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Abstract

Although short-grain rice accounts for less than 2% of U.S. rice production, the demand for short-grain rice is expected to increase because of the increasing popularity of sushi and sake. The objective of this study was to compare the physical, chemical and textural properties of short-grain rice cultivars grown in Japan and in the U.S. Seven short-grain rice cultivars from the 2016 crop year were collected, including five cultivars (Hatsushimo, Kinuhikari, Koshihikari, Nanatsuboshi, and Yumepirika) grown and purchased in grocery stores in Japan, one (RU9601099) grown in Arkansas, and one (CH-202) grown in California. The rice cultivars were characterized for kernel dimensions, color, chemical composition, amylopectin fine structure, and gelatinization, pasting and textural properties. RU9601099 had a smaller kernel width and a greater whiteness (L^*) value than the other cultivars. Japanese cultivars were comparable in protein content, while RU9601099 had the greatest and CH-202 had the lowest protein content. RU9601099, CH-202 and Kinuhikari shared a similar value of average amylopectin chain length and gelatinization temperatures and enthalpy, which were significantly greater than the other cultivars. Kinuhikari and RU9601099 displayed greater peak and trough viscosities, whereas Hatsushimo and Nanatsuboshi had lower peak and breakdown viscosities. When cooked, the Japanese cultivars exhibited significantly greater hardness than the U.S. cultivars. Based on Ward's cluster analysis considering all data, CH-202 shared similar properties with Kinuhikari, and RU9601099 was distinctively different from the other cultivars in most properties. The information obtained from this study will help future cultivar development and marketing of existing short-grain rice cultivars in the U.S.

Introduction

Although the U.S. produces less than 2% of the world's rice production (USDA, 2014), the U.S. accounts for approximately 10% global exports. Rice varieties in the U.S. are classified as long, medium, and short grain according to grain dimension. Long-grain rice is typically used for entrees and is dry and fluffy when cooked. Medium-grain rice is more tender than long-grain rice, and typically used for risotto and sushi. Short-grain rice is soft, plump, and almost round, and mostly used for sushi, desserts, and sake.

Short-grain rice is favored for sushi in Japan because of Japanese preference for sticky and soft texture. Koshihikari, Sasanishiki, and Akitakomachi are considered premium short-grain rice varieties in terms of flavor among Japanese domestic varieties (Isono et al., 1994). Koshihikari is especially recognized as premium short-grain rice for its sweetness, consistent and firm texture, and aroma (Das et al., 2015). During 1990s to 2000, a total of 200 to 280 non-waxy cultivars were grown in Japan, and 62% of them were Koshihikari and cultivars developed from Koshihikari, such as Akitakomachi and Hinohikari (Yokoo et al., 2005). Besides food applications, short-grain rice is also used for alcohol production such as *sake*, and Yamadanishiki is more suited for *sake* brewing because of its white core and a large grain size (Isono et al., 1994). Because lipids and protein contribute to undesired flavor and are predominantly present in the outer layer of the rice kernel, at least 30% of the rice kernel is polished off for sake brewing. Therefore, rice used for sake is preferred to be a large grain size, non-glutinous rice cultivar, low protein content, and white core (Akiyamaet al., 1997; Okuda et al., 2006; Tamaki et al., 2005). White core is important for sake brewing because it allows the invasion of *koji*-mold (Tamaki et al., 2005). Rice breeding has been conducted with focuses on economic and agronomic aspects, and a pedigree analysis reveals that eleven landraces and cultivars account for 70% of the ancestors of the modern cultivars in Japan (Yonemaru et al., 2012).

Although Arkansas accounts for more than 50% of U.S. rice production and the majority of southern medium-grain rice production, short-grain rice is grown almost exclusively in California. Because of the increasing demand of short-grain rice in the U.S. for sushi and sake, the economic impacts of short-grain rice to Arkansas would be significant because it is used in different markets than long- and medium-grain rice. However, the short-grain rice cultivars developed in Arkansas may be different from those grown in Japan and California because of different genetic backgrounds and growing environments. Cameron et al. (2008) compared medium-grain rice cultivars grown in Arkansas and California and found that rice cultivars grown in Arkansas tended to have higher protein and lipid contents but lower amylose content than the cultivars grown in California. Protein and amylose contents are important factors for rice eating quality, and both are influenced by environmental factors, such as solar radiation, temperature, and fertilization (Resurreccion et al., 1977; Asaoka et al., 1984; Perez et al., 1996; Dupont and Altenbach, 2003; Sar et al., 2014). Therefore, the objective of this study was to compare the physical, chemical and textural properties of rice cultivars grown in California and Arkansas versus those grown in Japan.

