Categorizing Rice Cultivars Based on Cluster Analysis of Amylose Content, Protein Content and Sensory Attributes

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ABSTRACT

Presently, rice cultivars are categorized according to grain dimensions, amylose content, and alkali spreading value (gelatinization temperature type). Categorization of rice cultivars based on total sensory impact is needed. This work endeavors to divide world rices into groups based on amylose, protein, flavor, and texture properties. Ninety-one rice samples representing 79 different cultivars and seven growing locations were separated into seven groups with Ward's Cluster Analysis. Cluster 1 included a third of the rice samples and had cultivars with a large diversity of grain shapes and amylose contents. Mean attribute scores for this cluster were near the grand mean for the collective rice samples for nearly every sensory attribute. Cluster 2 included conventional U.S. short- and medium-grain cultivars. Cluster 3 included conventional U.S. medium cultivars that were produced in Louisiana. Mean sensory scores for this cluster characterized these cultivars as having relatively undesirable flavor and texture attributes. Cluster 4 included Japanese premium quality cultivars and U.S. medium-grain cultivars developed for the Japanese market. Cluster 5 included high-amylose, indica types that had relatively firm textural properties. Cluster 6 included relatively soft cooking, aromatic cultivars. Cluster 7 included waxy cultivars and other soft cooking grains. In several cases, the production environment (location, weather effects, etc.) influenced flavor and texture characteristics and resulted in the cultivar falling into an unexpected cluster. This categorization serves as a catalyst for indexing rice cultivars for cooking and processing qualities.

U.S. rice cultivars are typically categorized according to grain dimensions, amylose content, and alkali spreading value (gelatinization temperature type). In the United States, this categorization serves as an indicator of rice cooking and processing qualities. Typically, U.S. long-grain cultivars cook dry and fluffy with grains remaining separate and they are characterized as having relatively high amylose contents (21–24%) and intermediate to high gelatinization temperatures. Medium- and short-grain U.S. cultivars are generally moist, chewy, and clingy after cooking, and have comparatively low amylose contents (14–19%) and low gelatinization temperatures (Webb 1985). The majority of rice cultivars that are developed in U.S. breeding programs are selected for particular physicochemical properties as dictated by the rice industry end-users. Cultivars that are developed for specialty markets or in breeding programs in other countries may have widely divergent physicochemical properties. The physicochemical methods that are widely used in the United States for categorizing rice have been developed for use in breeding programs where large numbers of cultivars are evaluated only on limited sample size. These methods have a limitation in only serving as indices to indicate whether a rice will cook to be dry and fluffy or soft and sticky. They do not describe the complexity of cooked rice texture or give indication of flavor characteristics. Analytical methods for evaluating texture or flavor components are more difficult and are not routinely used. Thus, most cultivars are released to the public with little knowledge of the sensory properties.

In today's global marketplace, consumers are demanding rice with specific texture and flavor characteristics. When trade opened with Japan in 1993, one of the problems faced by the U.S. rice industry was not readily knowing which U.S. cultivars have texture and flavor characteristics required for the premium quality Japanese market. Categorization of rice cultivars based on sensory flavor and texture impact is needed to help meet consumer demand for rice cultivars with specific sensory properties and assist the rice industry in global and high value markets.

This research endeavors to categorize 91 rice samples, representing 79 cultivars and seven growing regions. Rice samples were grouped using Ward's Cluster Analysis based on flavor and texture properties, as well as protein and amylose contents.

MATERIALS AND METHODS

Rice Samples

Seventy-nine short-, medium-, and long-grain rice cultivars developed in the United States, Italy, Australia, The Philippines, Korea, Japan, Taiwan, China, Uruguay, Brazil, and Columbia were obtained as representative of rice in the global marketplace. They were grown in Louisiana ($n = 40$), Arkansas ($n = 7$), Texas ($n = 23$), and California ($n = 10$) during 1996, harvested at ≈20% moisture and dried to 12% moisture. After drying, the rices were shipped to the USDA-ARS Rice Research Unit (Beaumont, TX) where they were stored in closed containers for two to three months at 18°C. One week before initiating sensory analyses, the samples were shelled using a Satake rice machine (model SB) and then immediately milled (Champagne et al 1999) using a laboratory one-pass mill (Satake pearler, model SKD). Milled samples were shipped overnight to the USDA-ARS Southern Regional Research Center (New Orleans, LA). Milled rice samples were also obtained from 1996 crops produced in Taiwan ($n = 3$), Korea ($n = 3$), and Australia ($n = 5$). Upon receipt, samples were preweighed into portions for sensory and chemical analyses and stored in glass jars under a nitrogen headspace at 4°C over the six months it took to present all samples to panelists.

Chemical Analyses

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

Sample Preparation for Sensory Analyses

The portions of rice (600 g) were rinsed three times in cold water covering the rice, strained to remove excess water, and then transferred to preweighed rice cooker insert bowls. Water was added in amounts to give rice-to-water weight ratios appropriate for three

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different cook types based on amylose content (1:1, 0%; 1:1.4, 10–19%; 1:1.7, 20–25%). For a few rice cultivars, rice-to-water ratios for cooking differed from the amylose-based categories. Century Patna, Langi, Amaroo, AB647, Nanking Sel, Goolarah, and Kyeema (Tables I and II) were cooked with the amount of water corresponding to a similar cook type. Following the procedure described by Champagne et al (1999), rice was presoaked in the cooker insert bowl for 20 min at room temperature, cooked in a rice cooker-steamer (Panasonic SR-W10GHP) to completion, held 10 min at the warm setting, and sampled. Cooking of sample was staggered so that they were analyzed by the panel at 20-min intervals.

