Sensory Characteristics of Diverse Rice Cultivars as Influenced by Genetic and Environmental Factors

E. T. Champagne,[1,2] K. L. Bett-Garber,[1] A. M. McClung,[3] and C. Bergman[3]

ABSTRACT

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An understanding of how genetic, preharvest, and postharvest factors affect the sensory characteristics of rice will help producers and processors meet the needs of specific customers and foster the development of a diversified rice market. In this study, differences in the texture and flavor of 17 diverse cultivars related to genetic differences were characterized and the stability of their flavor and texture from one crop year to the next was determined. Sensory attributes of cooked rice were measured by panelists using descriptive sensory analysis methodology. Cooked texture of the cultivars varied widely and correlated well with amylose content with correlation coefficient (*r*) values in the range 0.76–0.97 for 11 of the 14 attributes. Flavor attribute intensities were low and similar among cultivars, with the exception of grain flavor. Grain flavor ranged in intensity from 2.2 to 4.9 and correlated highly and negatively with amylose content (–0.88). Roughness and hardness were the only textural attributes which were significantly different ($P < 0.05$) in the crop year 2 cultivar set compared to the crop year 1 set with the higher values of these two attributes in crop year 2 being explained primarily by protein contents being ≈3% higher. Hay-like, sweet aromatic, sour, and astringent were the only flavor attributes which were significantly ($P < 0.05$) different between the crop year sets. Ward's Cluster Analysis grouped the cultivars into five clusters with cultivars belonging to each cluster having common texture and flavor characteristics. Changes in assignment to clusters from one crop year to the next allowed assessment of the stabilities of the sensory impact of the cultivars to environmental factors.

In today's diversified, global marketplace, consumers are demanding rice with specific flavor and texture characteristics. To meet consumer need, knowledge of the similarities and differences in both texture and flavor of cultivars is needed. In addition, an understanding of the sources of these similarities and differences is important. Cooked rice sensory quality has been affected by aspects of postharvest handling of rough rice such as drying and storage conditions (Champagne et al 1997, 1998; Lyon et al 1999; Meullenet et al 1999, 2000). Also, Bett-Garber et al (2001) demonstrated that the production environment influenced flavor and texture characteristics, resulting in some cultivars clustering into unexpected categories. Other cultivars, however, had flavor and texture characteristics stable across environments. For producers and processors to have control over the sensory quality of their products, they need to understand how genetic, preharvest, and postharvest factors influence texture and flavor in specific cultivars.

The objectives of this study were to gain an understanding of 1) flavor-texture differences among diverse cultivars related to genetic influences, and 2) stability of flavor and texture of the cultivars across crop years.

MATERIALS AND METHODS

Rice Samples

Seventeen cultivars adapted to the southern U.S. rice-growing region and representing a wide spectrum of grain types and cooking qualities were selected for evaluation. Dixiebelle (PI 595900) and L205 (PI 608664) are long grain cultivars that have intermediate gelatinization temperatures, relatively high amylose contents, and superior parboiling quality that is associated with CT 11 allele of the granule bound starch synthase (GBSS) gene which controls amylose content (Ayres et al 1997). AB647 is a private, medium grain indica cultivar that possesses this same CT 11 allele and superior parboiling quality, but has low gelatinization temperature. Jodon (PI 583831) is a long grain cultivar that has intermediate gelatinization temperature and high amylose content. However, it possesses the CT 20 allele for GBSS and does not have superior parboiling quality. The long grain cultivars Saber, Cypress (PI 561734), and Lavaca all have intermediate gelatinization temperatures and amylose contents (CT 20) that are typical of conventional U.S. long grain rice. Lavaca, however, also possesses the allele associated with cooked kernel elongation that is found in basmati-type rice cultivars. Bengal (PI 561735) and Baldo (PI 433496) are medium grain cultivars that have low gelatinization temperatures and low amylose contents due to the CT 18 allele of the GBSS gene. Jacinto (PI 605713) is a long grain specialty rice that also has the CT 18 allele but a high gelatinization temperature. M-401 (Clor 9975), Koshihikari (PI 514661), and Calhikari-201 (PVP 9900310) are considered to have Japanese premium quality as well as having the CT 18 GBSS allele and low gelatinization temperature. Three long grain waxy cultivars were selected: Mizuho Issun (PI 439690), IR29 (PI 393986), and Neches, as well as the short grain waxy cultivar Calmochi-101 (PI 494104). All of the waxy cultivars were characterized as having essentially no amylose and low gelatinization temperatures.