Materials and Methods

Materials

Seven short-grain milled rice samples from the 2016 crop year, including five cultivars grown in Japan and purchased in grocery stores in Japan, one cultivar (CH-202) grown in California and one cultivar (RU9601099) grown in Arkansas were used in this study. The five cultivars from Japan were, Yumepirika and Nanatsuboshi from the very north region, Koshihikari and Hatsuhsomo from the central part, and Kinuhikari from the relatively south region of Japan.

Kernel Appearance

Head rice color (*L*a*b**) was measured using a colorimeter (ColorFlex, Hunter Associates Laboratory, Reston, VA). Kernel dimensions (length, width, and thickness) of duplicate ~1000 kernels were measured using a digital image analysis system (SeedCount 5000; Next Instruments, New South Wales, Australia).

Chemical Composition

Milled rice flour samples were obtained by grinding head rice in a laboratory mill (Cyclone sample mill, Udy Corp., Ft. Collins, CO) fitted with a 0.5-mm screen. The flour was used to determine apparent amylose content by iodine colorimetry (Juliano 1971), moisture content by an oven-drying method (AACC Method 44-15A), crude protein by a micro-Kjeldahl method (AACC Method 46-13), lipid content by a lipid extraction system (Soxtec Avanti 2055, Foss North America, Eden Prairie, MN) according to AACC Method 30-20 (AACC International 2000) with modifications by Matsler and Siebenmorgen (2005), and ash content by a dry-ashing method (AACC Method 08-03). Duplicate measurements were conducted for each flour sample. Starch was extracted from milled rice flour with 0.1% NaOH, followed by lipid removal with water-saturated n-butyl alcohol (Patindol and Wang 2002).

Amylopectin Fine Structure

Defatted starch (10 mg) was mixed with 3.2 mL of deionized water and heated in a boiling water bath for 30 min. After cooled to room temperature, the pH of the mixture was adjusted to 3.5 with 0.4 mL of 0.1 M acetate buffer, added with 10 µL of isoamylase (*Pseudomonas* isoamylase, Megazyme International, Wicklow, Ireland), and incubated in a water bath shaker at 45ºC and 150 rpm for 2 h. The mixture was then adjusted to pH 6.5 with 0.21 mL of 0.2 M NaOH, heated in a boiling water bath for 15 min, and allowed to cool at room temperature for 5 min. A 1.5-mL aliquot was centrifuged at 5000 × g for 5 min to remove insoluble materials. The amylopectin chain-length distribution was analyzed by high performance anion-exchange chromatography with pulsed amperometric detection (HPAEC-PAD) using a Dionex ICS-3000 ion chromatography system (Dionex Corporation, Sunnyvale, CA) with an AS40 automated sampler, a 50-mm CarboPac PA1 guard column, and a 250-mm CarboPac PA1 analytical column. Two eluent systems (150 mM NaOH and 500 mM $NaNO_3$ in 150 mM NaOH) were used to separate the branch-chain fractions by gradient elution.

Gelatinization properties

The gelatinization properties of milled rice flour were determined using a differential scanning calorimeter (DSC; Pyris Diamond, PerkinElmer Instruments, Shelton, CT). Approximately 8 mg of rice flour was weighed into an aluminum pan and added with 16 µL of deionized water. The pan was hermetically sealed and equilibrated at room temperature for 1 h prior to scanning from 25 to 120°C at a rate of 10°C/min. The instrument was calibrated with indium, and an empty pan was used as the reference. Onset, peak, and end gelatinization temperatures (T_o, T_p, and T_e, respectively) and gelatinization enthalpy were calculated from each thermogram using the Pyris software.

Pasting characteristics

The pasting properties were characterized using a Rapid ViscoAnalyser (RVA; Model 4, Perten Instruments, Springfield, IL) according to AACC Method 61-02.01 (AACC International 2000). A slurry of 3 g rice flour (12% moisture content) and 25 mL deionized water were stirred initially at 960 rpm for 10 sec, then stirred at 120 rpm for 1.0 min at 50°C, heated from 50°C to 95°C at 11.8°C/min, held at 95°C for 2.5 min, cooled to 50°C at 11.8°C/min, and held at 50°C for 1.0 min. The pasting properties measured included peak viscosity, hot paste viscosity (trough), final viscosity, breakdown, and setback. Paste breakdown was calculated as peak viscosity minus trough viscosity, and setback as final viscosity minus peak viscosity.