Sensory Evaluation Protocol

Twelve panelists, previously trained in the principles and concepts of descriptive 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) (Fig. 1). The sensory texture profile included 13 attributes that described rice texture at different phases of sensory evaluation, beginning with the surface characteristics when it is first placed in the mouth and ending with characteristics after the rice was swallowed. The rice flavor lexicon was based on the work of Goodwin et al (1996) (Fig. 2). It included 12 unique flavor attributes. Flavor was determined by smelling and by evaluation in the mouth. The most intense experience for an attribute was recorded. Intensity was rated on an anchored scale of 0–15 with 0 being not detectable and 15 being more intense than most foods. Scores were recorded on a computerized ballot system (Compusense Inc., Guelph, ON, Canada) Each sample was presented to the panelists twice, in separate sessions, following the randomized design in which each session consisted of three samples, a standard, and a blind control (Calrose, commercial product). The standard was used as a warm-up sample and was presented at the beginning of each session for the panelists to calibrate themselves. Following the warm-up sample, coded test samples were presented to panelists individually at 20-min intervals immediately after cooking, 10-min holding, and portioning into serving cups. Evaluations were conducted at individual test stations under red lights masking color. Distilled, filtered water (Hydrotech drinking water filtration system) and soda crackers were used to cleanse the mouth between samples.

TABLE I
Description of Rice Samples in Clusters 1 Through 3

Cultivar	Location	Grain Type	Rice-to-Water Ratio[a]	Amylose	Protein
Cluster 1					
AB 869	LA	medium	1:1.4	12.4 ± 0.5	8.3 ± 0.1
Baldo	LA	medium	1:1.4	14.7 ± 0.1	9.9 ± 0.2
Brazos	LA	medium	1:1.4	14.2 ± 0.2	8.4 ± 0.2
Century Patna 231	TX	long	1:1.7*	12.3 ± 0.3	8.4 ± 0.2
Choochung	Korea	medium	1:1.4	18.2 ± 0.1	7.6 ± 0.1
Cypress	LA	long	1:1.7	21.5 ± 0.2	9.0 ± 0.2
Cypress	TX	long	1:1.7	20.3 ± 0.1	9.2 ± 0.1
Dawn	LA	long	1:1.7	22.6 ± 0.1	8.1 ± 0.1
Della	LA	long	1:1.7	21.4 ± 0.2	8.6 ± 0.0
Drew	AR	long	1:1.7	22.7 ± 0.4	8.3 ± 0.5
Illabong	Aust	medium	1:1.4	18.4 ± 0.3	8.5 ± 0.1
IR64	TX	long	1:1.7	21.5 ± 0.5	9.2 ± 0.2
IR72	TX	long	1:1.7	24.5 ± 0.4	7.6 ± 0.1
Kaybonnet	AR	long	1:1.7	22.4 ± 0.5	9.3 ± 0.2
L-202	TX	long	1:1.7	24.0 ± 0.1	8.6 ± 0.1
L-203	CA	long	1:1.7	24.8 ± 0.3	6.5 ± 0.0
Labelle	LA	long	1:1.7	20.9 ± 0.0	8.3 ± 0.1
Langi	Aust	long	1:1.7*	18.0 ± 0.0	8.6 ± 0.1
Leah	LA	long	1:1.7	22.3 ± 0.2	8.4 ± 0.1
Lebonnet	LA	long	1:1.7	21.7 ± 0.2	8.7 ± 0.1
Lemont	TX	long	1:1.7	20.7 ± 0.1	8.1 ± 0.3
Mercury	LA	medium	1:1.4	14.2 ± 0.3	8.6 ± 0.3
Millin	Aust	medium	1:1.4	17.5 ± 0.2	8.1 ± 0.1
Rexmont	AR	long	1:1.7	23.6 ± 0.0	9.1 ± 0.3
S-201	TX	short	1:1.4	13.6 ± 0.1	8.5 ± 0.1
Tebonnet	LA	long	1:1.7	22.0 ± 0.3	8.7 ± 0.5
Toro 2	LA	long	1:1.4	15.3 ± 0.3	8.0 ± 0.0
Zena	TX	long	1:1.4	12.7 ± 0.2	8.6 ± 0.0
Cluster 2					
Amaroo	Aust	medium	1:1.7*	17.6 ± 0.1	8.0 ± 0.2
Brazos	TX	medium	1:1.4	14.8 ± 0.1	7.3 ± 0.4
Calmochi-101	TX	short	1:1.0	0.7 ± 0.2	8.6 ± 0.0
Calrose 76	TX	medium	1:1.4	14.5 ± 0.1	7.8 ± 0.2
Donguin	Korea	medium	1:1.4	16.5 ± 0.2	8.3 ± 0.3
L-204	CA	long	1:1.7	22.7 ± 0.2	7.0 ± 0.2
M-202	CA	medium	1:1.4	14.8 ± 0.2	6.8 ± 0.1
M-401	TX	medium	1:1.4	12.4 ± 0.2	8.3 ± 0.0
Mars	LA	medium	1:1.4	14.0 ± 0.3	7.8 ± 0.3
Pelde	TX	long	1:1.4	12.2 ± 0.2	8.6 ± 0.3
Rico 1	TX	medium	1:1.4	15.1 ± 0.4	6.7 ± 0.1
S-102	CA	short	1:1.4	16.2 ± 0.3	7.0 ± 0.3
Saturn	LA	medium	1:1.4	13.1 ± 0.1	8.4 ± 0.3
Cluster 3					
Bengal	LA	medium	1:1.4	13.1 ± 0.1	8.4 ± 0.1
Nato	LA	medium	1:1.4	15.8 ± 0.2	8.9 ± 0.3
Pecos	LA	medium	1:1.4	15.4 ± 0.5	8.3 ± 0.1
V 4716	LA	medium	1:1.4	12.3 ± 0.2	9.2 ± 0.2

[a] Rice-to-water weight ratio (*) did not follow amylose content because rice was known to cook similarly to rice in a cook type not corresponding to the amylose content.

