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Characterization of Jasmine Rice Cultivars Grown in the United States

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ABSTRACT

Jasmine rice from Thailand accounts for about 60-70% of U.S. imported rice, primarily due to its preference by ethnic Asians as well as general American population. Recently new U.S. jasmine rice cultivars have been developed independently at three rice research stations in Arkansas, California, and Louisiana, but their properties have not been characterized. The objective of this research was to characterize and compare the physical appearance, chemical composition, thermal and pasting properties, cooked rice texture and starch structures of the newly-developed U.S. jasmine rice from Arkansas, California and Louisiana, to be compared with jasmine rice samples from Thailand. In general, the U.S. varieties had smaller length/width ratios, darker color, and greater ash and lipid contents than the Thai controls. The Arkansas samples were similar to each other as well as one Louisiana sample, CLJ01 2017, and the other Louisiana samples were similar to each other, but rice of both origins were different from Thai jasmine. Calaroma-201 was found to be the most similar to the Thai jasmine rice out of the U.S. varieties from Ward's hierarchical cluster analysis of all attributes. These findings can help the U.S. rice industry to develop U.S. jasmine rice cultivars closer to Thai jasmine rice.

Keywords: jasmine rice, kernel dimension, 2-acetyl-1-pyrroline; cooked rice texture

INTRODUCTION AND LITERATURE REVIEW

Rice (*Oryza sativa L.*) is the staple food of almost half of the world's population. While the U.S. accounts for only about 2% of global rice production, it exports more than 6% of global exports (USDA Economic Research Service). Arkansas is the leading rice producing state, accounting for about 50% of U.S. rice production, followed by California, Louisiana, Missouri, Texas, and Mississippi. Because of marked increases in Asian and Hispanic populations, U.S. rice imports have increased over the past 30 years, and aromatic rice accounts for about 90% of U.S. rice imports (Suwannaporn and Linnemann, 2008a). Most rice imports are aromatic varieties from Asia, i.e. jasmine from Thailand and basmati from India and Pakistan, and they are consumed by ethnic Asians and increasingly appreciated by the general American population. Thailand alone accounts for 60-70% of total U.S. imported rice. The demand for aromatic rice is expected to continue increasing in both domestic and international markets (Sakthivel et al., 2009).

Unlike most cereals, rice is usually consumed as whole kernels; therefore, the sensory attributes of rice become even more important (Champagne, 2008). Aromatic rices have characteristic taste, aroma, appearance, and texture that make them desirable when compared with other nonaromatic varieties. Although aroma is considered as one of the most important characteristics of aromatic rice when consumer acceptance is considered, Suwannaporn and Linnemann (2008a) found that rice aroma was not a decisive quality attribute for some consumers, especially for those from non-rice-eating countries and some Asians. Eating quality attributes of hardness and stickiness were also important factors in discriminating consumer preference in each country investigated.

Consumers are becoming more and more concerned about rice quality, and various factors influence on consumer perception of quality. In a study by Suwannaporn and Linnemann (2008b) on consumer preferences, attitudes, and buying criteria toward jasmine, country of origin was frequently mentioned as an important criterion in buying rice when participants from rice-eating countries were surveyed. This was a distinguishing factor between those from rice-eating countries and those who were not from rice-eating countries. Consumers from non-rice-eating countries had little knowledge about rice varieties. Currently, there are links in preferences and countries of origin in certain grain types such as Jasmine rice with Thailand. A total 51.3% of the respondents in the previously mentioned study preferred jasmine rice from Thailand.

Suwansri et al. (2002) evaluated three U.S. and 12 imported commercial jasmine rice varieties from Thailand by a trained sensory panel and by 105 Asian families who lived in the State of Arkansas. They found that Asian consumers preferred imported Jasmine rice more than the domestic products, and the sensory characteristics most important to the acceptance of cooked Jasmine rice were color, followed by flavor, aroma, stickiness, and hardness. Suwansri et al. (2004) further investigated the physicochemical properties of the same 15 jasmine rice varieties and found that the U.S. jasmine rice samples were associated with high amylose, high surface lipid, and high protein contents, resulting in cooked rice of harder texture, darker color, and inferior flavor. These qualities are influenced by the chemical properties inherent in the rice and can be modified through changes in rice breeding.

Recently, several jasmine rice cultivars have been released from different states, such as ARoma17 from the University of Arkansas System Division of Agriculture; CLJ01, a new Clearfield jasmine variety from Louisiana State University AgCenter which has previously released Jazzman; and Calaroma-201 from California Rice Experiment Station. There has been no study comparing jasmine rice cultivars grown in the U.S. against Thai jasmine. Therefore, the objective of this study was to characterize and compare the physiochemical properties and sensory attributes of these three newly released jasmine rice cultivars (from AR, CA, and LA) to be compared with two commercial Thai jasmine samples.