Cooked rice texture

Rice was cooked and evaluated following the method of Patindol et al. (2010) with modifications. Head rice (20 g) was placed in a 100-mL beaker with 30 g of deionized water and soaked for 30 min. Thereafter, rice was cooked in a household rice cooker (Aroma, model ARC-707, San Diego, CA, USA) containing 350 mL of water for 30 min, and cooked rice was kept at warm setting before the texture test within 30 min. Cooked rice hardness and stickiness were analyzed by a texture analyzer (TA-XT2 Plus, Texture Technologies, Scarsdale, NY, USA). Ten cooked rice kernels were compressed at a speed of pre-test 2.0 mm/s, test 0.5 mm/s, and post-test 0.5 mm/s to a distance defined to compress the kernels to 90% of their original height using a 5-kg load cell on a flat aluminum plate (100 mm dia.) under the Texture Profile Analysis test mode. Six replications were performed for each cooked rice sample, and two cooked rice samples were prepared for each rice cultivar.

Statistical Analysis

At least duplicate measurements were performed for each analysis and the experimental data were analyzed by JMP® software version Pro 12.0.1 (SAS Software Institute, Cary, NC). Tukey's honestly significant difference (HSD) test was used to detect significant differences among cluster means. Principal component analysis on correlations was performed to obtain a simplified view of the relationship among rice cultivars (sample loading), and between starch fine structure and gelatinization/pasting property (variable loading). Bivariate correlation analyses were performed by the Pearson-product moment approach to determine correlation between kernel appearance and chemical properties. Ward's hierarchical cluster analysis was used to classify seven rice cultivars according to similarities and differences in physical, chemical, gelatinization, pasting, and textural characteristics.

Results and Discussion

Kernel Appearance

The physical characteristics and appearance of milled head rice kernels from the seven rice cultivars are presented in Table 1 and Figure 1, respectively. Kinuhikari, Koshihikari, Nanatsuboshi, and RU9601099 shared a similar, intermediate kernel length, whereas Hatsushimo had the longest length (5.37 mm) and CH-202 was the shortest (4.77 mm). Kernel width was less variable among rice cultivars (2.86-2.92 mm), except that RU9601099 was significantly narrower in width (2.72 mm) ($p<0.05$). The smaller kernel width of RU9601099 may be partly attributed to the higher nighttime air temperature in Arkansas relative to other regions because Counce et al. (2005) reported that rice kernel width was negatively correlated with higher nighttime air temperatures. Nanatsuboshi and Yumepirika had a greater thickness than most cultivars. The Federal Grain Inspection Service (FGIS) of the U.S. Department of Agriculture classifies milled rice with a length-to-width ratio (L/W) equal to or less than 1.9 to 1 as short grain, thus all cultivars in this study belonged to short grain. Although Hatsuhimo and RU9601099 had a similar and significantly greater L/W ratio than the others, RU9601099 was shorter and narrower, but Hatsuhimo was longer and wider. Kernel dimensions are important factors for sake brewing because the categories of sake are established by the polishing degree. For example, the polishing degree for sake is usually about 70%, and that for Ginjoshu and Daiginjoshu, preminum grades of sake, is less than 60% and 50-30%, respectively (Tamaki et al., 2005). Therefore, the small width of RU9601099 is not desired for sake brewing.

RU9601099 had significantly greater whiteness (*L**), whereas Nanatsuboshi and Yumepirika had lower whiteness but greater yellowness (*b**). Although RU9601099 and Koshihikari shared a similar and greater L*/b* ratio, RU9601099 was significantly whiter, yet Koshihikari was less white, as evidenced in Figure 1. Bivariate correlation analysis (data not shown) shows that L*/b* ratio was significantly negatively correlated with yellowness. The greater whiteness of RU9601099 was due to its greater percentage of chalkiness, which was likely to result from a higher nighttime air temperature during maturity in Arkansas (Lanning et al., 2011; Chen et al., 2017). Chalky grain rice tends to leach more soluble solids during cooking, which is associated with low eating quality (Chun et al., 2009).

Chemical Composition

All rice cultivars in this study belonged to low-amylose rice (10-19%) according to USDA classification (Table 2). CH-202 from California had a higher amylose content (15.86%) but the lowest protein content (5.2%), whereas RU9601099 from Arkansas had the lowest amylose content (11.90%) and lipid content (0.31%), but the highest protein content (8.53%) and ash content (0.64%). The Japanese cultivars had a similar lipid and ash content, and an intermediate protein content, except for Koshihikari having a low protein content, but their amylose contents varied, ranging from 12.23 to 15.15%.

