Quality Evaluation of U.S. Medium-Grain Rice Using a Japanese Taste Analyzer

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ABSTRACT

Cereal Chem. 73(2):290–294

Taste analyzers, developed in Japan, convert various physicochemical parameters of rice into "taste" scores based on correlations between near-infrared reflectance (NIR) measurements of key constituents (e.g., amylose, protein, moisture, fat acidity) and preference sensory scores. These taste analyzers are being used by Japanese millers and wholesalers to grade rice, both domestic and imported. This study examines the applicability of using the Satake Neuro Fuzzy Rice Taster for evaluating U.S. medium-grain rice cultivars. The Rice Taster, as presently calibrated, does not appear to be a valid tool for assessing rice cultivars with low (<18%) amylose contents. The low-amylose cultivars fell outside the range of the calibration set used by Satake. The effects of degree-of-milling and U.S. shipping practices on Rice Taster scores (S) were also determined. Conditioning of the bran during four weeks refrigerated storage led to the bran being more readily removed from the kernel during milling. This resulted in the milled rice having significantly lower protein ($P < 0.0001$), free fatty acids ($P < 0.01$), and n-hexanal ($P < 0.0001$) levels, increased whiteness ($P < 0.0001$) and milling degree ($P < 0.0001$) measures, and higher S ($P < 0.0001$) values. Deep milling significantly increased ($P < 0.0001$) chemical measures of amylose and significantly decreased protein and free fatty acids contents ($P < 0.0001$). Rice Taster measurements of "amylose" (A) and protein (B) significantly decreased ($P < 0.0001$) with deep milling. Moisture (C), "fat acidity" (D^a), and milling yield (D^b) were not significantly ($P > 0.05$) affected. S significantly ($P < 0.0001$) increased (mean 5 points) with deep milling.

Taste analyzers developed in Japan convert various physicochemical parameters of rice into "taste" scores based on correlations between near-infrared reflectance (NIR) measurements of key constituents (e.g., amylose, protein, moisture, fat acidity) and preference sensory scores. These taste analyzers provide rapid screening and are being used by Japanese millers and wholesalers to grade rice, both domestic and imported. A Japanese rice scoring in the 80s (0–100 scale) is considered to be of excellent quality. Low scores have been reported for U.S. medium-grain rices considered by the U.S. industry to be of high quality. Why U.S. rice cultivars score low is unknown. The Japanese taste analyzers are not marketed in the United States and have not been evaluated by the U.S. industry.

Differences in constituent contents between U.S. and Japanese cultivars are expected to contribute to the low scoring of U.S. rices. U.S. medium-grain rice cultivars typically have higher protein contents and higher amylose-to-amylopectin ratios than premium Japanese rice cultivars. The Japanese consider rice with low protein content and low amylose-to-amylopectin ratio to have desirable taste and textural attributes. Such rice would receive a high preference sensory score, and consequently a high taste score.

Lower moisture content in U.S. rice as compared to Japanese rice is also expected to contribute to U.S. rice having lower taste scores. Rough rice is commonly dried to 12% moisture in the U.S., in contrast to 15% in Japan. Rice of higher moisture content produces a cooked rice that is softer and stickier, characteristics deemed desirable to the Japanese palate.

Other factors that may explain differences in scores in U.S. and Japanese rices include differences in U.S. and Japanese postharvest handling practices (drying, milling, shipping). In the U.S., rice is mechanically dried. In Japan, ≈45% is windrow dried on racks in the field, the remainder is mechanically dried. Abe et al (1991) reported that drying parameters (temperature, grain-to-air flow ratio, tempering conditions, exposure time) affected the scores of Japanese rice obtained on a prototype taste analyzer. Drying parameters leading to higher free fatty acids (FFA) development in the rice had lower scores.

This article reports the results of a collaborative study in which the applicability of using a Satake Neuro Fuzzy Rice Taster for evaluating U.S. medium-grain rice cultivars was assessed. In this initial study, it was of interest to determine the extent that lower protein content from deep milling would affect the taste score, and whether U.S. shipping practices result in scores being low. A later study will report the effects of drying conditions and final moisture content on taste scores and sensory characteristics. Understanding the impact of constituent content and postharvesting handling on taste scores and sensory characteristics will allow the U.S. industry to maximize the scores through optimization of postharvest handling and processing conditions and provide medium-grain cultivars with sensory characteristics desired by the Japanese market.