MATERIALS AND METHODS

Materials. Nine jasmine rice samples were used for this study, including seven from the United States and two from Thailand. The U.S. cultivars included ARoma17 from 2017 and RU1701105 from 2018 which were grown in Stuttgart, Arkansas, provided by Dr. Karen Moldenhauer of the University of Arkansas Rice Research & Extension Center (Stuttgart, Arkansas); Calaroma-201 from California from 2018 and grown in Richvale, CA, Butte County provided by Dr. Kent McKenzie of the California Rice Experiment Station, California Cooperative Rice Research Foundation, Inc. (Biggs, California); CLJ01 and Jazzman from both 2017 and 2018 crop years from Louisiana and grown in Crowley, LA provided by Dr. Adam Famoso of the Louisiana State University Agricultural Center, H. Rouse Caffey Rice Research Station, (Rayne, Louisiana). The two Thai jasmine rice samples were commercial products, Golden Phoenix purchased in Bangkok, Thailand, and Three Ladies Brand HOM MALI 105 purchased in Springdale, AR in 2018. All the jasmine rice cultivars grown in the U.S. were produced under continuous flooding conditions.

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

Chemical Composition. Milled rice flour samples were obtained by grinding head rice with 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), and mineral content by a dry-ashing method (AACC method 08-03). Duplicate measurements were conducted for each flour sample. Starch samples were extracted from milled rice flour with dilute alkali (0.1% NaOH), followed by lipid removal with water-saturated n-butyl alcohol (Patindol and Wang, 2002).

2-AP and Hexanal Analysis. Samples were analyzed for levels of 2-acetyl-1-pyrroline (Santa Cruz Biotechnology, Dallas, TX) and Hexanal (Sigma-Aldrich, St. Louis, MO) through Solid phase micro-extraction (SPME). The solid phase microextraction (SPME) fiber used in this analysis was a 1-cm 50/30, Carboxen/DVB/PDMS, Manual Supelco (Bellefonte, PA). A solution of 2 ppm 2,4,6-trimethylpyridine (TMP) (Sigma-Aldrich, St. Louis, MO) in 0.5% Tween 80® (Sigma-Aldrich, St. Louis, MO) was used as an internal standard. Vials with screw top lids with PTFE septa (15x45 mm) containing 1 g of milled rice, 75 µL deionized water, and 5 µL of internal standard samples were placed in a heating block at 80°C for 25 min. After preheating, the SPME fiber was inserted into the headspace above the sample and adsorption was timed for 15 min. Hexanal (Sigma-Aldrich, St. Louis, MO) and 2-acetyl-1-pyrroline (Santa Cruz Biotechnology, Dallas, TX) were quantified by performing linear regression from reference standards. The standards were dispersed in a 0.5% Tween 80® solution, and all further dilutions were also dispersed in a 0.5% Tween 80® solution. One mL of standard solution was placed in screw capped vials and the heating and adsorption was performed in the same manner as the samples. The 0.5%

Tween 80® solution was used instead of solvents since the solvents saturate the SPME fiber. The tween solution, when mixed thoroughly, allows for linear response with dilutions.

Characterization of amylopectin structure. The chain-length distribution of amylopectin was determined by high-performance anion-exchange chromatography with pulsed amperometic detection (HPAEC-PAD) according to Kasemsuwan et al (1995) 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.

Gelatinization properties. Milled rice flour gelatinization properties were determined with a differential scanning calorimeter (DSC; Pyris Diamond, Perkin Elmer Instruments, Shelton, CT). Approximately 4 mg of rice flour were weighed into an aluminum pan and added with 8 µL of deionized water. The pan was hermetically sealed and equilibrated at room temperature for 1 hour 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 will be used as a reference. Onset, peak, and conclusion gelatinization temperatures (T_o , T_p , and T_c , respectively), and gelatinization enthalpy were calculated from each thermogram using the Pyris software.

Pasting characteristics. Flour pasting properties were determined using a Rapid ViscoAnalyser (RVA; Model 4, Perten Instruments, Springfield, IL). 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 5°C/min, held at 95°C for 5 min, cooled to 50°C at 5°C/min, and held at 50°C for 5 min. The pasting properties measured include peak viscosity, hot paste viscosity (trough), final viscosity, breakdown, setback, and total setback. Paste breakdown is calculated as peak viscosity minus trough; setback as final viscosity minus peak viscosity; total setback as final viscosity minus trough.

