Cooking Quality of Sake Rice Variety “Yamadanishiki”
Tomochika Mizuma*§

In the present study, the cooking quality of the major sake rice variety Yamadanishiki was compared with that of the table-rice variety Koshihikari. (1) Yamadanishiki characteristically contains a certain percentage of white-core grains (grains having a white opaque structure in the center) apart from ordinary non-white-core grains. The water absorption rate of white-core grains was higher than that of their ordinary non-white-core counterparts. This difference in the water absorption rates could be associated with uneven cooking, particularly if the soaking periods were insufficient. (2) When compared to Koshihikari, Yamadanishiki yielded a larger volume of cooked rice from a smaller amount of raw rice. Sensory texture evaluation showed that cooked Yamadanishiki rice had a good eating quality that was comparable to Koshihikari. (3) Cooked Yamadanishiki rice showed unique texture properties (hard, elastic, and less sticky) that were not found in Koshihikari. From the above results, the application of the unique texture of Yamadanishiki rice in cooking is expected in the future. (4) These texture properties and the cooking quality of Yamadanishiki appear to be related to the high amylose content and unique characteristics of sake rice (i.e., white-core structure and large-sized kernels).

**Keyword**: sake rice, white-core grains, cooked rice, sensory evaluation, texture

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**INTRODUCTION**

Sake rice is a type of rice suitable for brewing Japanese sake (rice wine). Varieties and production areas are officially designated by the Ministry of Agriculture, Forestry and Fisheries (MAFF) of Japan (As of 2009, 178 types of sake rice of different varieties or geographical origin have been designated). They have been selected and established for quality sake production because of their unique brewing properties that allow them to be polished to a high degree, absorb water sufficiently, support favorable growth of *koji* mold when used as culture platforms, and be dissolved readily in a mixture of *koji* mold and yeast starter, all of which are important for successful sake brewing (Tadenuma, 2007). Additionally, sake rice possesses different morphological and compositional properties from rice suited for cooking (table-rice); for example, sake rice contains white-core grains that have a white opaque structure called the “white core” in the center. The opaque appearance of the white core results from a wide distribution of starch particles in this area, with small intervening spaces between particles that cause the diffuse reflection of light—a characteristic feature which brings about various beneficial effects on sake brewing (Yanagiuchi, 1996 and 1997).

To improve the current difficult situation, with diverse consumer needs and declining table-rice consumption, the Japanese rice farming industry has made considerable efforts to establish novel cultivars of rice with characteristic properties so as to increase national rice consumption. To this end, the MAFF launched the research project “Development of rice and paddy crops with novel characteristics for the promotion of rice consumption (Super Rice Project)” in 1989, aiming to characterize rice proteins and starches, establish rice cultivars for novel applications, and develop processing and utilization techniques. This project was followed by investigations exploring high-quality, highly-functional rice varieties and the subsequent research project (started in 2006) “Development of strategies and procedures to ensure stable supplies of low cost, high quality produce for the food industry,” in which related studies have focused on inexpensive rice cultivars for processing use, and positive results have been reported (MAFF, 2006).

Although breeding a new rice variety is carried out excellently in this manner, this study aimed to identify a new type of table-rice that was texturally different from conventional varieties. Thus, we examined the cooking characteristics of Yamadanishiki, which is a representative sake rice variety. Considering that sake rice has been traditionally grown and is well distributed in Japan and shown to have various characteristic properties, its use as a new type of table-rice may be a potential solution to diverse consumer needs.

