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Characterization of Short-grain Rice Cultivars Grown in Japan, California and Arkansas

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Cover Page Footnote
Michiyo Nishiwaki is an honors student in the Department of Food Science Eric Lii is a technical assistant in the Department of Food Science Andy Mauromoustakos, faculty sponsor, is a professor in the Department of Agricultural Statistical Laboratory Ya-Jane Wang, faculty mentor, is a professor in the Department of Food Science

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Meet the Student-Author

Michiyo Nishiwaki

I transferred to the University of Arkansas from Gakushuin University in Japan in 2016 Spring. The reason that I was interested in Food Science was that my family grew a short-grain rice cultivar in Japan and thought that learning this field in English could be exciting for me. Fortunately, I was given the chance to engage in research in May 2017. This research was awarded the 2nd prize at the 2018 Gamma Sigma Delta Poster Competition at the Univeristy of Arkansas. I also won 3rd place at the Bumpers Honors Student Board Poster Competition in April 2018.

During my time at the University of Arkansas, I was an active member in Gamma Beta Phi and Tau Sigma. I served for one year as an officer of the Japanese Student Association. As an international student, I have engaged in the International Cultural Team and played the violin for two years. During this summer, I am planning to do an internship in a food industry in California in Research & Development.

I would like to thank Dr. Wang for serving as a mentor and guiding me throughout this research. Without her, it would not have been completed successfully. Dr. Mauromoustakos supported this project with statistical knowledge. Eric Lii helped me conduct experiments in a lab.

Michiyo holding her second place award in the University of Arkansas Chapter Gamma Sigma Delta Honor Society of Agriculture's undergraduate poster presentation category.

Research at a Glance

- The research characterizes short-grain rice properties grown in Japanese, Arkansas, and California.
- The three short grain rice cultivars showed significantly different properties despite shared genetic background.
- The research demonstrates the effect of rice growing environments on the properties of rice.

Characterization of short-grain rice cultivars grown in Japan, California and Arkansas

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Abstract

Arkansas and California are the two leading rice-producing states in the U.S. Arkansas grows predominantly long- and medium-grain rice and California, primarily medium- and short-grain rice. Although short-grain rice accounts for less than 2% of U.S. rice production, the demand for short-grain rice is rising because of increasing popularity of sushi and sake. Short-grain rice may open new opportunities for rice farmers in Arkansas because of its premium price and different applications. The objective of this study was to characterize the physical, physicochemical and textural properties of rice cultivars grown in Arkansas versus in Japan and California. Three short-grain rice cultivars from the 2016 crop year were collected, including RU9601099 from Arkansas, CH-202 from California, and Koshihikari from Japan. The rice cultivars were characterized for kernel appearance, chemical composition, amylopectin chain-length distribution, and gelatinization, pasting and textural properties. Cultivar RU9601099 was found to have a smaller width and a greater length/width ratio and whiteness than the other cultivars; it was high in protein and ash contents, but low in amylose content. Cultivars RU9601099 and CH-202 shared a similar average chain-length of amylopectin. Cultivar RU9601099 had significantly greater gelatinization temperatures and enthalpy and peak and trough viscosities. When cooked, RU9601099 exhibited greater stickiness, whereas Koshihikari exhibited greater hardness. The results reveal significant differences in some properties among the three short-grain rice cultivars, although both RU9601099 and CH-202 are crosses of Koshihikari, and demonstrate the importance of environmental factors affecting rice properties.

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Introduction

Rice cultivars in the U.S. are characterized as long-, medium-, and short-grain according to grain dimensions. Long-grain rice is typically used for entrees and is dry and fluffy when cooked. Medium-grain rice is more moist and tender than long-grain rice, and typically used for risotto and sushi. Short-grain rice is soft, plump, and almost round, and mostly used in sushi, desserts or puddings. Short-grain rice is defined as such if the kernel length-to-width ratio is 1.9 to 1 (USDA, 2014). Short-grain rice is favored for sushi because the sticky and soft texture is important to Japanese preference for food. Short-grain rice is also used for alcohol production, such as sake, because of its large grain size that is suited for polishing to remove at least 40% of its weight for a cleaner flavor. Koshihikari from Japan has been recognized as a premium quality, short-grain cultivar because of its flavor and texture. The current short-grain rice cultivars in the United States are Koshihikari crosses. For example, cultivar RU9601099 from Arkansas is a cross of Koshihikari and Mars (Norman and Johnson, 1999) and CH-202 from California is derived from Koshihikari and Hitomebore (Andaya and McKenzie, 2014).