Statistical Analyzes

For the sensory data, a scatterplot consisting of the scores assigned to each sample in a panel session was produced for each panelist and attribute. For a given session, these scatterplots were visually examined to identify which panelists were not performing to consensus during a session. No outliers were identified for 12 attributes. For the other 13 attributes, two (three attributes), five (two attributes), and six (one attribute) outlier scores were removed (Bett et al 1993). Blind control samples were used to remove variation due to different panel sessions. Means obtained in panel sessions containing a blind control sample that fell outside 99% confidence limits of the grand blind control mean were adjusted inward to the 99 percentile. This occurred in less than two sessions for each descriptor. All data were standardized to zero mean and unit standard deviation before analysis. Ward's Cluster Analysis (SAS Institute, Cary, NC) was performed on the three sets of means (flavor, texture, and chemical composition [amylose and protein]) by weighting the three sets equally in the analysis. Tukey-Kramer honestly significant difference tests were used to compare cluster means (Tukey 1955 and Kramer 1956) using JMP v. 3 Statistical Discovery Software (SAS).

RESULTS AND DISCUSSION

The 91 rice samples were divided by Ward's Cluster Analysis into seven groups. Tables I and II shows the cultivars in each cluster, harvest locations, grain types, rice-to-water ratios used for cooking, and amylose and protein contents. The clusters have some logical divisions; however, many cultivars are included in clusters for unobvious reasons. Table III displays the means of each attribute for each cluster and indicates which cluster means are significantly different.

Cluster 1

This cluster includes approximately one third of all the rice samples and has cultivars with a large diversity of grain shapes and

TABLE II
Description of Rice Samples in Clusters 4 Through 7

Cultivar	Location	Grain Type	Rice to Water Ratio[a]	Amylose	Protein
Cluster 4					
Akitakomachi	CA	short	1:1.4	15.6 ± 0.1	6.4 ± 0.2
Bengal	TX	medium	1:1.4	13.0 ± 0.1	7.9 ± 0.1
Century Patna 231	AR	long	1:1.7*	14.0 ± 0.2	8.6 ± 0.0
Kaybonnet	TX	long	1:1.7	21.8 ± 0.0	8.0 ± 0.2
Kosanebare	LA	medium	1:1.4	15.1 ± 0.2	7.8 ± 0.1
Koshihikari	CA	short	1:1.4	16.0 ± 0.5	5.2 ± 0.1
M-204	CA	medium	1:1.4	17.5 ± 0.0	7.2 ± 0.1
M-401	CA	medium	1:1.4	17.1 ± 0.1	6.2 ± 0.2
Nipponbare	LA	short	1:1.4	16.1 ± 0.2	7.6 ± 0.0
Nortai	LA	short	1:1.4	15.8 ± 0.0	7.3 ± 0.0
Taichung 8	Taiwan	medium	1:1.4	15.2 ± 0.3	6.5 ± 0.2
Tebonnet	AR	long	1:1.7	22.3 ± 0.2	7.7 ± 0.3
Cluster 5					
AB 647	LA	medium	1:1.4*	24.2 ± 0.1	9.8 ± 0.4
Bellemont	LA	long	1:1.7	23.0 ± 0.4	8.1 ± 0.1
Bluebonnet	LA	long	1:1.7	21.5 ± 0.2	9.3 ± 0.2
Chui 1	LA	long	1:1.7	24.8 ± 0.1	8.6 ± 0.7
Dixiebelle	TX	long	1:1.7	24.9 ± 0.1	7.9 ± 0.3
El Passo 144	TX	long	1:1.7	24.5 ± 0.3	9.1 ± 0.4
Guichow	LA	short	1:1.7	24.1 ± 0.0	8.6 ± 0.3
IRGA409	TX	long	1:1.7	23.8 ± 0.1	9.5 ± 0.0
L-202	AR	long	1:1.7	24.1 ± 0.1	8.8 ± 0.1
LA-110	LA	medium	1:1.7	21.2 ± 0.1	9.8 ± 0.5
Nanking Sel	LA	medium	1:1.4*	24.5 ± 0.0	9.6 ± 0.4
Newrex	LA	long	1:1.7	23.5 ± 0.3	9.7 ± 0.3
Oryzicola Llamos	LA	long	1:1.7	23.2 ± 0.1	9.7 ± 0.0
Rexmont	LA	long	1:1.7	23.7 ± 0.1	8.4 ± 0.1
Starbonnet	LA	long	1:1.7	21.9 ± 0.1	7.6 ± 0.7
Taichung Sen 19	Taiwan	long	1:1.7	24.9 ± 0.1	6.8 ± 0.2
Taim	LA	long	1:1.7	24.3 ± 0.5	9.2 ± 0.0
Taro	TX	long	1:1.4	13.2 ± 0.2	7.4 ± 0.0
Cluster 6					
A-201	CA	long	1:1.7	24.1 ± 0.1	8.1 ± 0.2
A-301	LA	long	1:1.7	20.6 ± 0.4	9.6 ± 0.4
Dellmont	LA	long	1:1.7	21.8 ± 0.1	8.3 ± 0.3
Goolarah	LA	long	1:1.7*	14.4 ± 0.4	9.1 ± 0.2
Ilpoom	Korea	medium	1:1.4	17.9 ± 0.2	7.8 ± 0.3
Kyeema	Aust	long	1:1.7*	17.0 ± 0.4	8.3 ± 0.1
Kyeema	LA	long	1:1.7*	14.3 ± 0.0	8.6 ± 0.0
Lacassine	LA	long	1:1.7	21.6 ± 0.2	8.3 ± 0.1
Cluster 7					
Arborio	LA	medium	1:1.4	15.2 ± 0.2	9.4 ± 0.1
AS 3510	LA	long	1:1.7	20.0 ± 0.2	9.6 ± 0.2
Baldo	TX	medium	1:1.4	13.1 ± 0.3	9.0 ± 0.0
Calmochi-101	CA	short	1:1	0.4 ± 0.0	7.2 ± 0.2
Calmochi-101	AR	short	1:1	0.5 ± 0.1	8.2 ± 0.0
M-201	TX	medium	1:1.4	10.7 ± 0.1	10.9 ± 0.2
M-202	TX	medium	1:1.4	10.3 ± 0.2	8.4 ± 0.1
Taichung Sen Waxy	Taiwan	short	1:1	0.9 ± 0.2	11.2 ± 0.2

