

연구노트

In-vitro 전분 소화 모델에서 백미와 현미 가루의 물성학적 특성 분석

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Rheological Behaviors of White and Brown Rice Flours During *In-vitro* Simulation of Starch Digestion

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Abstract The *in-vitro* starch digestibility of white and brown rice flours was continuously characterized from a rheological point of view. Specifically, the *in-vitro* viscosities of the rice digesta samples were monitored under simulated oral, gastric, and intestinal conditions. A trend of decreasing viscosities in all the digesta samples was observed during the *in-vitro* digestion. After cooking, the brown rice sample exhibited lower viscosity than that of the white rice flour due to the presence of more non-starch components. A similar tendency was observed during the simulated oral and gastric digestions. However, the viscosity crossover between the white and brown rice samples was observed during intestinal digestion. In addition, the amount of glucose released from the brown rice flour was significantly lower than that from the white rice flour. Thus, the slower rate of starch hydrolysis in the brown rice flour could be related to its *in-vitro* rheological behaviors.

Keywords: whole-grain, brown rice, *in-vitro* starch digestion, viscosity

Introduction

Current consumers become increasingly aware of the relationship between diet and health. There are thus steadily growing demands for the balanced diets with health benefits (1). With this trend, the industrial and scientific interests have been placed on whole-grain flour as a health functional ingredient. Whole-grain flour is well-recognized to include all naturally occurring and essential substances since it contains three principal grain components (starch endosperm, germ, and bran) in the same proportion to the intact grains (2). Hence, the physiological properties of whole-grain flour have been extensively studied in a number of preceding studies (3,4). It was furthermore reported that the starch in whole grains has more resistance to digestion than refined starch, probably playing a positive role in improving the gut environment (4,5). However, compared to whole wheat flour, brown rice that belongs to whole-grains has not been widely studied due to its limited application into food products. In addition, the studies on the starch digestibility of brown rice

flour in a food system have not been reported yet to our knowledge. In this study, the cooked flours of white and brown rice were subjected to *in-vitro* simulation of starch digestion whose conditions were implemented in a rotational rheometer. The rheological behaviors (specifically, *in-vitro* viscosity) of the white and brown rice digesta were continuously characterized under the oral-gastric-intestinal simulated conditions and correlated to their glucose release pattern.

Materials and Methods

Materials

White and brown rice grains (Sindongjin variety, Jeollabuk-do, Korea) harvested in 2013 were purchased from a commercial source. The rice grains were soaked in water with a ratio of rice to water of 1:1 (w/w) at room temperature for 12 h. They were drained and then ground by using an airmill machine (MCM-3, Nara Machinery Co., Ltd., Tokyo, Japan). The ground rice (less than 100 mesh) was dried in a dryer (Tonesh dryer TRD-100A, Nara Machinery Co., Ltd.) at 95°C.

In-vitro enzymatic starch digestion

The *in-vitro* simulation of starch digestion of the white and brown rice flours were investigated based on the study of Beer *et al.* (6) and Minekus *et al.* (7). Prior to the *in-vitro* starch digestibility analysis, the content of starch in the rice flours was determined by using total starch assay kits (Megazyme International

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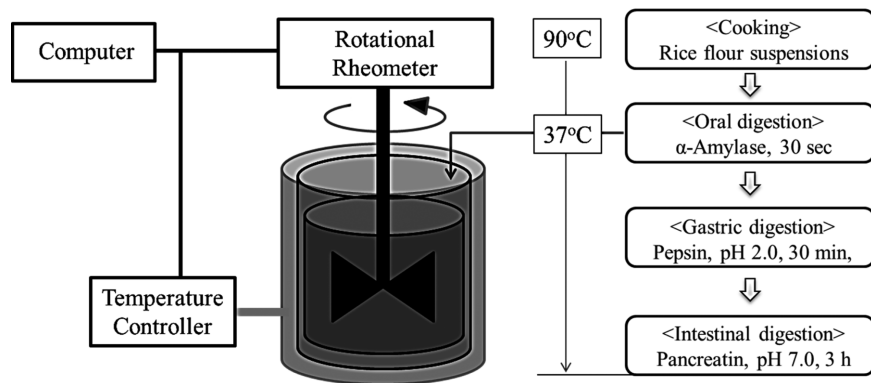


Fig. 1. Experimental setup for the viscosity measurement of white and brown rice samples during the *in-vitro* starch digestion.