Cooked rice texture. Rice was cooked and evaluated following a modified method of Sesmat and Meullenet (2001). Rice (10 g) was placed in a 100-mL beaker with 15 g of deionized water, steamed in a rice cooker (National, model SR-W10FN) for 30 min, and set on warm for 5 min. 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 texture analyzer (TA.XT Plus Texture Analyzer, Texture Technologies, Hamilton, MA). The test was performed with a large flat plate (100-mm dia.) under the TPA test mode. The maximum compression force (peak force, g) and adhesiveness (area of negative force, g·s) were recorded as cooked rice hardness and stickiness, respectively. Six replications were performed for each cooked sample, and two cooked samples were prepared for each rice sample.

Statistical Analysis. This study used a comparative, non-experimental quantitative design. 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. Ward's hierarchical cluster analysis was used to classify nine rice cultivars according to similarities and differences in physical, chemical, gelatinization, pasting, and textural characteristics.

RESULTS AND DISCUSSION

Kernel Appearance. Jasmine rice has a strong popcorn-like aroma and translucent slender kernels and a soft cooked texture. Calaroma-201 shared a similar kernel length with the two Thai jasmine rice samples (Golden Phoenix and 3 Ladies HOM MALI), which were significantly greater than the others (Table 1), followed by Jazzman 2017, ARoma17, and RU1701105. Apart from Jazzman 2017, the Louisiana cultivars were significantly shorter than the other cultivars, with CLJ01 2018 being the shortest. In terms of kernel width, RU1701105 was significantly wider than the others, whereas Calaroma-201 had a much smaller kernel width. The kernel thickness exhibited less variation with Arkansas cultivars slightly thicker than Golden Phoenix. For kernel color, both commercial Thai jasmine rice samples had the highest lightness ($L*$) values, followed by Calaroma-201; whereas ARoma17 and Jazzman 2017 had the lowest lightness values. Calaroma-201 was significantly lower in yellowness ($b*$) than the other cultivars.

The Federal Grain Inspection Service (FGIS) of the United States Department of Agriculture classifies milled rice with kernels having a length-to-width ratio (L/W) of greater than 3 as a long-grain type, and 2.0-2.9 as a medium-grain type (USDA, 2014). The length to width ratio (L/W) of RU1701105 was 2.63, which was significantly smaller than the other cultivars and classified as a medium-grain type. In contrast, the two Thai rice samples and Calaroma-201 had significantly greater length-to-width ratios. In a study by Bett-Garber et. al. (2017) comparing U.S. basmati and jasmine rice varieties, the jasmine control had a L/W ratio of 3.33, which is similar to the Thai controls in this study. Genetics strongly influences rice kernel dimensions. McKenzie and Rutger (1983) evaluated inheritance and interrelationships in rice of amylose content, alkali spreading score, and grain dimensions of six crosses each involving a low amylose medium-grain parental line and found kernel length and width appeared to be governed by quantitative genes. Based on the kernel dimension and color, Calaroma-201 was most similar to Thai jasmine.

Chemical Composition. The chemical composition varied greatly among the jasmine rice samples in this study. RU1701105 had the highest protein content, 1.8 percentage point greater than the next highest one CLJ01 2017 (Table 2), while Calaroma-201 and Jazzman 2018 had the lowest protein contents. RU1701105 and Calaroma-201 had the highest amylose contents, while CLJ01 2018 had the lowest amylose content. ARoma17 and 2017-RU1701105 had the highest lipid contents, while the two Thai jasmine samples had the lowest. Jazzman 2018 had a significantly lower lipid content than Jazzman 2017, while CLJ01 2018 and CLJ01 2017 were similar to each other, indicating cultivar and crop year interaction. RU1701105 had the highest ash content, followed by ARoma17, and the two Thai jasmine rice samples had the lowest ash contents. The two Arkansas cultivars generally had higher protein, lipid and ash contents, whereas the two jasmine rice samples had lower lipid and ash contents. Out of all chemical characteristics, Jazzman 2018 seems the closest to the Thai varieties due to its relative similarity in 3 out of 4 chemical attributes.

The Thai jasmine samples were commercial samples, which were likely milled differently, e.g. to a greater extent, compared with the U.S. grown rice cultivars that were milled in the laboratory, thus resulting in lower protein, lipid, and ash contents, which could account for their lighter color (higher L^*). The higher b^* values (yellowness) of ARoma17, RU1701105, and CLJ01 2017 could be attributed to their greater protein contents (Wang et al., 2014). Calaroma-201 had the lowest protein content and exhibited the lowest b^* value among all the cultivars. Suwansri and Meullenet (2004) reported that domestic U.S. jasmine rice samples were less preferred than the imported samples from Thailand because of their high surface lipid and protein contents and darker appearance.