[a] Rice-to-water weight ratio (*) did not follow amylose content because rice was known to cook similarly to rice in a cook type not corresponding to the amylose content.

amylose contents. Average attribute scores for this cluster are near the grand mean for nearly every sensory attribute of the collective rice samples. Thus, although this cluster represents widely diverse cultivars grown in different locations, the panelists gave the cultivars very similar scores. In general, the cultivars in this cluster were scored as relatively low for haylike flavor, residuals and loose particles, and toothpacking. Scores for moisture absorption were relatively high.

The cultivars in Cluster 1 are nonaromatic, with the exception of Della. The high popcorn (2.2) and corn (1.5) flavors of Della indicate a fit in Cluster 6 with the other fragrant cultivars, including its progeny Dellmont and A-301. But Della had a higher sewer-animal flavor (1.6) than the other cultivars in Cluster 6, which probably contributed to it being in Cluster 1.

Cluster 2

Cluster 2 consists predominantly of low amylose, nonaromatic, medium-grain cultivars. Exceptions to this are the short grains S-102 and Calmochi-101, and long grains L-204 and Pelde. This cluster includes the U.S. medium-grain cultivars Calrose 76, M-202, M-401, Mars, Rico 1, and Saturn. Cluster 2 is ranked one of the lowest for corn, sewer-animal, sour, and waterlike flavors, but one of the highest in floral flavor. The cluster is also one of the lowest for astringent mouthfeel. The cluster is high in moisture absorption, slickness, and uniformity of bite. It has the second lowest mean protein content of the seven clusters and a mean amylose content similar to Cluster 3.

Some of the cultivars in Cluster 2 have common parentage. Amaroo, an Australian cultivar, and Calrose 76 have Calrose in their parentage (M. Fitzgerald, NSW Agriculture, *personal communication*) (Rutger et al 1977). Mars has Saturn in its parentage (Johnston et al 1979). S-102 is a short-grain cultivar with Calmochi-101, a waxy cultivar, in its parentage (McKenzie et al 1997). Only Calmochi-101 grown in Texas belongs to this cluster. The Calmochi-101 grown in Arkansas and California are in Cluster 7. Characteristic of Cluster 2, Calmochi-101 grown in Texas was low in sewer-animal (1.2), sour (0.3), and waterlike (0.8) flavors; high in floral (1.0) flavor; and low in astringent mouthfeel (1.7). In contrast, Calmochi-101 grown in Arkansas and California had higher sewer-animal (2.1, 1.8); sour (1.0, .3); and waterlike (1.7, 1.4) flavors; lower floral (0.4, 0.4) flavor; and higher astringent mouthfeel (2.6, 2.4). Calmochi-101 grown in Texas also had textural properties characteristic of Cluster 2 with high moisture absorption (5.1) and uniformity of bite (8.4). Grown in Arkansas and California, the cultivar had lower moisture absorption (4.6, 4.7) and uniformity of bite (7.3, 8.1). Environmental factors were probably responsible for the flavor and texture differences of Calmochi-101 grown in Texas when compared with that grown in Arkansas and California.

The long-grain cultivar L-204 had textural properties similar to the medium-grain cultivars in Cluster 2, even though the amylose content is high (22.7%) suggesting a rice that cooks dry and fluffy. L-204 had high moisture absorption (5.2) and slickness (5.9), textural properties characteristic of Cluster 2. Pelde, the other long-grain cultivar in Cluster 2, also had textural properties characteristic of Cluster 2 with high moisture absorption (5.2) and uniformity of bite (8.8). The low (12.2%) amylose content of Pelde suggests that it would have these textural properties.

Cluster 3

Cluster 3 consists of four low-amylose, medium-grain rice cultivars that were grown in Louisiana. These cultivars are nonaromatic and were low in seven of the 12 flavor attributes. The attributes which were low are the desirable flavor attributes corn, dairy, floral, grain-starchy, popcorn, sweet aromatic, and sweet. This cluster was high for astringent mouthfeel and less desirable flavor attributes sewer-animal and haylike. Cluster means for corn and dairy flavors were significantly lower ($P < 0.05$) than the means for these attributes for Clusters 4–7. The cluster mean for sweet aromatic was significantly lower ($P < 0.05$) than the means for this attribute for all the other clusters. The means for sewer-animal and haylike flavors were significantly higher ($P < 0.05$) for Cluster 3 than for Clusters 1, 2, 4, 5, and 6 and Clusters 1, 2, 5, and 6, respectively.

The cluster scored high for chewiness and roughness, which can be considered undesirable attributes. Although, not the highest group, Cluster 3 was high in cohesiveness, cohesiveness of mass, and residuals-loose particles.

Two medium-grain cultivars, Brazos and Mercury, grown in the same environment in Louisiana, did not share the flavor and texture attribute intensities characteristic of Cluster 3 and loaded in Cluster 1.