Protein was found to be positively correlated with yellowness (*b**) ($r = 0.5610$). Crude protein content has been shown to have an adverse effect on the appearance, flavor and stickiness of cooked rice (Furukawa et al., 2006) and aroma and flavor of sake (Okuda et al., 2018; Furukawa et al., 2006). Furukawa et al. (2006) confirmed the negative impact of protein on flavor by adding extracted rice protein fractions, including glutelin, prolamin and their combination, to cooked rice and sake brewing, and concluded that prolamin was primarily responsible for the decreased qualities. Because of its high protein content, RU9601099 may impart more negative attribute to sushi rice and sake applications, whereas CH-202 is desired for both applications because of its low protein content.

Amylopectin Fine Structure

The average chain lengths and the proportions of branch chains of amylopectins from the seven rice cultivars are presented in Table 2. Amylopectin chains were classified according to Hanashiro et al. (1996) into A (degree of polymerization, DP6-12), B1 (DP13-24), B2 (DP25-36), and B3+ (DP37-65) chains. The average chain length of Kinuhikari, RU9601099 and CH-202 was longer than the other cultivars, which was ascribed to their greater proportions of B2 and B3+ chains. Studies have shown that elevated temperatures during the grain filling stage reduced amylose content but increased amylopectin long chains (Resurreccion et al., 1977; Asaoka et al., 1985; Counce et al., 2005; Cooper et al., 2008). Thus, the lower amylose content and the greater amylopectin average chain length of RU9601099 were proposed to result from its elevated growing temperature relative to other cultivars. Kinuhikari is grown in relatively southern part of Japan, which has a higher growing temperature than the regions of the other Japanese cultivars. Kinuhikari and CH-202 shared a similar and greater apparent amylose content and amylopectin average chain length, which can be attributed to their similar genetics and growing environments.

Cameron et al. (2008) demonstrated that two medium-grain cultivars from California (M202 and M204) had increased protein content, decreased amylose content and increased B2 chains when grown in Arkansas compared to when grown in California, indicating the importance of growing environment besides genetic background. Okuda et al. (2005) reported that the enzyme digestibility of cooked rice during sake brewing was affected by both amylose content and amylopectin structure. Rice cultivars with a lower amylose content and a greater proportion of amylopectin short-chains were more digestible, thus resulting more sugar production and greater alcohol fermentation. Kinuhikari and CH-202 had a greater amylose content but a lower proportion of A chains, which could produce less sugar during sake brewing.

Gelatinization, Pasting, and Textural Properties

Table 3 presents the gelatinization and pasting properties of rice flours and textural characteristics of cooked rice samples; their pasting profiles are shown in Figure 2. Kinuhikari and RU9601099 exhibited significantly greater gelatinization temperatures, followed by CH-202; the other Japanese cultivars displayed significantly lower gelatinization temperatures. Gelatinization temperatures and enthalpy were strongly negatively correlated with A and B1 chains, but positively correlated with B2 and B3+ chains. The greater gelatinization temperatures of Kinuhikari, RU9601099, and CH-202 can be explained by their greater proportions of amylopectin B2 and B3+ chains (Table 2), which could be partly due to their higher environmental temperatures compared with the other Japanese cultivars. Kinuhikari and RU961099 also differed from the other cultivars for their significantly greater gelatinization enthalpies. The greater proportions of B2 and B3+ chains in Kinuhikari and RU9601099 could contribute a greater extent of retrogradation, which is undesirable for sushi because it shortens sushi’s shelf life. The present results agree with Patindol et al. (2016), who reported that medium- and short-grain rice cultivars grown in Arkansas displayed higher gelatinization temperatures and enthalpies than those grown in California. Among the Japanese cultivars, Kinuhikari from the southern, warmer region, showed greater gelatinization temperatures than those from the northern regions. Although Koshihikari is one of the ancestral cultivars of Kinuhikari (Tabuchi et al., 2000), Kinuhikari and Koshihikari did not share similar gelatinization properties, suggesting that gelatinization properties may be influenced more by environmental factors than by genetic background.

For pasting characteristics, Kinuhikari and RU9601099 showed higher peak and trough viscosities, while Nanastuboshi displayed lower peak and breakdown viscosities. CH-202 was similar to most Japanese cultivars in pasting properties, and particularly CH-202, Koshihikari and Yumepirika shared a similar pasting profile. Chun et al. (2015), found that high ripening temperatures increased the peak, trough, and final viscosities due to reduced amylose and increased long amylopectin chains. Patindol et al. (2006) found that peak and breakdown viscosities were positively correlated with A chains and negatively correlated with amylose content. The present results, nevertheless, show that peak, trough and final viscosities were negatively correlated with A chains but positively correlated with B2 and B3 chains, and setback viscosity was positively correlated with amylose content and A chains, but negatively correlated with B2 and B3+ chains for short-grain rice samples.