2-Acetyl-l-pyrroline and Hexanal. Jasmine rice has a distinctive and characteristic popcorn-like aroma. Buttery and Ling (1982) identified and determined the concentration of 2-acetyl-l-pyrroline (2-AP) as an important compound contributing to a popcorn-like aroma in several Asian fragrant rice varieties, including jasmine and basmati rice. This compound is present in all rice but is found in significantly higher levels in these aromatic varieties (Buttery, et. al., 1983). Calaroma-201 had the highest level of 2-AP, followed by CLJ01 2017, while the two Thai samples had significant lower levels of 2-AP. The greatest amount of 2-AP in Calaroma-201 could be attributed to its genetic makeup, as certain alleles have been isolated to account for this compound which Calaroma-201 may possess (Niu and Huang, 2008). Although the exact crop year of both Thai samples were unknown, it is speculated that their low 2-AP contents could be due to storage conditions and/or duration. The 2-AP content varied by crop year as shown by the cultivars of CLJ01 and Jazzman from crop year 2017 vs. 2018. It appears that for CLJ01 and Jazzman, the 2017 crops contained a greater amount of 2-AP, despite the age of the 2017 samples. 2-AP has also been shown to be influenced by the growth temperature. Itani et al. (2004) found that the 2-AP concentration was higher in brown rice ripened at a low temperature (day 25°C/night 20°C) than that ripened at a high temperature (day 35°C/night 30°C) in both a short-grain aromatic cultivar 'Hieri' and a long-grain aromatic cultivar 'Sari Queen'.

Hexanal content is directly related to oxidative off-flavors and is easily recognized because of its low odor threshold (5 ng/g) in rice (Buttery, Turnbaugh and Ling, 1988). CLJ01 2017 had significantly higher levels of hexanal than the other varieties (Table 3), followed by the two Thai samples, and RU1701105 had the lowest concentration of hexanal. CLJ01 2017 and Jazzman 2017 had higher levels of hexanal than their respective 2018 counterparts, implying the association of high hexanal content and storage duration. The high hexanal content in the two Thai samples supports the speculation that they may have been stored for a long period of time. None of the other varieties are alike to the Thai varieties in both hexanal and 2-AP content.

Chain-length Distribution of Amylopectin. All jasmine rice samples were similar in their percentage of amylopectin A chains (DP 6-12) when amylopectin chain-length distribution was characterized by HPAEC-PAD (Table 4). ARoma17 and CLJ01 2017 comprised a slightly greater proportion of B1 (DP 13-24) chains; RU1701105 consisted a smaller proportion of B2 (DP 25-36) chains; Golden Phoenix, 3 Ladies HOM MALI, 2017-RU1701105, CLJ01 2018, Jazzman 2018 and Jazzman 2017 are similar in their greater proportion of B3+ (DP37-65) chains. Golden Phoenix, 3 Ladies HOM MALI, CLJ01 2018 and Jazzman 2017 had the greatest proportions of B2 and B3+ chains. CLJ01 2018 had the longest average chain length, which can be ascribed to its greater proportion of B2 and B3+ chains. The 3 Ladies HOM MALI, ARoma17, RU1701105, Calaroma-201, and CLJ01 2017 had shorter average chain lengths, which can be attributed to their smaller proportion of B2 and B3+ chains. Jazzman 2018 and Jazzman 2017 were most similar to the Thai varieties in average chain length.

Gelatinization Properties. Overall, Jazzman 2018 and Jazzman 2017 exhibited higher gelatinization temperatures, whereas Calaroma-201 displayed lower gelatinization temperatures (Table 5). It has been shown that elevated growing temperature is associated with reduced amylose content and increased amylopectin long chains, which result in higher gelatinization temperatures (Patindol et al., 2014; Asaoka, Okuno, and Fuwa, 1985). Jazzman has the highest gelatinization temperatures, which could be ascribed to its greatest average amylopectin chain length. Calaroma-201 and CLJ01 2017 had lower gelatinization temperatures, which could be explained by their shorter average amylopectin chain length. The high gelatinization temperatures of Jazzman suggest that a higher temperature is required to cook the rice, so cooked rice texture could be affected. Because the U.S. jasmine rice cultivars were grown in different regions, with temperatures highest in Louisiana, followed by Arkansas and then California, their gelatinization temperatures reflect their respective growth temperatures, higher growth temperatures resulting in higher gelatinization temperatures. Crop year could also be a contributing factor affecting gelatinization temperatures as demonstrated by Jazzman 2018 and CLJ01 2018 both having higher gelatinization temperatures than the 2017 crop year, which corresponded to shorter average chain lengths in the 2017 crop years. The Thai varieties had mid-range gelatinization temperatures. RU1701105 most closely matched the gelatinization temperatures of the Thai varieties.