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METHODS

Samples

The major sake rice variety Yamadanishiki, which is the most widely cultivated sake rice in Japan, was compared with the table-rice variety Koshihikari. In this study, both rice cultivars were harvested in Hyogo and Niigata Prefecture, respectively in 2011. Sake rice characteristically contains grains with and without the white core (white opaque structure) in the center. To explore the general cooking quality of sake rice, this study focused on the most widely cultivated and popular sake rice Yamadanishiki and table-rice Koshihikari varieties. Grains of both varieties were polished to 90% of their original brown rice weight (polishing rate, 90%) by a rice mill (RSKM5B, Satake Corporation, Japan). The cooking quality of sake rice was examined separately on white-core and non white-core grains sorted using a grain sorter (RGQI20A, Satake Corporation, Japan), as well as on unsorted grains. As compared with Koshihikari (19.9 g), Yamadanishiki showed a larger thousand kernel weight (6.0 g and 3.8 g larger for white-core and non white-core grains, respectively). The weight percentages of white-core and non white-core grains of Yamadanishiki are shown in Table 1.

Table 1. Weight percentages of white-core and non white-core grains of Yamadanishiki

<table>
<thead>
<tr>
<th>weight percentages (%)</th>
<th>67.7</th>
<th>32.3</th>
</tr>
</thead>
<tbody>
<tr>
<td>white-core grains</td>
<td></td>
<td></td>
</tr>
<tr>
<td>non white-core grains</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Composition and relative density

Using powdered samples of polished rice, the amounts of major components were measured according to the procedures described in a guidebook on the Standard Tables of Food Composition in Japan (5th revision) (Kumagaya, 2001), including an ambient-pressure drying method at 105°C for moisture content, the Kjeldahl method for protein content, and simplified iodine colorimetry method for amylose content (Juliano, 1971). The relative density of grains was determined by the sink–float method in a carbon tetrachloride/toluene mixture (Momose, 1978).

Measurement of water absorption

The amount of water absorbed was measured by standard methods (Brewing Society of Japan, 1993). In brief, 10 g of sample was placed in a stainless steel sample basket, which was then soaked in water (20°C) for a variable period of time (0–60 min). The rice was then removed from the basket and the water on the surface of the grains removed by immediate centrifuging (1,500×g, 2 min). In each experiment, samples were analyzed in quadruplicate (standard deviation, 0.020 g). The values used in this paper are averages. The water absorption ratio $x$ was expressed by

$$x = \frac{w - w_0}{w_0}$$

where $w$ (g) is the weight of the water–absorbed sample at any given absorption time (min). The subscript 0 indicates the values of the initial (unsoaked) states.

Cooking characteristics

Cooking characteristics were assessed based on standard procedures recommended by the Food Agency of Japan (Chikubu, 1963). A rice sample (weight, 8 g) was measured into a wire basket (diameter, 40 mm; depth, 75 mm) and soaked in 160 mL of deionized water in a beaker at 20°C for 1 hr. Thereafter, the beaker and contents were transferred to an electric rice cooker (SRNF101, Panasonic Corporation, Japan), the inner bowl of which was filled with 1 L of boiling water and heated (double boiled) for 25 min. The basket and cooked rice were immediately removed from the heat and allowed to stand at room temperature for 10 min, after which the weight and volume of cooked rice were measured to calculate water uptake and volume expansion using the following formulae:

Water uptake ratio = cooked rice weight/initial (uncooked) rice weight

Volume expansion ratio = cooked rice volume/initial (uncooked) rice volume

For measurement of the blue value of the starch–iodine complex (hereafter referred to as starch–iodine blue value), the residual liquid (gruel) remaining in the beaker was allowed to cool to room temperature and diluted to 200 mL with distilled water (DW). The solution (1 mL) was mixed with approximately 50 mL of DW and 2 mL of iodine solution (mixture of 2 g of iodine and 20 g of potassium iodide made up to 1 L with DW) and diluted to 100 mL with DW, and the starch–iodine blue value was determined by measuring the absorbance at 600 nm with a spectrophotometer. Furthermore, 20 mL of the gruel was placed in an aluminum container and incubated to dryness at 80°C for 20 h, followed by 105°C for 4 hr. The resulting solid component was weighed, and the value was converted to the total weight of extracted solids by multiplying it by 10.
Physical properties of cooked rice (Instrumental texture evaluation)

The physical properties of a single kernel and a mass of cooked rice, prepared using a rice: water ratio of 1 : 1.4, were measured with a tensipresser (My Boy II system, Taketomo Electric Inc., Japan).