MATERIALS AND METHODS

Rice Sample Preparation

Conventionally harvested, dried (12–13% moisture), and stored (three months) rice from the 1993 crops of Mars, Orion, Bengal, and Rico grown in Louisiana, Arkansas, and Texas; Koshihikari grown in Arkansas; and M401 and Calrose grown in California were shelled using a Satake Rice Machine model SB. The result-

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Publication no. C-1996-0313-01R.

ing brown rice was immediately milled or stored in commercial polyweave bags at ambient temperature (30°C) for one or four days, followed by refrigeration for two- or four-week periods. These storage conditions simulate the handling of rice from the time of shelling through refrigerated transit to Japan by ship from California (10–17 days) or Louisiana (30 days). Following storage and after equilibration to room temperature, the brown rice was milled. Light (regular) milling was accomplished using a laboratory Satake one-pass mill (pearler, model SKD). The first pass was with a 50-g weight in the 5th position; the second pass was with a 50-g weight in the 3rd position. Deep milling was performed on a portion of the light-milled rice using a laboratory Satake grain testing mill (model TM05). Milling conditions were 1 min at 1,250 rpm using the 36-mesh abrasive wheel. Brokens were removed with appropriate sizing devices using standard indented plates and cylinders. Whiteness (*W*), translucency (*T*), and milling degree (*MD*) were measured using a Satake Milling Meter (model MM-1B). *MD* of regular-milled rice ranged from 70–110; deep-milled rice had *MD* scores ranging from 120–150.

Satake Neuro Fuzzy Rice Taster Measurements

Milled rice samples were ground and measured on the Rice Taster the day after milling. Before taking Rice Taster measurements, updated *F*-value coefficients were obtained for correcting calibration curves. Koshihikari from the prefecture of Niigata served as the high-scoring standard for the *F*-value calibrations. Koshihikari is considered a premium rice in Japan of excellent quality; it generally scores in the 80s on the Rice Taster. Michikogane from the prefecture of Hokkaido was chosen as the low-scoring standard. These calibration standards were obtained from Satake as milled rice in sealed bags. Following sample preparation procedures established by Satake, rice samples were ground at 40°C to a particle size of about 20-µm using a Satake mill. The ground samples were tempered for 2 hr at 25°C. Samples were evaluated on the Rice Taster using standard and modified software. The instrument's standard software reports measures of "amylose" (*A*), protein (*B*), moisture (*C*), and "fat acidity" (D^a). These are correlated with preference sensory analyses to give a score (*S*) for the rice. Measures for *A*, *B*, and *C* are the same using the modified software; D^b is a measure of estimated milling yield (1 – increase of whiteness from brown to white rice/200).

Chemical Analyses

Amylose was determined by the simplified assay method developed by Juliano (1971). Protein contents (N × 5.95) were determined by the combustion method on a LECO FP-428 nitrogen determinator (LECO, St. Joseph, MI). Moisture contents of milled kernels were determined by oven-drying ground material at 130°C for 1 hr (AMS 1959). As measures of the extent of lipolytic hydrolysis and oxidative deterioration in the kernels during handling and storage, FFA and *n*–hexanal contents, respectively, were determined on portions of the tempered sample. FFA content was measured by a microtitration method (Hoffpauir et al 1947); n–hexanal content was determined by dynamic headspace and gas chromatographic analysis (Champagne and Hron 1993).