Pasting Properties. Jazzman 2018 exhibited the highest peak and breakdown viscosities, but the lowest setback and total setback viscosities (Table 6). CLJ01 2017 displayed the lowest peak viscosity, the smallest breakdown, and higher final, setback and total setback viscosities. The two Thai jasmine samples differed significantly from each other in peak, breakdown, final, setback, and total setback viscosities. ARoma17 had significantly greater peak and breakdown viscosities than RU1701105 but lower final, setback, and total setback viscosities than RU1701105. Both Arkansas cultivars had significantly lower peak and trough viscosities than the Thai controls. Calaroma-201 was similar to ARoma17 in pasting except for a lower final viscosity, which was similar to that of Jazzman 2018. The U.S. variety most similar to the Thai jasmine in pasting properties was CLJ01 2018.

The pasting properties of rice flour are affected by its chemical composition, including protein and lipid contents and by starch composition and structures. Amylopectin content contributes to swelling of starch granules and pasting, whereas amylose and lipids inhibit the swelling (Tester and Morrison 1990). Protein content may negatively impact peak viscosity (Wang et al., 2014), and protein-starch interactions may also affect viscosity (Hamaker and Griffin, 1990). Amylose content has been reported to negatively correlate with peak, final, and breakdown viscosity, but positively correlate with setback viscosity (Patindol et al., 2014), which indicates the tendency of starch to retrograde during cooking. An increase in amylose contents, along increase in lipids and phospholipids, can significantly increase starch pasting temperature, decrease peak viscosity and shear thinning, and increase setback viscosity (Jane et al., 1999). The lower peak and breakdown viscosities, and greater final, setback and total setback viscosities of RU1701105 and CLJ01 2017 were attributed to their higher protein and amylose contents. In contrast, the higher peak and breakdown viscosities and lower setback and total setback of Jazzman 2018 were proposed to be due to its low protein and amylose contents. The high amylose contents of RU1701105 and Calaroma-201 were correlated with lower pasting viscosities. ARoma17 and RU1701105 had high lipid contents and showed lower overall pasting viscosities.

Cooked Rice Texture. When cooked, RU1701105 had greater hardness but lower stickiness compared with most other samples (Table 7). Jazzman 2018 and Calaroma-201 were slightly stickier than the other samples. In a previous study, rice high in amylose and protein contents were found to have increased cooked rice hardness but reduced stickiness, and gelatinization temperature was positively correlated with cooked rice hardness. (Mestres et al., 2011). RU1701105 had the greatest hardness value and was the least sticky, which is attributed to its high amylose and protein contents. Calaroma-201 and Jazzman 2018 had greater stickiness values, which can be attributed to their low protein contents. For the Louisiana samples, hardness and stickiness were not significantly different between the 2017 and 2018 crop years. The CLJ01 2018 had the hardness and stickiness which was closest to that of the Thai varieties.

Statistical Analysis. Three clusters were found among the nine rice samples based on all data according to similarities and differences by the Ward's hierarchical cluster analysis (Figure 2): Cluster 1 of ARoma17, RU1701105, and CLJ01 2017, Cluster 2 of Golden Phoenix, 3 Ladies HOM MALI, Calaroma-201, and Cluster 3 of Jazzman 2018, Jazzman 2017, CLJ01 2018. Calaroma-201 was most similar to the Thai jasmine rice among the U.S. jasmine cultivars. The Arkansas cultivars were more similar to each other and CLJ01 2017, while the Louisiana cultivars were more similar to each other as well. Cluster 3 of Louisiana cultivars were more similar to the Thai jasmine than Cluster 1 of Arkansas cultivars. Thai and Calaroma-201 rices had greater L/W ratio and lightness, and they were lower in ash contents, lipid contents, and gelatinization temperatures than the other rices.

CONCLUSIONS

Based on the kernel dimension and color, Calaroma-201 was most similar to Thai jasmine. Jazzman 2018 was closer to the Thai varieties in chemical attributes, and both Jazzman 2018 and Jazzman 2017 were similar to the Thai in average amylopectin chain length. RU1701105 and the Thai jasmine rice samples had similar gelatinization temperatures. ClJ01 2018 was most similar to the Thai jasmine in pasting properties and cooked rice texture. Calaroma-201 was most similar to Thai jasmine rice samples when considering all properties. The Arkansas varieties were generally similar to each other, and Louisiana varieties were similar to each other, but each of these categories are different from the Thai jasmine rice samples. This study demonstrates that the properties of jasmine rice are strongly influenced by genetics, growing location, and crop year.

