Correlation Between Cooked Rice Texture and Rapid Visco Analyser Measurements

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ABSTRACT

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Although amylose content is considered the most important determinant of cooked rice texture, this constituent falls short as a predictor, because cultivars with similar amylose contents may differ in textural properties. Thus, amylography is used as one of a battery of tests, in addition to measuring amylose content, to improve differentiation of cultivars. The purpose of our study was to determine how well amylography conducted with a Rapid Visco Analyser (RVA) serves as a predictor of cooked rice texture, alone and in combination, with amylose content. Textural properties of 87 samples representing short-, medium-, and long-grain rice cultivars were assessed by descriptive sensory and instrumental texture profile (TPA) analyses and related to RVA measurements. None of the cooked rice textural attributes, whether measured by descriptive analysis or TPA, were modeled by RVA with high accuracy (i.e., high r^2). Sensory texture attributes cohesiveness of mass, stickiness, and initial starchy coating and TPA attribute adhesiveness had the strongest correlations with RVA measurements. Setback explained most of the variance attributed to models describing these attributes; the strongest correlation was with cohesiveness of mass ($r = 0.69$; equivalent to coefficient of determination, $r^2 = 0.47$). Inclusion of amylose and protein contents in regression analyses did not strengthen models. Exclusion of samples that cook atypically, based on amylose content or gelatinization temperature types, slightly improved the accuracy of RVA measurements for predicting cooked rice texture.

The economic value of rice in domestic and international markets is strongly affected by the sensory quality of cooked rice. Conventionally, sensory quality of rice has been assessed by a combination of preference sensory evaluation and a series of physicochemical property evaluations. Evaluations are typically time-consuming and only assess whether the rice cultivar has quality characteristics deemed desirable by a target population or for a specific application, falling short in measuring subtle differences in sensory quality. Rapid, accurate, universal methodologies that relate physicochemical measurements to objective measurements of sensory attributes are needed.

Amylography is one of a battery of commonly conducted physicochemical property tests that serve as indices for sensory quality. Amylography, which is used for determining gelatinization and paste viscosity characteristics, traditionally was performed on a Brabender Viscoamylograph and required ≈1.5 hr to perform. Today the test is routinely conducted with a Rapid Visco Analyser (RVA; Newport Scientific, Warriewood, Australia). Viscosity properties measured on an RVA are similar to those measured with a Brabender Viscoamylograph and are obtained in ≈15 min (Blakeney et al 1991).

Relationships exist between amylographic measurements, amylose and protein contents (two components influencing texture of cooked rice) (Halick and Kelly 1959; Juliano et al 1964a,b; Juliano and Pascual 1980; Del Mundo et al 1989; Sandhya Rani and Bhattacharya 1995), and instrumental measurements of textural properties (Juliano and Pascual 1980, Okuno and Yanase 1983, Lee 1988, Sandhya Rani and Bhattacharya 1995). Preference and difference sensory tests have been used to relate cooked rice hardness and stickiness to amylographic measurements (Tani et al 1969, Sandhya Rani and Bhattacharya 1995); the relationships between these measurements and descriptive sensory evaluations of cooked rice texture have not been reported.

The purpose of our study was to determine the extent to which RVA can be used to predict the textural properties of cooked rice. Textural properties were assessed by descriptive sensory analysis (an analytical, objective methodology) and instrumental texture profile analysis (TPA) and related to RVA measurements.

MATERIALS AND METHODS

Rice Samples

Samples of short-, medium-, and long-grain rice cultivars ($N = 76$) grown in Louisiana, Arkansas, Texas, and California were harvested at 20% moisture and dried to ≈12% moisture. After drying, rice samples 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 prior to initiating sensory analyses, samples were shelled with a rice machine (Satake model SB) and immediately milled. Milling was accomplished with a laboratory one-pass mill (Satake Pearler, model SKD). A milling protocol appropriate for yielding rice with whiteness values in the targeted 40 ± 2 range considered typical of regular-milled rice was established for each grain-length type. Whiteness was measured with a milling meter (Satake model MM-1B). Broken grains were removed with appropriate laboratory-sizing devices with standard indented plates and cylinders. Milled samples were shipped overnight to the USDA-ARS, Southern Regional Research Center, New Orleans, LA. Milled rice samples also were obtained from 1996 crops in Taiwan ($N = 2$), Korea ($N = 3$), and Australia ($N = 6$). When received, samples were immediately preweighed into portions for sensory, chemical, and RVA analyses and stored in glass jars under a nitrogen headspace at 4°C.