The cultivars were grown at the USDA-ARS Rice Research Unit in Beaumont, TX, during the 2000 and 2001 field seasons and are referred to as crop years 1 and 2, respectively. In both years, the cultivars were planted at mid- to late-May using a typical seeding rate of 112 kg/ha. Herbicide, insecticide, irrigation, and fertilizer (224 kg of nitrogen/ha) were applied in manner to maximize yield potential. Weather conditions were monitored throughout the growing season. Flowering occurred during the end of July and early August, with harvest occurring during late September for both years. Plots were harvested at ≈18–22% grain moisture using a small-plot combine. The rough rice was dried using a forced-air drier until samples reached 12% grain moisture.

Samples were stored for approximately three months in air conditioning before milling. The rough rice was dehulled (Satake model SB-2B, Chiyodaku, Tokyo) and then milled following standard protocol (Champagne et al 1999) using a laboratory one-pass mill (Satake model SKD) to whiteness values of 40 ± 2 which are considered typical of regular milled rice. Broken kernels were separated from whole grain milled rice using a rice grader

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[1] USDA ARS Southern Regional Research Center, New Orleans, LA. Names are necessary to report factually on available data; however, the USDA neither guarantees nor warrants the standard of the product, and the use of the name by the USDA implies no approval of the product to the exclusion of others that may also be suitable.

[2] Corresponding author. Fax 504-286-4430. E-mail: etchamp@srrc.ars.usda.gov

[3] USDA ARS Rice Research Unit, Beaumont, TX.

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(Satake model RG-06A). Milled, whole grain samples were shipped overnight to the USDA, ARS, Southern Regional Research Center (New Orleans, LA). When received, samples were immediately preweighed into portions for sensory and chemical analyses and stored in glass jars under nitrogen headspace at 4°C.

Chemical Analyses

Apparent amylose content was determined on the samples in duplicate by the simplified assay method developed by Juliano (1971). Protein contents (N × 5.95) were determined in duplicate by the combustion method on a nitrogen determinator (FP-428, LECO, St. Joseph, MI).

Rapid Visco Analyser (RVA) Analyses

Paste viscosity properties of rice samples were determined using an RVA (Newport Scientific model 3D) and Approved Method 61-02 (AACC 2000). The definitions for measured properties are initial gelatinization temperature (temperature of initial viscosity increase); peak (maximum viscosity recorded during heating and holding cycles which usually occurs soon after heating cycle reaches 95°C); hot paste viscosity (minimum viscosity after peak); cool paste viscosity (viscosity at test finish); breakdown (difference [–] between peak and trough, indication of breakdown in viscosity of paste during 95°C holding period); and setback (difference [–] between final viscosity and peak).

Sample Preparation for Sensory Analyses

Portions of rice (600 g) were rinsed by covering the rice three times with cold water followed by straining to remove excess water. After rinsing, the samples were transferred to preweighed rice cooker insert bowls and water was added to give a rice-to-water weight ratio of 1:1.4. The rice was soaked for 20 min and then cooked in a 5-cup rice cooker-steamer (Panasonic SR-W10G HP) to completion, followed by a 10-min holding period. Samples were removed from the cookers as described by Champagne et al (1999). Cooking was staggered so that samples were analyzed by the panel at 20-min intervals.

Sensory Evaluation Protocol

Ten panelists trained in the principles and concepts of descriptive sensory analysis (Meilgaard et al 1991) participated in the study. The lexicon for rice texture used by the panel was based on that developed by Lyon et al (1999) and Goodwin et al (1996) and is described in Table I. The sensory texture profile used by the panelists included 14 sensory attributes that described rice texture at different phases of sensory evaluation, beginning with the feel of the rice when it was first placed in the mouth and ending with mouthfeel characteristics after the rice was swallowed. The rice flavor lexicon included 12 unique flavor attributes which were determined by smelling and evaluating in the mouth (Table II). Each sample was presented to the panelists

TABLE I
Sensory Descriptive Texture Attributes and Their Definitions Used to Evaluate Cooked Rice Texture