Although short-grain rice only accounts for 1-2% of total U.S. rice production and is exclusively grown in California, its demand is expected to continue growing because of the increasing sake brewing industry and international trade. If the quality of Arkansas short-grain rice is similar to those cultivars from Japan and California, the economic impacts of short-grain rice to Arkansas will be significant. This is because it is used in different markets than long- and medium-grain rice and it commands a premium price. 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, which are hypothesized to result in differences in chemical composition and starch fine structures. Therefore, the objective of this study was to compare the physical, chemical and textural properties of rice cultivars grown in Arkansas, California, and Japan to provide breeders information to develop suitable short-grain cultivars for Arkansas.

Materials and Methods

Three short-grain milled rice samples from the 2016 crop year, including one cultivar (Koshihikari) grown in Nagano prefecture, Japan and purchased in a grocery store in Japan, one cultivar (CH-202) grown in California and provided by Dr. Stanley Samonte of Texas A&M University and Dr. Kent McKenzie of California Cooperative Rice Research Foundation (Biggs, California), and one cultivar (RU9601099) grown in Arkansas and provided by Dr. Karen Moldenhauer of the University of Arkansas System Division of Agriculture's Arkansas Rice Research and Extension Center (Stuttgart, Arkansas), were used for this study.

Kernel Appearance

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

Chemical Composition

Milled rice flour samples were obtained by grinding head rice in a laboratory mill (Cyclone Sample Mill, Udy Corp., Ft. Collins, Colorado) 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, Minnesota) 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 Chain-length Distribution

Starch was debranched and analyzed according to Patindol and Wang (2002). The amylopectin chain-length distribution in the supernatant was analyzed by high performance anion-exchange chromatography with pulsed amperometric detection (HPAEC-PAD) analysis using a Dionex ICS-3000 ion chromatography system (Dionex Corporation, Sunnyvale, California) with an AS40 automated sampler, a 50-mm CarboPac PA1 guard column, and a 250-mm CarboPac PA1 analytical column. Amylopectin chains were divided into A chain (DP, degree of polymerization in glucose unit, 6-12), B1 chain (DP 13-24), B2 chain (DP 25-36), B3+ chain (DP 37-65) (Hanashiro et al., 1996).

Gelatinization Properties

The gelatinization properties of milled rice flour were determined using a differential scanning calorimeter (DSC; Pyris Diamond, Perkin Elmer Instruments, Shelton, Connecticut). 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 a 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 Properties

The pasting properties of milled rice flour were characterized using a Rapid ViscoAnalyser (RVA; Model 4, Perten Instruments, Springfield, Illinois) according to AACC Method 61-02.01. The pasting properties measured included peak viscosity, hot paste viscosity (trough), final viscosity, breakdown, setback, and total setback. Paste breakdown was calculated as peak viscosity minus trough viscosity, setback as final viscosity minus peak viscosity, and total setback as final viscosity minus trough viscosity.

Cooked Rice Texture

The cooked rice texture was 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, California, U.S.) containing 350 mL of water for 30 min, and cooked rice was kept at a 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, New York, U.S.). 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 sample, and two cooked samples were prepared for each rice cultivar.

Results and Discussion

Kernel Appearance

Cultivars Koshihikari and RU9601099 shared a similar kernel length, whereas CH-202 was shorter (Table 1).

Table 1. Physical properties, chemical composition and amylopectin chain-length distribution of three short-grain rice cultivars†

	Koshihikari Nagano, Japan	RU9601099 Arkansas, U.S.	CH-202 California, U.S.
Physical properties			
Length (L) (mm)	4.92 a	4.95 a	4.77 b
Width (W) (mm)	2.87 a	2.72 b	2.87 a
Thickness (mm)	2.05 a	2.03 a	2.04 a
L/W ratio	1.72 b	1.82 a	1.67 c
Whiteness (L*)	72.69 b	77.09 a	73.08 b
Yellowness (b*)	15.23 b	16.09 a	15.88 a
Chemical compositions			
Amylose (%, db)	14.89 a	11.90 b	15.68 a
Protein (%, db)	5.65 b	8.53 a	5.20 c
Lipid (%, db)	0.43 a	0.31 b	0.42 a
Ash (%, db)	0.38 b	0.64 a	0.40 b
Amylopectin Chain-Length Distribution			
Average Chain Length	20.2 c	20.9 a	20.7 b
A (DP 6-12) (%)	27.9 a	27.0 c	27.4 b
B1 (DP 13-24) (%)	47.5 a	46.0 c	46.5 b
B2 (DP 25-36) (%)	13.2 c	14.1 a	13.5 b
B3+ (DP 37-65) (%)	11.5 c	13.0 a	12.6 b

† Means of duplicate measurements followed by a common letter across a row are not significantly different at $P < 0.05$.