Chemical Analyses

Amylose content of samples was determined in duplicate by the simplified assay method developed by Juliano (1971). Protein contents (N × 5.95) were determined in duplicate by the combustion method on a nitrogen determinator (FP-428, Leco Corp., St. Joseph, MI). Moisture contents of milled kernels were determined in duplicate on ground material oven-dried at 130°C for 1 hr (AMS 1959). The alkali spreading value of whole-grain milled rice was determined in accordance with the method of Little et al (1958) with minor modifications. Six grains from each sample were immersed in 1.5% KOH solution overnight at room temperature. Each grain was examined visually the next morning for the level of intactness and assigned a numerical score of 2–7 (2 = relatively intact, 7 = greatly dispersed). Values for six grains were averaged to produce one value per sample.

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RVA Analysis

Paste viscosity properties of rice samples were determined using an RVA (Newport Scientific model 3D) and Approved Method 61-02 (AACC 1995). Two RVA runs were conducted on each sample following the schedule established for sensory analyses. The definitions for measured properties are pasting temperature: temperature of initial viscosity increase; peak: maximum viscosity recorded during heating and holding cycles, usually occurs soon after heating cycle reaches 95°C; peaktime: time required to reach peak; trough: minimum viscosity after peak; final viscosity: viscosity at test finish, corresponds to amylograph cool paste viscosity; breakdown: difference (–) between peak and trough, indication of breakdown in viscosity of paste during 95°C holding period; and setback: difference (–) between final viscosity and trough.

Sample Preparation for Sensory Analyses

Rice samples (600 g) were rinsed by covering rice three times with cold water followed by straining to remove excess water. After rinsing, samples were transferred to preweighed rice-cooker insert bowls. Water was added to produce rice-to-water weight ratios appropriate for three cook types based on amylose content (0%, 1:1; 10–19%, 1:1.4; 20–25%, 1:1.7). Rice known to cook similarly to a cook type that does not correspond to its amylose content was cooked with an amount of water corresponding to the similar cook type. Rice was presoaked in the cooker insert bowl for 20 min at room temperature and then cooked in the rice cooker-steamer (Panasonic SR-W10G HP) to completion, as indicated by the automatic shift of the cooker to the warm setting. Rice was held for an additional 10 min at the warm setting. The top 1-cm layer of cooked rice and rice adhering to the sides of the cooker were not used for tasting. Cooked rice for sampling was taken directly from the middle of the pot, transferred to a glass bowl prewarmed to 120°C, and mixed thoroughly while minimizing kernel breakage. Rice samples (≈48 g) were transferred with a size 18 stainless-steel ice cream scoop to prewarmed (120°C) 175-mL (6-oz) glass custard cups (Anchor Hocking) insulated by fitted polystyrene bowls, and covered with 125-mm watch glasses. One sample was used for TPA; the remaining samples were presented to the sensory panel. Cooking of samples was staggered so that samples were analyzed by the panel or texture analyzer at 20-min intervals.

