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Viscoelastic properties and bubble structure of rice-gel made from high-amylose rice and its effects on bread

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ABSTRACT

Rice gel is a novel form of processed rice, where gelatinized rice is sheared at high speed to create a gel with unique viscoelastic properties, which can partially replace wheat flour in bakery products. In this study, the viscoelastic properties and bubble structures of rice gels made from two high-amylose rice cultivars and two different ratios of rice to water were studied, focusing on the effect of cooling the gelatinized rice before high-speed shearing (cooled rice gel) as opposed to shearing the gelatinized rice while hot (hot rice gel). Increasing the water content and cooling the rice before high-speed shearing generally decreased the dynamic storage (E′) and loss moduli (E″) in the viscoelasticity measurement and introduced fewer but larger and uniform bubbles in the rice gel. In addition, breads made from cooled rice gel showed significantly higher volume than those made from hot rice gel. The application of mechanical shearing to gelatinized starch has a great potential in creating novel food materials with characteristic textures, and can also be used for the processing of cereals other than rice.

1. Introduction

Rice is the staple food in many East and Middle Asian countries, sustaining two-thirds of the world's population (Arendt and Bello, 2008). However, rice consumption has steadily decreased in developed countries, and in Japan, the consumption of rice has fallen to half of what it was in the late 1950s due to Westernization of the traditional diet (Ministry of Agriculture, Forestry and Fisheries of Japan, 2015, http://www.maff.go.jp/j/seisan/keikaku/soukatu/kome_antei_torihiki/pdf/sankou1_150310.pdf). This tendency has promoted the development of new and innovative rice-based products, for example, bakery products in which wheat flour is partially or totally replaced with rice flour.

However, replacing wheat flour with rice flour in breads and baked goods is beset with many difficulties such as low specific volume and early firming (Nakamura et al., 2009; Sabanis and Tzia, 2009). Rice proteins are hydrophobic, and therefore are unable to form the viscoelastic dough necessary to hold the carbon dioxide produced by the yeast during proofing (Arendt and Bello, 2008). Moreover, for such bakery products, rice flours with fine particles but with low starch damage are suitable (Araki et al., 2009), that can be difficult fulfilled or require costly special milling methods such as wet jet milling.

To address this problem, Iwashita et al. (2011) proposed a type of bread made by substituting wheat flour with cooked rice, and showed that specific loaf volumes (loaf volume divided by loaf weight) of bread where 30% of wheat flour was substituted with cooked rice was equal to or higher than that made from 100% wheat flour. Tsai et al. (2012) also showed that the addition of gelatinized rice delayed the retrogradation and firming of bread, contrary to rice flour which accelerates it. However, rice cultivars that showed these favorable results were low in amylose and protein content, which essentially are the characteristics of rice with high palatability when eaten in the conventional way of boiling or steaming (Matsuzaki et al., 1992). Conversely, Shibata et al. (2012a) showed that high-amylose varieties of rice that are high yielding but have low palatability characteristics, produced breads with significantly low specific volume.

To increase the specific volume of breads made with cooked high-amylose rice, Shibata et al. (2015) processed the cooked rice with high-speed shear treatment (HST) before adding it to the

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Abbreviations: CT, computer tomography; HST, high-speed shear treatment.
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bread dough. Not only did HST increase the volume of bread dramatically, but the gelatinized and sheared high-amylose rice, hereafter referred to as rice gel, showed unique viscoelastic properties. In particular, the high-amylose rice gel showed high shear storage moduli and low tan δ (ratio of loss to storage moduli) values compared to similar pastes made from low and normal-amylose rice, and its texture did not change greatly during a 3-day storage period (Shibata et al., 2012b). In addition, the relatively high shear storage modulus of this rice gel made it possible to vary its texture over a wide range by changing the ratio of rice to water during gelatinization, indicating its high potential to be used as a texture modifier.

Shibata et al. (2012b) also reported that the texture of the rice gel which was sheared immediately after gelatinization (while hot) was different to that which was sheared after cooling down to room temperature. However, this experiment was performed with only one rice cultivar, and the authors did not provide any explanation about its mechanisms. If the texture of the rice gel could be adjusted by changing the sample temperature during HST while keeping the water content constant, the versatility of rice gel as an additive would increase. In particular, it could improve the properties of rice gel as an ingredient in bread dough, since physical properties of the rice gel directly affect the specific volumes of the bread (Shibata et al., 2012a). Therefore, this paper explores the effect of shearing temperature on the physical properties of rice gel and the suitability of the resulting gel when used in bread dough. In addition, the rice gels were observed with X-ray computer tomography (CT) to determine the differences in air bubble properties between different manufacturing conditions and to analyze the relationship between the microstructure and physical properties of the rice gel.