Phases/Attributes	Definition
PHASE I	Place 6–7 grains of rice in mouth behind front teeth; press tongue over surface and evaluate
Initial starchy coating	Amount of paste-like thickness perceived on the product before mixing with saliva (three passes)
Slickness	Maximum ease of passing tongue over the rice surface when saliva starts to mix with sample
Roughness	Amount of irregularities in the surface of the product
Stickiness to lips	Degree to which kernels adhere to lips
Stickiness between grains	Degree to which the kernels adhere to each other
PHASE II	Place 1/2 teaspoon of rice in mouth; evaluate before or at first bite
Springiness	Degree to which grains return to original shape after partial compression
Cohesiveness	Degree to which the grains deform rather than crumble, crack, or break when biting with molars
Hardness	Force required to bite through the sample with the molars
PHASE III	Evaluate during chew
Cohesiveness of mass	Maximum degree to which the sample holds together in a mass while chewing
Chewiness	Amount of work to chew sample
Uniformity of bite	Evenness of force throughout bites to chew
Moisture absorption	Amount of saliva absorbed by sample during chewing
PHASE IV	Evaluate after swallow
Residual loose particles	Amount of loose particles in mouth
Toothpack	Amount of product adhering in/on the teeth

TABLE II
Descriptive Sensory Analysis Attributes and Definitions Used to Evaluate Cooked Rice Flavor

Sewer/Animal An immediate and distinct pungent aromatic in the flavor characterized as sulfur-like and generic animal. The animal aromatic in the flavor can sometimes be identified as "piggy".

Floral Aromatics associated with dried flowers, such as lilac and/or lavender. This aromatic is characterized as spicy floral as in an old-fashioned sachet.

Grain/Starchy A general term used to describe the aromatics in the flavor associated with grains such as corn, oats and wheat. It is an overall grainy impression characterized as sweet, brown, sometimes dusty, and sometimes generic nutty or starchy.

Hay-like/Musty A dry, dusty, slightly brown aroma/flavor with a possible trace of musty.

Popcorn A dry, dusty, slightly toasted and slightly sweet aromatic in the flavor that can be specifically identified as popcorn.

Corn The sweet aromatics of the combination of corn kernels, corn milk, and corn germ found in canned yellow creamed-style corn.

Alfalfa/Grassy/Green beans A dried, green, slightly earthy, slightly sweet aroma/flavor including grassy and fresh green bean aroma/flavor.

Dairy A general term associated with the aromatics of pasteurized cow's milk. Most apparent just before swallowing.

Sweet Aromatic A sweet impression such as cotton candy, caramel, or sweet fruity that may appear in the aroma and or aromatics.

Water-like/Metallic Aromatics and mouthfeel of the minerals and metals commonly associated with tap water. This excludes any chlorine aromatics that may be perceived.

Sweet Taste Basic sweet taste associated with sugar.

Sour/Silage A sour fermented vegetation aroma/flavor, not decaying vegetation.

Astringent The chemical feeling factor on the tongue, described as puckering/dry and associated with tannins or alum.

twice, in separate sessions, following a randomized design. The details of the procedure followed for presenting samples, standard (warm-up sample of commercial long-grain) and blind control (commercial long-grain), to panelists at each session are described by Champagne et al (1999).

Statistical Analyses

PROC ANOVA in SAS-Analyst (SAS Institute, Cary, NC) was used to determine differences in sensory attributes between crop years for each cultivar. The means over all panelists within each replicate and crop year were used for comparisons of sensory attributes.

Correlations among descriptive sensory analyses and compositional data were examined and are reported as correlation coefficient (*r*) values. Ward's Cluster Analysis (SAS) was performed on the sensory data following standardization to zero mean and unit standard deviation to look for groups of cultivars with similar characteristics.

RESULTS AND DISCUSSION

Differences in Amylose and Protein Contents Between Crop Years 1 and 2

Amylose content is considered the most important determinant of cooked rice texture, with low amylose cultivars being moist and clingy when cooked, while those with high amylose are dry and firm when cooked (Webb 1985). Protein content also appears to affect cooked rice texture to some extent, particularly tenderness and cohesiveness (Primo et al 1962; Onate et al 1964; Juliano et al 1965; Hamaker 1994; Champagne et al 1999). The influences of these components on cooked rice flavor have not been established. In this study, amylose and protein contents were measured to determine whether changes between crop years would explain changes in sensory properties from one crop year to next.

The 17 diverse cultivars are briefly described and their apparent amylose and protein contents are listed for the two crop years in Table III. Amylose content was ≈2% lower for crop year 2 for the high amylose cultivars Dixiebelle, Jodon, L205, and AB647 and the low amylose cultivar Calhikari-201. The other nonwaxy cultivars had stable amylose contents across the two years. In contrast, two of the waxy cultivars had higher amylose contents in year 2. Protein contents were ≈3% higher for all cultivars in crop year 2 than in crop year 1.