Single-kernel measurements were performed by a two-bite method with a combination of low- and high-compression tests, in which a kernel of cooked rice was compressed on a sample table by a plunger to 25% and subsequently to 90% of its thickness. The plunger was connected to a sensor detecting the levels of pressure (transmitted from the sample) to the plunger that occurred during compression. In this study, the following attributes were computed from tensipresser curves and employed as the texture parameters (parameters in parenthesis): positive peak height (surface hardness), negative peak height (surface adhesiveness), and negative peak area (surface stickiness) from the low-compression test; and positive peak height (overall hardness), negative peak height (overall adhesiveness), and negative peak area (overall stickiness) from the high-compression test. Additionally, the ratio of overall/surface chewiness values, calculated from positive peak area, was used as a parameter for elasticity.

For the measurement of a cooked rice mass, 10 g of cooked rice was accurately measured into an aluminum dish (φ42x13.5 mm) and compressed with a plunger (contact area, 2.5 cm²) using the same compression rates and detection methods described for single-grain measurement. Attributes analyzed based on the tensipresser curves included positive peak height (as a parameter for hardness), negative peak height (adhesiveness), and negative peak area (stickiness) from the high-compression test, along with the ratio of chewiness values calculated from the low- and high-compression tests (elasticity). Unlike the single-kernel measurements, for the measurements of the cooked rice mass, it was assumed that the low- and high-compression tests did not necessarily reflect the surface and overall physical properties of cooked rice, respectively; therefore, data from the high-compression test were analyzed. The area efficiency, which was reported as a useful measure of texture quality, was calculated as follows: \((\text{the ratio of adhesiveness to hardness}) \times (\text{the ratio of stickiness to elasticity})\) (Hirata, 2002).

Sensory evaluation

As performed for the instrumental measurements, rice samples were cooked using a rice: water ratio of 1 : 1.4 and evaluated by 21 panels consisting of faculty members and students at Seinan Jo Gakuin University in terms of 6 parameters (hardness, stickiness, appearance, flavor, taste, and overall quality) on a 7-point scale from −3 to +3, in which a score of 0 indicated no difference from a reference variety (Koshihikari).

RESULTS AND DISCUSSION

Composition and relative density

Table 2 shows the amounts of major components and relative density of sake rice Yamadanishiki (unsorted, white-core, and non white-core grains) and table-rice Koshihikari. There were no differences between the white-core and non white-core grains of Yamadanishiki in terms of water, protein, and amylose content. The white-core grains had a lower relative density than the non white-core ones, indicating the former’s larger kernel size. This was consistent with previous research demonstrating that the white-core area has a less aggregated structure because of the dispersed distribution of starch particles and wider intervening spaces between the particles (Ando and Ichikawa, 1974). As compared with Koshihikari, Yamadanishiki showed a higher amylose content.

Table 2. Composition and relative density

<table>
<thead>
<tr>
<th></th>
<th>Water content (%)</th>
<th>Protein content (%)</th>
<th>Amylose content (%)</th>
<th>Relative density</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yamadanishiki</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>unsorted grains</td>
<td>13.2</td>
<td>5.61</td>
<td>19.0</td>
<td>1.421</td>
</tr>
<tr>
<td>white-core grains</td>
<td>13.2</td>
<td>5.61</td>
<td>19.0</td>
<td>1.415</td>
</tr>
<tr>
<td>non white-core grains</td>
<td>13.1</td>
<td>5.61</td>
<td>19.0</td>
<td>1.429</td>
</tr>
<tr>
<td>Koshihikari (table-rice)</td>
<td>13.1</td>
<td>5.51</td>
<td>19.0</td>
<td>1.433</td>
</tr>
</tbody>
</table>

Water absorption during soaking

Fig. 1 illustrates the time course of water absorption. Despite showing a similar water absorption ratio to the non white-core grains at the end of soaking, the white-core grains of Yamadanishiki absorbed water more rapidly, suggesting that sake rice is likely to cook unevenly and, thus, requires sufficient time for soaking when used in the cooked form. The non white-core grains of Yamadanishiki followed a similar pattern of water absorption curve as that observed for Koshihikari, suggesting that the presence of the white-core structure may be a critical factor for the water absorption properties of Yamadanishiki.