TABLE I
Wavelengths and Corresponding Coefficients Used by the Satake Neuro Fuzzy Rice Taster

Wavelength (nm)	"Amylose" *A*	Protein *B*	Moisture *C*	"Fat Acidity" D^a
1940	1268.4	181.17	–216.98	–2858
2030	–371.56	0	0	251.7
2100	256.71	233.18	0	1553
2130	–1103.9	–387.22	16.343	0
2270	0	0	120.705	0
2370	–167.55	0	63.089	1291

RESULTS AND DISCUSSION

Evaluating U.S. Medium-Grain Cultivars Using the Satake Neuro Fuzzy Rice Taster

The development of the Satake rice taster technology and the apparatus employed are described in patents issued to Satake (1988, 1989) and in *Modern Rice Milling Technology* (Satake 1990). The Satake Neuro Fuzzy Rice Taster is a second-generation instrument employing a Technicon six-filter NIR spectrometer. This instrument measures the four components *A*, *B*, *C*, and *D* and correlates these through a fuzzy logic algorithm to sensory preference scores to give a taste score (*S*). *B* and *C* are direct measures of protein and moisture contents, respectively. *A* and *D* are related to amylose and fat acidity, respectively, but are not direct measures. They are measured values of amylose and fat acidity multiplied by corresponding factors. According to Satake, each factor was designed to reflect the value of the component and its effect on taste after the rice has been cooked. Satake regards the composition of the factors to be proprietary.

The wavelengths and corresponding coefficients used by the Rice Taster for determining *A*, *B*, *C*, and D^a are listed in Table I. The values displayed on the instrument panel can be calculated using the equation

$$X = F_{00} + F_{21}(\Sigma_i K_i m_i)$$

where $X = A$, B, C, or D^a; F_{00} = bias; F_{21} = skew; K_i = fixed value for each filter; and m_i = absorption value of each filter. Apparently, the factors for *A* and D^a are incorporated in the K_i values.

TABLE II
Correlation Between Chemical Analyses and Satake Neuro Fuzzy Rice Taster Measurements[a]

Component	Coefficient of Determination (r^2)
Amylose	0.2671
Amylose (>18.4%)	0.6476
Protein	0.8668
Moisture	0.7500
Fat acidity	No correlation
Estimated milling yield	No correlation

[a] *A* (amylose × factor), *B* (protein), *C* (moisture), D^a (fat acidity × factor), D^b (estimated milling yield).

TABLE III
Comparison of Chemical Amylose Values Obtained for U.S. Medium-Grain Rice Cultivars and *A* (amylose × factor) Values Obtained on a Satake Neuro Fuzzy Rice Taster

Chemical Amylose[a]	*A*
22.6	19.8
21.2	21.2
19.7	21.6
19.3	20.2
19.1	17.0
18.5	19.0
18.4	18.4
15.2	22.3
15.1	21.3
15.0	21.8
14.6	21.1
14.1	20.8
0.7[b]	22.4

[a] Starch basis.

[b] Waxy rice cultivar.

The preference sensory scores that are correlated with A, B, C, and D to obtain S were evaluations based on Japan's Food Agency's enforcement code for rice taste tests. Sensory assessment included appearance, flavor, viscosity, hardness, taste, and overall acceptability.

The relationships between chemical analyses and Rice Taster measurements were determined for the U.S. medium-grain cultivars evaluated in this study; values for the coefficient of determination (r^2) are listed in Table II. The correlation between chemical amylose values and A was very low; the correlation was closer, but poor, when chemical amylose values of 18.4% (starch basis) and larger were compared to A values. Table III allows a comparison of select chemical amylose values obtained for the U.S. medium-grain cultivars and their A values. Cultivars with amylose values in the 14–15% range had A values of 21–22. These high A values were probably the result of these cultivars having amylose contents falling outside the range of the calibration set used by Satake and are, therefore, invalid. (Japanese cultivars generally have amylose contents in the 18–23% range.) A falsely high A value will have a negative impact on S. The Rice Taster, as presently calibrated, does not appear to be a valid tool for assessing rice cultivars with low amylose contents. Satake has indicated to the authors that the instrument will be recalibrated with a set including low-amylose U.S. cultivars.

In examining the effects of storage and degree-of-milling on Satake A and S value measurements, samples with chemical amylose contents <18.4% have been removed from the data set.