Sensory Evaluation Protocol

Twelve panelists who were previously trained in the principles and concepts of descriptive analysis (Civille and Szczesniak 1973, Civille and Liska 1975, Munoz 1986, Skinner 1988) were selected to participate in the study. The lexicon for rice texture used by the panel was based on the lexicon developed by Lyon et al (1999) and Goodwin et al (1996) (Fig. 1). The sensory texture profile included 13 sensory attributes that described rice texture at different phases of sensory evaluation, beginning with the feel of the rice when it is first placed in the mouth and ending with mouthfeel characteristics after the rice is swallowed. Each sample was presented to the panelists twice following a randomized design in which each session consisted of three samples, a standard, and a blind control (Calrose, a commercial cultivar). The standard, the warm-up sample presented at the beginning of each session, was used to calibrate the panel. After the warm-up sample, coded test samples were presented to panelists individually at 20-min intervals immediately after cooking, holding, and portioning into serving cups. Evaluations were conducted at individual test stations under red masking lights. Distilled, filtered water (Hydrotech drinking water filtration system) was used to cleanse the mouth between samples.

Phases/Attributes	**Definition**
PHASE I.	***Place 6-7 grains of rice in mouth behind front teeth. Press tongue over surface and evaluate.***
Initial Starchy Coating	amount of paste-like thickness perceived on the product before mixing with saliva (three passes).
Slickness	maximum ease of passing tongue over the rice surface when saliva starts to mix with sample.
Roughness	amount of irregularities in the surface of the product
Stickiness	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 the grains deform rather than crumble, crack, or break when biting with molars.
Hardness	force required to bite through the sample with the molars.
PHASE III.	***Evaluate during chew.***
Cohesiveness of Mass	maximum degree to which the sample hold 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.***
Residual Loose Particles	amount of loose particles in mouth.
Toothpack	amount of product adhering in/on the teeth.

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

Instrumental Texture Analyses

TPA was conducted with a texture analyzer (TA.XT2, Texture Technologies Corp., Scarsdale, NY). A 1-g aliquot of warm rice from an insulated custard cup was weighed and arranged in a single-grain layer on the base plate. A compression plate was set at 5 mm above the base. A two-cycle compression, force-versus-distance program was used to allow the plate to travel 4.9 mm, return, and repeat. Test speed was 1 mm/sec. A cylinder plunger with a 50-mm diameter was used.

The test was repeated on two duplicate samples ($n = 3$). Parameters recorded from test curves (Fig. 2) included hardness (H1), adhesiveness (A3), cohesiveness (A2/A1), springiness (D2/D1), and resilience (A5/A4). Gumminess was obtained by multiplying hardness by cohesiveness; chewiness is gumminess multiplied by springiness. Values represent standard calculations of curve attributes of TPA as described by Bourne (1982) and defined by Munoz et al (1992). A distance (rather than percent) compression test was used for TPA because of concerns that height or placement of single grains in the 1-g aliquots might unduly influence the sensed contact height that determined the beginning of the D1 measurement used in percent compression tests. Using settings for a constant 5-mm start and 4.9 mm of travel, rice samples were compressed to within 0.1 mm of the bottom plate.

Statistical Analyses

For 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, scatterplots were examined visually to identify which panelists were not performing to consensus during a session. No outliers were identified for six attributes. For the other seven attributes, one (three attributes), two (three attributes), and three (one attribute) outlier scores were removed. Blind control samples were used to adjust out-session effects. All sample means obtained in panel sessions containing a blind control sample that fell outside the 99% confidence limit of the blind control grand mean were adjusted inward to 99%. This occurred in either no sessions or only one or two sessions for each descriptor.

Correlations were examined among two groups of responses by multivariate factor analyses: 1) RVA versus sensory texture and 2) RVA versus instrumental texture. All data were standardized to zero mean and unit standard deviation prior to analysis. The promax method of oblique factor rotation was used to accommodate the presence of correlations among extracted factors. For each factor in the factor analysis solution, the response variables loading onto the factor were used in stepwise multiple regression. Variables from one group (RVA) were used as regressors to predict variables from the