Monitoring weather conditions throughout the growing seasons indicated that crop year 1 (2000) was hotter and drier than crop year 2 (2001). During the grainfill period (between flowering and harvest), the air temperature for crop year 1 and 2 averaged 28.2°C and 27.5°C, respectively. Crop year 1 had higher maximum air temperatures (≈2.2°C), higher soil temperature (≈1.8°C), greater evaporation (6.7 cm), and lower rainfall (9.5 cm) than crop year 2.

TABLE III
Seventeen Diverse Cultivars and Their Amylose and Protein Contents

Cultivar	Description[a]	Amylose Year 1	Amylose Year 2	Protein Year 1	Protein Year 2
Dixiebelle	LG, Int GT, superior parboiling	25.4	23.4	6.1	9.1
L205	LG, Int GT, superior parboiling	24.7	22.7	6.4	10.3
Jodon	LG, Int GT, high amylose	26.3	23.2	6.0	10.1
Saber	conventional LG, Int GT	20.5	20.4	7.1	9.4
Lavaca	LG, Int GT, elongates	20.9	20.9	6.7	9.7
Cypress	conventional LG, Int GT	20.9	20.7	7.2	10.4
AB647	MG, low GT, high amylose	25.2	23.2	7.3	10.5
Baldo	MG, low GT, speciality	13.8	13.5	7.5	9.4
Bengal	conventional MG, low GT	11.5	11.9	6.7	9.3
Jacinto	LG, low GT, speciality	11.3	11.0	8.1	10.8
M401	MG, low GT, Japanese premium	13.5	13.9	6.4	9.0
Koshihikari	MG, low GT, Japanese premium	14.9	14.5	5.7	8.1
Calhikari-201	MG, low GT, Japanese premium	15.4	12.8	6.7	9.0
Mizuho Issun	LG, waxy	0.1	0.3	7.6	11.9
Calmochi-101	SG, waxy	0.1	0.6	6.3	8.3
IR29	LG, waxy	0.5	0.2	6.1	9.0
Neches	LG, waxy	1.0	2.7	6.4	10.4

[a] Long grain (LG); medium grain (MG); short grain (SG); intermediate (Int); gelatinization temperature (GT).

TABLE IV
Rapid Visco Analyser (RVA) Measurements on 17 Diverse Cultivars for Crop Years 1 and 2

Cultivar	Peak 1	Peak 2	Hot Paste 1	Hot Paste 2	Cool Paste 1	Cool Paste 2	Breakdown 1	Breakdown 2	Setback 1	Setback 2	Initial Temp. 1	Initial Temp. 2
Dixiebelle	264	240	153	156	366	410	110	84	102	170	80.9	83.0
L205	241	289	164	191	411	374	98	78	122	132	80.8	80.8
Jodon	185	157	107	91	265	224	79	67	80	66	81.6	81.6
Saber	257	235	169	131	301	289	88	104	44	54	81.4	81.4
Lavaca	250	237	104	114	225	243	146	123	–25	6	80.0	79.3
Cypress	250	219	126	113	258	274	124	106	8	55	79.9	79.9
AB647	254	250	180	202	344	371	74	48	90	121	75.4	75.2
Baldo	296	287	156	147	260	257	140	140	–36	–30	77.4	76.7
Bengal	307	258	156	125	241	224	151	133	–66	–34	76.8	75.3
Jacinto	292	240	149	129	245	250	142	111	–47	10	83.0	84.0
M401	288	263	134	139	219	226	154	124	–69	–37	75.3	73.8
Koshihikari	311	93	149	163	248	269	162	130	–63	–24	76.0	74.4
Calhikari-201	299	270	154	147	259	260	146	124	–40	–10	77.4	78.4
Mizuho Issun	205	112	118	67	153	87	68	46	–38	–26	71.4	69.7
Calmochi-101	156	153	89	81	112	103	67	72	–44	–50	72.9	72.1
IR29	234	193	113	101	146	133	120	93	–88	–60	72.2	70.6
Neches	156	113	89	66	119	87	68	47	–38	–25	71.4	70.3