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APPENDIX

Table 1. Kernel appearance of jasmine rice samples from Thailand and grown in the U.S.

	Kernel Dimension				Kernel Color	
Sample	**Length (mm)**	**Width (mm)**	**Thickness (mm)**	**L/W ratio**	***L****	***b****
Golden Phoenix	7.22±0.02a	2.14±0.00cd	1.84±0.03b	3.37±0.01a	75.2±0.5a	17.0±0.6ab
3 Ladies HOM MALI	7.22±0.01a	2.14±0.01cd	1.86±0.02ab	3.38±0.01a	73.9±0.1b	16.9±0.2b
ARoma17	6.80±0.02b	2.22±0.01b	1.95±0.04a	3.07±0.00b	68.8±0.0f	18.1±0.3a
RU1701105	6.73±0.03b	2.56±0.01a	1.95±0.01a	2.63±0.03c	70.4±0.1de	17.4±0.2ab
Calaroma-201	7.21±0.06a	2.07±0.04e	1.89±0.00ab	3.49±0.09a	72.2±0.1c	12.7±0.0e
CLJ01 2018	6.30±0.01d	2.11±0.01de	1.90±0.01ab	2.99±0.00b	69.6±0.1e	16.8±0.2bc
CLJ01 2017	6.48±0.03c	2.15±0.01cd	1.91±0.05ab	3.01±0.01b	70.9±0.2d	17.8±0.4ab
Jazzman 2018	6.53±0.08c	2.19±0.02bc	1.91±0.02ab	2.99±0.01b	71.0±0.3d	14.6±0.3d
Jazzman 2017	6.83±0.05b	2.21±0.02b	1.89±0.02ab	3.09±0.01b	68.6±0.2f	15.7±0.5cd

Means ± standard deviations of duplicate measurements followed by a common letter in a column are not significantly different at $P < 0.05$.

Table 2. Chemical composition (%, dry basis) of jasmine rice samples from Thailand and grown in the U.S.

Sample	Protein	Amylose	Lipid	Ash
Golden Phoenix	7.61±0.01d	16.08±0.14d	0.15±0.00g	0.26±0.01d
3 Ladies HOM MALI	7.65±0.01d	16.18±0.07cd	0.19±0.00f	0.23±0.00d
ARoma17	8.39±0.02c	16.65±0.21bc	0.56±0.02a	0.48±0.01b
RU1701105	10.89±0.15a	19.57±0.07a	0.54±0.01a	0.60±0.02a
Calaroma-201	6.99±0.03e	19.37±0.14a	0.31±0.01d	0.33±0.00c
CLJ01 2018	7.87±0.01d	14.13±0.11f	0.43±0.01bc	0.37±0.00c
CLJ01 2017	9.09±0.02b	16.76±0.07b	0.40±0.01c	0.34±0.02c
Jazzman 2018	6.87±0.00e	16.66±0.21bc	0.26±0.01e	0.36±0.01c
Jazzman 2017	8.41±0.13c	14.71±0.11e	0.45±0.01b	0.37±0.01c

Means ± standard deviations of duplicate measurements followed by a common letter in a column are not significantly different at $P < 0.05$.

Table 3. Hexanal and 2-acetyl-1-pyrroline (2-AP) in raw milled jasmine rice samples from Thailand and grown in the U.S.

Sample	2-AP (ng/g)	Hexanal (ng/g)
Golden Phoenix	977.4±54.6fg	344.8±21.9b
3 Ladies HOM MALI	396.2±35.6h	364.1±9.9b
ARoma17	1331.5±68.1cdef	197.8±5.6cd
RU1701105	1608.7±88.7c	44.1±2.8g
Calaroma-201	3434.3±60.2a	167.8±9.7def
CLJ01 2018	1385.1±60.7cde	233.9±12.5c
CLJ01 2017	2328.7±191.8b	437.6±34.8a
Jazzman 2018	1092.4±28.0efg	111.4±8.4f
Jazzman 2017	1167.7±38.9defg	154.4±12.8def

Means ± standard deviations of duplicate measurements followed by a common letter in a column are not significantly different at $P < 0.05$.

Table 4. Amylopectin chain-length distribution of jasmine rice samples from Thailand and grown in the U.S.