Cluster 4

The cultivars in Cluster 4 are low-intermediate amylose, short- or medium-grain cultivars, with the exception of three long-grain culti-

Phase	Attribute	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 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	Degree to which the kernels adhere to each other
Phase II (Place ½ teaspoon of rice in mouth. Evaluate before or at first bite.)		
	Springiness	Degree grains return to original shape after partial compression
	Cohesiveness	Degree to which 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 the 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.)		
	Residuals or loose particles	Amount of loose particles in mouth
	Toothpack	Amount of product adhering in or on the teeth

Fig. 1. Descriptive sensory analysis attributes and definitions used to evaluate cooked rice texture.

vars. Tebonnet and Kaybonnet, long-grain cultivars with high-amylose content, have relatively slender grains and may have cooked soft relative to other high amylose grains (Kuenzel et al 1985, Gravois et al 1995). Century Patna 231, the other long-grain cultivar in Cluster 4, has a low-amylose content. Cluster 4 is characterized as high in dairy, sweet and waterlike flavors. It is low in roughness and high in initial starchy coating and slickness. The cluster has the lowest protein content.

Cluster 4 includes all of the Japanese premium quality rices such as Koshihkari, Akitakomachi, Kosanbare, and Nipponbare (Carnahan et al 1981). The U.S. cultivars M-204 and M-401 (grown in California) are in this cluster. M-401 was developed for the premium quality medium grain market (Carnahan et al 1981). M-401 produced in Texas loaded in Cluster 2, instead of Cluster 4. The amylose and protein contents of the M-401 grown in the two locations were markedly different. M-401 grown in California had amylose and protein contents of 17.1% and 6.2%, respectively. These amounts are consistent with those of the other cultivars in Cluster 4. In contrast, M-401 grown in Texas had amylose and protein contents of 12.4 and 8.3%, respectively. The low amylose content of the Texas grown M-401 is consistent with the mean amylose content of Cluster 2. The protein content was higher than the mean content of Cluster 2. Even with these large differences in amylose and protein contents, the cultivar grown in Texas and that grown in California had the same chewiness, hardness, and cohesiveness of mass scores. However, the intensities of cohesiveness (5.2 vs. 4.9), initial starchy coating (3.1 vs. 2.5), slickness (5.7 vs. 5.2), springiness (3.8 vs. 3.4), and stickiness (6.0 vs. 5.7), were higher in the M-401 grown in California compared with that grown in Texas. The high initial starchy coating and slickness of M-401 grown in California is consistent with the cultivar in Cluster 4. The high uniformity of bite (8.8 vs. 8.1) is consistent with the M-401 grown in Texas in Cluster 2.

The intensities of the flavor attributes were also consistent with M-401 grown in California in Cluster 4 and that grown in Texas in Cluster 2. Consistent with Cluster 4, M-401 grown in California was high in dairy (1.6), sweet (1.3), and waterlike (1.7) flavor. M-401 grown in Texas was lower in dairy (1.2) and sweet (1.1) flavors, and the same in waterlike (1.7) flavor. Characteristic of Cluster 2, M-401 grown in Texas was very low in corn (0.7) and sewer-animal (0.8) flavors. M-401 grown in California was higher in both corn and sewer-animal (1.3 and 1.2, respectively).

Century Patna 231 is a cultivar that had excellent yield potential when it was released in 1951, but was considered undesirable by the industry because of poor grain integrity after cooking (McKenzie 1994). The Century Patna 231 grown in Arkansas loaded in Cluster 4, while that grown in Texas was loaded in Cluster 1. The amylose content of the cultivar grown in Texas was lower (12.3%) than that (14.0%) of the cultivar grown in Arkansas. Protein contents were about the same (8.4 vs. 8.6%). Several of the texture attributes were of lower intensity in the Texas grown cultivar: initial starchy coating (2.6 vs. 3.0), slickness (3.8 vs. 4.9), and springiness (3.5 vs. 4.2). These attributes were also lower in the M-401 grown in Texas, which had lower amylose content than its counterpart grown in California. As with the M-401 grown in Texas, the Texas-grown Century Patna 231 had higher uniformity of bite than that grown in Arkansas (8.9 vs. 8.4). Characteristic of Cluster 4, the Century Patna 231 grown in Arkansas was high in dairy (2.2) and sweet (1.2) flavors. The cultivar grown in Texas had lower intensities for dairy (1.7) and sweet (0.8), consistent with Cluster 1.

The short-grain cultivar, Nortai is a U.S. variety with Taiwanese parentage (Johnston et al 1973), whereas Taichung 8 is a medium-grain cultivar developed and produced in Taiwan.

Of interest to the U.S. industry is understanding the nuances in flavor and texture differences between traditional U.S. medium-grain cultivars (Cluster 2) and Japanese or Japanese-like premium quality

Attributes	Definition
Aromatics	
Sewer or animal	An immediate and distinct pungent aromatic in the flavor characterized as sulfurlike and generic animal. The animal aromatic in the flavor can sometimes be identified as "piggy".
Floral	Aromatics associated with dried flowers, such as lilac or lavender. This aromatic is characterized as spicy floral as in an "old fashioned sachet".
Grain or 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.
Haylike or musty	A dry, dusty, slightly brown aroma or 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.
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 or aromatics.
Tastes	
Sweet	Basic sweet taste associated with sugar.
Sour or silage	A sour fermented vegetation aroma or flavor, not decaying vegetation.
Feeling Factors	
Astringent	The chemical feeling factor on the tongue, described as puckering or dry and associated with tannins or alum.
Waterlike or metallic	Aromatics and mouthfeel of the minerals and metals commonly associated with tap water. This excludes any chlorine aromatics that may be perceived.