Our previous studies on sake rice polished to 70% (with
a higher proportion of white-core structure relative to the total grain volume) demonstrated that the white-core structure had a marked influence on its water absorption properties (Mizuma, 2007). These findings were confirmed in the present study, even in sake rice milled to a conventionally-used (for table-rice) polishing rate of 90% (having a lower proportion of the white-core structure).

**Cooking characteristics**

The water uptake and volume expansion ratios represent the degrees of increase in the weight and volume during cooking, respectively, both of which can be used as indicators for the amount of cooked rice prepared from a unit amount of raw rice. The extracted solid weight and starch–iodine blue value reflect the amounts of starch and amylose leached during cooking, respectively (Inazu, 1982).

As shown in Table 3, water uptake and volume expansion ratios were higher in the white-core than in the non white-core grains of Yamadanishiki. No differences were observed in the maximum water absorption ratio between these types of grains during soaking at 20°C (Fig. 1); furthermore, water uptake ratio indicates the amount of water absorbed by rice grains at temperatures above those required for starch gelatinization. Therefore, the observed difference in the water uptake ratio indicates the possibility of a difference in the degree of gelatinization between the white-core and non white-core grains. The water uptake and volume expansion ratios of each type of Yamadanishiki grain were higher than those of Koshihikari grains, demonstrating that a smaller amount of raw Yamadanishiki rice yields a larger volume of cooked rice. The extracted solid weight and starch–iodine blue value of the gruel were not different between the white-core and non white-core grains, suggesting no differences in their amylose content, whereas these indices were higher in Yamadanishiki than in Koshihikari gruel, possibly due to the variation in the amylose content.

**Physical properties of cooked rice (Instrumental texture evaluation)**

In this study, measurements were performed on single kernels and masses of cooked rice so as to evaluate the physical properties of cooked rice both on a single kernel and whole mass basis, as well as to evaluate the density of the cooked rice mass and amount of intervening spaces between rice kernels.

1. **Physical properties of a single kernel**

The results of the low- and high-compression tests on a single cooked rice kernel (Fig. 2 and 3, respectively) represent its surface and overall physical properties, respectively. Yamadanishiki kernels assessed in the single-kernel measurements belonged either to white-core or non white-core grains; unsorted grains were not included in these measurements. The surface and overall physical properties of Yamadanishiki showed similar trends, with higher values for hardness and lower values for adhesiveness and stickiness compared with Koshihikari. A possible explanation is that a high level of hardness and low level of adhesiveness have been considered as desirable characteristics of rice for use in sake brewing, because such properties facilitate the homogeneous growth of inoculated *koji* mold when used as culture plat-

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**Table 3. Property of cooked rice and the cooking solution**

<table>
<thead>
<tr>
<th></th>
<th>Water uptake ratio (%)</th>
<th>Volume expansion ratio (%)</th>
<th>Extracted solid weight (mg)</th>
<th>Starch–iodine blue value (absorbance)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yamadanishiki</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>unsorted grains</td>
<td>312 ± 22 a</td>
<td>309 ± 16 a</td>
<td>317 ± 49 a</td>
<td>0.33 ± 0.13 a</td>
</tr>
<tr>
<td>white-core grains</td>
<td>314 ± 23 a</td>
<td>309 ± 14 a</td>
<td>321 ± 51 a</td>
<td>0.35 ± 0.13 a</td>
</tr>
<tr>
<td>non white-core grains</td>
<td>292 ± 30 b</td>
<td>294 ± 20 b</td>
<td>321 ± 39 a</td>
<td>0.28 ± 0.08 a</td>
</tr>
<tr>
<td>Koshihikari</td>
<td>279 ± 31 c</td>
<td>287 ± 18 c</td>
<td>249 ± 33 b</td>
<td>0.13 ± 0.06 b</td>
</tr>
</tbody>
</table>

