Sensory and Instrumental Relationships of Texture of Cooked Rice from Selected Cultivars and Postharvest Handling Practices

Brenda G. Lyon,[1,2] Elaine T. Champagne,[3] Bryan T. Vinyard,[4] and William R. Windham[1]

Cereal Chem. 77(1):64–69

ABSTRACT

Measurement of cooked rice texture attributes by sensory and instrumental methods is important because of the increased popularity of rice and rice products by globally diverse cultures. Many factors influence cooked rice texture, including cultivar, physicochemical properties, postharvest handling practices (milling degree, drying conditions, and final moisture), and cooking method. Information on the relationships between sensory, physical, and chemical characteristics will lead to better methods to quickly evaluate and predict end-use qualities, which will help to match rices with specific characteristics to populations that demand those attributes. This article reports the relationships between two modes of measuring texture attributes of rices: sensory and instrumental texture analyzers. Six medium- and short-grain rice samples differing by cultivar or growing location were dried to achieve final moisture levels of 12 or 15% and then regular- or deep-milled (n = 120). Correlations between individual sensory descriptive attributes and instrumental texture profile parameters were weak. Of only 12 significant correlations, the highest value was r = 0.624. Combined sensory and instrumental data were factor-analyzed. This analysis revealed that sensory attributes still accounted for the most variation (35.32% out of 76.55%). Sensory descriptive analysis was more sensitive to subtle changes in initial texture perception including parameters relating to stickiness and adhesiveness. The two-cycle compression test for texture profile parameters (i.e., hardness, cohesiveness, adhesiveness, gumminess, springiness, and chewiness) accounted for less variation in the data on texture differences.

Although rice is a universal food item, not all rices are universal. The cooked products of rice cultivars differ in many characteristics. Different rice properties (aromatic, sticky, dry, firm) appeal to different consumers from different regions of the globe (Kaosa-ard and Juliano 1991). For example, the Japanese prefer soft, sticky rice (short-grain, japonica). Thais prefer soft, nonsticky rice (long-grain, indica). Consumers in the United States, South America, and the Middle East favor firm, nonsticky rice (medium- and long-grain rice). Fragrant or scented rices are favored in India, Pakistan, and Thailand.

The sensory properties of cooked rice are very subtle and can be influenced by many factors. To meet worldwide consumer needs for rice with specific sensory attributes, the industry needs universal tools for assessment of these sensory properties. Information on the sensory, physical, and chemical characteristics and how these characteristics are interrelated will lead to better methods to quickly evaluate and predict the end-use qualities. This, in turn, will help to match rices with specific characteristics to the populations that demand those attributes. If end-use characteristics are to be predicted, then it is reasonable to start with defining what those characteristics are and adapt or develop specific methods to measure those characteristics.

One of the first steps in developing universal methods is adoption of sensory profile terminology by trained panelists (Windham et al 1997, Meullenet et al 1998, Lyon et al 1999). Terminology developed by a French panel (Rousset et al 1995) included elasticity, stickiness, pastiness, mealiness, firmness, crunchiness, time in mouth, brittle texture, and juiciness. Del Mundo et al (1989) reported terminology for granular, spongy, smooth-grain, sticky, watery, dry, soft bite, and firm-hard bite used by a European panel. Reported in the same study was terminology used by an American panel that included surface qualities before placing in the mouth like wetness, roughness, plumpness, and clumpiness, as well as firmness, rubberiness, and crumbliness after five chews, and grainy and gritty particle characteristics.

The search for instrumental methods to measure parameters that could relate to the sensory attributes has been equally varied. Deshpande and Bhattacharya (1982) cited studies that used the Haake consistometer, back-extrusion methods, sieving, and compression methods. Some common instrumental parameters on which measurements have been attempted include hardness, adhesiveness, cohesiveness, springiness, and gumminess. These terms are well grounded in accepted rheological definitions developed by Szczesniak et al (1963). Different instruments and procedures are capable of measuring these parameters. For example, Suzuki (1979) reviewed the texturometer from General Foods Corp. (now commercially manufactured by Zenken Co., Ltd., Tokyo, Japan); Perez and Juliano (1979) used an Instron testing machine with an Ottawa texture measuring system (OTMS) cell (Canners Machinery Ltd., Simcoe, ON, Canada). Blakeney (1979) also used a tensile testing machine. Champagne et al (1997) reported the texture profile analysis (TPA) values from a table-top TA.XT2 texture analyzer (Texture Technologies Corp., Scarsdale, NY).