Effect of Storage on Chemical and Rice Taster Measurements

Brown rice samples were immediately milled or stored in bags at ambient temperature (30°C) for one or four days, followed by refrigeration for two or four weeks. These storage conditions simulated the handling of rice from the time of shelling through refrigerated transit to Japan by ship from California (10–17 days) or Louisiana (30 days). W, as determined by the Satake Milling Meter, was not affected ($P > 0.05$) by increasing the storage time at ambient temperature from zero to one or four days, or at refrigerated temperature from zero to two weeks. However, samples stored at refrigerated temperatures for four weeks were significantly ($P < 0.0001$) whiter than those stored for two weeks. W increased from means of 41.9–43.4 and 46.9–51.3 for regular- and deep-milled rice, respectively. MD was not significantly affected ($P > 0.05$) for regular-milled rice. MD of deep-milled rice samples stored for four weeks (mean 149) was significantly ($P < 0.0001$) higher than that of those stored for two weeks (mean 126). T was not significantly affected ($P > 0.05$) by storage conditions.

Samples deep milled after four weeks of storage at refrigerated temperatures had significantly lower ($P < 0.0001$) protein contents (5.45%) than those stored two weeks (5.94%).

Figures 1 and 2 show the effects of storage on FFA and n-hexanal levels, respectively. Overall, FFA ($P < 0.01$) and n-hexanal ($P < 0.0001$) levels significantly decreased in regular- and deep-milled rice. These results were not foreseen. During storage, FFA and n-hexanal levels would be expected to remain constant or increase.

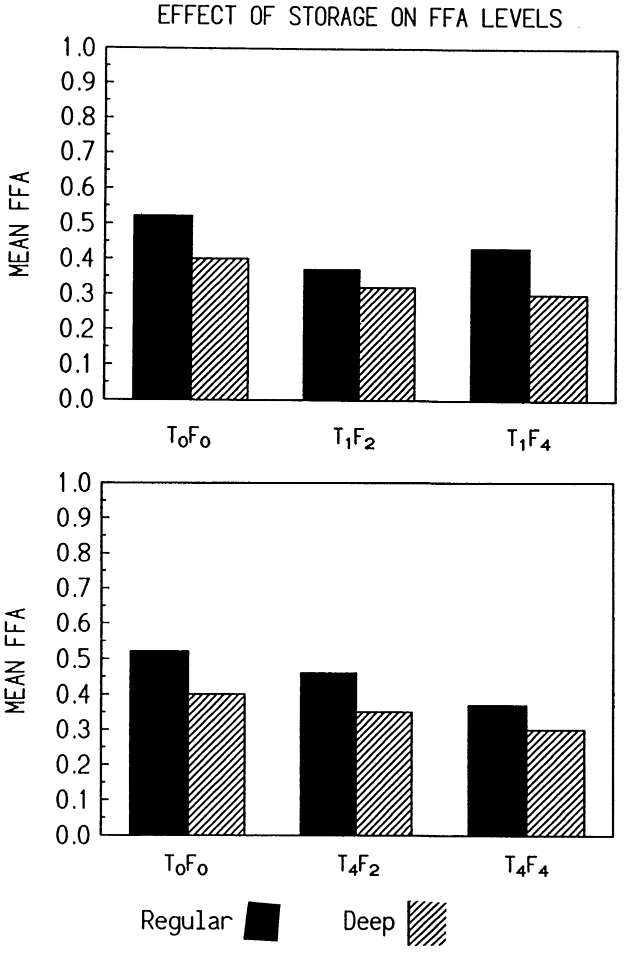

Fig. 1. Effects of storage on free fatty acid (FFA) levels. Samples were regular or deep-milled immediately (T_0F_0) or stored in bags at 30°C for one or four days (T_1 and T_4) followed by refrigeration for two or four weeks (F_2 and F_4). FFA content was calculated as oleic acid.