Apparent amylose content, messenger RNA levels, quantity of GBSS, and activity of GBSS were higher in japonica cultivars when the grain developed at lower temperatures (15–20°C) than at higher temperatures (Asaoka et al 1984, 1985; Sano et al 1985; He et al 1990; Hirano and Sano 1998; Ueda et al 1998). No correlation has been observed between apparent amylose content and temperature during development for indica cultivars or in near isogenic lines of japonica rice which contained the W_x^a allele typical of indica cultivars (Asaoka et al 1985; Wang and Wessler 1998). Recently, Larkin and Park (1999) have shown that the critical difference is not whether the GBSS allele is characteristic of indica or japonica cultivars, but rather whether the 5' leader intron splice site is AGGTATA or AGTTATA. In the cultivars they examined, amylose content increased by 8–9.5% in AGTTATA cultivars when the grain was allowed to develop at 18°C compared with 32°C. In the AGGTATA cultivars, amylose content at the lower temperature compared with the higher temperature ranged from decreasing by 3.2% to increasing by 1.8%. In the study reported here, the 2°C difference in maximum air temperatures was too small to affect the amylose contents of the AGTTATA cultivars Baldo, Jacinto, Koshihikari, M401, and Bengal. The amylose contents of the three AGGTATA cultivars (Cypress, Lavaca, and Saber) also did not change and were thus not affected by temperature. It is unlikely that the small temperature difference resulted in the amylose contents of the four cultivars (Dixiebelle, Jodon, L205, AB647) being lower in crop year 2 based on their AGGTATA assignment.

Higher protein contents in crop year 2 may explain the amylose contents of the four high amylose cultivars (Dixiebelle, Jodon, L205, and AB647) being lower in the second year. Protein is higher in rice grown at cooler temperatures (Matsue 1995; Lin et al 1995; Hirano and Sano 1998; Ueda et al 1998) and decreases with increasing soil temperature (Subhani et al 2001). The higher protein contents of crop year 2 rice are consistent with these observations.

Differences in RVA Measurements Between Crop Years 1 and 2

RVA is a commonly conducted physiochemical property test used to predict cooked rice texture (Tani et al 1969; Sandhya Rani and Bhattacharya 1995; Champagne et al 1999). Table IV lists the RVA measurements for crop years 1 and 2. Cultivars had significantly ($P < 0.0001$) different values across the two years for peak, hot paste, breakdown, and setback. Mean values for crop year 2 were significantly lower than crop year 1 for all of these measures, except for setback, which was significantly higher. A comparison of the two years shows markedly lower peak, hot paste, and cool paste measurements for crop year 2 Mizuho Issun, a waxy cultivar.

As discussed above, the protein contents of the crop year 2 samples were ≈3% higher than those of the crop year 1 samples. However, this increase in protein content did not appear to affect most RVA parameters and was significantly ($P < 0.05$) associated only with the observed decreases in peak viscosity ($r = -0.43$) and breakdown ($r = -0.41$). The negative relationships of amylograph viscosity and protein content were probably due to suppression of starch granule swelling by protein (Juliano et al 1964a,b; Juliano and Pascual 1980).

Differences in Texture and Flavor Between Crop Years 1 and 2

Tables V and VI list the mean texture and flavor scores, respectively, for crop years 1 and 2. Correlations between the mean

TABLE V
Correlations Between Mean Texture Scores Over Two Years with Amylose and Protein Contents

Attribute	Amylose Correlation[a]	Protein Correlation[a]	Crop Year 1 Mean[b]	Crop Year 2 Mean[b]
Initial starchy coating	–0.91	ns	3.5	3.2
Slickness	–0.36	ns	5.0	5.3
Roughness	0.76	0.49	**4.3**	**5.1**
Stickiness to lips	–0.91	ns	6.8	6.5
Stickiness between kernels	–0.91	ns	6.3	5.9
Springiness	0.85	ns	3.5	3.7
Cohesiveness	–0.80	ns	5.2	5.3
Hardness	0.90	ns	**3.7**	**4.3**
Cohesiveness of mass	–0.92	ns	5.8	5.8
Chewiness	0.75	ns	5.0	5.0
Uniformity of bite	–0.85	ns	6.4	6.9
Moisture absorption	–0.39	ns	4.7	4.6
Residual loose particles	0.50	ns	4.6	4.5
Toothpack	–0.78	ns	4.5	4.1

[a] Correlation coefficient (r); ns = not significant ($P > 0.05$).
[b] Bold type indicates means are significantly different ($P < 0.05$).