This article reports the relationships between individual sets of texture attributes from selected rice cultivars and postharvest handling practices that were measured by a sensory descriptive analysis panel and by instrumental texture profile analysis derived from a table-top texture analyzer (TA.XT2)

MATERIALS AND METHODS

Rice Samples

Six rice samples from 1994 crops were harvested at 20% moisture and then dried to 12 and 15% moisture content by one of five processes, and milled as described by Champagne et al (1997). The six samples, combinations of cultivar and location grown, were Bengal grown in Arkansas (BNGL-AR), Koshihikari grown in Arkansas (K-AR), Koshihikari grown in California (K-CA), M-401 grown in Arkansas (M401-AR), M401 grown in California (M401-CA), and M202 grown in California (M202-CA). For sensory and texture evaluations, samples were blocked by milling degree (regular and deep) and moisture content (12 and 15%). Within each treatment block (6 × 2 × 2, n = 24), there were samples representing five drying conditions that were included in the test session. According to a randomized complete block design, each treatment block was assigned to a single test session in which

[1] USDA/ARS, Richard B. Russell Agricultural Research Center, P.O. Box 5677, Athens, GA 30604-5677.
[2] Corresponding author. Phone (706) 546-3167. Fax (706) 546-3607. E-mail: bglyon@ars.usda.gov
[3] USDA/ARS, Southern Regional Research Center, 1100 Robert E. Lee Blvd., New Orleans, LA 70124.
[4] USDA/ARS, Biometrical Consulting Service, Bldg. 001 BARC-West, 10300 Baltimore Blvd., Beltsville, MD 20705-2325.

Publication no. C-1999-1206-06R.

sensory and instrumental evaluations were conducted on the same samples at the same time. The sessions (n = 24) were conducted twice a week for 12 weeks.

Sample Preparation for Sensory Analyses

The individual test samples at each session were cooked and presented one at a time to the panelists at 20-min intervals. Milled rice was cooked as described by Champagne et al (1997a,b) in rice cooker-steamers (1-L capacity, Panasonic, JFC International, Norcross, GA). The rice-to-water ratio (by weight) was 1:1.3, accounting for the water retained on washing. When the cooker automatically shifted to the warm setting to indicate completion of cooking, the rice was held an additional 10–15 min at that setting. The top 1-cm layer of cooked rice and rice adhering to the sides of the cooker were discarded. Cooked rice for sampling was taken directly from the middle of the pot and transferred to a prewarmed (120°C) glass bowl. A test portion (0.5 g) of cooked rice was transferred to each of 10 individual prewarmed (120°C) 6-oz glass custard cups (Anchor Hocking). Each glass cup was placed into a fitted Styrofoam caddy for insulation and covered with a 125-mm diameter watch glass. Samples were immediately presented to panelists for evaluation of texture attributes. A 1-g aliquot was weighed, covered, and set aside for instrumental texture analysis within 30–45 min.

Sensory Evaluation Protocol

Rice samples were evaluated by 10 panelists trained in texture profile analysis (Civille and Szczesniak 1973, Civille and Liska 1975, Munoz 1986, Skinner 1988). Specific attributes and definitions for rice texture evaluations were previously described (Windham et al 1977, Champagne et al 1997, Lyon et al 1998). There were 16 sensory attributes that described rice texture at different phases of sensory evaluation, beginning with characteristics outside the mouth, and ending with mouthfeel characteristics after the rice was swallowed (Fig. 1). Evaluations were conducted at individual test stations under low-pressure sodium vapor masking lights (CML-18, Trimble House, Norcross, GA). Panelists recorded their responses on 15-point intensity line scales presented by the computerized sensory analysis system (CSA, v4.3, Compusense, Inc., Guelph, ON).