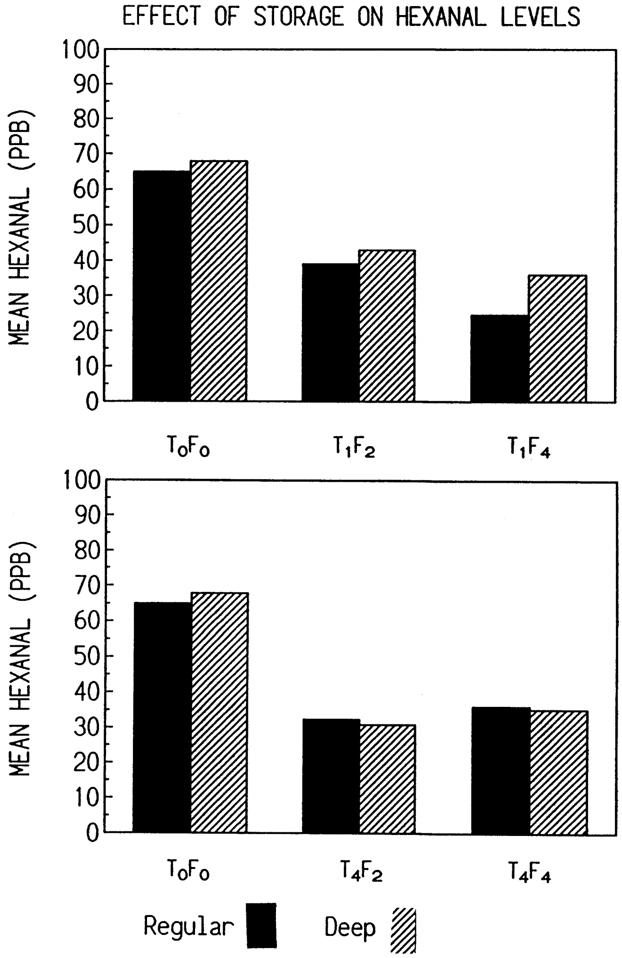

Fig. 2. Effects of storage on hexanal levels. Samples were regular or deep-milled immediately (T_0F_0) or stored in bags at 30°C for one or four days (T_1 and T_4) followed by refrigeration for two or four weeks (F_2 and F_4).

The decrease in protein, FFA, and *n*-hexanal levels, along with the increase in W and MD, can be explained by conditioning of the bran during refrigerated storage. With conditioning, the bran is more readily removed from the kernel during milling. Thus, under standard milling conditions (as used in this study), more bran is removed. This results in a deeper milled kernel that is whiter and has lower protein, FFA, and *n*-hexanal levels.

Amylose and moisture contents measured chemically did not significantly change ($P > 0.05$) with storage. Storage did not significantly affect Satake measurements of A, B, C, D^a, D^b, or S for regular- and deep-milled rice, with the exception of B and S for deep-milled rice. B was significantly lower ($P < 0.0001$) and S significantly higher ($P < 0.0003$) in deep-milled rice stored for four weeks ($B = 5.43\%$, $S = 80$) compared to that stored for two weeks ($B = 5.74\%$, $S = 77$) at refrigerated temperature. These Rice Taster protein results follow the trend observed for the chemical protein analyses and resulted from deeper milling of the conditioned bran under standard conditions. The lower the measured protein content, the higher the Rice Taster taste score.

Effect of Degree-of-Milling on Chemical and Rice Taster Measurements

The effects of degree-of-milling (DOM) on chemical measures of amylose, protein, FFA, and *n*-hexanal and Satake Milling Meter determinations of W, T, and MD are shown in Table IV. Deep milling significantly increased ($P < 0.0001$) amylose and W; protein and FFA contents significantly decreased ($P < 0.0001$). The significantly higher ($P < 0.0269$) *n*-hexanal levels in deep-milled rice compared to regular-milled rice is unexplained.

Table V depicts the effects of DOM on Rice Taster measurements. A and B significantly decreased ($P < 0.0001$) with deep milling; C, D^a, and D^b (milling yield) were not significantly affected. S significantly increased ($P < 0.0001$) with deep milling.