Fig. 1. Milled rice kernels of three short-grain rice cultivars Koshihikari (Japan), RU9601099 (Arkansas), and CH-202 (California).

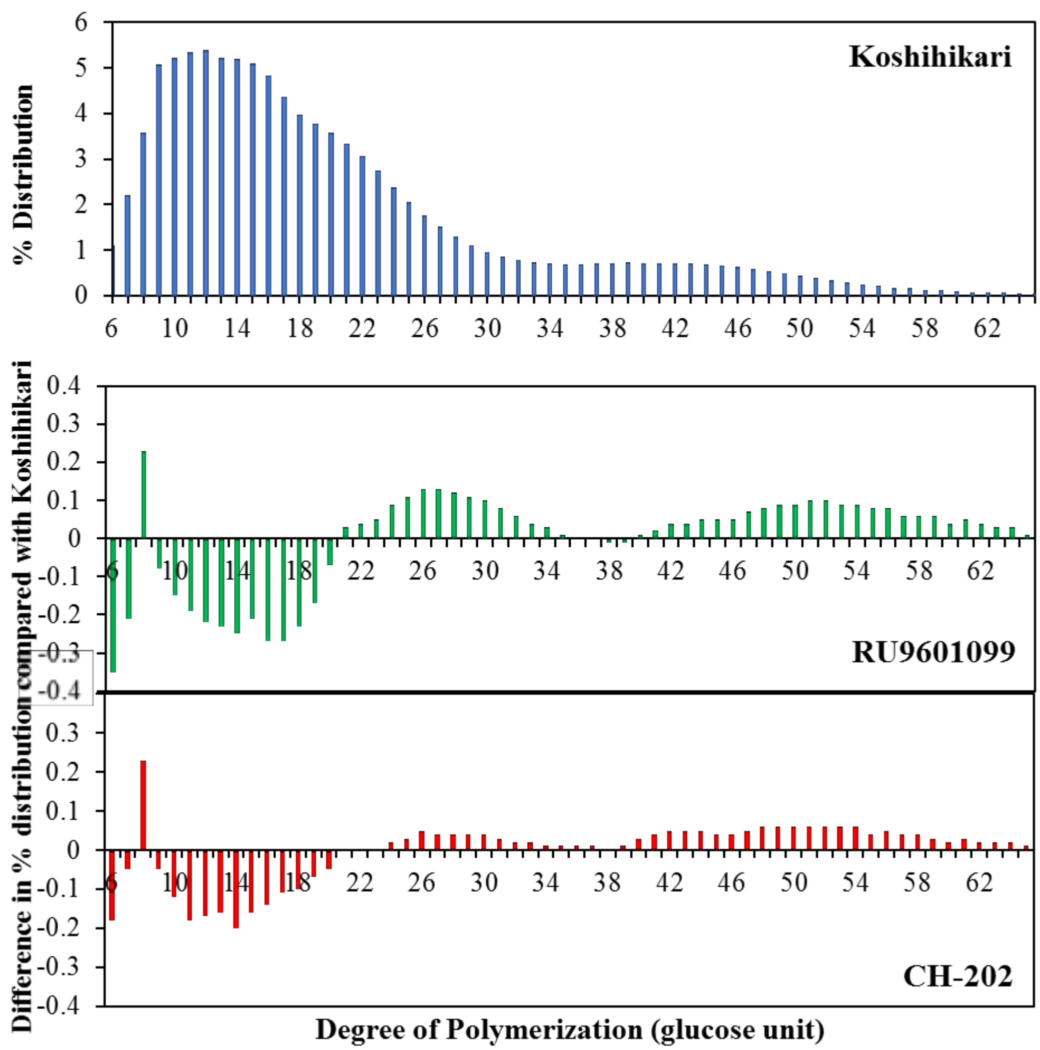

Fig. 2. Amylopectin chain-length distribution of the control short-grain rice cultivar, Koshihikari, and the differences in the percentage distribution of amylopectin chains between the control cultivar and short-grain rice cultivars RU9601099 or CH-202.

Koshihikari and CH-202 were similar in kernel width, whereas RU9601099 was slightly narrower in width. All three cultivars had a similar thickness value. Cultivar RU9601099 appeared less rounded in shape than Koshihikari and CH-202 according to L/W ratio. Cultivar RU9601099 was significantly greater in whiteness (L*) and yellowness (b*) than Koshihikari. The presence of chalkiness in RU9601099 (Fig. 1) was presumed to be responsible for its greater whiteness. Overall, RU961099 differed more in terms of kernel appearance from Koshihikari than CH-202. The less rounded shape of RU9601099 suggests that RU9601099 is not as suitable for sake application as CH-202.

