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Influence of ultrasonic enzyme treatment on the cooking and eating quality of brown rice

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In this study, a novel processing technology was developed to selectively modify brown rice by combining ultrasound and enzyme action. The microstructure of the brown rice surface and the cooking, hydration, pasting, textural properties and sensory attributes of treated brown rice were investigated. The taste value of cooked rice was also studied using a rice taste analyzer. The ultrasonic-enzyme treatment resulted in a loss in the natural morphology of the rice bran, allowing water to penetrate into the rice kernels easily during cooking. Furthermore, the conversion rate of bound to structured water, which is related to the pasting properties of rice, was significantly increased by ultrasonic-enzyme treatment. Brown rice treated with ultrasonic-enzyme provided the lowest cooking time and the highest peak, hold and final viscosities among the groups investigated. Furthermore, the cooked brown rice presented a softer texture and was easier to chew. The taste value of the cooked brown rice increased from 45 to 59 after ultrasonic-enzyme treatment. Sensory analysis showed that odor and flavor of the cooked brown rice were also significantly improved ($p < 0.05$). All these results indicate a great improvement in eating quality. Thus, ultrasonic-enzyme treatment can be used to produce quick-cooking brown rice with high quality.

1. Introduction

Brown rice in the form of the grain with just the hull removed is composed of a bran layer, an embryo and an endosperm. It is recognized as a healthy cereal and more nutritious than white rice because it contains not only abundant essential nutrients such as proteins, lipids, dietary fibers, minerals and vitamins, but also various bio-activators such as GABA, octacosanol and oryzanol. These nutrients and bio-activators exist mainly in rice bran layers and endosperm (Champagne, 2004). Despite its better nutritional qualities, brown rice is not widely accepted by consumers, many of whom dislike it due to its poor cooking quality, undesirable flavor and hardness. These disadvantages can be attributed to its outer seed coating, which is rich in tough fibers. The impervious compact fibrous layer prevents water from penetrating into the interior of the rice grain, resulting in a lengthy cooking time. In addition, it toughens the texture of the cooked rice and gives it a different flavor (Hirokawa et al., 1986; Roberts, 1979).

According to nutritionists, brown rice is nutritionally better than white rice. Considerable work has been done to modify the cooking and eating quality of brown rice, using, for instance, partial milling treatment (Marshall, 1992; Roberts, 1979), heat-cool treatment (Hirokawa et al., 1986), plasma treatment (Chen et al., 2012), ultrasonic treatment (Cui et al., 2010), pre-gelatinization (Hirokawa et al., 1986), enzymatic treatment (Das et al., 2008a, 2008b), germination treatment (Charoenthaikij et al., 2009; Kayahara et al., 2001) and soaking treatment (Smith et al., 1985). However, none of these approaches has produced desirable results, and there remains a very strong interest in seeking new processing methods to produce quick-cooking brown rice of a high quality.

The enzymatic treatment was modified in this study. Although enzymatic degradation of cellulose in the bran layer decreases the resistance of water absorption during cooking and improves the eating quality of brown rice, the entire process takes a long time (about 27 h). Pre-soaking, which is an essential step in promoting

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water absorption before enzymatic treatment, is responsible for nearly nine tenths of the total time. This may result in a loss of water-soluble nutrients, which is not acceptable in practice (Das et al., 2008b). Studies have shown that ultrasound treatment can promote water uptake with a much shorter time (about 360 s) by changing the morphological structure of the cellulose (Aimin et al., 2005). Furthermore, research has indicated that a number of fissures will result within 30 min if the rice grains in water are subjected to sonication (Mason et al., 1996). Therefore, it is assumed that ultrasonic treatment can be used to replace the pre-soaking step in enzymatic treatment, shorten the whole process time and improve the cooking and eating properties of brown rice. This modified technique is known as the ultrasonic-enzymatic (U-E) technique. A cursory survey of the literature revealed that no studies have considered the use of the U-E technique for modifying the properties of brown rice. To confirm the effect of the U-E technique on brown rice, changes in the rice's surface structure, water-absorbing quality, cooking and eating quality were examined in this study.

2. Experimental

2.1. Sample preparation

Brown rice produced by Huaidao 5, a Chinese rice cultivar, was procured from Wuxi, China. The paddy was harvested in October 2012. The initial water content of the brown rice was 16.34%, which was determined using the air oven method at 105 °C (GB/T 5497-85). Brown rice, with all foreign substances, damaged kernels and immature kernels removed, was milled using a rice mill (PSKM5B, Tohoku Satake, Japan) to obtain fully milled white rice. Samples of brown and white rice were packed in plastic containers and stored at 4 °C.