Instrumental Analyses

An instrumental texture profile analysis was performed on 1-g aliquots using a table-top TA-XT2 texture analyzer. The sample was arranged in a single-grain layer on the base platform of the analyzer. A 2-in. (50-mm) diameter cylinder plunger was set at 5 mm above the base. A two-cycle compression, force vs. distance program was used. The upper compression plunger traveled 4.9 mm at a test speed of 1 mm/sec, returned, and repeated the cycle. Three replicate aliquots were tested on each sample. The values recorded from the resulting two curves for each test were texture profile analysis (TPA) attributes of TA-hardness (peak height of first curve), TA-adhesiveness (negative force on the upstroke representing work to pull plunger away from sample), TA-cohesiveness (ratio of area under second compression to area under first compression), and TA-springiness (ratio of distance traveled by the plunger on the two curves that relates to sample recovery after first compression). TA-gumminess was derived by multiplying hardness × cohesiveness. TA-chewiness was derived by multiplying gumminess × springiness. These values represent standard calculations of TPA curve attributes as described by Bourne (1982). A distance (rather than percent) compression test was used for the TPA because of concerns that height or placement of single grains in the 1-g aliquots might unduly influence the sensed contact height that would account for the beginning of the first distance measurement used in percent compression tests. These settings of a constant 5-mm start and a 4.9-mm travel meant that the rice grains were compressed to within 0.1 mm of the bottom plate.

Statistical Analyses

Sensory and instrumental data sets were merged by cultivar and location, milling treatment, and moisture treatment. Pearson correlation coefficients were obtained between the individual sensory and

SENSORY ATTRIBUTES

PHASE I. *Place one teaspoon of rice on plate and manipulate with back of spoon.*		
Manual Adhesiveness	MADHES	force required to separate individual grains adhering to each other.
Visual Adhesiveness	VADHES	degree to which the grains stick together in a mass.
PHASE II. *Compress sample lightly between lips and release.*		
Stickiness to Lips	STICKI	degree to which the surface of the sample adheres to the lips.
PHASE III. *Place 6-7 grains of rice in mouth behind front teeth. Press tongue over surface and evaluate.*		
Initial Starchy Coating	ISTARCHI	amount of paste-like thickness perceived on the product before mixing with saliva (three passes).
Surface Slickness	SLICK	maximum ease of passing tongue over the rice surface when saliva starts to mix with sample.
Roughness	ROUGH	amount of irregularities in the surface of the product
PHASE IV. *Place ½ teaspoon of rice in mouth. Evaluate before or at first bite.*		
Self-Adhesiveness	SADHES	force required to separate individual grains with the tongue and palate
Springiness	SPRING	degree grains return to original shape after partial compression
Cohesiveness	COHES	degree to which the grains deform rather than crumble, crack, or break when biting with molars.
Hardness	HARDN	force required to bite through the sample with the molars.
PHASE V. *Evaluate during chew.*		
Cohesiveness of Mass	COHESM	maximum degree to which the sample holds together in a mass while chewing.
Chewiness	CHEWI	amount of work to chew the sample.
Uniformity of Bite	UNIFORM	evenness of force throughout bites to chew.
PHASE VI. *Evaluate after swallow.*		
Residual Loose Particles	RESID	amount of loose particles in mouth.
Toothpack	TOOTHPCK	amount of product adhering in/on the teeth.
Starchy Mouthcoating	SMCOAT	starchiness/pastiness of coating in mouth evaluated by pressing tongue to palate.

TEXTURE ANALYZER (TA) INSTRUMENTAL PARAMETERS

Hardness	TA-hardness	peak height of first curve
Springiness	TA-springiness	ratio of distance traveled by plunger on the two curves; relates to sample recovery after first compression
Cohesiveness	TA-cohesiveness	ratio of area under second compression to area under first compression
Adhesiveness	TA-adhesiveness	negative force on the upstroke representing work to pull plunger away from sample
Gumminess	TA-gumminess	product of hardness x cohesiveness
Chewiness	TA-chewiness	product of gumminess x springiness

Fig. 1. Attributes, abbreviations, and definitions of sensory attributes and texture analyzer (TA) instrumental parameters used to evaluate cooked rice.

texture attributes. Principal component factor analysis was conducted on the merged individual sensory and instrumental parameters. Various combinations of raw data sets and derived factor data sets were subjected to correlation analysis. Statistical programs of SPSS v.8.0 (SPSS, Inc., Chicago, IL) and SAS v.6.12 (SAS Institute, Cary, NC) were used.