Fig. 2. Descriptive sensory analysis attributes and definitions used to evaluate cooked rice flavor.

rices (Cluster 4). The means for dairy and waterlike flavor and astringent mouthfeel were significantly higher ($P < 0.05$) for Cluster 4 than for Cluster 2. No significant differences were observed in the mean intensities for the textural attributes when compared between these two clusters.

Cluster 5

Cluster 5 consists primarily of the indica type rices, which characteristically have high amylose content (23.2%), high protein content (8.8%), and cook relatively firm. As expected, this cluster has high intensities for springingess and hardness but low intensities for cohesiveness, initial starchy coating, cohesiveness of mass, moisture absorption, slickness, stickiness, toothpacking, and uniformity of bite. Mean hardness was significantly higher ($P < 0.05$) and mean cohesiveness of mass and mean stickiness were significantly lower ($P < 0.05$) for Cluster 5 than the means for the respective attributes for all the other clusters. The mean for initial starchy coating was significantly lower ($P < 0.05$) than the means for all the other clusters, except Cluster 3. The cultivars in Cluster 5 were not particularly unique for any of the flavor attributes. They were low in waterlike flavor and astringent mouthfeel.

Many of the cultivars in this cluster have been derived from indica parentage and possess a unique allele of the waxy gene that has been associated with a specific microsatellite marker (Ayers et al 1997). The presence of this gene is generally associated with cultivars that have superior parboiling and canning stability. Examples of U.S. cultivars that have this property and belong to this cluster include Rexmont (Bollich et al 1990), Newrex (Bollich et al 1980), and Dixiebelle (McClung et al 1998). However, only Rexmont grown in Louisiana loaded in this cluster; Rexmont grown in Arkansas loaded in Cluster 1. Amylose content was the same for both locations, while protein content was higher (9.1 vs. 8.4) in the Rexmont grown in Louisiana. Rexmont grown in Louisiana was higher in cohesiveness (5.3 vs. 4.9) and cohesiveness of mass (5.5 vs. 4.9).

Likewise, IR64 and IR72 were expected to be in Cluster 5 instead of Cluster 1, based on amylose content and indica parentage. IR64 and IR72 scored relatively high for moisture absorption (4.9, 5.3) and stickiness (5.5, 5.0) but relatively low for springiness (3.9, 3.9), which differentiated them from the means of Cluster 5. IR64 was also very low in hardness (4.2), which was characteristic of Cluster 1 and not Cluster 5.

Taro, a low amylose long grain from Italy, was atypical of other cultivars in Cluster 5. Its inclusion in this cluster may be due to the lower water ratio used in cooking this cultivar, resulting in it cooking firm. LA-110 was developed as a brewer's rice with Taichung 1 in its lineage (McIlrath et al 1979). El Passo-144 is a high-yielding cultivar from Uruguay. Oryzicola Liamos is a nonaromatic Colombian rice. AB 647, Nanking Selection, and Guichow are medium-grain cultivars that perform like long-grain cultivars.

Cluster 6

All of the cultivars in Cluster 6 are aromatic long-grain rices with the exception of Ilpoom, a Korean aromatic medium-grain cultivar. Goolarah and Kyeema are fragrant Jasmine-type Australian cultivars, while Dellmont, A-201, and A-301 are fragrant U.S. cultivars. This cluster scored high for five flavor traits including floral, corn, sweet aromatic and sweet taste, and had very high scores for popcorn flavor. Mean corn, popcorn, and sweet aromatic flavors were significantly higher ($P < 0.05$) than the means for the respective attributes in all the other clusters. Cluster 6 scored low in haylike and sewer-animal flavors. It is fairly intense in grain-starchy flavor. The cultivars in Cluster 6 typically cooked soft, moist and clingy. Means of this cluster were relatively low for springiness, chewiness, hardness, residual loose particles and toothpacking. Low intensities for these traits indicate a soft cooking rice. Mean chewiness score was lowest for all the clusters and significantly lower ($P < 0.05$) than the means for Clusters 2, 3, 5, and 7. A-301 and Dellmont have Della in their lineage (Tseng et al 1987, Bollich et al 1993).

TABLE III
Means and Standard Error of Seven Clusters for Each Attribute Analyzed[a]

