Research Note

Microstructure of Olbyeossal, Partially Milled Parboiled Glutinous Rice Made by Modified Parboiling Method

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Abstract The microstructure of partially milled parboiled glutinous rice (PMPGR) before and after cooking was investigated using scanning electron microscopy to identify the changes in the microstructure due to parboiling treatments. Parboiling was performed in two different ways: conventional and modified. The conventional parboiling method involved soaking at room temperature for 24 h, followed by steaming and drying. The modified parboiling method involved tumbling to replace soaking of the rice grains, tempering, retorting, and drying. The microstructures of the PMPGR made using both methods were compared. The modified parboiling method significantly changed the microstructure of the rice, but cooking did not cause considerable changes in the microstructure of PMPGR.

Keywords: parboiling, partially milled, glutinous rice, cooking, microstructure

Introduction

Parboiling is an age-old process in various parts of Asia, particularly India, in Africa, and to a limited extent, in some European countries and the United States (1). Parboiling is a hydrothermal treatment applied to paddy rice to improve storage stability and involves the three basic processes of soaking or steeping, steaming, and drying. This process improves the milling recovery of paddy rice, salvages the quality of spoiled paddy rice, and meets the demand of some consumers. Along with the traditional method, a number of modern parboiling processes have been developed using new or existing technologies to improve product quality in different countries (2). *Olbyeossal*, partially milled parboiled glutinous rice (PMPGR) has been consumed as a snack in Korea. Recently, PMPGR has been used to be added when rice has been cooked at some Korean households.

Soaking rice at room temperature is widely practiced for cooking or parboiling but requires a long time to reach a moisture content of about 30% wb. Warm- or hot-water soaking is a common method to shorten soaking time because increasing temperature increases the hydration rate. A soaking temperature below that of starch gelatinization is recommended to minimize splitting of the kernels and subsequent leaching of solids and phytochemicals (3). Several parboiling rice plants still use the conventional approach for making parboiled rice, involving cold-water soaking and steaming at 100°C, to avoid high solid leaching by warm-water soaking. However, a problem arises when cracks occur in the final product for PMPGR. The cracks may occur during steaming in large cylindrical tanks, which causes rice at

the bottom to split. Furthermore, excessive water absorption can also cause rice kernels to split. Due to these reasons, parboiling requires a shorter soaking time to prevent excessive water absorption and shelves to prevent excessive pressure on rice during steaming. To provide an alternative approach, tumbling, tempering, and retorting are introduced in this study. Tumbling is defined as a process when paddy rice and water roll together inside a tumbler for several hours to force water into the rice kernel. Tumbling is performed to replace soaking. Tempering is defined as the process when wet paddy rice is kept at room temperature for several hours to equalize the moisture content inside the rice kernel. A decrease in the moisture gradient inside the rice kernel during tempering has been observed objectively by magnetic resonance imaging (4). The moisture content of wet paddy rice prior to retorting was 31% wb. Retorting is a high temperature and high pressure heating process that replaces steaming. Although the moisture content of wet paddy rice prior to retorting was slightly lower than that of paddy rice prior to steaming, the high temperature and high pressure forced water to penetrate the rice kernel more quickly and effectively compared to conventional method which have been in agreement with results from Unnikhrisnan and Bhattacharya (5).

It has been demonstrated in the previous studies that modified parboiling methods can increase milled rice yield and head rice yield compared to the conventional method (6). Based on the results, an investigation of the microstructure of PMPGR was necessary. Therefore, the objective of this study was to investigate the microstructure of *Olbyeossal*, partially milled parboiled glutinous rice made by a

modified parboiling method using scanning electron microscopy.

Materials and Methods

Materials Paddy rice of the early harvested Korean glutinous rice variety (*Sinseonchalbyeol*), harvested in early autumn 2012, was obtained from Ungchi, Boseong, Korea. The paddy rice was vacuum packaged in plastic bags laminated with polyethylene and nylon, and stored at 4°C before treatment. The initial moisture content of this paddy rice prior to storage was 13–14%.

Conventional parboiling process Parboiled rice is conventionally made in Korea by soaking at room temperature for 1–1.5 days followed by steaming at 100°C for 1 h. The method also has been studied by Priestley (7). Parboiling was performed on a lab scale for comparison with modified-parboiled rice. Five hundred grams of paddy rice was washed, separated from foreign material and dried before soaking. Soaking was done at room temperature (25°C) for 24 h in a laboratory incubator (Daihan Labtech, Namyangju, Korea). The moisture content of the wet paddy rice after soaking was 33% wb (data not shown). Afterward, the soaked paddy rice was steamed at 100°C for 30 minutes to gelatinize the rice starch. After steaming, the paddy rice was dried prior to milling. Drying was done using a hot-air dryer (DSD-060; Daesun Genertec, Seoul, Korea) at 38°C for 4 h. Finally, the dried paddy rice was milled using a small scale rice mill (FS-3000; Misul Brown Rice System, Seoul, Korea) to produce partially milled parboiled rice. The degree of milling was 7.5% and was calculated using the method described by Marshall (8).