Sample	Percent Composition (%)				
	A (DP6-12)	B1 (DP13-24)	B2 (DP25-36)	B3+ (DP37-65)	Average Chain Length
Golden Phoenix	26.71±0.33a	47.98±0.22b	14.25±0.15ab	11.05±0.40abc	20.49±0.17abc
3 Ladies HOM MALI	26.87±0.49a	47.75±0.37b	14.56±0.14a	10.82±0.01abc	20.42±0.05abcde
ARoma17	26.99±0.05a	48.83±0.15a	13.69±0.06bc	10.48±0.16c	20.14±0.05e
RU1701105	27.13±0.31a	48.35±0.13ab	13.45±0.49c	11.06±0.32abc	20.29±0.02bcde
Calaroma-201	27.17±0.40a	48.32±0.15ab	13.76±0.15bc	10.74±0.10bc	20.23±0.09cde
CLJ01 2018	26.20±0.16a	47.93±0.04b	14.27±0.03ab	11.60±0.09a	20.62±0.05a
CLJ01 2017	26.77±0.13a	48.84±0.22a	13.91±0.03abc	10.50±0.13c	20.18±0.03de
Jazzman 2018	26.34±0.00a	48.39±0.02ab	13.94±0.01abc	11.33±0.01ab	20.53±0.01ab
Jazzman 2017	26.35±0.07a	48.17±0.14ab	14.24±0.02ab	11.23±0.20abc	20.45±0.07abcd

Means ± standard deviations of duplicate measurements followed by a common letter in a column are not significantly different at $P < 0.05$.

Table 5. Gelatinization properties of jasmine rice samples from Thailand and grown in the U.S.

Sample	**Onset (°C)**	**Peak (°C)**	**End (°C)**	**Enthalpy (J/g)**
Golden Phoenix	65.6±0.7cd	71.7±0.2cd	79.1±0.6cd	8.28±0.11a
3 Ladies HOM MALI	65.8±0.1c	72.1±0.0c	79.1±0.2bcd	7.93±0.08a
ARoma17	66.4±0.0bc	73.0±0.0b	80.6±0.0abc	7.39±0.32a
RU1701105	64.9±0.1cde	71.6±0.0cd	79.1±0.0cd	6.11±0.14a
Calaroma-201	64.3±0.1de	70.1±0.2e	77.1±0.4d	7.62±0.17a
CLJ01 2018	67.4±0.0b	74.3±0.0a	82.8±1.4a	8.08±0.34a
CLJ01 2017	63.8±0.4e	71.1±0.1d	78.8±0.3cd	8.42±0.02a
Jazzman 2018	69.1±0.1a	74.6±0.2a	82.0±0.1a	8.00±0.21a
Jazzman 2017	67.7±0.3ab	74.0±0.2a	81.5±0.2ab	8.31±0.08a

Means ± standard deviations of duplicate measurements followed by a common letter in a column are not significantly different at $P < 0.05$.

Table 6. Pasting properties of rice flour of jasmine rice samples from Thailand and grown in the U.S. by a Rapid ViscoAnalyser

	Pasting Viscosities (cP)					
Sample	**Peak**	**Trough**	**Breakdown**	**Final**	**Setback**	**Total Setback**
Golden Phoenix	3849±22b	1971±108ab	1878±130bc	3411±42d	-438±64e	1441±66cd
3 Ladies HOM MALI	3603±13c	2035±17a	1568±30de	3611±31c	8±44c	1576±14b
ARoma17	3301±7d	1662±5d	1640±12cd	3058±7e	-243±0d	1397±12de
RU1701105	3106±47e	1757±28cd	1349±75e	3758±27b	653±74b	2002±1a
Calaroma-201	3368±4d	1651±11d	1717±7bcd	2947±15f	-421±11de	1296±4ef
CLJ01 2018	3654±12c	1868±4abc	1786±16bcd	3393±4d	-261±16de	1524±0bc
CLJ01 2017	2776±17f	1880±62abc	897±80f	3865±27a	1089±44a	1986±35a
Jazzman 2018	4093±46a	1856±0bc	2237±46a	2944±13f	-1149±59g	1089±13g
Jazzman 2017	3691±41c	1783±30cd	1908±70b	3066±2e	-625±43f	1283±28f

Means ± standard deviations of duplicate measurements followed by a common letter in a column are not significantly different at $P < 0.05$.

Table 7. Cooked rice texture of jasmine rice samples from Thailand and grown in the U.S. by a texture analyzer

Sample	Hardness (g)	Stickiness (g.sec)
Golden Phoenix	6048±421b	-403±6cde
3 Ladies HOM MALI	6778±233ab	-333±43abc
ARoma17	5474±519b	-348±35bc
RU1701105	8464±736a	-206±5a
Calaroma-201	6377±204b	-521±57de
CLJ01 2018	6005±245b	-359±17bc
CLJ01 2017	5930±711b	-258±59ab
Jazzman 2018	5540±46b	-534±26e
Jazzman 2017	6896±351ab	-386±26bcd

Means ± standard deviations of duplicate measurements followed by a common letter in a column are not significantly different at $P < 0.05$.

