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Changes in histological tissue structure and textural characteristics of rice grain during cooking process

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ABSTRACT

Textural-related property including histological tissue structure changes in rice grain (*Oryza sativa* L.) during cooking process was investigated in this study. Forty grams of polished grain were added to 60 ml of water, and cooked using the Japanese style cooking method. Rice grains were removed at 30, 50, 70, 85, and 100 °C during cooking, and moisture content, overall firmness, surface firmness, and histological tissue structures were examined. The leached material amount in cooking water at each temperature was also measured. Results showed moisture content in rice grains linearly increased from 70 °C to 100 °C, while moisture remained almost constant at from 30 °C to 50 °C. The overall firmness almost linearly decreased from 30 °C to 85 °C and decreased from 85 °C to 100 °C significantly, though no significant difference in surface firmness change between 70 °C and 85 °C was found. The leached material amount increased approximately 1.5 times between 50 °C and 70 °C. Voids in the cooked grains were generated between 85 °C and 100 °C, where gelatinization and morphological changes in grain shape, with histological cell wall disruptions occurred. The results shown in this study indicate that structural tissue properties, *i.e.* cell wall properties, are one of the important factors responsible for the textural-related properties of cooked rice grains.

1. Introduction

Unlike other major grains, which are milled into flour before cooking, rice is principally cooked and consumed as a whole grain. Rice grain is a heterogeneous assemblage of distinct constituents, *i.e.* membrane-bound protein bodies and starch granules, *etc.*, which are encased in endosperm cells (Champagne, Wood, Juliano, & Bechtel, 2006). The cell wall maintains the organization and separation of such constituents in the raw grain, however it allows moisture penetration.

The Japanese rice cooking style includes soaking with an optimum amount of cooking water, and heating until the water disappears, *i.e.* the water has evaporated and absorbed in the grain. The water absorption into cells during grain soaking is related to a gelatinization of stored starches when the grains are cooked. In general, starch gelatinization depends on the physiological characteristics of rice and moisture absorption, and the influences on the cooked rice texture, which is one of the most important factors for rice eating quality (Okabe, 1979; Ramesh, Bhattacharya, & Mitchell, 2000; Rousset, Pons, & Martin, 1999). Therefore, eating quality

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is affected not only by grain characteristics inherent in different cultivars, but also cooking procedures and/or conditions, *e.g.* amount of cooking water (Juliano & Perez, 1983; Srisawas & Jindal, 2007; Tamura & Ogawa, 2012).

Horigane et al. (1999) observed structural changes in single cooked rice grains under an experimental cooking model using NMR micro imaging, and detected voids/spaces in cooked grains. Ogawa, Glenn, Orts, and Wood (2003) observed histological structures, and confirmed the voids under ordinary cooking procedures using a fluorescent microscopy method with a tape-aid sectioning technique. These reports suggested the voids likely resulted from pre-existing internal cracks in the grains, which expanded upon exposure to steam. Due to an abundance of cell wall disruptions surrounding the voids in the cooked grain (Ogawa, Wood, Whitehand, Orts, & Glenn, 2006), the grain structural changes during cooking are presumably an important textural factor.

Shibuya and Iwasaki (1984) treated rice grains with cell wall degrading enzymes prior to cooking, and found the resulting cooked rice texture had softened and was stickier. In addition, the enzymatic treatment affected the cell wall structure as well as the cell wall chemistry. Nakamura, Machida, and Ohtsubo (2012) found that activity of xylanase and cellulase in the rice endosperm had considerably correlations with cooked rice texture. Therefore, the changes in histological tissue structures related to cell wall disruptions could affect a textural property of cooked rice grain, *i.e.* grain firmness. The relationships between changes in textural-related properties and histological changes in tissue structure during cooking were investigated and examined in this study.

2. Materials and methods

2.1. Materials

Brown, nonwaxy, japonica rice grains (*Oryza sativa* L. cv. Nipponbare) harvested in 2009 in Shiga, Japan, were purchased from the Japan rice millers association (Chuo, Tokyo, Japan) in April, 2010, stored in a refrigerator at 4 °C, and polished by a household rice polisher (BT-AE05; Zojirushi, Osaka, Japan) before examination. The polished grains were 91% of the original brown grain weight. The initial moisture content of the polished grain sample was 13.7% wet basis (w.b.). The residual bran on the polished grain surface was removed using a thin paper cloth. The sample grains were examined within three months following purchase.

2.2. Rice cooking

The Japanese style rice cooking procedure followed Okadome's method (Okadome, Toyoshima, & Ohtsubo, 1999) was applied in this study. Forty grams of polished rice grains were placed into a commercial use net-type polyethylene bag, where grain samples could be easily collected from the cooking water. Four sets of polished, bagged, and weighed grains were placed in individual 100 ml beakers with 60 ml distilled water set in an electric rice cooker (TK-RC12; Eupa, Tokyo, Japan) with 250 ml of distilled water poured around the 100 ml beakers, and the heat set to medium. The samples were soaked in the water for 30 min at 30 °C using water bath, and then heated using the rice cooker. Water temperature changes during cooking were measured using T-type thermocouple devices connected with a data logger (GL220; Graphtec, Yokohama, Japan). Changes in water temperature during cooking process are shown in Fig. 1. The heating time was approximately 35 min, with a 10 min interval to ripen the boiled rice. The grain samples were removed at 30, 50, 70, 85, and 100 °C during cooking, wrapped in plastic film, cooled to 30 °C for 2 h in an incubator (MIR-253; Sanyo, Osaka, Japan) to homogenize the sample moisture distribution, and used for physical measurements, and microscopic observations. Note that samples at 100 °C were removed from the cooking apparatus when 30 min of heating had elapsed. Polished (pre-cooked), and cooked grain properties were also measured.

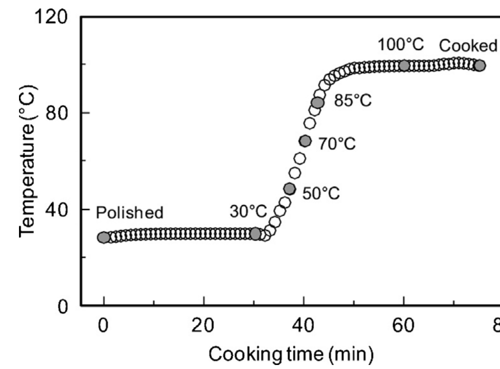

Fig. 1 – Changes in water temperature and sample removal stages during cooking process.

2.3. Moisture content

The moisture content of sample grains during cooking was measured by incubating approximately 10 g of grains for 1 h at 30 °C, and then drying at 135 °C for 24 h using a dryer (SSN-115; Isuzu, Niigata, Japan). Wet basis (w.b.) moisture content was calculated as the water weight percentage divided by the original sample weight.

2.4. Amount of leached materials

Ikeda (2001) reported the eluted rice grain material measured during the cooking process within cooking water. After rice grain removal from grain–water mixture in the 200 ml beakers during cooking, the residual cooking water at 30, 50, 70, and 85 °C, which included soluble and insoluble leached materials, were dried (135 °C, 24 h) using a dryer (SSN-115; Isuzu). Dried material weight was converted into the weight per 100 g of dried polished rice.

2.5. Firmness

A Creep Meter (RE2-33005B(XZ); Yamaden, Tokyo, Japan) was used to conduct compression tests to measure firmness in individual grains. Sample cooked grains were maintained for 2 h at 30 °C in plastic wrap film to homogenize the sample