For cooked rice textural attributes, including hardness and stickiness, RU9601099 and CH-202 were characterized by their lower hardness values than the Japanese cultivars with Hatsushimo displaying the highest hardness value. Hardness and stickiness of cooked rice are highly affected by its chemical composition, particularly protein and amylose. It has been demonstrated that amylose and protein were positively correlated with firmness but negatively correlated with stickiness of cooked rice (Cameron and Wang, 2005; Champagne et al., 2009; Mestres et al., 2011; Thanompolkrung et al., 2017). Hardness was found to be negatively correlated with peak and trough viscosity and B2 and B3+ chains, but positively correlated with setback viscosity, lipid content, B2 and B3+ chains and A/B1 ratio. RU9601099 had a high protein content but a low amylose and lipid content, whereas CH-202 had the opposite trend, which may explain their similar hardness. Kinuhikari, RU9601099, CH-202, and Yumepirika showed lower hardness compared to the other Japanese cultivars due to greater portion of longer (B2 and B3+) chains of amylopectin. The greater stickiness of Hatushimo and Nanatsuboshi could be influenced by their higher amylopectin A/B1 ratios because stickiness was negatively correlated with protein (r = -0.5855) and A/B1 ratio (r = -0.7072) but positively correlated with breakdown (r = 0.7399). Patindol et al. (2010) investigated23 U.S. long-grain rice cultivars and found that a negative correlation between A/B1 ratio and leached materials, which were emerged on cooked rice surface, thus cooked rice stickiness could be affected.

Statistical Analysis

Based on Principle Component (PC) analysis on correlations, a total of six PCs fully explained the variance for kernel appearance (Figure 3A). PC 1 (Eigenvalue = 3.72) and PC 2 (Eigenvalue = 2.14) accounted for 53.2% and 30.5%, respectively, of the total variation in kernel dimension and color. The most important component of PC 1 was L*/b* (r = -0.98), and that of PC 2 was L/W (r = 0.98). Overall, both Japanese and the U.S. cultivars were clustered dispersedly. PC 1 (Eigenvalue = 5.84) and PC 2 (Eigenvalue = 2.60) accounted for 58.7% and 25.9%, respectively of a total of six PCs fully explained chemical composition and amylopectin fine structure (Figure 3B). The most important component of PC 1 was B2 chain (r = 0.95), and that of PC 2 was protein content (r = 0.81). Yumepirika, Nanatsuboshi, and Hatsushimo were clustered together and loaded in the second quadrant. Kinuhikari and CH-202 were loaded in the fourth quadrant, while RU9601099 in the first quadrant and Koshihikari in third quadrant, separately. For gelatinization, pasting, and cooked rice properties, PC 1 (Eigen value = 7.65) and PC 2 (Eigen value = 1.73) accounted for 69.5% and 15.7%, respectively, by a total of six PCs (Figure 3C). The most important component of PC 1 was gelatinization enthalpy (r = 0.97), and that of PC 2 was breakdown viscosity (r = -0.85). Hatsushimo and Nanastuboshi were loaded close on the third quadrant, and Koshihikari and Yumepirika were clustered together on the second quadrant. Although CH-202, Kinuhikari, RU9601099 were loaded close to the x-axis, they displayed more dispersion than the other clusters.

The classification of seven rice cultivars according to similarities and differences by the Ward's hierarchical cluster analysis in shown in Figure 4. Japanese cultivars, except Kinuhikari, were categorized into the same cluster, and Nanatsuboshi and Yumepirika shared similar properties. CH-202 and Kinuhikari were categorized into the same cluster, indicating that Kinihukari was closer to CH-202 from California than to the other Japanese cultivars. Tabuchi et al. (2000) reported that Kinuhikari can be highly adapted to environmental conditions. Kinuhikari was developed by breeding with a Koshihikari paternal cultivar to be tolerant to lodging and rice blight (Uehara et al. 1999). In this study, Kinuhikari was grown in Shiga, that was located at the southern province in Japan, which could contribute to its differences from the other Japanese cultivars that were grown in the northern provinces, but more similar to CH-202. RU9601099 from Arkansas was distinctly different from both Japanese and California cultivars based on categorized to separated clusters. This result suggests that cultivars from the genetic background could display different properties because of different growing environments.

Conclusions

The results reveal the differences between rice cultivars grown in Japan and in the U. S. Both U.S. cultivars showed higher gelatinization temperatures, and lower cooked rice hardness; however, their chemical compositions varied greatly. In contrast, Japanese cultivars were grown in relatively similar environment, thus exhibiting more similar properties. Overall, CH-202 from California shared more similar physical, physicochemical and textural characteristics with Japanese cultivars, whereas RU9601099 was distinctly different from the other cultivars. The growing environment plays a significant role in rice physical and chemical characteristics, which then control physicochemical and textural properties. The development of new short-grain cultivars needs to consider both genetic and environmental factors in order to adapt to specific environment and markets.