RESULTS AND DISCUSSION

Discrimination of Samples by Sensory and Instrumental Parameters

Table I shows the *F*-ratios and probability values for the sensory and instrumental parameters in general linear model (GLM) analyses evaluating differences in samples (over all treatment main effects). All sensory attributes had statistically significant *F*-ratios ($P < 0.05$), with the exception of toothpack (TOOTHPCK) and starchy mouthcoating (SMCOAT). Although these two attributes were not significantly different by the GLM model, they did show contributions to the explanation of variation in the data on the factor analysis. Therefore, they were retained for continued analyses of relationships among the sensory and instrumental sets of data. The highest *F*-ratios were for stickiness to lips (STICKI) and surface slickness (SLICK). All instrumental parameters showed statistically significant ($P < 0.01$) *F* values. TA-hardness and TA-gumminess had the largest *F*-ratios. Instrumental texture profile parameters of TA-adhesiveness, TA-cohesiveness, TA-hardness, and TA-springiness were affected by final moisture content and degree of milling of the selected rice cultivars (Champagne 1997b). TA-hardness was lower and TA-cohesiveness, TA-adhesiveness, and TA-springiness were higher for 15% moisture, deep-milled rices compared with 12% moisture, deep-milled rices. Deep-milled rices were less hard and more cohesive, adhesive, and springy than regular-milled rices. Thus, both the sensory and the instrumental assessments showed differences in the rice samples. Correlational tests were conducted to determine the extent to which the sensory and instrumental methods were measuring the same parameters.

TABLE I
***F*-Ratio and Probability of >*F* Values from Analysis of Variance (ANOVA) of Sensory Attributes and Texture Analyzer (TA) Instrumental Parameters of Cooked Rice[a]**

	ANOVA	
	F-Ratio	Prob. > *F*
Sensory attributes[b]		
1. MADHES	6.84	0.00
2. VADHES	5.73	0.00
3. STICKI	10.43	0.00
4. ISTARCHI	6.65	0.00
5. SLICK	8.15	0.00
6. ROUGH	3.12	0.00
7. SADHES	4.22	0.00
8. SPRING	5.41	0.00
9. COHES	2.85	0.00
10. HARDN	3.85	0.00
11. COHESM	2.59	0.00
12. CHEWI	2.93	0.00
13. UNIFORM	3.09	0.00
14. RESID	1.41	0.13
15. TOOTHPCK	1.26	0.22
16. SMCOAT	3.21	0.00
Instrumental parameters[c]		
17. TA-springiness	3.00	0.00
18. TA-hardness	36.27	0.00
19. TA-cohesiveness	4.23	0.00
20. TA-adhesiveness	12.11	0.00
21. TA-gumminess	21.40	0.00
22. TA-chewiness	4.28	0.00

[a] Prob > *F* values are probabilities of obtaining a greater *F*-ratio using the main effect of sample ($n = 24$) in the general linear model.

[b] MADHES = manual adhesiveness; VADHES = visual adhesiveness; STICKI = stickiness to lips; ISTARCHI = initial starchy coating; SLICK = surface slickness; ROUGH = roughness; SADHES = self-adhesiveness; SPRING = springiness; COHES = cohesiveness; HARDN = hardness; COHESM = cohesiveness of mass; CHEWI = chewiness; UNIFORM = uniformity of bite; RESID = residual loose particles; TOOTHPCK = toothpack; SMCOAT = starchy mouthcoating.

[c] TA-hardness = peak height of first curve. TA-springiness = ratio of distance traveled by plunger on the two curves; relates to sample recovery after first compression. TA-cohesiveness = ratio of area under second compression to area under first compression. TA-adhesiveness = negative force on the upstroke representing work to pull plunger away from sample. TA-gumminess = product of hardness × cohesiveness. TA-chewiness = product of gumminess × springiness.

Correlations of Sensory and Instrumental Parameters

Pearson correlation coefficients were computed for individual sensory attributes versus individual instrumental parameters. A correlation value of $r \geq 0.40$ was needed for statistical significance at $P \leq 0.05$ (Table II). For practical purposes, that correlation is considered too low. Nevertheless, there were 12 statistically significant values between the sensory set of 16 individual attributes and the instrumental set of seven individual TA-parameters. Manual adhesiveness (MADHES) and visual adhesiveness (VADHES) correlated negatively with TA-hardness (–0.597 and –0.578, respectively) and positively with TA-cohesiveness (0.484 and 0.569, respectively). Stickiness (STICKI) was correlated negatively with TA-hardness (–0.624) and positively with TA-adhesiveness (0.522). Initial starchiness (ISTARCHI) was correlated negatively with TA-hardness (–0.441) and positively with TA-adhesiveness (0.426). TA-hardness was correlated negatively with slickness (SLICK, –0.414) and positively with hardness (HARDN, 0.419) and uniformity (UNIFORM, 0.452). Self-adhesiveness (SADHES) and cohesiveness of mass (COHESM) correlated positively with TA-cohesiveness (0.514 and 0.422, respectively).

