amylopectin amount and total solids in the leachate, exhibited improved consumer palatability. The processing technology using pressure is a novel method to enhance the acceptability of reheated convenience rice. These findings indicated that the leachate and morphological characteristics of convenience rice, as well as its textural attributes, are significantly influenced by the processing technology employed.

METHODS

Rice materials

Rice cultivar Boramchan, a *japonica* type with 18.9% apparent amylose content, is widely consumed in Korea and was harvested in 2022. It was purchased from a rice processing complex in Asan, Korea. The rice grains were dehulled and milled to obtain 90% milled rice, and then stored at 4 ºC to preserve quality before experiments.

Preparation of reheated convenience rice samples

Convenience rice was prepared using three different processing technologies from the food industry (CheilJedang, Jincheon, Korea): auto-electric cooking (AEC), super-heated steaming (SHS), and pressurized-steam cooking (PSC). For AEC, the rice was soaked for 30 min in distilled water with a ratio of 1:1.3 and 1:1.6 (rice to water) to achieve the target water content (58% and 63%) for reheated convenience rice, respectively. The rice was reheated convenience using an electronic rice cooker (NA-DAH10K, Zojirushi Co. Ltd., Ichikawa, Japan) in auto-cooking mode for 55 min after being soaked for 30 min.

For SHS, the rinsed rice was reheated convenience for 25 min at 125 ºC steaming temperature with the cooker's inner temperature at 97 ºC in a super-heated steaming cooker (MSC-30, Ace system Co. Ltd., Osaka, Japan). The target water content of the convenience rice was achieved by controlling the water nozzle flow at 2.6 and 3.5 L/min for 58% and 63%, respectively.

For PSC, the rinsed and soaked rice was pre-reheated convenience at 100 ºC for 30 min and then sterilized at 130–150 ºC for 4 to 8 s, 4–10 times. After packing the sterilized rice with distilled water, it was steamed for 12 min and then cooled for 15 min. PSC rice with only 63% water content was used, as the commercial product in Korea (Haetban, CheilJedang) has 63% water content.

The processed convenience rice samples were sealed in plastic containers and stored at room temperature. The provided convenience rice was reheated in a microwave (RE-C21VB, Samsung, Seoul, Korea) at 1 000 W for 2 min before experiments. After reheating, the convenience rice samples were allowed to cool to room temperature, and the rice sample from the middle layer was selected for experiments.

Leachate characteristics of reheated convenience rice

To extract leachate, leached material on the surface of reheated convenience rice (20 g) was extracted by rinsing with 100 mL of hot distilled water (95 ºC) with stirring for 10 s gently before filtering through a 250 μm sieve. This extraction procedure was repeated with 50 mL of hot distilled water. The collected rinse water was freeze-dried immediately for further analysis. The weight of the freeze-dried leachate was measured to determine the total solids in the leachate. The total starch content of the leachate was determined using a Megazyme assay kit (Megazyme International Ireland Ltd., Bray, Ireland) and the apparent amylose content of leachate was determined using a colorimetric method reported by Williams et al (1970). The amylopectin amount of the leachate was calculated using the formula: total solids × amylopectin content in the leachate.

The amylopectin chain length distribution in the leachate was analyzed using a high-performance anion exchange chromatography system (HPAEC, Dionex ICS-5000, Dionex Corp., Sunnyvale, CA, USA) equipped with a pulse amperometric detector (PAD) according to the method of Lin et al (2016) and Ha et al (2022). Briefly, leachate (10 mg) was dissolved in dimethyl sulfoxide and heated in a boiling water bath with stirring. Ethanol was added to the solution and centrifuged. The precipitate was dispersed in sodium acetate buffer and incubated for 20 h after adding isoamylase (E-ISAMY, Megazyme International Ireland Ltd.). The debranched solution (20 μL) was diluted with 150 mmol/L NaOH before the injection. The distribution of chain length was characterized as a percentage of the total peak area (Lin et al, 2016).

Morphological characteristics of reheated convenience rice

To determine the morphological characteristics of reheated convenience rice using scanning electron microscopy (SEM), the freeze-dried samples were fractured into halves and attached to a metal plate with carbon tape. Samples were then coated using a sputter coater (180auto, Cressington, Watford, UK), and examined with a scanning electron microscope (JAM-540, JEOL Ltd., Tokyo, Japan) at 15 kV, with magnifications of 250× and 500×.