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Table 1. Physical Characteristics of Seven Short-grain Rice Cultivars[1]

Cultivar Origin	Hatsuhimo Gifu, Japan	Kinuhikari Shiga, Japan	Koshihikari Nagano, Japan	Nanatsuboshi Hokkaido, Japan	Yumepirika Hokkaido, Japan	RU9601099 AR, USA	CH-202 CA, USA
Kernel Dimension							
Length (L, mm)	5.37a	4.88c	4.92c	4.94c	5.06b	4.95c	4.77d
Width (W) (mm)	2.86a	2.92a	2.87a	2.87a	2.91a	2.72b	2.87a
Thickness (mm)	2.06bc	2.05bc	2.05c	2.12a	2.11ab	2.03c	2.04c
L/W ratio	1.88a	1.67d	1.72cd	1.72cd	1.74c	1.82b	1.66d
Color							
Whiteness (L*)	72.49d	73.47b	72.69cd	71.22e	71.70e	77.09a	73.08bc
Yellowness (b*)	16.32bc	16.00c	15.23d	16.75ab	17.22a	16.09c	15.88c
L*/b*	4.44c	4.59bc	4.78a	4.26d	4.17d	4.80a	4.61b

[1] Means of duplicate measurements followed by a common letter within a column are not significantly different at $P<0.05$.

Table 2. Chemical Composition and Amylopectin Fine Structure of Seven Short-grain Rice Cultivars[1]

Cultivar	Hatsushimo	Kinuhikari	Koshihikari	Nanatsuboshi	Yumepirika	RU9601099	CH-202
Chemical Properties							
Apparent amylose content (%, db)	15.15a	14.70a	14.89a	13.58b	12.23c	11.90c	15.86a
Protein content (%, db)	6.84c	6.66c	5.64d	7.68b	7.38b	8.53a	5.2e
Lipid content (%, db)	0.46a	0.43ab	0.43a	0.44a	0.36b	0.31c	0.42ab
Ash content (%, db)	0.41bc	0.40bc	0.38c	0.44b	0.40bc	0.64a	0.40bc
Amylopectin Structure							
Average Chain Length	20.2b	20.9a	20.2b	20.3b	20.2b	20.9a	20.7a
A chain (DP[2]6-12) (%)	28.5a	26.9c	27.9abc	28.2ab	28.1ab	27.0c	27.4bc
B1 chains (DP13-24) (%)	46.5bc	46.4bc	47.5a	46.7b	47.0ab	46.0c	46.5bc
B2 chains (DP25-36) (%)	13.3c	13.8ab	13.2c	13.1c	13.2c	14.1a	13.5bc
B3+ chains (DP37-65) (%)	11.7b	12.9a	11.5b	12.0b	11.7b	13.0a	12.6a
A/B1 Ratio	0.61a	0.58b	0.59ab	0.60ab	0.60ab	0.59ab	0.59ab

[1] Means of duplicate measurements followed by a common letter within a column are not significantly different at $P<0.05$.

[2] DP: Degree of polymerization in glucose unit.

Table 3. Pasting and gelatinization Properties and Cooked Rice Texture of Seven Short-grain Rice Cultivars[1]

Cultivar	Hatsushimo	Kinuhikari	Koshihikari	Nanatsuboshi	Yumepirika	RU9601099	CH-202
Gelatinization Properties							
Onset temperature (℃)	63.0c	67.4a	61.4d	62.0d	60.7e	67.5a	65.2b
Peak temperature (℃)	68.5c	72.9a	68.0c	68.3c	68.5c	73.5a	71.7b
End temperature (℃)	74.7c	79.6b	74.3c	74.8c	75.5c	81.7a	78.8b
Enthalpy (J/g)	8.74c	10.88a	9.01bc	8.76c	9.39bc	10.72a	9.55b
Pasting Properties							
Peak viscosity (cP)	2903cd	3425a	3140b	2779d	3087bc	3398a	3111bc
Trough viscosity (cP)	1512b	1900a	1569b	1468b	1512b	1930a	1635b
Final viscosity (cP)	2700abc	2978a	2829ab	2543c	2614bc	2840ab	2827ab
Breakdown (cP)	1391bc	1526ab	1571a	1311c	1574a	1468ab	1476ab
Setback (cP)	-204a	-448b	-312a	-236a	-472b	-558b	-284a
Cooked Rice Texture							
Hardness (N)	84.9a	64.1c	73.2b	72.1b	65.9c	54.5d	54.6d
Stickiness (N)	3.8a	2.5cd	2.5cd	3.5ab	2.7cd	3.0bc	2.1d

[1] Means of duplicate measurements followed by a common letter within a column are not significantly different at $P<0.05$.