Ireland Ltd., Bray, Ireland). The rice flour (2 g) was mixed with 20 mL of simulated salivary fluid (SSF) electrolyte stock solution (7). For cooking, the samples were heated to 90°C at a rate of 12°C/min, held at 90°C for 2.5 min, and cooled to 37°C at a rate of 12°C/min. Then, porcine pancreatic α -amylase (0.5 mL, Sigma-Aldrich, St. Louis, MO, USA) was added at 37°C and incubated for 30 s. Pepsin (250 μ L, Sigma-Aldrich) was added, the pH was adjusted with 1 N HCl to 2.0, and the mixture was incubated at 37°C for 30 min. Pancreatin solution (0.5 mL, Sigma-Aldrich) and amylogucosidase (0.2 mL, A9913, Sigma-Aldrich) per gram of starch in the sample were added to the mixture, the pH was adjusted to 7.0 with 1 M NaOH, and the mixture was then incubated for 3 h. Finally, the glucose concentration in the resultant sample was measured using a glucose released GOPDO kit (Megazyme International Ireland Ltd.)

Rheological measurement during *in-vitro* starch digestion

The rheological properties of white and brown rice samples during the *in-vitro* starch digestion were monitored by using a starch pasting cell attached to a controlled-stress rheometer (AR1500ex, TA Instruments Co., New Castle, DE, USA). As shown in Figure 1, the reaction of the *in-vitro* starch digestion was carried out in aluminum canister that was surrounded by a temperature chamber (37°C). The impeller was rotated at a speed of 160 rpm in the rice samples and the viscosity change during the *in-vitro* digestion was continuously monitored.

Statistical analysis

All experimental measurements were triplicated and the results were reported as mean values \pm standard deviations

Results and Discussion

White and brown rice suspensions were subjected to the programmed heating and cooking in order to simulate the food cooking process. Figure 2(A) exhibits the viscosities of white and brown rice suspensions during the heating and cooling. The closely-packed structure derived from starch gelatinization led to the distinct increased viscosity (8). Thereafter, the viscosities were further increased due to starch retrogradation during the cooling

stage. It was noted that the brown rice sample exhibited lower viscosity than the white rice because of the presence of more non-starch components such as dietary fibers. This result was in good agreement with the preceding study where brown rice flour was utilized in extruded noodle (9). When α -amylase was added for the simulation of oral digestion (Fig. 2(B)), the viscosities of all the samples continued to decrease for 30 s. Specifically, a distinct viscosity decrease from 1.69 to 0.21 Pa·s was observed in the white rice, compared to the brown rice (from 0.87 to 0.20 Pa·s). As shown in Fig. 2(C), the viscosities of the samples were monitored for 30 min after pepsin was added. The viscosities were reduced at the initial stage of the gastric digestion and became constant as the gastric digestion further progressed. The white rice gastric digesta showed higher viscosity than the brown rice digesta. Fig. 2(D) presents the viscosity changes during the *in-vitro* intestinal digestion. The viscosities for both samples were distinctly lowered during the first 30 min digestion. Thereafter, the viscosity of the white rice digesta continued to decrease whereas that of the brown rice digesta became relatively constant or slightly decreased. Thus, the crossover of the viscosities between the white and brown rice samples was obviously observed at 50 min. The brown rice digesta exhibited therefore higher viscosity than the white rice digesta at the end of the *in-vitro* intestinal digestion. It suggested that the enzymatic degradation of the white rice sample that was mainly composed of starch, was in progress during the whole process of *in-vitro* intestinal digestion.

Figure 3 exhibits the glucose release profiles of white and brown rice flours by the *in-vitro* enzymatic starch digestion. The glucose release patterns varied substantially during the early stage of hydrolysis (specifically, the first 30 min digestion for the white rice sample). The amounts of released glucose were significantly higher in the white rice than that in the brown rice, showing more enzymatic degradation of starch in the white rice sample. Thereby, the greater enzymatic digestion of starch in the white rice sample could be correlated to its rheological changes during the *in-vitro* simulated digestion, that is, a distinctly reduced viscosity (Fig. 2). In the case of the brown rice sample, the presence of non-starch components such as fiber-rich fractions might make starch molecules less available