Correlations of Sensory Factor Variables and Instrumental Parameters

A factor analysis of sensory attributes only (Lyon et al 1998) indicated three groupings of sensory terms that explained most of the variation in the sensory data. Sensory factor variables (SNFAC1, SNFAC2, and SNFAC3) were computed from factor-scoring coefficients and then correlated with individual instrumental texture attributes (Table III). SNFAC1, represented by the individual sensory attributes of MADHES, VADHES, ISTARCHI, was significantly correlated with TA-cohesiveness and TA-adhesiveness. Rousset et al (1995) reported significant correlations of white core incidence with sensory brittleness and crunchiness. However, the only instrumental measurements obtained in that study were firmness by Instron universal testing machine and viscoelastograph. The correlation of SNFAC1 with TA-hardness in this study was not significant ($r = –0.277$).

SNFAC2 represented by RESID, TOOTHPCK, and SMCOAT, was not significantly correlated with any of the individual instrumental parameters. These attributes are perceived after the sample has been swallowed. Instrumental texture parameters did not relate to these attributes. SNFAC3 represented by CHEWI and ROUGH was significantly correlated with TA-cohesiveness. Instrumental cohesiveness relates to the resistance by the sample to a deforming force. It is calculated by the ratio of work under the two compression curves of the texture profile analysis. The relationship with CHEWI can be explained but not the relationship with ROUGH. It had been expected that the new variables SNFAC1, SNFAC2, and SNFAC3 would be able to explain the relationships with the instrumental parameters more easily than individual sensory attributes, but this did not appear to be the case.

Factor Analysis of Sensory and Instrumental Data

The 16 sensory attributes and the seven instrumental parameters were combined in a dataset and then subjected to factor analysis (Table IV). A normalization procedure was used to set the sensory

TABLE II
Correlation Coefficients of Sensory Attributes and Texture Analyzer (TA) Instrumental Parameters[a]

Sensory Attributes[b]	Instrumental Parameters[c]					
	TA-Springiness	TA-Hardness	TA-Cohesiveness	TA-Adhesiveness	TA-Gumminess	TA-Chewiness
1. MADHES	–0.174	**–0.597**	**0.484**	0.369	0.124	–0.203
2. VADHES	–0.214	**–0.578**	**0.569**	0.358	–0.073	–0.208
3. STICKI	–0.215	**–0.624**	0.326	**0.522**	–0.247	–0.297
4. ISTARCHI	–0.251	**–0.441**	0.222	**0.426**	–0.260	–0.312
5. SLICK	–0.256	**–0.414**	0.310	0.274	–0.112	–0.270
6. ROUGH	–0.097	0.131	–0.131	0.031	–0.054	–0.052
7. SADHES	0.084	–0.374	**0.514**	0.208	–0.104	0.019
8. SPRING	0.158	–0.061	0.040	–0.080	0 .015	0.151
9. COHES	0.229	0.103	0.331	–0.039	0.102	0.202
10. HARDN	0.087	**0.419**	–0.306	–0.321	0.136	0.131
11. COHESM	0.090	–0.352	**0.422**	0.130	–0.078	–0.036
12. CHEWI	–0.356	–0.087	0.117	0.279	–0.200	–0.383
13. UNIFORM	0.014	**0.452**	0.163	0.354	–0.235	–0.081
14. RESID	–0.107	0.124	–0.141	0.103	–0.356	–0.221
15. TOOTHPCK	–0.247	–0.079	–0.116	0.319	–0.287	–0.323
16. SMCOAT	0.146	0.237	0.083	–0.112	0.140	0.168

[a] Correlation value of $r \geq 0.40$ needed for statistical significance at $P < 0.05$. Significant values are indicated by bold type.
[b] MADHES = manual adhesiveness; VADHES = visual adhesiveness; STICKI = stickiness to lips; ISTARCHI = initial starchy coating; SLICK = surface slickness; ROUGH = roughness; SADHES = self-adhesiveness; SPRING = springiness; COHES = cohesiveness; HARDN = hardness; COHESM = cohesiveness of mass; CHEWI = chewiness; UNIFORM = uniformity of bite; RESID = residual loose particles; TOOTHPCK = toothpack; SMCOAT = starchy mouthcoating.
[c] TA-hardness = peak height of first curve. TA-springiness = ratio of distance traveled by plunger on the two curves; relates to sample recovery after first compression. TA-cohesiveness = ratio of area under second compression to area under first compression. TA-adhesiveness = negative force on the upstroke representing work to pull plunger away from sample. TA-gumminess = product of hardness × cohesiveness. TA-chewiness = product of gumminess × springiness.