Hatsushimo **Kinuhikari** **Koshihikari** **Nanatsuboshi**

Yumepirika **RU9601099** **CH-202**

Figure 1. Milled rice kernels of seven short-grain rice cultivars Hatsuhimo (Gifu, Japan), Kinuhikari (Shiga, Japan), Koshihikari (Nagano, Japan), Nanatsuboshi (Hokkaido, Japan), Yumepirika (Hokkaido, Japan), RU9601099 (Arkansas, USA), and CH-202 (California, USA).

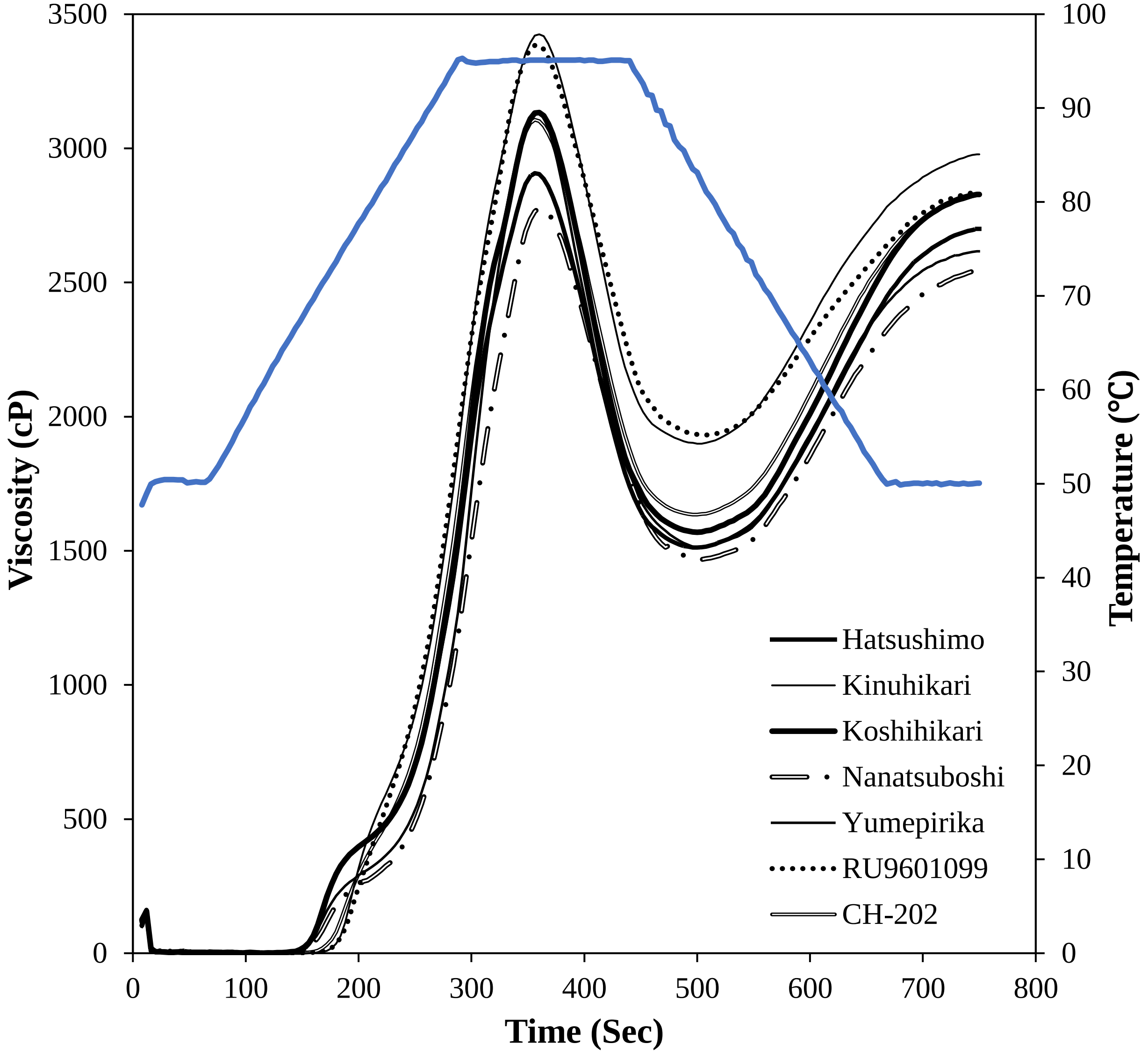

Figure 2. Pasting characteristics of seven short-grain rice cultivars obtained with a Rapid ViscoAnalyzer.