Each value is the mean ± standard deviation of five determinations. The same letters at same lines show significant difference at the p<0.05.
forms or ensure proper dissolution and fermentation when mixed with koji mold and sake yeast. It is highly likely that Yamadanishiki, the major variety of sake rice, possesses these characteristics. The single-kernel measurements revealed no marked differences between the white-core and non white-core grains. The characteristic structure of white-core grains (i.e., a wide intervening space between starch particles) did not produce any significant differences in the physical properties of cooked rice measured in this study. It was observed that the white-core grains showed higher water uptake and volume expansion ratios (Table 3); therefore, it is possible that the intervening spaces were occluded during the breakdown and gelatinization of starch particles in these grains. As shown in Fig. 4, there were no significant differences among the 3 types of kernels in elasticity (the ratio of chewiness values at high/low compression).

2. Physical properties of a mass of cooked rice
Similar to the results of the single-kernel measurements, a mass of cooked Yamadanishiki rice showed a higher value for hardness and lower value for stickiness than Koshihikari, with no marked differences in the measured parameters between the white-core and non white-core grains (Fig. 5). Yamadanishiki exhibited a higher value for elasticity (the ratio of overall/surface chewiness) than Koshihikari (Fig. 6), indicating that a mass of cooked Yamadanishiki rice shows a tender texture at the beginning of chewing, followed by a chewy texture that increases upon deformation of the food mass. These findings are different from those observed in the single-kernel measurements (Fig. 4), and this is likely due to the differ-

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**Fig. 2.** Physical properties of a single kernel of cooked rice by low-compression test.
Bars show the standard deviation (SD) (n = 20)
whitecore: white-core grains (of Yamadanishiki), non whitecore: non white-core grains (of Yamadanishiki)
*: Significance at the 5% level

**Fig. 3.** Physical properties of a single kernel of cooked rice by high-compression test.
Bars show the standard deviation (SD) (n = 20)
whitecore: white-core grains (of Yamadanishiki), non whitecore: non white-core grains (of Yamadanishiki)
*: Significance at the 5% level

**Fig. 4.** The ratio of chewiness values at high/low compression is used as a parameter for elasticity.
Bars show the standard deviation (SD) (n = 20)
whitecore: white-core grains (of Yamadanishiki), non whitecore: non white-core grains (of Yamadanishiki)

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**Fig. 5.** Physical properties of a mass of cooked rice (by high-compression test).
Bars show the standard deviation (SD) (n = 20)
unsorted: unsorted grains (of Yamadanishiki), whitecore: white-core grains (of Yamadanishiki), non whitecore: non white-core grains (of Yamadanishiki)
*: Significance at the 5% level
The ratio of chewiness values at high/low compression is used as a parameter for elasticity of a mass of cooked rice. Area efficiency is calculated as follows: (the ratio of adhesiveness to hardness) × (the ratio of stickiness to elasticity). Bars show the standard deviation (SD) (n=20).

Bars: unsorted grains (of Yamadanishiki), whitecore: white-core grains (of Yamadanishiki), non whitecore: non white-core grains (of Yamadanishiki)

*: Significance at the 5% level

ence in the size of the kernels, given that the thousand kernel weights of Yamadanishiki (25.1 g for unsorted grains) and Koshihikari (19.9 g) differed by 5.2 g. In a unit mass of cooked rice, the larger the size of the kernels, the larger the volume of the intervening space. Therefore, it is possible that when a mass of cooked Yamadanishiki rice (consisting of large-sized kernels) was compressed at a low compression rate, the space between the kernels was first broken down, thereby resulting in a lower chewiness value in the low-compression test. In the subsequent high-compression test (in which the intervening space had disappeared), kernels were compressed and broken down, exhibiting a higher chewiness value. The area efficiency, which has been shown to increase relative to the texture quality (Hirata, 2002), was lower in Yamadanishiki than Koshihikari (Fig. 6), indicating that cooked Yamadanishiki rice showed poor texture in terms of instrumental physical parameters.