TABLE VI
Correlations Between Mean Flavor Scores Over Two Years with Amylose and Protein Contents

Attribute	Amylose Correlation[a]	Protein Correlation[a]	Crop Year 1 Mean[b]	Crop Year 2 Mean[b]
Sewer/animal	ns	ns	0.9	1.0
Floral	ns	ns	0.2	0.1
Grain	–0.88	ns	3.4	3.2
Hay-like	ns	0.53	**0.8**	**1.2**
Popcorn	ns	ns	0.7	0.8
Corn	ns	ns	0.9	0.9
Alfalfa	–0.36	ns	0.1	0.1
Dairy	ns	ns	0.8	0.8
Sweet aromatic	ns	–0.49	**0.5**	**0.4**
Water-like metallic	ns	ns	0.6	0.6
Sweet	0.40	ns	1.5	1.4
Sour	–0.39	ns	**0.8**	**0.6**
Astringent	–0.43	ns	**0.5**	**0.3**

[a] Correlation coefficient (r); ns = not significant ($P > 0.05$).
[b] Bold type indicates means are significantly different ($P < 0.05$).

sensory scores over two years and amylose and protein contents are also listed.

In a comparison of the crop years, roughness and hardness were the only textural attributes that were significantly different ($P < 0.05$) between crop years 1 and 2. Roughness and hardness were both higher in crop year 2 for all cultivars. This is in agreement with setback, which correlated (r) with roughness (0.85) and hardness (0.87), which was higher in crop year 2.

The correlation (r) between roughness and protein was 0.49 ($P < 0.005$). There was no relationship between hardness and protein ($P > 0.05$). Amylose correlated significantly ($P < 0.0001$) and positively with roughness (0.76) and hardness (0.90). Thus, based on the increase in protein contents, the cultivars whose amylose content did not change from one crop year to the next were expected to be rougher and possibly harder in crop year 2. However, the resultant hardness and roughness of the crop year 2 cultivars with lower amylose content were expected to be less based on amylose, but higher based on higher protein. The resultant hardness and roughness of all cultivars can be modeled by multiple linear regression with full-cross validation as

$$\text{Roughness} = (0.256 \times \text{protein}) + (0.072 \times \text{amylose}) + 1.565$$
$$\text{with } r_{\text{calibration}} = 0.92 \text{ and } r_{\text{validation}} = 0.90$$

$$\text{Hardness} = (0.200 \times \text{protein}) + (0.116 \times \text{amylose}) + 0.729$$
$$\text{with } r_{\text{calibration}} = 0.95 \text{ and } r_{\text{validation}} = 0.94$$

Flavor attribute intensities were low in all the cultivars, with grain flavor being the predominant note (Table VI). Grain flavor ranged in intensity from 2.2 to 4.9 and correlated highly and negatively with amylose content ($r = -0.88$). Thus, the waxy cultivars, which are known to have a grainy-starchy aroma (Grimm et al 2001), had the highest grain flavor scores. Grain flavor did not significantly change ($P > 0.1$) over crop years. Hay-like, sweet aromatic, sour, and astringent were significantly different ($P < 0.05$) between crop years 1 and 2. The mean sweet aromatic, sour, and astringent scores were lower for crop year 2, while the mean hay-like score was higher. Hay-like and sweet aromatic were significantly ($P < 0.005$) correlated positively (0.53) and negatively (–0.49), respectively, with protein content. Amylose content correlated significantly ($P < 0.02$) and negatively with sour (–0.39) and astringent (–0.43). The remaining flavor attributes were stable over crop years and, with the exception of alfalfa, did not significantly ($P > 0.05$) correlate with protein or amylose contents. Alfalfa was significantly ($P < 0.05$) correlated negatively with amylose content ($r = -0.36$).

Ward's Cluster Analysis

Ward's Cluster Analysis was employed to identify significant groups (clusters) of cultivars with common texture or flavor characteristics for each crop year and compare the stability of the cultivars to environmental factors. The analysis of sensory attributes (flavor and texture) clustered the cultivars into five groups (Table VII). These five groups were five of the seven clusters identified in Bett-Garber et al (2001). The two clusters not accounted for in this set of samples that were found in the earlier work were a cluster consisting of diverse cultivars with average attribute scores and a cluster that contained low amylose cultivars that were high in less desirable flavor and texture attributes.