2. Material and methods

2.1. Materials

Two high-amylose cultivars of rice, ‘Momiroman’ (harvested in Tochigi prefecture in 2014) and ‘Mizuhochikara’ (harvested in Ibaraki prefecture in 2014) were used. After polishing, their amylose contents were measured according to Juliano (1971) and were shown to be 24.7% and 20.2%, respectively. Their protein contents were 5.1% and 6.1%, respectively.

2.2. Preparation and sampling of rice gel

Pre-experiments showed that the two cultivars produced rice gels with very different physical properties. Consequently, to achieve rice gels within a similar range of viscoelasticity, the ratio of rice to water was set differently between Momiroman and Mizuhochikara. For the rice gels made from Momiroman, the amount of water was twice (800 g) or three times (1200 g) the amount of polished rice (400 g). For those made from Mizuhochikara, the amount of water was 1.5 times (600 g) or twice (800 g) the amount of polished rice (400 g). The polished rice was measured, washed with filtered water until the water was clear, and left for water absorption for at least 2 h before gelatinization. The water added to the washed rice included the amount absorbed by the rice during washing. Gelatinization was performed with a rice cooker (NP-NC10, Zojirusi Corporation), using the “rice porridge mode”. At least three batches were cooked for each combination of rice cultivar and rice to water ratio.

After gelatinization, the weight of gelatinized rice was measured and water was added to compensate for the amount that had evaporated during gelatinization. Half of the gelatinized rice was immediately transferred to a food processor (Blixer-5Plus, Robot-coupe) and went through the HST process. The HST process consisted of four “flash” shearing steps (rotating the cutting knife for approximately 1 s to level out the contents) followed by shearing for 3 min at 3000 rpm. The rotating radius of the food processor was 11.25 cm. The remaining half of the gelatinized rice was sealed with polyethylene film and rapidly cooled with ice water until the average temperature was below 15 °C before going through the HST process. Hereafter, rice gel samples which went through HST immediately after gelatinization will be referred to as “hot rice gel”, and those which were cooled before HST will be referred to as “cooled rice gel”. The average temperatures of the hot rice gel before and after HST were 85 °C and 62 °C, and those of the cooled rice gel before and after HST were 8.3 °C and 43 °C, respectively. The increase in temperature of the cooled rice gel during HST was caused by the friction between sample and blade.

Immediately after HST, the rice gel was sampled for dynamic viscoelasticity, X-ray CT, and water content measurements. For dynamic viscoelasticity measurements, the rice gel was packed into acrylic tubes with inner diameters and heights of 16 mm, and kept at 4 °C for 3 h before measurement. For X-ray CT scans, the rice gel was packed into plastic straws of 1 mm diameter and approximately 5 cm length. The openings of the straws were sealed with polyethylene film to prevent drying, and CT scans were performed within 3 h after the HST process.

2.3. Dynamic viscoelasticity measurement

The dynamic storage and loss modulus of the rice gel samples were measured by a dynamic mechanical analysis tester (Rheolograph-Solid L-1R, Toyo Seiki Seisaku-Sho, Ltd.). The samples were carefully taken out of the acrylic tubes and a sinusoidal strain of amplitude 101 μm was applied in the axial direction with a 20-mm-diameter plunger. Measurements were performed at room temperature and 4 samples were measured for every batch of rice gel, resulting in a minimum of 12 measurements for each combination of rice cultivar, water ratio and shearing temperature.

2.4. Measurement of water content

Water content of the rice gel samples were measured by the oven drying method. Immediately after HST, a minimum of three samples of approximately 3 g were measured into aluminum weighing cans and dried for 3 h at 130 °C. The aluminum cans containing the dried rice gel samples were cooled in a desiccator and the differences in weight before and after drying were used to calculate the water content (wet basis).

2.5. Micro focus X-ray CT measurements

The HST process introduces small air bubbles into the rice gel. Differences in bubble population or size distribution between different manufacturing conditions could affect the physical properties of the rice gel. Therefore, X-ray CT measurements were performed to visualize the air bubbles in the rice gel. X-ray CT has been increasingly applied to food and agricultural products in the last two decades and has proved to be especially useful in studying the three-dimensional structure of cellular food materials (Babin et al., 2006; Lim and Barigou, 2004; Schoeman et al., 2016). One of its advantages is that it can be applied non-destructively to porous samples which would otherwise be difficult to measure due to their fragile structures.

The straws packed with rice gel samples were attached to thin strips of carbon with double-faced tape, and the carbon strips were attached to plastic sticks which held the samples in the air during measurement. This configuration allows the X-ray source to be set