Sensory evaluation

In the present sensory evaluation, texture properties of cooked Yamadanishiki rice were rated relative to those of the reference variety Koshihikari (Fig. 7). No marked differences were found between the white-core and non white-core grains with respect to the texture parameters evaluated, while Yamadanishiki and Koshihikari were rated as having significantly different levels of hardness and stickiness; namely, Yamadanishiki was perceived as harder and less sticky. These results were consistent with the data from the instrumental measurements (Fig. 2, 3, 5). Rice varieties with high amylose content are perceived as harder and less sticky (Suzuki, 2006). Therefore, Yamadanishiki, with its higher amylose content than Koshihikari (Table 2), showed this texture. Additionally, despite showing a lower area efficiency score than Koshihikari in the instrumental measurements (Fig. 6), no significant difference between Yamadanishiki and Koshihikari was exhibited in the texture parameters, including appearance, flavor, taste, and overall quality, which is a discrepancy (Fig. 7). These results demonstrated that the sake rice variety Yamadanishiki had different physical properties from table-rice, but achieved high ratings similar to those of Koshihikari for the sensory parameters evaluated, indicating that Yamadanishiki can
be served as an alternative table-rice exhibiting unique physical texture properties and good eating quality. The above results indicate the likelihood of the culinary applications of the unique texture of Yamadanishiki in the future.

CONCLUSIONS

In the present study, the cooking quality of the major sake rice variety Yamadanishiki was compared with the table-rice variety Koshihikari.

(1) Sake rice characteristically contains a certain percentage of white-core grains (grains having a white opaque structure in the center) apart from ordinary non-white-core grains, causing a difference in the water absorption rate that is often associated with uneven cooking. Sake rice was found to require a prolonged soaking period to avoid this problem.

(2) Yamadanishiki yields a larger volume of cooked rice from a smaller amount of raw rice, as compared with Koshihikari. Sensory texture evaluation showed that cooked Yamadanishiki rice had a good eating quality that was comparable to Koshihikari.

(3) Cooked Yamadanishiki rice showed unique physical texture properties (hard, elastic, and less sticky) that were not found in Koshihikari. The above results indicate that this difference in texture can find future applications in cooking.

(4) These texture properties and the cooking quality of Yamadanishiki appear to be related to the high amylose content and unique characteristics of sake rice (i.e., its white-core structure and large-sized kernels).

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酒米品種 山田錦の炊飯特性

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和文抄録

酒米の炊飯特性について、代表的な酒米品種の山田錦と食用米品種のコシヒカリを比較検討することによって、以下のことを明らかにした。 (1) 酒米に特異的に一定の割合で混在する心白米（心白構造を持つ米粒）は、通常形態の無白米（心白構造を持たない米粒）と吸水速度が異なるため、炊きムラが生じやすい。これを防止するには十分な浸漬時間が必要であると考えられた。（2）山田錦はコシヒカリに比較して、少ない白米で多くの炊飯米ができ、「釜増え」が大きかった。官能評価結果より、山田錦は、コシヒカリと同程度の良食味性を有することが明らかとなった。（3）山田錦の炊飯米はコシヒカリとは異なる新しい物性特性（硬くてこしが強いが、粘性は低い）を持つことがわかった。今後は、食感の違いをいかした調理面での応用も期待される。（4）これらの特性には、山田錦の高いアミロース含量や酒米固有の心白構造及び大粒性が関与していると推察された。

キーワード：酒米、心白米、炊飯、食味、食感

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