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Moisture distribution in rice grains used for sake brewing analyzed by magnetic resonance imaging

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ABSTRACT

Water absorption in individual white-core and non-white-core grains of rice varieties used in sake brewing was observed during soaking by magnetic resonance imaging (MRI). Water was absorbed faster in white-core grains than in non-white-core grains and was pooled in the core. Moisture distributions were compared using the line profiles of nuclear magnetic resonance signal intensities (SI profiles) generated from magnetic resonance images of grains soaked for 2 h. SI profiles of white-core and non-white-core grains overlapped despite slight differences in the central and intermediate regions of the grains. A white-core-like structure with loosely packed starch granules was found to exist in the endosperm of non-white-core grains. SI profiles of grains polished to 70% of the yield weight of brown rice were similar in shape to those of grains polished to 90% of the yield, but their overall moisture content was higher after the removal of the hydrophobic grain periphery. A varietal difference in the thickness of the intermediate region, which may affect fissuring resistance in the polishing process, was detected in SI profiles. Differences in water absorbability between parents and their offspring were also apparent from their SI profiles. MRI enabled the detection of variety-specific water-absorption properties in grains.

1. Introduction

Rice is mainly consumed as a diet staple and is also used as the raw material in sake, a traditional alcoholic beverage in Japan. Sake is made of steamed rice and water with koji fungus (*Aspergillus oryzae*) and yeast (*Saccharomyces cerevisiae*), through many alcohol fermentation processes. Non-waxy short grains of japonica rice varieties, including both the types grown primarily for eating and for sake brewing, can be used in sake production. Grains of sake-type varieties generally have more suitable properties for sake brewing in terms of water absorbability, development of koji fungi and yeast, and the saccharification of starch than cooking-type varieties (Iemura and Fujita, 1982; Iemura et al., 1996; Okuda et al., 2006; Yoshizawa and Ogawa, 2004).

Grains of sake-type varieties frequently have a white opaque part in the central region of a grain, called the white core, in which endosperm cells are loosely arranged, starch granules are also loosely packed and various types of cavity are observed. The dimensions of the white core, which are most commonly evaluated visually, can be objectively analyzed using stereo-microscopy image analyses, and their morphological structure was observed by scanning electron microscopy (Akiyama et al., 1997; Takahashi et al., 1999; Yamada et al., 1998). The loose morphological structure of the white core affects the suitability of rice for sake brewing (Aramaki et al., 2004; Yanagiuchi et al., 1996). Water absorbability is an essential property affecting the gelatinization of steamed rice and the development of koji fungi. The moisture content of grains in the steeping and steaming processes is strictly controlled as water is absorbed quickly due to the loose structure of the endosperm (Mizuma et al., 2008; Tamaki et al., 2005; Yoshizawa and Ogawa, 2004).

Chalky grains with a white core are generally considered to have undesirable properties for cooking and eating qualities, and grain breakage occurs in the tempering and polishing process (Lisle et al., 2000; Moldenhauer et al., 2004; Yanagiuchi et al., 1996). Grains in sake production are polished to below 70% of the brown rice weight, and to 30% for high-grade sake, in order to remove the

Abbreviations: MR, magnetic resonance; MRI, magnetic resonance imaging; NMR, nuclear magnetic resonance; SI, signal intensity.

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proteins, lipids, and minerals that are distributed more in the embryo and surface of grains. These chemical components generate an undesirable taste in sake and accelerate the deterioration of its quality (Iwano et al., 2004; Yoshizawa and Ogawa, 2004). Therefore, water absorption needs to be more strictly controlled in grains polished at a lower yield, and fissuring resistance in the polishing process is also an important property for sake-type varieties to maintain the high yields of whole grain under heavy polishing conditions (Tamaki et al., 2007).

The properties required for sake brewing and grain hardness have been separately examined in white-core grains and non-white-core (translucent) grains (Aramaki et al., 1995; Takahashi et al., 1999; Mizuma et al., 2008; Tamaki et al., 2006). Tamaki et al. (2006) analyzed the distribution of hardness in a grain in detail using a micro-hardness tester to calculate the Vickers hardness. Water absorption and starch digestion were faster in white-core grains than in non-white-core grains, and the difference in hardness between the two grain types was large in the white-core part and small in the translucent part surrounding the white core. However, in some varieties, non-white-core grains had similar water absorbability and starch digestibility to white-core grains (Takahashi et al., 1999; Mizuma et al., 2008). Study of the physical function of the white core would be useful to clarify the advantages of white-core grains over non-white-core grains in terms of sake brewing properties and to aid in breeding new sake-type varieties.