TABLE III
Correlation Coefficients of Sensory Factor Scores and Texture Analyzer (TA) Instrumental Parameters[a]

Instrumental Parameters[b]	Sensory Factor Scores		
	I[c]	II[d]	III[e]
TA-Springiness	–0.186 (0.385)	–0.089 (0.678)	0.223 (0.296)
TA-Hardness	–0.277 (0.191)	–0.158 (0.462)	0.018 (0.932)
TA-Adhesiveness	0.430 (0.036)	0.096 (0.654)	–0.007 (0.976)
TA-Cohesiveness	0.414 (0.044)	–0.004 (0.985)	0.487 (0.016)
TA-Gumminess	–0.191 (0.371)	–0.145 (0.498)	0.101 (0.638)
TA-Chewiness	–0.242 (0.254)	–0.138 (0.521)	0.201 (0.346)

[a] Correlation value of $r \geq 0.40$ needed for statistical significance at $P < 0.05$. Probability of $>r$ values in parentheses.
[b] TA-hardness = peak height of first curve. TA-springiness = ratio of distance traveled by plunger on the two curves; relates to sample recovery after first compression. TA-cohesiveness = ratio of area under second compression to area under first compression. TA-adhesiveness = negative force on the upstroke representing work to pull plunger away from sample. TA-gumminess = product of hardness × cohesiveness. TA-chewiness = product of gumminess × springiness.
[c] Represented by MADHES = manual adhesiveness; VADHES = visual adhesiveness; STICKI = stickiness to lips; ISTARCHI = initial starchy coating; SLICK = surface slickness; SADHES = self-adhesiveness.
[d] Represented by RESID = residual loose particles; TOOTHPCK = toothpack; SMCOAT = starchy mouthcoating.
[e] Represented by CHEWI = chewiness; ROUGH = roughness.

and instrumental parameters to the same scale. This analysis extracted five factors that explained 76.55% variation in the data. The percentage of variation explained was greater for this analysis of sensory and instrumental data combined than for the sensory data alone (68.5%). Factor I accounted for 35.32% of the variation. The highest loading attributes were the sensory attributes MADHES, VADHES, STICKI, ISTARCHI, SLICK, and SADHES. These attributes were also the highest loading attributes on the factor analysis of only sensory data. TA-cohesiveness was the highest loading instrumental parameter with a loading (correlation with the factor) of 0.687. However, the loading for TA-cohesiveness on Factor II was not much lower (0.506), indicating that it contributed almost the same to both factors. Factor II (16.99%) included the instrumental parameters TA-hardness, TA-adhesiveness, and TA-gumminess, in addition to TA-cohesiveness. Factor III included TA-springiness and TA-chewiness. Factor IV included the sensory attributes RESID, TOOTHPCK, and SMCOAT. Factor V included sensory SPRING. In the work reported by Rousset et al (1995), the attribute of springiness (called elasticity) was one of the significant discriminators of differences in rices in that study.

These different analyses showed consistent groupings of various parameters. First, the attributes of the sensory profile that were evaluated in the first phases were in the first factor and explained more variation associated with the data when the sensory data were considered alone or when combined with the instrumental data. These attributes represented the adhesive and sticky properties of the cooked rice. Secondly, the instrumental texture parameters accounted for the next portion of variation explained and included TA-hardness, TA-adhesiveness, and TA-gumminess as the instrumental parameters that loaded highest on this factor. Instrumental TA-springiness and TA-chewiness explained 11.05% in Factor III, followed by RESID, TOOTHPCK, and SMCT in Factor IV (7.0%).

CONCLUSIONS

The sensory texture profile that was developed to evaluate the properties of the cooked rices was sufficiently sensitive to find distinct (though small) differences in the rices. The primary variations in the data were due to the initial adhesive properties of the rices. Lyon et al (1998) reported that sensory properties relating to stickiness had statistically significant correlation coefficients with amylose content (+0.31) and protein content (–0.67). Amylose and protein are the primary chemical components of rice that affect eating quality. The second most important sensory characteristics were the mouthfeel properties of RESID, TOOTHPCK, and SMCT, which showed significant correlation coefficients with protein content (+0.31).