The morphological properties of reheated convenience rice were determined using confocal laser scanning microscopy (CLSM) according to a previous method (Ha et al, 2022). The reheated convenience rice was soaked in a solution containing 2% glutaraldehyde and 2% paraformaldehyde before being embedded in LR White Resin (London Resin Co., London, UK). The embedded samples were sectioned with an ultramicrotome (RMC PowerTome-PC, Tucson, AZ, USA), equipped with a diamond knife, and then stained using a combination of 0.01% rhodamine B (RhB) in acetone and 0.2% fluorescein-5-isothiocyanate (FITC). The stained microstructure characteristics were examined using a CLSM (LSM-900, Carl Zeiss, Oberkochen, Germany) at the wavelength of 500–520 nm for FITC and 600–635 nm for RhB.

Textural analysis of reheated convenience rice

Ten intact reheated convenience rice grains were selected and placed in the middle of the plate to analyze their textural properties using a texture analyzer (TA-XTplus, Stable Micro Systems, Surrey, UK) in texture profile analysis (TPA) mode with a 20 mm cylindrical probe. The probe descended and returned at a speed of 1.0 mm/s, and the compression force was set to 50% strain. Textural measurements were carried out using three different reheated samples for each sample, resulting in a total of 15 measurements.

Sensory evaluation

The sensory evaluation of reheated convenience rice was performed by 22 panelists (21 females and 1 male). Each sample (20 g) was provided to the panelists in an opaque plastic container labeled with a random three-digit number. The panelists were given definitions of the attributes to be assessed and were instructed to evaluate these attributes in the order presented in Table S2. The sensory attributes were established according to a previous study (Chusak et al, 2019). The attributes assessed included appearance (glossiness and whiteness), aroma (roasted aroma), and texture (hardness, stickiness, and moistness), all rated on a 9-point intensity rating scale. At the final stage, a preference test was conducted using a 9-point hedonic scale to evaluate the overall acceptability.

Statistical analysis

Statistical significance was estimated by one-way analysis of variance (ANOVA) with Duncan's multiple range test using the SPSS software (Version 12.0, SPSS Institute, Inc., Cary, NC, USA) at the significance level of $P < 0.05$. PCA was conducted using SIMCA software (Sartorius, Gottingen, Germany).

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SUPPLEMENTAL DATA

The following material are available in the online version of this article at http://www.sciencedirect.com/journal/rice-science; http://www.ricescience.org.

Fig. S1. Normalized HPAEC-PAD chromatogram of debranched amylopectin in the leachate of cooked rice with different processing technologies.

Table S1. Sensory characteristics of cooked rice with different processing technologies.

Table S2. Procedure and definition of sensory attributes for evaluation.

REFERENCES

Bett-Garber K L, Champagne E T, Ingram D A, McClung A M. 2007. Influence of water-to-rice ratio on cooked rice flavor and texture. *Cereal Chem*, **84**(6): 614–619.

Bhattacharya K R. 2011. Cooking quality of rice. *In*: Bhattacharya K R. Rice Quality. Sawston, Cambrige, UK: Woodhead Publishing: 64–192.

Bi J C, Yang Z, Li Y, Li B, Gao Y Y, Ping C Y, Chen Z, Li C F. 2023. Effects of different cooking methods on volatile flavor compounds in garlic. *Int J Gastron Food Sci*, **31**: 100642.

Briffaz A, Mestres C, Escoute J, Lartaud M, Dornier M. 2012. Starch gelatinization distribution and peripheral cell disruption in cooking rice grains monitored by microscopy. *J Cereal Sci*, **56**(3): 699–705.

Brown L G, McEnally M R. 1992. Convenience: Definition, structure, and application. *J Mark Manag*, 2: 47–56.

Bui L T T, Coad R A, Stanley R A. 2018. Properties of rehydrated freeze dried rice as a function of processing treatments. *LWT*, **91**: 143–150.