Modified parboiling process First, 500 g of paddy rice was washed, separated from foreign material and dried. After washing, the rice was tumbled in a tumbler for several hours to increase the moisture content, then drained, and allowed to stand at 25°C in a laboratory incubator for a specific length of time (Table 1) to equalize the moisture prior to retorting. Tumbling was a process by which paddy rice and excess water (1:5, w/v) were rolled together inside a tumbler (GR-200; Shijiazhuang Helper Food Machinery Company, Hebei, China) to force the water to permeate into the rice kernels. The tumbler was a V-shaped mixer that moved counter clockwise with a rotation speed of 21 rpm. Tempering was the process in which wet paddy rice was placed in a sealed pouch at 25°C for several hours

after tumbling to equalize the moisture content inside the rice kernel. Tumbling and tempering were used to raise the moisture content of the paddy rice to 31% wb. Pre-experiment had proved tumbling and tempering time affect the extent of hydration and showed that paddy rice did not have enough hydration if the tumbling time less than 4 h. High-moisture paddy rice was steamed by retorting (STERI-ACE; KRS-300/Touch Sc. Type, Seoul, Korea) for 5 minutes at 120°C (1.5 kgf/cm²) to gelatinize the starch. The high temperature and high pressure used during retorting caused the water to penetrate the rice kernels more quickly and effectively so that it could gelatinize the rice faster compared to steaming. The paddy rice was dried after retorting. Direct drying at high temperature tended to increase breakage during milling, so low temperature air drying was applied. The retorted paddy rice was placed on a metal basket to facilitate drying and dried using a hot-air dryer (NA-20; NOA Co., Gwangju, Korea) at 30°C for 5 h then allowed to stand overnight at 25°C before milling. Finally, the dried paddy rice was milled using a small scale rice mill (FS-3000; Misul Brown Rice System) with 7.5% degree of milling. The degree of milling was calculated using the method described by Marshall (8). The conditions for tumbling, tempering, and retorting are shown in Table 1.

Cooking method PMPGR (14% wb of moisture content) was placed in an electric rice cooker with a 1:1.5 (w/v) ratio of rice and water and the cooking process was completed automatically. The rice was not washed before cooking though there was a lot of powder left over from milling.

Scanning electron microscopy (SEM) The microstructure of PMPGR before and after cooking was observed by SEM (SE-2400; Hitachi, Tokyo, Japan). PMPGR samples were fixed in a mixture of freshly prepared 2% glutaraldehyde (v/v) and 2% paraformaldehyde (v/v) dissolved in 0.05 M cacodylate buffer (pH 7.2) at room temperature for 4 h. A 0.1 M cacodylate buffer was prepared from 50 mL of 0.2 M sodium cacodylate and 4.2 mL of 0.2 M HCl then diluted to 100 mL with distilled water. Glutaraldehyde (2%) and 2% paraformaldehyde in 0.05 M cacodylate buffer were prepared from 50 mL of 0.1 M cacodylate buffer, 6.25 mL of 32% paraformaldehyde, 8 mL of 25% glutaraldehyde, and 35.75 mL of distilled water. After washing three times at 30 min intervals using 0.05 M cacodylate buffer, the rice samples were post-fixed with 1% OsO₄ in 0.05 M cacodylate buffer at

Table 1. Tumbling, tempering, and retorting conditions of partially milled parboiled glutinous rice by a modified method

Samples	Tumbling time (h)	Tempering time (h)	Retorting temperature (°C)	Retorting pressure (kgf/cm ²)	Retorting time (min)
4H ₁ 4H ₂ ¹⁾	4	4	120	1.5	5
4H ₁ 5H ₂	4	5	120	1.5	5
4H ₁ 6H ₂	4	6	120	1.5	5
5H ₁ 4H ₂	5	4	120	1.5	5
6H ₁ 2H ₂	6	2	120	1.5	5

¹⁾H₁ represents tumbling time using a rotating steeper and H₂ represents tempering time at 25°C.

Fig. 1. Scanning electron micrograph of cross-section of partially milled parboiled glutinous rice at (a) 30 $\times$ and (b) 2000 $\times$ magnification. A: PMGR; B: 24S; C: 4H₁4H₂; D: 4H₁5H₂; E: 4H₁6H₂; F: 5H₁4H₂; and G: 6H₁2H₂. PMGR: partially milled untreated glutinous rice; 24S: rice soaked for 24 h and steamed for 30 min; 4H₁4H₂: rice tumbled for 4 h, tempered for 4 h and retorted at 120°C for 5 min; 4H₁5H₂: rice tumbled for 4 h, tempered for 5 h and retorted at 120°C for 5 min; 4H₁6H₂: rice tumbled for 4 h, tempered for 6 h and retorted at 120°C for 5 min; 5H₁4H₂: rice tumbled for 5 h, tempered for 4 h and retorted at 120°C for 5 min; and 6H₁2H₂: rice tumbled for 6 h, tempered for 2 h and retorted at 120°C for 5 min. Tumbling and tempering were performed at room temperature.

room temperature for 1 h. Cacodylate buffer (0.05 M) was prepared from 50 mL of 0.2 M sodium cacodylate and 4.2 mL of 0.2 M HCl, then diluted to 200 mL with distilled water. After post-fixation, the samples were washed with 0.05 M cacodylate buffer and dehydrated for 30 min intervals using 50, 75, 90, 95 and 100% ethanol. The rice samples were dried with a critical point dryer (HCP-2; Hitachi) and coated with gold. A cross-section of the rice was examined by SEM.