Chemical Composition and Amylopectin Chain-length Distribution

Cultivars Koshihikari and CH-202 had similar amylose, lipid, and ash contents; RU9601099 was low in amylose and lipid contents but high in protein and ash contents (Table 1). The greater protein and ash contents in RU9601099 were proposed to be responsible for its greater yellowness (Wang at al., 2014). Cultivars RU9601099 and CH-202 had longer average amylopectin chains than Koshihikari, which was ascribed to their greater proportions of B2 and B3+ chains as illustrated by the differential plots (Fig. 2). Compared with Koshihikari, RU9601099 and CH-202 consisted of a lesser proportion of DP 6-20 and a greater proportion of DP 21-65. Furthermore, the difference in chain length distribution was less in CH-202 and greater in RU9601099, indicating CH-202 was more similar to Koshihikari in amylopectin structure. It has been shown that growing temperature affects rice amylose content and amylopectin chains. Elevated temperatures reduced amylose content but increased amylopectin long chains (Resurreccion et al., 1977; Asaoka et al., 1985; Patindol et al., 2014); whereas low temperatures supported amylose biosynthesis in the endosperm during grain ripening (Umemoto et al., 1995). Cameron et al. (2008) compared medium-grain rice cultivars grown in Arkansas and in California and found that Arkansas cultivars had higher protein contents but lower amylose contents, and their differences diminished when California cultivars were grown in Arkansas. Sushi rice with a low protein is usually preferred by the Japanese as a cleaner flavor, thus RU9601099 may not be as desirable as CH-202 for sushi application.

Gelatinization, Pasting, and Textural Properties

Cultivar RU9601099 had the highest gelatinization temperatures, followed by CH-202, and Koshihikari had the lowest (Table 2). The higher gelatinization temperatures of RU9601099 and CH-202 were attributed to their greater proportions of B2 and B3+ starch chains and a greater average chain length. It has been established that

Table 2. Gelatinization, pasting and textural properties of three short-grain rice cultivars.†

	Koshihikari	RU9601099	CH-202
Gelatinization Properties			
Onset (°C)	61.4 c	67.5 a	65.2 b
Peak (°C)	68.0 c	73.5 a	71.7 b
End (°C)	74.3 c	81.7 a	78.8 b
Enthalpy (J/g)	9.01 b	10.72 a	9.55 b
Pasting Properties			
Peak viscosity (cP)	3140 b	3398 a	3111 b
Trough viscosity (cP)‡	1569 b	1930 a	1635 b
Final viscosity (cP)	2829 a	2840 a	2827 a
Breakdown (cP)[b]	1571 a	1468 a	1476 a
Setback (cP)[b]	-312 a	-558 b	-284 a
Cooked Rice Texture			
Hardness (N)	73.2 a	54.6 b	54.6 b
Stickiness (N)	2.5 ab	3.0 a	2.1 b

† Means of duplicate measurements followed by a common letter across a row are not significantly different at $P < 0.05$.

‡ Trough viscosity = minimum viscosity achieved after holding at the maximum temperature; Breakdown = peak - trough; setback = final – peak.

starch gelatinization temperatures and enthalpy increase with elevating ripening temperature (Chun et al., 2015) and nighttime air temperature (Lanning et al., 2012; Patindol et al., 2014; Wang et al., 2014). The nighttime air temperature is higher in Arkansas, followed by California and then Nagano, Japan, which may explain their differences in their starch composition and structure and consequently gelatinization properties. The high gelatinization temperatures of RU9601099 and CH-202 relative to Koshihikari indicate that a higher temperature is required to cook them, thus the cooked rice texture would be affected.

Pasting properties of rice flour are strongly correlated with quality and stability of rice products. Peak viscosity is the maximum viscosity developed during heating; whereas trough viscosity is the minimum viscosity achieved after holding at the maximum temperature. Breakdown viscosity is the difference between peak and trough viscosities and an index of the stability of starch. It was reported that rice cultivar with the greatest breakdown viscosity was the most palatable (Tren et al., 2001). Setback viscosity is the final viscosity minus the peak viscosity and indicates the tendency of starch to retrograde during cooking. Cultivars Koshihikari and CH-202 exhibited similar pasting profiles (Fig. 3), except that Koshihikari had a lower pasting temperature; RU9601099 displayed higher peak and trough viscosities (Table 2), which were due to its lower amylose content and higher protein content. Amylose content was reported to be negatively correlated with peak, final, and breakdown viscosity, but positively correlated with setback viscosity (Patindol et al., 2014). Besides amylose content, peak viscosity was negatively impacted by protein content (Wang et al., 2014). Therefore, the combination of higher protein and lower amylose contents resulted in a higher peak viscosity but comparable breakdown viscosity of RU9601099 compared with Koshihikari and CH-202. The similar pasting properties of CH-202 and Koshihikari suggest they may share similar sensory attributes.