Evaluation of U.S. Medium-Grain Rice

Tables VI and VII list the chemical and Rice Taster measurements obtained for regular and deep-milled U.S. medium-grain rice cultivars, respectively, immediately after shelling. Measurements obtained for the regular-milled Japanese calibration rices, Koshihikari and Michikogane, are listed for comparison. According to Satake, the weighting of A and B values in the Rice Taster score is 70–80%. The data for the 140 samples evaluated in this study, however, indicate that the effect of A on S is small. Using the data in Table VI as an example, regular-milled Koshihikari (AR) has an S value that is not significantly different ($P > 0.05$) from that of M401 (CA), although its A value is markedly lower (17.8 vs. 19.5). (The B, C, and D^a values of these two rice cultivars are not significantly [$P > 0.05$] different.) In contrast, B values appear to have a marked effect on S. For example, the A, C, D^a, and D^b values of regularly-milled Mars from Louisiana and Texas are not significantly different. The B value (6.2) of Mars (LA) is significantly ($P < 0.0009$) smaller than that of Mars (TX) (6.6), resulting in a S value of 68 that is significantly ($P < 0.0209$) larger than 63. In general, lowering B values by 0.3–0.4 increased S values by ≈5 points.

Regular- and deep-milled samples of Rico, Koshihikari, and M401 scored high (78–85) on the Rice Taster. They had low protein contents (4.6–5.6%). Regular and deep-milled Bengal, Mars, Orion, and Calrose samples scored lower (49–73). The lower scores of these rice cultivars can be primarily attributed to their higher protein contents (6.0–7.7%). The false high A values of Bengal, Mars, and Orion also contributed to their lower scores. If the A values had corresponded to the low chemical amylose values of these cultivars, the scores would have been higher. However, based on the observations discussed earlier concerning the small effect of A on S, the score may not have been markedly higher.

CONCLUSIONS

In conclusion, the Satake Neuro Fuzzy Rice Taster provides direct measures of protein and moisture contents and an estimation of milling yield. Values given for amylose and fat acidity are the direct measures multiplied by factors that reflect the value of the component and its effect on taste after the rice has been cooked. Through a fuzzy logic algorithm, the Rice Taster correlates these components to sensory preference scores to give a taste score. The taste score is a general indicator of cooked rice texture. A low-amylose, low-protein, high-moisture rice scores high because it generally produces a cooked rice that is softer and stickier, characteristics deemed desirable by the Japanese palate. The taste score may also give some indication of taste; rice low in fat acidity and protein presumably would have more desirable taste. The taste score, however, is not an indicator of other flavor characteristics of the rice. The score does not give any indication of the aromatic quality of the rice or flavors imparted from other volatile compounds.

The U.S. rice industry has expressed concern about U.S. cultivars of high quality scoring low on Japanese taste analyzers. This study indicates protein content differences of 0.3–0.4% can result in ≈5 points difference in the taste score. With the exception of Rico and M401, the U.S. medium-grain cultivars in this study had protein contents 0.3–1.4% higher than that of the high-scoring premium Japanese cultivar Koshihikari. Deep milling to lower the protein content of these U.S. cultivars was effective in increasing their taste scores by ≈5 points. There was no indication from the results of this study that U.S. shipping practices (storage at ambient temperature followed by refrigerated storage of brown rice before milling) may adversely affect taste scores. Conversely, conditioning of the bran during refrigeration resulted in a deeper milled kernel with lower protein content and thus a higher taste score.

A taste analyzer calibrated using preference sensory scores (e.g., Satake Neuro Fuzzy Rice Taster) can only assess whether the rice has quality characteristics deemed desirable by the target population represented by the sensory panel. These analyzers are not universal or objective. We have research in progress to develop an universal taste analyzer that will be calibrated with descriptive analytical sensory scores and will provide an objective

TABLE IV
Effect of Degree-of-Milling on Chemical Analyses Values[a]

Component	Regular	Deep Milled	Probability
Amylose	13.8	14.2	0.0001
Protein	6.5	6.0	0.0001
Free fatty acids	0.43	0.34	0.0001
Hexanal	39.4	42.7	0.0269
Whiteness	43.0	49.8	0.0001
Translucency	2.7	2.7	ns[b]
Milling degree	109.0	138.1	0.0001

[a] Values are means of 140 samples.

[b] Not significant.

TABLE V
Effect of Degree-of-Milling on Satake Neuro Fuzzy Rice Taster Values[a]

Component	Regular	Deep-Milled	Probability
A ("Amylose")	21.1	19.8	0.0001
B (Protein)	6.3	5.8	0.0001
C (Moisture)	13.3	13.3	ns[b]
D^a ("Fat acidity")	6.7	6.7	ns
D^b (Milling yield)	0.95	0.95	ns
S (Taste score)	66.3	74.1	0.0001

[a] Values are means of 140 samples.