Results and Discussion

Cross sections of the PMPGR visualized by SEM are shown in Fig. 1. Figure 1 shows that the center of partially milled untreated glutinous rice (PMGR) and the rice which are tumbled for 4 h, tempered for 4 h and retorted at 120°C for 5 min (4H₁4H₂) appeared distinct from the surrounding areas (arrows in Fig. 1a A and C). This phenomenon was

Fig. 2. Scanning electron micrograph of cross section of partially milled parboiled glutinous rice after cooking at (a) 30 $\times$ and (b) 2000 $\times$ magnification. A: PMGR; B: 24S; C: 4H₁4H₂; D: 4H₁5H₂; E: 4H₁6H₂; F: 5H₁4H₂; and G: 6H₁2H₂. A: PMGR; B: 24S; C: 4H₁4H₂; D: 4H₁5H₂; E: 4H₁6H₂; F: 5H₁4H₂; and G: 6H₁2H₂. PMR: partially milled untreated glutinous rice; 24S: rice soaked for 24 h and steamed for 30 min; 4H₁4H₂: rice tumbled for 4 h, tempered for 4 h and retorted at 120°C for 5 min; 4H₁5H₂: rice tumbled for 4 h, tempered for 5 h and retorted at 120°C for 5 min; 4H₁6H₂: rice tumbled for 4 h, tempered for 6 h and retorted at 120°C for 5 min; 5H₁4H₂: rice tumbled for 5 h, tempered for 4 h and retorted at 120°C for 5 min; and 6H₁2H₂: rice tumbled for 6 h, tempered for 2 h and retorted at 120°C for 5 min. Tumbling and tempering were performed at room temperature.

not observed in the other PMPGRs. And as the tempering time increased the porosity was obviously increased in 4H₁4H₂ rice which tumbled for 4 h, tempered for 5 h and retorted at 120°C for 5 min (4H₁5H₂) and rice which tumbled for 4 h, tempered for 6 h and retorted at 120°C for 5 min (4H₁6H₂). This result could be related to the moisture content available to facilitate starch gelatinization, indicating that tempering plays a significant role in moisture content equalization under the same retorting conditions. Tumbling for 4 h

and tempering for 4 h (4H₁4H₂) seemed to be enough to strengthen the structure of PMPGR, but the shorter tempering time did not equalize moisture inside the kernel as in 4H₁5H₂ and 4H₁6H₂. However, as the tumbling time increased, there has obvious difference in porosity between 4H₁4H₂ and rice which tumbled for 4 h, tempered for 5 h and retorted at 120°C for 5 min (5H₁4H₂) could be discerned. Poly-hexagonal starch granules, seen clearly in PMGR, were still observed in rice which were soaked for 24 h and steamed for 30 min

(24S), but were not as distinct in the modified PMPGR. Apparently, the severe parboiling process destroyed the natural shape of the starch granules in the rice kernels. Partially milled parboiled rice was shaped like nets bound to each other and had hollow spaces. The glutinous rice starch gelatinized by heating with and without pressure lost their granule integrity and showed similar broken structures. The same results were reported by Hu *et al.* (9).

Figure 2 shows cross-sections of the cooked PMPGR. Before cooking, the center of PMGR and 4H₁4H₂ rice appeared distinct from the surrounding areas, but appeared less so after cooking. Although the moisture content inside 4H₁4H₂ rice was not enough to gelatinize the rice during parboiling, cooking resolved that problem. None of the PMPGR samples showed granule-shaped starch after cooking while the surface of treatment grain showed fissures and depression. Notably, some granule-shaped starch remained in PMGR after cooking. Cooking did not affect the microstructure of the rice, and the microstructures of all PMPGR before and after cooking were relatively similar. The broken structure of starch granules after parboiling did not undergo additional changes after cooking.

The microstructure of glutinous rice was changed by parboiling. Due to the gelatinization of starch, the modified parboiling method caused considerable changes in the microstructure of rice compared to the conventional method. Dutta *et al.* (10) also has reported the roasting technique can improve the quality of waxy rice due to increase hydration of the paddy. Gelatinization in PMPGR produced using the modified parboiling method resulted in harder structures for the PMPGR, which led to higher milled rice yield and head rice yield. In the recent years high pressure steaming and roasting have been applied to the parboiling rice as reported in a previous study (11).

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