Four long grain cultivars with intermediate gelatinization temperatures (Dixiebelle, Saber, Jodon, L205) and a medium grain cultivar with low gelatinization temperature (AB647) grown in both crop years are in Cluster 1. The two remaining long grain cultivars with intermediate gelatinization temperatures (Lavaca and Cypress) from crop year 2 are also in Cluster 1. These culti-

TABLE VII
Cluster Mean Comparisons for 17 Diverse Rice Cultivars Grown in Crop Years 1 and 2

Attribute	Cluster 1[a]	Cluster 2[b]	Cluster 3[c]	Cluster 4[d]	Cluster 5[e]
Texture					
Initial starchy coating	2.1d[f]	3.4c	4.0bc	5.1ab	5.4a
Slickness	4.8b	5.3b	5.3ab	5.1b	6.7a
Roughness	5.5a	4.4b	4.7ab	3.7b	3.8b
Stickiness to lips	4.4c	6.6c	8.6b	9.5ab	10.7a
Stickiness between kernels	4.1c	6.1b	6.8b	9.2a	9.9a
Springiness	4.2a	3.7b	3.3b	2.5c	2.1c
Cohesiveness	4.7c	5.1bc	5.8ab	6.0a	6.6a
Hardness	5.3a	3.7b	3.7b	2.3c	2.6c
Cohesiveness of mass	4.5c	5.7b	6.5b	7.7a	8.2a
Chewiness	5.4a	5.0a	5.1a	4.4b	4.6ab
Uniformity of bite	5.7c	6.3c	7.4b	8.2ab	9.2a
Moisture absorption	4.5b	4.7ab	4.7ab	4.7ab	5.1a
Residuals	4.7	4.5	4.7	4.4	4.3
Toothpack	3.6c	4.3b	4.9a	5.4a	5.2ab
Flavor					
Sewer/animal	1.0	0.8	0.9	0.9	1.1
Floral	0.1	0.1	0.0	0.2	0.1
Grain	2.7c	3.2b	3.2b	4.6a	4.6a
Hay-like	0.9b	0.9b	1.6a	0.8b	1.2ab
Popcorn	0.7	0.8	0.5	0.9	0.3
Corn	0.8ab	0.9ab	0.8ab	1.0a	0.4b
Alfalfa	0.1c	0.1bc	0.3ab	0.1ac	0.3a
Dairy	0.8	0.9	0.6	0.9	0.7
Sweet aromatic	0.4b	0.5a	0.3b	0.4a	0.4a
Water-like metallic	0.6	0.6	0.4	0.6	0.8
Sweet	1.6a	1.6ab	1.1c	1.3a–c	1.1bc
Sour	0.5	0.8	0.9	1.0	0.7
Astringent	0.3b	0.3b	0.1b	0.7a	0.6ab

[a] Jodon (yr 1, 2); Saber (yr 1, 2); AB647 (yr 1,2); Dixiebelle (yr 1, 2); L-205 (yr 1, 2); Cypress (yr 2); Lavaca (yr 2).

[b] Koshihikari (yr 1, 2); Calhikari-201 (yr 1, 2); Baldo (yr 1, 2); Jacinto (yr 1, 2); Bengal (yr 1); M401 (yr 1); Cypress (yr 1); Lavaca (yr 1).

[c] M401 (yr 2); Bengal (yr 2); Mizuho Issun (yr 2).

[d] Neches (yr 1,2); Calmochi-101 (yr 1); IR29 (yr 1); Mizuho Issun (yr 1).

[e] Calmochi-101 (yr 2); IR29 (yr 2).

[f] Means with same letters are not significantly different based on Tukey's HSD mean comparison test.

vars all have intermediate-to-high apparent amylose contents. Unexpectedly, Lavaca and Cypress from crop year 1 are in Cluster 2. Cluster 1 cultivars were significantly ($P < 0.05$) the lowest in grain flavor (2.7), initial starchy coating (2.1), stickiness between kernels (4.1), cohesiveness of mass (4.5), and toothpack (3.6). They were significantly ($P < 0.05$) the highest in hardness (5.3) and springiness (4.2) and, along with Cluster 3 cultivars, were the highest in roughness (5.5).

Cluster 2 consists of the medium grain cultivars with low gelatinization temperature and low amylose contents: Baldo and Jacinto from both crop years and M401 from crop year 1. Koshihikari and Calhikari-201, two short grain cultivars which typically have the texture of medium grain cultivars, from both crop years are also in Cluster 2. Additionally, Cluster 2 includes Lavaca and Cypress grown in crop year 1. The cultivars in Cluster 2 had grain flavor and texture (stickiness between grains, slickness, springiness, hardness, cohesiveness of mass, chewiness) intensities the same as Cluster 3 and intermediate to those of Clusters 1 and 4, and 5 (Table VII).