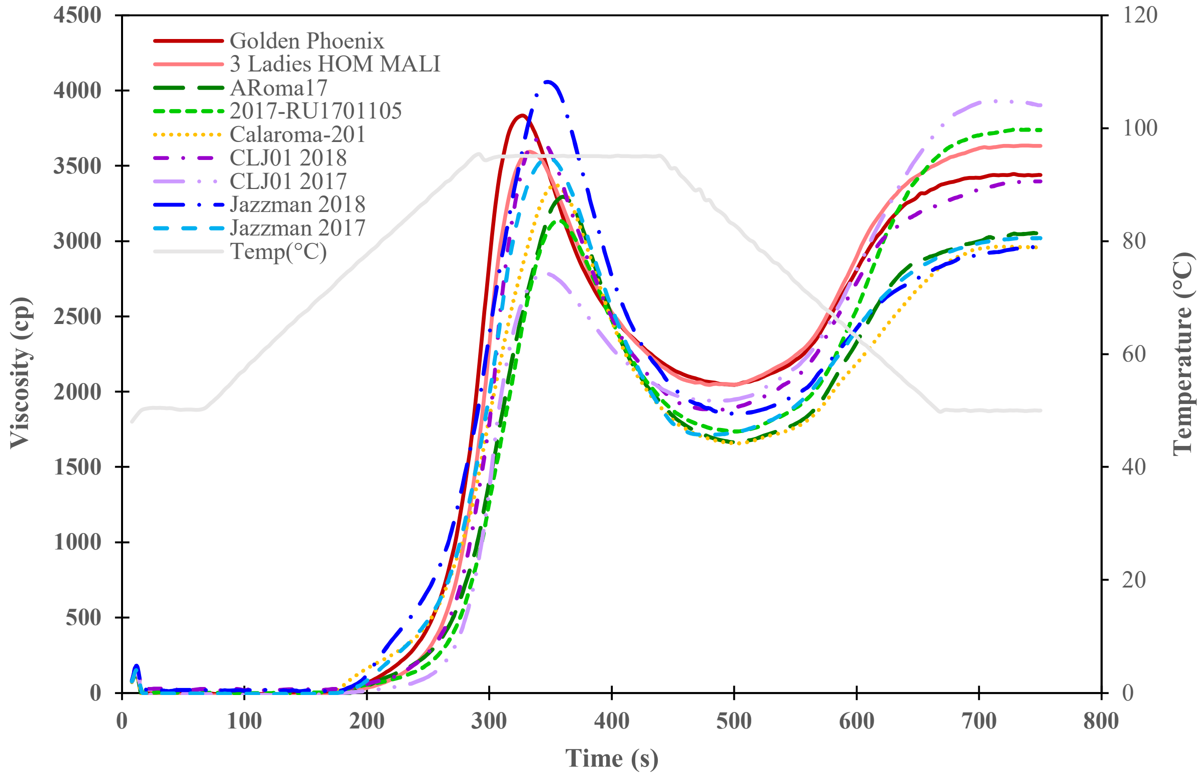

Figure 1. Pasting profiles of jasmine rice samples from Thailand and grown in the U.S. with a Rapid ViscoAnalyzer.

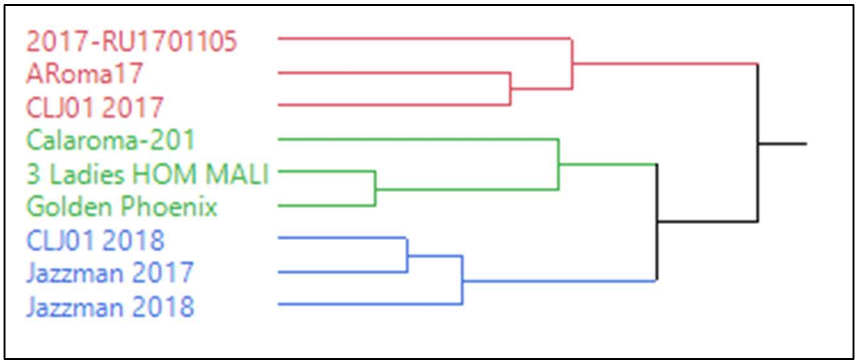

Figure 2. A dendrogram obtained from the Ward's hierarchical cluster analysis of the kernel appearance, chemical composition, starch fine structure, pasting characteristics, and cooked rice texture of nine jasmine cultivars.