The relationships between the sensory attributes and instrumental texture profile measurements indicated weak, single correlations. Other researchers have also reported weak correlations between sensory and instrumental measurements of texture. The lack of strong significant correlations could mean that the instrumental parameters do not measure the same parameters that are described by the sensory attributes. The treatment effects on rices

TABLE IV
Pattern Matrix Loadings of Factor Analysis of Individual Sensory Attributes and Instrumental Parameters[a,b]

	Newly Created Factor Groups				
	I	II	III	IV	V
Sensory attributes					
MADHES	**0.983**	0.000	–0.045	–0.067	–0.062
VADHES	**0.940**	0.091	–0.097	–0.029	0.066
STICKI	**0.853**	–0.126	–0.171	–0.143	–0.133
ISTARCHI	**0.758**	–0.102	–0.169	0.122	0.047
SLICK	**0.705**	0.162	–0.307	0.293	0.134
ROUGH	–0.394	–0.145	–0.077	–0.253	–0.559
SADHES	**0.929**	–0.075	0.270	0.149	–0.122
SPRING	–0.103	0.004	0.080	–0.117	**0.865**
COHES	0.582	0.053	0.427	0.259	–0.282
HARDN	**–0.718**	0.164	–0.103	0.377	0.111
COHESM	**0.733**	0.015	0.133	0.146	0.193
CHEWI	0.436	0.057	–0.446	0.284	–0.182
UNIFORM	**0.615**	–0.279	0.153	–0.120	0.407
RESID	–0.070	–0.342	–0.024	**0.795**	–0.062
TOOTHPCK	0.140	–0.188	–0.225	**0.758**	0.009
SMCOAT	–0.065	0.157	0.128	0.536	0.531
Instrumental parameters					
Springiness	–0.013	–0.273	**1.058**	–0.060	0.096
TA-Hardness	–0.046	**1.033**	–0.139	–0.218	0.052
TA-Cohesiveness	**0.687**	0.506	0.197	–0.175	–0.145
TA-Adhesiveness	0.269	**–0.745**	0.026	0.019	–0.049
TA-Chewiness	0.020	0.255	**0.807**	–0.159	0.082
TA-Gumminess	0.072	**1.037**	–0.089	–0.228	0.017
Variation accounted for (VAF)	35.32	16.99	11.05	7.09	6.08
Cumulative VAF	35.32	52.32	63.37	70.46	76.55

[a] Extraction method: principal component analysis. Rotation method: Promax with Kaiser normalization. Rotation converged in eight iterations. Loadings are correlations of individual attributes and parameters to the factor groups. Bold face indicates loadings (correlations with factors) > 0.60.

[b] MADHES = manual adhesiveness; VADHES = visual adhesiveness; STICKI = stickiness to lips; ISTARCHI = initial starchy coating; SLICK = surface slickness; ROUGH = roughness; SADHES = self-adhesiveness; SPRING = springiness; COHES = cohesiveness; HARDN = hardness; COHESM = cohesiveness of mass; CHEWI = chewiness; UNIFORM = uniformity of bite; RESID = residual loose particles; TOOTHPCK = toothpack; SMCOAT = starchy mouthcoating. TA-hardness = peak height of first curve. TA-springiness = ratio of distance traveled by plunger on the two curves; relates to sample recovery after first compression. TA-cohesiveness = ratio of area under second compression to area under first compression. TA-adhesiveness = negative force on the upstroke representing work to pull plunger away from sample. TA-gumminess = product of hardness × cohesiveness. TA-chewiness = product of gumminess × springiness.

in this study (primarily milling and final moisture) showed significant effects on some attributes but not others (Lyon 1998). Also, the differences that were perceived in sensory characteristics of the rices in this study were very small. However, the implication of these subtle, yet detectable differences, makes it all the more important to find sensitive methods that can provide rapid assessments of measured or predicted quality. Additional instrumental methods for rice evaluation are needed to find those that correlate with sensory concepts. The TPA compression test on 1-g aliquots was one procedure tested in this study. Sensory descriptive panels appear to be more sensitive at discerning very subtle differences in texture. This is in agreement with Rousset et al (1995). Additional work needs to be done to develop more sensitive procedures to measure and predict texture and quality.

ACKNOWLEDGMENTS

We gratefully acknowledge the technical assistance of Elizabeth Savage.

LITERATURE CITED

AOAC. 1990. Association Official Analytical Chemists Official Methods of Analysis, 15th ed. The Association: Arlington, VA.