In terms of cooked rice texture, Koshihikari showed significantly greater hardness, whereas RU9601099 showed greater stickiness. Cooked rice texture is strongly linked to chemical characteristics. Amylose and protein contents were positively correlated with cooked rice firmness, but negatively correlated with cooked rice stickiness; gelatinization temperature was positively correlated with firmness of core (Mestres et al., 2011). The greater stickiness of RU960199 was attributed its low amylose content, and the greater hardness of Koshihikari was proposed to be due to its high amylose content and low gelatinization temperatures that resulted in more leached amylose to increase cooked rice hardness (Ong and Blanshard, 1995). Although CH-202 also had a high amylose content as Koshihikari, its high gelatinization temperatures may limit the amount of leached amylose,

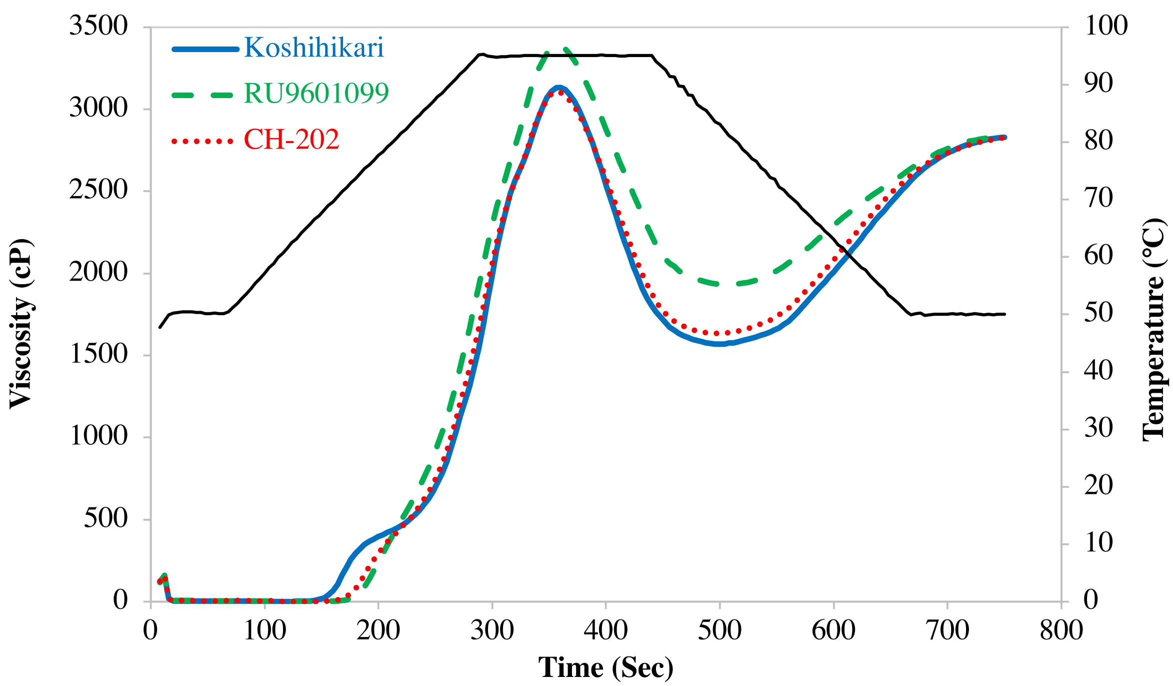

Fig. 3. Pasting profiles of short-grain rice cultivars Koshihikari, RU9601099, and CH-202 with a Rapid ViscoAnalyser.

thus reducing cooked rice hardness. The cooked rice texture results indicate that RU9601099 and CH-202 are soft and not as firm as Koshihikari when cooked and have a different texture compared with Koshihikari.

Conclusions

The results from this study revealed differences among the three cultivars, despite both RU9601099 and CH-202 being crosses of Koshihikari, and CH-202 having more similar properties to Koshihikari. It is proposed that the growing environment affects rice physical and chemical characteristics, which then alter physicochemical and textural properties. Therefore, rice quality depends on not only the genetic background but also the growth environment, and the development of new cultivars needs to take both factors into consideration.

Acknowledgements

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