Champagne E T, Bett-Garber K L, Fitzgerald M A, Grimm C C, Lea J, Ohtsubo K, Jongdee S, Xie L H, Bassinello P Z, Resurreccion A, Ahmad R, Habibi F, Reinke R. 2010. Important sensory properties differentiating premium rice varieties. *Rice*, **3**(4): 270–281.

Chen X, Zhang X X, Wang B Y, Chen P R, Xu Y, Du X F. 2019. Investigation of water migration and its impacts on eating qualities of black rice during cooking process. *J Cereal Sci*, **89**: 102810.

Choi I D, Oh Y G, Kwak J E, Chun A, Kim M J, Hyun W J. 2021. Water-absorption characteristics and cooked rice texture of milled rice. *Korean J Food Sci Technol*, **53**(4): 486–494.

Chusak C, Ying J A Y, Zhien J L, Pasukamonset P, Henry C J, Ngamukote S, Adisakwattana S. 2019. Impact of *Clitoria ternatea* (butterfly pea) flower on *in vitro* starch digestibility, texture and sensory attributes of cooked rice using domestic cooking methods. *Food Chem*, **295**: 646–652.

Concepcion J C T, Ouk M, Zhao D L, Fitzgerald M A. 2015. The need for new tools and investment to improve the accuracy of selecting for grain quality in rice. *Field Crops Res*, **182**: 60–67.

Crowhurst D G, Creed P G. 2001. Effect of cooking method and variety on the sensory quality of rice. *Food Serv Technol*, **1**(3): 133–140.

Cui T Q, Wu Y, Ni C L, Sun Y X, Cheng J J. 2022. Rheology and texture analysis of gelatin/dialdehyde starch hydrogel carriers for curcumin controlled release. *Carbohydr Polym*, **283**: 119154.

de Boer M, McCarthy M, Cowan C, Ryan I. 2004. The influence of lifestyle characteristics and beliefs about convenience food on the demand for convenience foods in the Irish market. *Food Qual Prefer*, **15**(2): 155–165.

Deng F, Yang F, Li Q P, Zeng Y L, Li B, Zhong X Y, Lu H, Wang L, Chen H, Chen Y, Ren W J. 2021. Differences in starch structural and physicochemical properties and texture characteristics of cooked rice between the main crop and ratoon rice. *Food Hydrocoll*, **116**: 106643.

Ha M, Jeong H Y, Lim S T, Chung H J. 2022. The cooking method features controlling eating quality of cooked rice: An explanation from the view of starch structure in leachate and morphological characteristics. *Food Res Int*, **162**: 111980.

Hanashiro I, Abe J I, Hizukuri S. 1996. A periodic distribution of the chain length of amylopectin as revealed by high-performance anion-exchange chromatography. *Carbohydr Res*, **283**: 151–159.

Huang M, Kennedy J F, Li B, Xu X, Xie B J. 2007. Characters of rice starch gel modified by gellan, carrageenan, and glucomannan: A texture profile analysis study. *Carbohydr Polym*, **69**(3): 411–418.

Ikeda H. 2001. Relationship between the saccharides extracted from rice grains during cooking and the sensory taste of cooked rice. *J Home Econ*, **52**: 401–409.

Kim D H, Kim H S. 2007. Effects of pressure cooker brand awareness on the consumer acceptability of reheated convenience rice. *J Korean Soc Food Cult*, **1**(1): 34–39.

Kim H R, Kwon Y H, Kim J H, Ahn B H. 2011. Quality analysis of diverse rice species for rice products. *Korean J Food Sci Technol*, **43**(2): 142–148.

Li C, Li E P, Gong B. 2022. Main starch molecular structures controlling the textural attributes of cooked instant rice. *Food Hydrocoll*, **132**: 107866.

Li H Y, Prakash S, Nicholson T M, Fitzgerald M A, Gilbert R G. 2016. The importance of amylose and amylopectin fine structure for textural properties of cooked rice grains. *Food Chem*, **196**: 702–711.

Li H Y, Prakash S, Nicholson T M, Fitzgerald M A, Gilbert R G. 2016. Instrumental measurement of cooked rice texture by dynamic rheological testing and its relation to the fine structure of rice starch. *Carbohydr Polym*, **146**: 253–263.