Attribute	Mean	Cluster 1	2	3	4	5	6	7
Astringent mouthfeel	1.7	1.6 ± 0.0^{7}	1.5 ± 0.1^{347}	2.0 ± 0.1^{25}	1.8 ± 0.1^{2}	1.6 ± 0.1^{37}	1.6 ± 0.1^{7}	2.1 ± 0.1^{1256}
Corn flavor	1.3	1.2 ± 0.0^{6}	1.1 ± 0.1^{6}	0.8 ± 0.1^{4567}	1.3 ± 0.1^{36}	1.2 ± 0.1^{36}	2.1 ± 0.1^{123457}	1.3 ± 0.1^{36}
Dairy flavor	1.5	1.5 ± 0.1^{47}	1.3 ± 0.1^{467}	1.1 ± 0.1^{4567}	1.8 ± 0.1^{123}	1.6 ± 0.1^{3}	1.7 ± 0.1^{23}	1.8 ± 0.1^{123}
Floral flavor	0.5	0.5 ± 0.0	0.6 ± 0.1	0.3 ± 0.1	0.5 ± 0.1	0.5 ± 0.0	0.6 ± 0.1	0.5 ± 0.1
Grain-starchy flavor	2.7	2.8 ± 0.0^{37}	2.7 ± 0.1^{7}	2.3 ± 0.1^{167}	2.8 ± 0.1	2.6 ± 0.1^{7}	2.8 ± 0.1^{3}	3.1 ± 0.1^{1235}
Haylike flavor	1.2	1.0 ± 0.1^{37}	1.1 ± 0.1^{37}	1.7 ± 0.1^{1256}	1.3 ± 0.1	1.1 ± 0.1^{37}	1.1 ± 0.1^{37}	1.5 ± 0.1^{1256}
Popcorn flavor	1.0	0.9 ± 0.1^{6}	0.8 ± 0.1^{6}	0.7 ± 0.1^{6}	0.9 ± 0.1^{6}	1.0 ± 0.1^{6}	2.3 ± 0.1^{123457}	1.0 ± 0.1^{6}
Sewer-animal flavor	1.5	1.5 ± 0.1^{3}	1.2 ± 0.1^{37}	2.6 ± 0.2^{12456}	1.3 ± 0.1^{3}	1.7 ± 0.1^{3}	1.2 ± 0.1^{37}	1.9 ± 0.1^{26}
Sour taste	0.4	0.4 ± 0.0	0.4 ± 0.0^{37}	0.7 ± 0.1^{24}	0.4 ± 0.0^{37}	0.4 ± 0.0	0.4 ± 0.1	0.6 ± 0.1^{24}
Sweet aromatic flavor	0.8	0.7 ± 0.1^{36}	0.9 ± 0.1^{36}	0.3 ± 0.1^{124567}	0.8 ± 0.1^{36}	0.8 ± 0.1^{36}	1.3 ± 0.1^{123457}	0.9 ± 0.1^{36}
Sweet taste	1.0	1.0 ± 0.0	1.0 ± 0.1	0.8 ± 0.1^{46}	1.1 ± 0.1^{3}	0.9 ± 0.0^{6}	1.2 ± 0.1^{35}	1.0 ± 0.1
Waterlike flavor	1.6	1.8 ± 0.0^{25}	1.3 ± 0.1^{1467}	1.6 ± 0.1	1.8 ± 0.1^{25}	1.5 ± 0.1^{14}	1.7 ± 0.1^{2}	1.7 ± 0.1^{2}
Chewiness	5.5	5.4 ± 0.0^{257}	5.6 ± 0.1^{16}	5.7 ± 0.1^{6}	5.4 ± 0.1	5.6 ± 0.1^{16}	5.2 ± 0.1^{2357}	5.7 ± 0.1^{16}
Cohesiveness	5.0	5.0 ± 0.1	5.2 ± 0.1^{5}	5.2 ± 0.2	5.0 ± 0.1	4.7 ± 0.1^{27}	4.8 ± 0.1	5.4 ± 0.1^{5}
Hardness	4.5	4.3 ± 0.1^{5}	4.3 ± 0.1^{5}	4.3 ± 0.2^{5}	4.3 ± 0.1^{5}	5.2 ± 0.1^{123467}	4.0 ± 0.2^{5}	4.4 ± 0.2^{5}
Initial starchy coating	2.4	2.3 ± 0.1^{457}	2.5 ± 0.1^{57}	2.3 ± 0.2^{7}	2.7 ± 0.1^{15}	1.8 ± 0.1^{12467}	2.5 ± 0.1^{57}	3.1 ± 0.1^{12356}
Cohesiveness of mass	5.8	5.7 ± 0.1^{57}	6.2 ± 0.1^{5}	6.1 ± 0.2^{5}	6.0 ± 0.1^{5}	5.0 ± 0.1^{123467}	5.7 ± 0.1^{57}	6.5 ± 0.1^{156}
Moisture absorption	4.9	5.1 ± 0.0^{57}	5.1 ± 0.1^{57}	5.0 ± 0.1	4.9 ± 0.1^{5}	4.7 ± 0.2^{1246}	5.0 ± 0.1^{5}	4.8 ± 0.1^{12}
Roughness	6.1	6.3 ± 0.1^{4}	6.1 ± 0.1	6.5 ± 0.2^{4}	5.8 ± 0.1^{13}	6.2 ± 0.1	5.9 ± 0.1	6.1 ± 0.1
Residuals-loose particles	4.1	4.1 ± 0.0^{7}	4.1 ± 0.0^{7}	4.2 ± 0.1	4.2 ± 0.0	4.2 ± 0.0	4.0 ± 0.1^{7}	4.4 ± 0.1^{126}
Slickness	4.8	4.5 ± 0.1^{247}	5.3 ± 0.1^{156}	4.6 ± 0.2	5.2 ± 0.1^{15}	4.6 ± 0.2^{247}	4.6 ± 0.4^{2}	5.1 ± 0.2^{15}
Springiness	3.9	3.9 ± 0.1^{5}	3.8 ± 0.1^{5}	3.9 ± 0.1	4.0 ± 0.1	4.2 ± 0.1^{126}	3.7 ± 0.1^{5}	4.0 ± 0.1
Stickiness	5.1	4.9 ± 0.1^{257}	5.5 ± 0.1^{15}	5.2 ± 0.2^{5}	5.3 ± 0.1^{5}	4.3 ± 0.1^{123467}	5.3 ± 0.2^{5}	5.7 ± 0.2^{15}
Tooth packing	4.3	4.2 ± 0.0^{7}	4.4 ± 0.1^{7}	4.5 ± 0.1	4.5 ± 0.1	4.2 ± 0.1^{7}	4.2 ± 0.1^{7}	4.7 ± 0.1^{1256}
Uniformity of bite	8.0	8.1 ± 0.1^{5}	8.4 ± 0.1^{5}	8.1 ± 0.1	8.0 ± 0.1	7.6 ± 0.1^{126}	8.4 ± 0.1^{5}	7.9 ± 0.2
Protein	8.34	8.46 ± 0.2^{4}	7.70 ± 0.2^{57}	8.61 ± 0.4	7.37 ± 0.2^{157}	8.81 ± 0.2^{24}	8.48 ± 0.3	9.26 ± 0.3^{24}
Amylose	17.76	19.20 ± 0.8^{257}	14.18 ± 1.1^{15}	14.11 ± 2.1^{5}	17.02 ± 1.1^{57}	23.17 ± 1.0^{12347}	18.97 ± 1.5^{7}	8.87 ± 1.5^{1456}

[a] Superscripts 1–7 indicate mean is significantly different from the means of clusters 1–7 based on Tukey-Kramer honestly significant difference test.