[b] Not significant.

TABLE VI
Satake Neuro Fuzzy Rice Taster Measurements Obtained for Regular-Milled U.S. Medium-Grain Rice Cultivars[a]

Cultivar[b]	Locale[c]	Amylose[d]	Values[e]					
			A	B	C	D^a	D^b	S
Koshihikari	JA	18.2	19.2	6.3	14.0	6.8	0.90	74
Michikogane	JA	23.9	23.3	7.8	13.5	6.9	0.92	45
Bengal	AR	14.5	21.6	7.7	12.7	6.6	0.91	49
	LA	14.0	21.0	6.9	13.0	6.9	0.93	60
	TX	14.3	21.3	7.1	13.0	6.7	0.92	57
Mars	AR	15.2	21.6	7.1	13.0	6.8	0.91	58
	LA	14.6	20.6	6.2	13.0	6.6	0.92	68
	TX	19.7	20.7	6.6	13.1	6.7	0.92	63
Rico	LA	17.9	19.6	5.6	12.9	6.7	0.93	78
	TX	17.6	19.2	5.3	13.2	6.7	0.93	83
Orion	LA	15.0	21.2	6.8	13.0	6.9	0.91	60
	AR	15.2	21.3	7.0	13.1	6.6	0.91	59
Koshihikari	AR	18.5	17.8	5.4	13.3	6.6	0.93	85
M401	CA	22.5	19.5	5.2	13.4	6.8	0.95	82
Calrose	CA	19.2	20.8	6.6	13.2	6.6	0.92	67

[a] Regular-milled immediately after shelling.
[b] Japanese calibration rices Koshihikari and Michikogane are listed for comparison.
[c] JA = Japan, AR = Arkansas, LA = Louisiana, TX = Texas, CA = California.
[d] Chemical amylose values shown as percentages of starch content.
[e] "Amylose" (A), protein (B), moisture (C), "fat acidity" (D^a), milling yield (D^b), taste score (S).

TABLE VII
Satake Neuro Fuzzy Rice Taster Measurements Obtained for Deep-Milled U.S. Medium-Grain Rice Cultivars[a]

Cultivar	Locale[b]	Amylose[c]	Values[d]					
			A	B	C	D^a	D^b	S
Bengal	AR	14.9	21.3	7.2	12.9	6.7	0.90	56
	LA	14.1	19.9	6.3	13.0	6.8	0.92	70
	TX	14.4	19.9	6.5	13.0	6.8	0.92	68
Mars	AR	15.2	21.0	6.8	13.0	6.6	0.92	61
	LA	15.4	20.0	6.0	13.0	6.9	0.94	73
	TX	19.6	20.1	6.2	13.0	6.7	0.90	69
Rico	LA	18.4	18.2	5.1	12.9	6.5	0.93	85
	TX	17.9	17.9	4.9	13.2	6.7	0.92	85
Orion	LA	14.9	20.2	6.6	13.0	6.5	0.91	67
	AR	15.1	20.3	6.6	13.1	6.7	0.91	65
Koshihikari	AR	19.1	16.6	4.6	13.3	6.8	0.92	85
M401	CA	22.6	18.9	5.0	13.4	6.8	0.95	85
Calrose	CA	20.0	20.4	6.3	13.2	6.7	0.93	70

[a] Deep-milled immediately after shelling.
[b] AR = Arkansas, LA = Louisiana, TX = Texas, CA = California.
[c] Chemical amylose values shown as percentages of starch content.
[d] "Amylose" (A), protein (B), moisture (C), "fat acidity" (D^a), milling yield (D^b), taste score (S).

measure relating the intensity of sensory descriptors with physicochemical measurements. The taste scores provided by this universal taste analyzer will be related to preference sensory scores and Japanese taste analyzer scores to identify quality characteristics desired by various domestic and foreign markets.

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[Received July 24, 1995. Accepted December 6, 1995.]