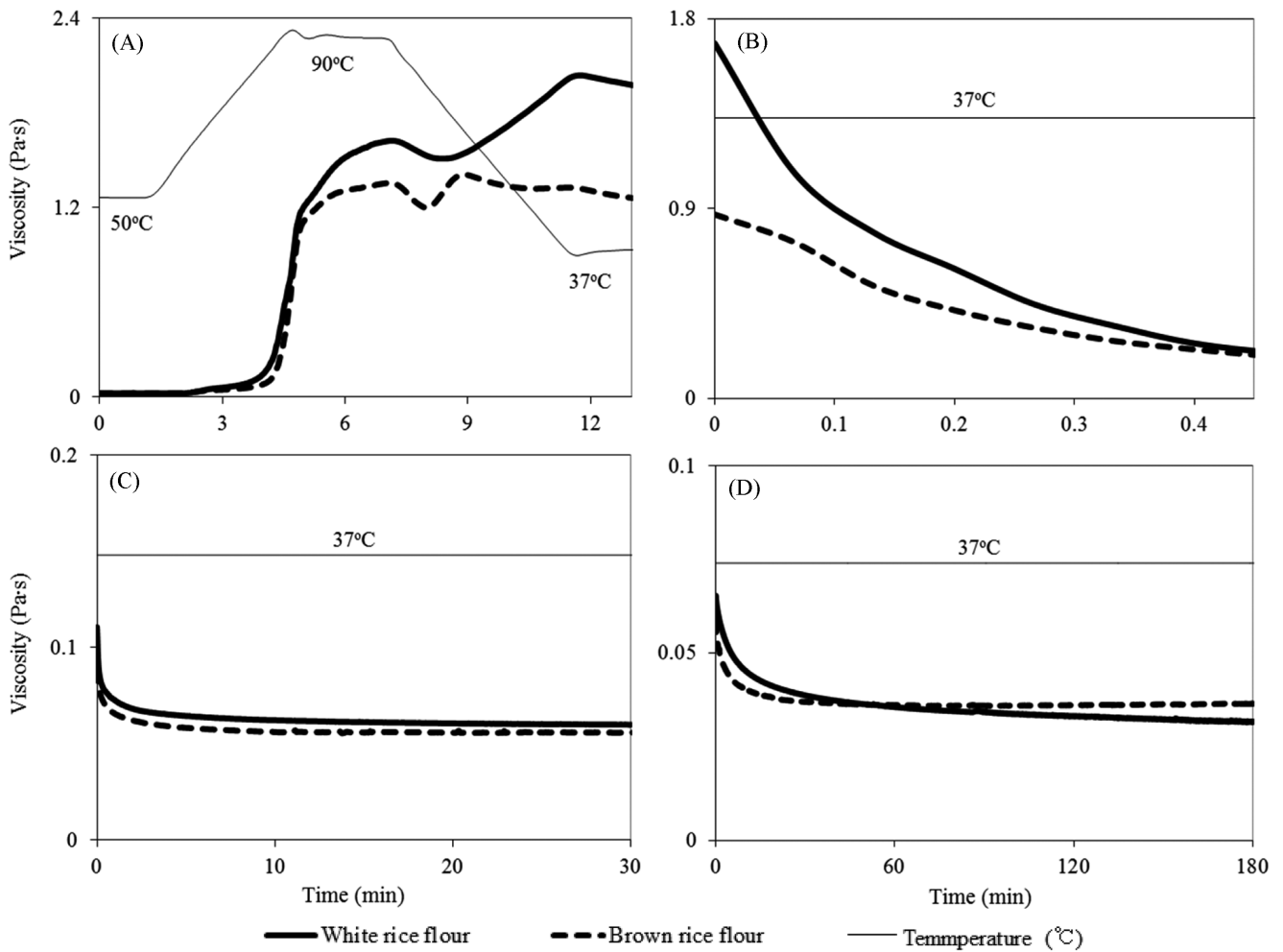


Fig. 2. *In-vitro* rheological changes of white and brown rice samples under simulated digestion conditions ((a) before digestion, (b) oral, (c) gastric, and (d) intestinal digestion).

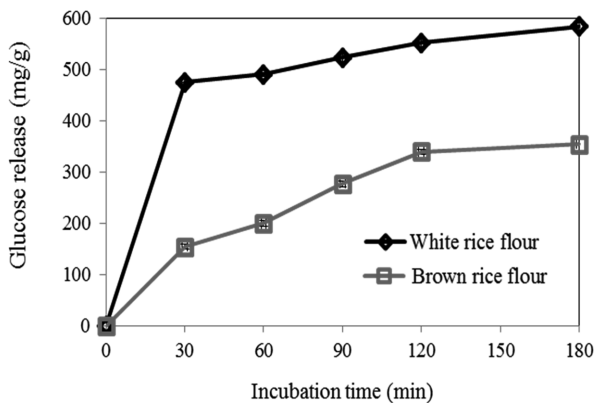


Fig. 3. The glucose release patterns of white and brown rice samples by the *in-vitro* enzymatic starch hydrolysis.

to the digestive enzymes, consequently releasing glucose at a slower rate. This behavior indicates that the enzymatic hydrolysis of starch in the brown rice was retarded, showing the resistance to enzymatic digestion (10). This glucose release pattern seemed to be correlated to the viscosity change as shown in Fig. 2(D).

Conclusions

The *in-vitro* starch digestibility of white and brown rice flours was continuously studied by using a rotational rheometer. The *in-vitro* viscosities of all the rice digesta samples were distinctly reduced under the simulated oral-gastric-intestinal conditions. After cooking, the brown rice sample containing more non-starch components exhibited lower viscosity throughout the *in-vitro* oral and gastric digestion, compared to the white rice sample. However, the viscosity crossover was observed during the intestinal digestion. These results were correlated with the lower amount of released glucose in the brown rice flour, implying its resistance to enzymatic starch digestion. Further studies are necessary to investigate the inhibitory effect of brown rice flour on the starch hydrolysis in a variety of food matrix.

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