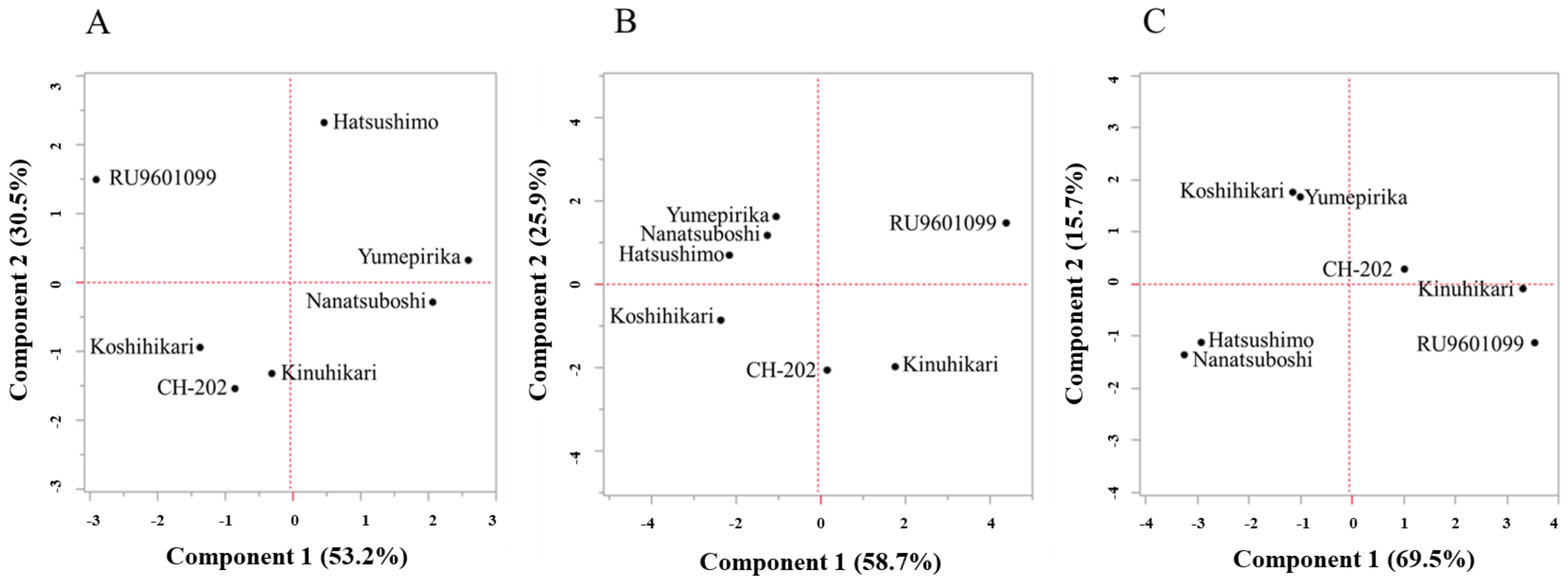

Figure 3. A similarity map of seven samples analyzed by principal component analysis of A) kernel appearance, B) chemical and amylopectin fine structure, and C) gelatinization, pasting, and cooked rice texture properties.

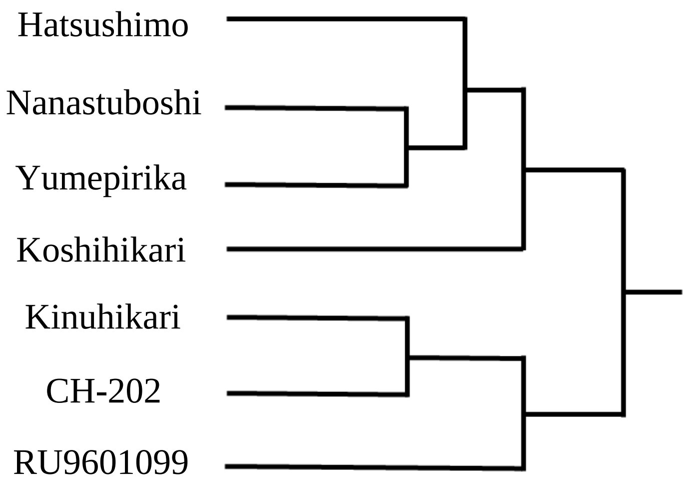

Figure 4. A dendrogram obtained from the Ward’s hierarchical cluster analysis of the kernel appearance, chemical composition, starch fine structure, pasting characteristics, and cooking properties of seven short-grain rice cultivars.