As noted above, the inclusion of Cypress and Lavaca from crop year 1 with the cultivars in Cluster 2 instead of with those in Cluster 1, which have similar physicochemical properties, was unexpected. This grouping is particularly surprising in that at the less than ideal (1:1.9) rice-to-water ratio of 1:1.4 for an intermediate amylose (21%) rice, one would expect Cypress and Lavaca to cook up very firm (Juliano and Perez 1983). However, the textural and flavor properties of the crop year 1 samples were like those of the medium and short grain cultivars in Cluster 2 and therefore grouped with them. In crop year 1 samples, stickiness to lips and stickiness between grains were significantly ($P < 0.05$) higher in Lavaca and stickiness of lips and roughness were significantly ($P < 0.05$) higher and lower, respectively, in Cypress than in crop year 2.

M-401, Bengal, and Mizuho Issun, grown in crop year 2, form Cluster 3. It is not surprising that Mizuho Issun, a waxy cultivar, is clustered with these two medium grain nonwaxy cultivars. These medium grain cultivars were similar to the waxy cultivars of Clusters 4 and 5, being high in slickness, stickiness to lips, uniformity, and toothpack. Cluster 3 cultivars also had high hay-like flavor similar to that of Cluster 5. In crop year 2, in addition to having textural properties like those of the nonwaxy cultivars of Cluster 3, Mizuho Issun had grain flavor (3.4) lower than that of the other waxy cultivars and consistent with the mean for Cluster 3.

Cluster 4 consists of the waxy rice cultivars Mizuho Issun, Calmochi-101, and IR29 from crop year 1, and Neches from crop years 1 and 2. These cultivars are distinguished by soft texture and high grain flavor. Along with the cultivars of Cluster 5, they are characterized by being significantly ($P < 0.05$) the highest in grain flavor (4.6), stickiness between kernels (9.2), and cohesiveness of mass (7.7). These two clusters were significantly ($P < 0.05$) lowest in hardness (2.3), springiness (2.5), and chewiness (4.4).

Cluster 5 consists of the waxy cultivars Calmochi-101 and IR-29 grown in crop year 2. These waxy cultivars differed from those in Cluster 4 by having significantly lower ($P < 0.05$) corn flavor and significantly higher ($P < 0.05$) slickness.

CONCLUSIONS

The texture and flavor of 17 diverse cultivars grown at the same time in adjacent plots, harvested within a two-week timeframe, and processed the same, were characterized for two crop years. This provided knowledge of differences in sensory properties among cultivars related to genetic differences and the stability of these properties in the cultivars to year-to-year variation in environment. Differences in weather conditions between the two crop years appear to have resulted in all crop year 2 cultivars having higher protein contents and five having lower amylose contents when compared with crop year 1. With the exception of one nonwaxy cultivar (Calhikari-201), the cultivars whose amylose contents were affected by weather conditions are high-amylose cultivars. Cooked texture of the cultivars varied widely and correlated well with amylose content with correlation coefficient (r) values in the range 0.76–0.97 for 11 of the 14 attributes. Flavor attribute intensities were low and similar, with the exception of grain flavor. Grain flavor ranged in intensity from 2.2 to 4.9 and correlated highly and negatively with amylose content (–0.88). Thus, the waxy cultivars displayed high grain flavor. Roughness and hardness were the only textural attributes that were significantly higher ($P < 0.05$) in the crop year 2 compared with crop year 1 and are explained primarily by the protein contents of the crop year 2 cultivars being 3% higher. Roughness and hardness can be modeled by multiple linear regression with full-cross validation with $r_{\text{calibration}} = 0.92$ and 0.95, respectively. Hay-like, sweet aromatic, sour, and astringent were the only flavor attributes that were significantly ($P < 0.05$) different between the crop year sets, with hay-like being higher, and sweet aromatic and astringent being lower in crop year 2. Ward's Cluster Analysis grouped the cultivars into five clusters with cultivars belonging to each cluster having common texture and flavor characteristics. Changes in cluster assignments from crop year 1 to 2 resulted from overall sensory changes in cultivars. These clusters provide insight into similarities and differences in both texture and flavor of cultivars that cannot be gleaned from physicochemical data (amylose and protein contents).

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