Li H Y, Wen Y Y, Wang J, Sun B G. 2017. The molecular structures of leached starch during rice cooking are controlled by thermodynamic effects, rather than kinetic effects. *Food Hydrocoll*, **73**: 295–299.

Li H Y, Gilbert R G. 2018. Starch molecular structure: The basis for an improved understanding of cooked rice texture. *Carbohydr Polym*, **195**: 9–17.

Li H Y, Lei N Y, Yan S, Gao M Y, Yang J Y, Wang J, Sun B G. 2019. Molecular causes for the effect of cooking methods on rice stickiness: A mechanism explanation from the view of starch leaching. *Int J Biol Macromol*, **128**: 49–53.

Li H Y, Yu L, Yu W W, Li H T, Gilbert R. 2019. Autoclaved rice: The textural property and its relation to starch leaching and the molecular structure of leached starch. *Food Chem*, **283**: 199–205.

Li H Y, Xu M H, Chen Z J, Li J, Wen Y Y, Liu Y L, Wang J. 2021. Effects of the degree of milling on starch leaching characteristics and its relation to rice stickiness. *J Cereal Sci*, **98**: 103163.

Lin L S, Guo D W, Huang J, Zhang X D, Zhang L, Wei C X. 2016. Molecular structure and enzymatic hydrolysis properties of starches from high-amylose maize inbred lines and their hybrids. *Food Hydrocoll*, **58**: 246–254.

Mar N N, Umemoto T, Ismail M, Abdullah S N A, Maziah M. 2013. Determination of amylopectin structure and physicochemical properties in rice endosperm starch of mutant lines derived from Malaysian rice cultivar MR219. *J Sci Food Agric*, **93**(1): 110–117.

Meng L, Zhang W C, Wu Z Y, Hui A L, Gao H, Chen P P, He Y W. 2018. Effect of pressure-soaking treatments on texture and retrogradation properties of black rice. *LWT*, **93**: 485–490.

Mestres C, Briffaz A, Valentin D. 2019. Rice cooking and sensory quality. *In*: Bao J S. Rice. 4th edn. AACC International Press: 385–426.

Mohapatra D, Bal S. 2006. Cooking quality and instrumental textural attributes of cooked rice for different milling fractions. *J Food Eng*, **73**(3): 253–259.

Ogawa Y, Glenn G M, Orts W J, Wood D F. 2003. Histological structures of reheated convenience rice grain. *J Agric Food Chem*, **51**: 7019–7023.

Okuda R, Ishimura T, Kanatani A. 2009. Study on rice cooking. Part 1: Effect of solid components in the rice cooking liquid on the rice grain surface. *J Cookery Sci Jpn*, **42**(6): 394–403.

Park H Y, Shin D S, Woo K S, Sim E Y, Kim H J, Lee S K, Won Y J, Lee S B, Oh S K. 2016. Mechanical quality evaluation of rice cultivars that could potentially be used to produce processed cooked rice. *Korean J Crop Sci*, **61**: 145–152.

Park S G, Park H S, Baek M K, Jeong J M, Cho Y C, Lee G M, Lee C M, Suh J P, Kim C S, Kim S M. 2019. Improving the glossiness of cooked rice, an important component of visual rice grain quality. *Rice*, **12**(1): 87.

Patindol J, Gu X F, Wang Y J. 2010. Chemometric analysis of cooked rice texture in relation to starch fine structure and leaching characteristics. *Starch-Starke*, **62**(3/4): 188–197.

Pematilleke N, Kaur M, Adhikari B, Torley P J. 2022. Relationship between instrumental and sensory texture profile of beef semitendinosus muscles with different textures. *J Texture Stud*, **53**(2): 232–241.

Prasert W, Suwannaporn P. 2009. Optimization of instant jasmine rice process and its physicochemical properties. *J Food Eng*, **95**(1): 54–61.

Rewthong O, Soponronnarit S, Taechapairoj C, Tungtrakul P, Prachayawarakorn S. 2011. Effects of cooking, drying and pretreatment methods on texture and starch digestibility of instant rice. *J Food Eng*, **103**(3): 258–264.

Scholliers P. 2015. Convenience foods. what, why, and when. *Appetite*, **94**: 2–6.