Brown rice flour was prepared using a high-speed multi-function mill (Q-250A3, Bingdu Shanghai Co., Ltd., China) to study its pasting properties.

Preparation of cooked brown rice: 10 g rice samples were quickly washed with distilled water three times and then soaked in 14 ml of distilled water in an aluminum specimen box for 30 min at 30 °C. The soaked rice samples were then heated using a rice cooker for 30 min. The rice samples were removed at 10, 20 and 30 min during cooking and then cooled to room temperature, whereupon their T2 values were measured. In addition, the brown rice was cooked for 30 min with a 10-min interval to ripen the boiled rice, and then prepared to measure its textural properties.

2.2. U-E treatment of brown rice

Brown rice grains (20 g) were soaked in 125 ml of water and ultrasonically treated with a probe soaked in water for 30 min at 40 °C using a sonicator (SONICS VCX750). The beaker containing rice was placed in a water bath kettle and ice was added to the kettle to keep the temperature constant when necessary. After the treatment, the brown rice was strained out and spread onto filter paper for 10 min to allow the surface water to evaporate. It was then treated with 60 ml of cellulase solution (acetate buffer, 1.6 IU/ml) at PH 5 for 4.5 h at 50 °C. The enzymes were removed by washing the rice grains after enzymatic treatment. The treated sample was dried to the original moisture content of the untreated brown rice at room temperature for about 1 day.

In addition, the enzyme treated rice was prepared following the preceding steps, excluding the ultrasonic treating step.

2.3. Scanning electron microscopic (SEM) observation

The rice kernels were dried completely under low pressure and then fixed. Gold was then sputtered onto the surface of the kernels, and the sputtered samples were observed by scanning electron microscopy (s-4800, Hitachi, Japan).

2.4. NMR measurement

2.4.1. NM imaging

The MRI experiments were conducted at approximately 32 °C on a microimaging system (NMI20, Niumag, Shanghai, China) with a vertical 0.52 T magnet. An individual rice grain soaked for a certain amount of time was held in position by paper inside a 5-mm o.d. NMR sample tube and MRI measurements were immediately taken. MSE sequencing was used to acquire MR images of the grains, and the two-dimensional images were recorded using the following parameters: repetition time = 100 ms, echo time = 0.002 ms, recycle delay = 100 ms, k-space = 256*128.

2.4.2. Measurement of bound and structure water in cooked brown rice

A Niumag Shanghai PQ001 NMR spectrometer operating at 23.217 MHz (0.55 T) was used for the experiments. 1 g of cooked brown rice was placed at the bottom of an NMR sample tube (25 mm o.d.). The decay curve of the T2 was obtained by iterative optimization. The CPMG decay curve was then fitted to the following model:

$$M(t) = \sum_{i=1}^{n} A_i e^{(-t/T_{2i})}$$

The relaxation time (T2) and the corresponding relaxation signal component were obtained in this way. The acquisition parameters, including the recycle delay, echo time and echo count, were 500 ms, 100 μs and 2,000, respectively.

Any T2 values less than 10 ms were defined as bound water and the corresponding peak area represented the water content. The T2 values ranging from 10 to 80 ms indicated structured water and the corresponding peak area represented the water content.

2.4.3. Water content of soaked brown rice

A manganese chloride aqueous solution with the same T2 values as the samples was prepared as the standard sample. The water content of the standard sample was calculated using NMR analysis software.

The scaling test parameters, including the recycle delay, echo time and echo count, were 500 ms, 100 μs and 2,000, respectively.

After the moisture content standard curve was established, the water content of the brown rice samples was measured using the same parameters. 1 g of brown rice soaked for 10, 20, 30, 40, 50, 60 and 90 min was prepared for measurement. The area amplitudes of the brown rice soaked for certain amounts of time were fitted to the moisture content standard curve to determine the water quality. The water content of soaked brown rice was calculated as the ratio of the quality of the water absorbed during soaking to the initial quality of the rice.

2.5. Optimal cooking time

The optimal cooking time is an important parameter for evaluating the time needed to cook certain rice under specific conditions. In this study, the optimal cooking time of regular, enzyme treated and U-E treated brown rice was measured using the glass plate-white center method (Juliano and Bechtel, 1985). First, 100 ml