Champagne, E. T., Bett, K. L., Vinyard, B. T., Webb, B. D., McClung, A. M., Barton, F. E., II, Lyon, B. G., Moldenhauer, K., Linscombe, S., and Kohlwey, D. E. 1997a. Effects of drying conditions, final moisture content, and degree-of-milling on rice flavor. Cereal Chem. 74:566-570.

Champagne, E. T., Lyon, B. G., Min, B. M., Vinyard, B. T., Bett, K. L., Barton, F. E., II, Webb, B. D., McClung, A. M., Moldenhauer, K. A., Linscombe, S., McKenzie, K. S., and Kohlwey, D. E. 1997b. Effects of postharvest processing on rice texture profile analysis. Cereal Chem. 75:181-186.

Civille, C. V., and Liska, I. H. 1975. Modification and applications to foods of the general foods sensory texture profile technique. J. Texture Stud. 6:19-32.

Civille, C. V., and Szczesniak, A. S. 1973. Guidelines to training a texture profile panel. J. Texture Stud. 4:204-223.

Del Mundo, A., Kosco, D. A., Juliano, B. G., Siscar, J. J. H., and Perez, C. M. 1989. Sensory and instrumental evaluation of texture of cooked and raw milled rices with similar starch properties. J. Texture Stud. 20:97-110.

Deshpande, S. S., and Bhattacharya, K. R. 1982. The texture of cooked rice. J. Texture Stud. 13:31-42.

Hamaker, B. R. 1994. The influence of rice protein on rice quality. In: Rice Science and Technology. W. E. Marshall and J. I. Wadsworth, eds. Marcel Dekker: New York.

Juliano, B. O. 1971. A simplified assay for milled rice amylose. Cereal Sci. Today 16:334-340, 360.

Juliano, B. O., ed. 1985. Criteria and tests for rice grain qualities. In: Rice Chemistry and Technology. Am. Assoc. Cereal Chem.: St. Paul, MN.

Kaosa-ard, M., and Juliano, B. O. 1991. Assessing rice quality characteristics and prices in selected international markets. In: Rice Grain Marketing and Quality Issues. International Rice Research Institute: Los Banos, Laguna, The Philippines.

Lyon, B. G., Champagne, E. T., Vinyard, B. T., Windham, W. R., Barton, F. E., Webb, B. D., McClung, A. M., Moldenhauer, K. A., Linscombe, S., McKenzie, K. S., and Kohlwey, D. E. 1999. Effects of degree of milling, drying condition, and final moisture content on sensory texture of cooked rice. Cereal Chem. 76:56-62.

Meullenet, J. F. C., Gross, J., Marks, B. P., and Daniels, M. 1998. Sensory descriptive texture analyses of cooked rice and its correlation to instrumental parameters using an extrusion cell. Cereal Chem. 75:714-720.

Munoz, A. M. 1986. Development and application of texture reference scales. J. Sensory Stud. 1:55-83.

Okabe, M. 1979. Texture measurement of cooked rice and its relationship to the eating quality. J. Texture Stud. 10:131-152.

Primo, E., Casas, A., and Barber, C. B. 1962. Factores de calidad del arroz.

VI. Influencia de las proteinas sobre la calidad de coccion. Proteinas en la capa externa. Rev. Agroquim. Technol. Alimentos 2:315.
Rousset, S., Pons, B., and Pilandon, C. 1995. Sensory texture profile, grain physico-chemical characteristics and instrumental measurements of cooked rice. J. Texture Stud. 26:119-135.
Satake, T. 1988. Apparatus for evaluating the quality of rice grains. U.S. patent 4,752,689.
Skinner, E. Z. 1988. The texture profile method. Pages 89-107 in: Applied Sensory Analysis of Foods. H. Moskowitz, ed. CRC Press: Boca Raton, FL.
Szczesniak, A. S., Brandt, M. A., and Friedman, H. H. 1963. Development of standard rating scales for mechanical parameters of texture and correlation between the objective and the sensory methods of texture evaluation. J. Food Sci. 28:397-403.
Windham, W. R., Lyon, B. G., Champagne, E. T., Barton, F. E., II, Webb, B. D., McClung, A. M., Moldenhauer, K. A., Linscombe, S., and McKenzie, K. S. 1997. Prediction of cooked rice texture quality using near-infrared reflectance analysis of whole-grain milled samples. Cereal Chem. 74:626-632.

[Received January 19, 1999. Accepted September 16, 1999.]