Magnetic resonance imaging (MRI) is a useful technique for observing the morphological structure and moisture distribution in a sample. Magnetic resonance (MR) images mainly represent the distribution of water and lipids from which proton nuclear magnetic resonance (^{1}H-NMR) signals are derived. This analytical technique has been effectively used in studies of rice grains in various stages from ripening to cooking, as discussed in our previous report (Horigane et al., 2013). Moisture distribution in grains with a white core were observed by MRI three-dimensionally, non-destructively, and continuously during soaking in our previous research (Horigane et al., 2006). Different patterns of water absorption between white-core grains and non-white-core grains were clear from the MR images, and their moisture distributions were characterized in the line profile of NMR signal intensities (SI profile). In a subsequent study (Horigane et al., 2013), the moisture distribution in rice grains was examined in cooking-type varieties with varying amylose contents. SI profiles were derived to compare the moisture distribution among varieties and to estimate the hardness distribution in a grain from its moisture distribution.

In this study the moisture distributions in grains of sake-type rice varieties were observed during soaking by MRI, and SI profiles of grains at the completion of the water absorption process were obtained. Moisture distributions were compared among grains based on SI profiles in terms of the presence and absence of a white core, difference in harvest years, varieties of the parent and their offspring in breeding, and difference in polishing yield. The advantages of white-core grains in water absorbability and hardness are discussed.

2. Materials and methods

2.1. Rice samples

Samples of rice from six sake-type varieties (Table 1) and one cooking-type variety were used in this study. Of the sake-type varieties tested, Yamadanishiki and Gohyakumangoku are major varieties and the others were the newly bred varieties of Gin'nosato, Koshikagura, and Hokurikusake217 (all bred between Yamadanishiki and japonica rice cooking-type varieties to enhance characteristics that are useful for cultivation), and Rakuhumai which was descended from Gohyakumangoku. The cooking-type variety used here, Koshihikari, is the most famous cooking-type variety in Japan. Rice samples were harvested in 2007 and 2008 from conventionally managed paddy fields at the Hyogo Prefectural Technology Center for Agriculture, Forestry and Fisheries (34°31′N, 134°80′E) for Yamadanishiki and Gohyakumangoku, the National Agriculture and Food Research Organization (NARO) Kyushu Okinawa Agricultural Research Center (32°52′N, 130°44′E) for Gin'nosato, and the NARO/Agricultural Research Center (ARC) Hokuriku Research Center (37°6′N, 138°16′E) for Koshikagura, Hokurikusake217, and Rakuhumai. Koshihikari was harvested in 2008 at the NARO/ARC Hokuriku Research Center.

The brown rice grains were polished with a test-scale mill (Satake TM-05, Hiroshima, Japan) at a yield of 90 or 70% of the original brown rice weight (hereinafter referred as a 90 or 70% polished grain). Rice grains stored at 4 °C were kept at room temperature (≈23 °C) for over 3 h before MRI measurement and all other analyses, which were performed within a year of harvest.

Grains harvested in 2007 were visually separated into white-core and non-white-core grains and examined. In grains harvested in 2008, either white-core grains or non-white-core grains were used as representatives of the variety. For Yamadanishiki, Gohyakumangoku, Gin'nosato, and Koshikagura white-core grains were examined, for Hokurikusake217 and Rakuhumai non-white-core grains were used, and for Koshihikari, the usual non-white-core translucent grains were examined.

2.2. Percentage of white-core grain, amylose content, and moisture content

The percentage of white-core grains to the total number of grains was counted in 2 g samples of polished grains (about 100 grains) with four repetitions. The apparent amylose content (% dry basis, hereinafter defined as amylose content) was determined by the iodine colorimetric method (Juliano, 1971), in which a mixture

Table 1
Percentage of white-core grains, amylose content, and moisture content in polished grains of rice varieties used for sake brewing, harvested in 2008.

Variety	Percent of white-core grains (%)	Amylose content (% db)	Moisture content (% wb)			
			Before soaking		At 2 h of soaking	
Polishing yield (%)	90	90	90	70	90	70
Yamadanishiki	66.0	20.6	14.7	14.3	31.9	35.0
Gohyakumangoku	73.4	16.9	14.2	14.0	33.2	34.7
Gin'nosato	86.0	20.1	14.4	13.7	33.2	35.1
Koshikagura	34.7	17.1	14.3	13.6	33.1	35.9
Hokurikusake217	35.3	19.5	14.3	13.6	32.9	35.5
Rakuhumai	14.0	20.1	14.3	13.6	32.4	34.9

Amylose and moisture contents are expressed on a dry basis (%db) and wet basis (%wb), respectively.
Polishing yield is the weight percentage of white rice after polishing to the original brown rice weight.