Dellmont had the most intense floral flavor (0.9) and Kyeema grown in Louisiana had the most intense popcorn flavor (3.0). The Kyeema grown in Louisiana had higher corn (2.3 vs. 1.7), popcorn (3.0 vs. 1.8), sweet aromatic (1.5 vs. 1.1) and sweet taste (1.5 vs. 1.1) flavors than that grown in Australia. The textural properties of the two rice samples also differed. The intensities of the texture attributes of Kyeema grown in Louisiana were consistent with cluster means and indicative of a soft cooking rice. The texture of Kyeema grown in Australia, however, was not characteristic of Cluster 6. This sample was high in hardness (4.9), springiness (4.4), and roughness (6.9) which are indicative of a rice that cooks firm (cultivars in Cluster 5).

Cluster 7

Cluster 7 contains three waxy cultivars and other soft cooking grains. The nonwaxy cultivars in Cluster 7 have high protein content. This cluster, therefore, has the highest mean protein and lowest mean amylose content. The cultivars in this cluster were highest in chewiness, cohesiveness, cohesiveness of mass, initial starchy coating, residual loose particles, stickiness, and toothpacking. They were also the highest in astringent mouthfeel, dairy, and grain-starchy flavors, and sour taste. Mean astringent mouthfeel and haylike flavors, initial starchy coating, and toothpacking were significantly higher ($P < 0.05$) for Cluster 7 than the means for the respective attributes for Clusters 1, 2, 5, and 6. Mean initial starchy coating for Cluster 7 was also significantly higher ($P < 0.05$) than the mean score for Cluster 3. The mean for grain-starchy flavor was significantly higher ($P < 0.05$) for Cluster 7 than the mean scores for Clusters 1, 2, 3, and 5.

Calmochi-101 grown in California and Arkansas belonged to Cluster 7, while that grown in Texas was in Cluster 2. Calmochi-101 produced in Texas had dairy (1.0), grain-starchy, (2.5), haylike (1.0), sewer-animal (1.2), sour (0.3), and waterlike (0.7) flavors; astringent feeling factor (1.7); and residual loose particles (4.0), springiness (3.7), and moisture absorption (5.1) intensities consistent with the means of Cluster 2, not Cluster 7.

In addition to the waxy rices, the nonwaxy medium grain cultivars, M-201, Baldo, M-202 (grown in Texas), and Arborio, were included in this cluster. The M-202 grown in California loaded in Cluster 2 with the California medium grain rice cultivars and scored lower than the sample grown in Texas for astringent feeling factor (1.4 vs. 2.1) and dairy (1.0 versus 2.0), haylike (0.7 vs. 1.6), grain-starchy (2.8 vs. 3.1), sewer-animal (0.9 vs. 1.8), and waterlike (1.5 vs. 2.1) flavors. It was less hard (3.7 vs. 4.3) and springy (3.5 vs. 4.1) and had lower initial starchy coating (2.8 vs. 3.0) and toothpacking (4.1 vs. 4.4), which was consistent with Cluster 2 compared with Cluster 7. The Texas-grown M-202 was lower than the California grown sample in amylose (10.3, 14.8%) and higher in protein (8.4, 6.8%). The production environment affected the texture and flavor attributes of M-202.

The nonwaxy cultivars, AS3510, M-201, M-202, Baldo, and Arborio were much lower in initial starchy coating (2.1, 2,5, 2.8, 3.1, and 2.7, respectively) than the Calmochi-101 grown in California (4.0) and Arkansas (4.0). The same pattern occurred in stickiness (4.9, 5.2, 5.4, 5.7, 5.1) vs. 7.1 and 6.6 for the Calmochi-101 grown in Arkansas and California, respectively. The Taichung Sen Waxy was more in line with the nonwaxy cultivars in these two attributes (3.3 initial starchy coating, 5.6 stickiness).

CONCLUSIONS

Seven clusters were identified which help establish unique categories for rice cultivars. Cluster 1 included a third of the cultivars evaluated in this study as well as all but one of the testing environments. As a result of this diversity, Cluster 1 produced mean values that were similar to the grand mean for many of the traits. Cluster 2 was predominated by conventional U.S. short- and medium-grain cultivars. Cluster 3 contained conventional U.S. medium cultivars that were produced in Louisiana. Mean sensory scores for this cluster characterized these cultivars as having relatively undesirable flavor and textural attributes. Cluster 4 included the Japanese premium quality cultivars and U.S. medium-grain cultivars developed for the Japanese market. Cluster 5 was represented by high-amylose indica types that had relatively firm textural properties. Cluster 6 was predominated by relatively soft cooking, aromatic cultivars. Cluster 7 contained the waxy cultivars and other soft cooking grains. Because flavor and texture, in addition to amylose and protein contents, were included in grouping the cultivars, these clusters capture more sensory impact than the grain size categories. Knowing similarities and differences in both texture and flavor of cultivars will help guide cultivar development and marketing of existing cultivars. These clusters illustrate that the production environment affects the total sensory perception and can prevent a cultivar from meeting expectations for performance. Future research is needed to evaluate cultivar clusters using instrumental methods for assessment of sensory and processing qualities.

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