Son J S, Do V B, Kim K O, Cho M S, Suwonsichon T, Valentin D. 2013. Consumers' attitude towards rice cooking processes in Korea, Japan, Thailand and France. *Food Qual Prefer*, **29**(1): 65–75.

Srisawas W, Jindal V K. 2007. Sensory evaluation of cooked rice in relation to water-to-rice ratio and physicochemical properties. *J Texture Stud*, **38**(1): 21–41.

Tamura M, Ogawa Y. 2012. Visualization of the coated layer at the surface of rice grain cooked with varying amounts of cooking water. *J Cereal Sci*, **56**(2): 404–409.

Tamura M, Nagai T, Hidaka Y, Noda T, Yokoe M, Ogawa Y. 2014. Changes in histological tissue structure and textural characteristics of rice grain during cooking process. *Food Struct*, **1**(2): 164–170.

Tao K Y, Yu W W, Prakash S, Gilbert R G. 2019. High-amylose rice: Starch molecular structural features controlling cooked rice texture and preference. *Carbohydr Polym*, **219**: 251–260.

Tao K Y, Yu W W, Prakash S, Gilbert R G. 2020. Investigating cooked rice textural properties by instrumental measurements. *Food Sci Hum Wellness*, **9**(2): 130–135.

Tian Y Q, Zhao J W, Xie Z J, Wang J P, Xu X M, Jin Z Y. 2014. Effect of different pressure-soaking treatments on color, texture, morphology and retrogradation properties of cooked rice. *LWT-Food Sci Technol*, **55**(1): 368–373.

Williams P C, Kuzina F D, Hlynka I. 1970. A rapid colorimetric procedure for estimating the amylose content of starches and flours. *Cereal Chem*, **47**: 411–420.

Wong K S, Jane J. 1995. Effects of pushing agents on the separation and detection of debranched amylopectin by high-performance anion-exchange chromatography with pulsed amperometric detection. *J Liq Chromatogr*, **18**(1): 63–80.

Xu D P, Hong Y, Gu Z B, Cheng L, Li Z F, Li C M. 2019. Effect of high-pressure steam on the eating quality of reheated convenience rice. *LWT-Food Sci Technol*, **104**: 100–108.

Xu D P, Hong Y, Gu Z B, Li Z F, Cheng L, Li C M. 2020. Effect of increased pressure on the coated layer profile of steamed rice. *Food Chem*, **310**: 125971.

Yu L, Turner M S, Fitzgerald M, Stokes J R, Witt T. 2017. Review of the effects of different processing technologies on cooked and convenience rice quality. *Trends Food Sci Technol*, **59**: 124–138.

Yu Y, Pan F, Ramaswamy H S, Zhu S M, Yu L, Zhang Q T. 2017. Effect of soaking and single/two cycle high pressure treatment on water absorption, color, morphology and cooked texture of brown rice. *J Food Sci Technol*, **54**(6): 1655–1664.

Zhang Y, Li F, Huang K, Li S, Cao H W, Xie J, Guan X. 2023. Structural changes of starch under different milling degrees affect the cooking and textural properties of rice. *Food Chem X*, **17**: 100627.

Zhong Y Y, Liu L S, Qu J Z, Blennow A, Hansen A R, Wu Y X, Guo D W, Liu X X. 2020. Amylose content and specific fine structures affect lamellar structure and digestibility of maize starches. *Food Hydrocoll*, **108**: 105994.

Zhu L, Cheng L L, Zhang H, Wang L, Qian H F, Qi X G, Wu G C. 2019. Research on migration path and structuring role of water in rice grain during soaking. *Food Hydrocoll*, **92**: 41–50.

Zhu L, Bi S L, Wu G C, Gong B, Zhang H, Wang L, Qian H F, Qi X G. 2020. Study of the migration and molecular structure of starch and protein in rice kernel during heating. *Int J Biol Macromol*, **147**: 1116–1124.

Zhu L, Wu G C, Cheng L L, Zhang H, Wang L, Qian H F, Qi X G. 2020. Investigation on molecular and morphology changes of protein and starch in rice kernel during cooking. *Food Chem*, **316**: 126262.

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