TABLE I
Physicochemical Data for Rice Cultivars

Cultivar	Location[a]	Grain Type	% Amylose	% Protein	1.5% Alkali	Gel Type
M202	TX	M	10.3 ± 0.2	8.4 ± 0.1	6.0 ± 0.0	Low
M202	CA	M	14.8 ± 0.2	6.8 ± 0.1	6.1 ± 0.1	Low
M201	TX	M	10.7 ± 0.1	10.9 ± 0.2	5.8 ± 0.1	Low-intermediate
Pelde	TX	L	12.2 ± 0.2	8.6 ± 0.3	2.0 ± 0.0	High
V 4716	LA	M	12.3 ± 0.2	9.2 ± 0.2	6.0 ± 0.0	Low
AB 869	LA	M	12.4 ± 0.5	8.3 ± 0.1	6.0 ± 0.0	Low
CP231	TX	L	12.3 ± 0.3	8.4 ± 0.2	2.0 ± 0.0	High
CP231	AR	L	14.0 ± 0.2	8.6 ± 0.0	2.0 ± 0.0	High
M401	TX	M	12.4 ± 0.2	8.3 ± 0.0	5.4 ± 0.1	Intermediate-low
M401	CA	M	17.1 ± 0.1	6.2 ± 0.2	7.0 ± 0.0	Low
Saturn	LA	M	13.1 ± 0.1	8.4 ± 0.3	6.0 ± 0.0	Low
Toro 2	TX	L	13.2 ± 0.2	7.4 ± 0.0	5.9 ± 0.1	Low-intermediate
Baldo	TX	M	13.1 ± 0.3	9.0 ± 0.0	6.0 ± 0.0	Low
Baldo	LA	M	14.7 ± 0.1	9.9 ± 0.2	5.4 ± 0.4	Intermediate-low
Bengal	LA	M	13.1 ± 0.1	8.4 ± 0.1	6.0 ± 0.0	Low
Bengal	TX	M	13.0 ± 0.1	7.9 ± 0.1	6.0 ± 0.0	Low
S201	TX	S	13.6 ± 0.1	8.5 ± 0.1	4.8 ± 0.3	Intermediate
Mars	LA	M	14.0 ± 0.3	7.8 ± 0.3	6.0 ± 0.0	Low
Mercury	LA	M	14.1 ± 0.3	8.6 ± 0.3	5.8 ± 0.3	Low-intermediate
Kyeema	LA	L	14.3 ± 0.0	8.6 ± 0.0	2.0 ± 0.0	High
Goolarah	LA	L	14.4 ± 0.4	9.1 ± 0.2	2.0 ± 0.0	High
Calrose 76	TX	M	14.5 ± 0.1	7.8 ± 0.2	6.0 ± 0.0	Low
Brazos	LA	M	14.2 ± 0.2	8.4 ± 0.2	5.6 ± 0.3	Low-high
Brazos	TX	M	14.8 ± 0.1	7.3 ± 0.4	6.0 ± 0.0	Low
Rico I	TX	M	15.1 ± 0.4	6.7 ± 0.1	6.0 ± 0.0	Low
Kosanbare	LA	M	15.1 ± 0.2	7.8 ± 0.1	6.0 ± 0.0	Low
Arborio	LA	M	15.2 ± 0.2	9.4 ± 0.1	6.0 ± 0.0	Low
Taichung 8	Taiwan	M	15.2 ± 0.3	6.5 ± 0.2	5.8 ± 0.1	Low-intermediate
Toro 2	LA	L	15.3 ± 0.3	8.0 ± 0.0	5.9 ± 0.1	Low-intermediate
Pecos	LA	M	15.4 ± 0.5	8.3 ± 0.1	5.9 ± 0.2	Low-intermediate
Akitakamochi	CA	M	15.6 ± 0.1	6.4 ± 0.2	6.0 ± 0.0	Low
Nortai	LA	S	15.8 ± 0.0	7.3 ± 0.0	6.0 ± 0.0	Low
Nato	LA	M	15.8 ± 0.2	8.9 ± 0.3	5.8 ± 0.0	Low-intermediate
Koshihikari	CA	M	16.0 ± 0.5	5.2 ± 0.1	6.3 ± 0.3	Low
Nipponbare	LA	S	16.1 ± 0.2	7.6 ± 0.0	5.9 ± 0.1	Low-intermediate
S102	CA	S	16.2 ± 0.3	7.0 ± 0.3	6.0 ± 0.0	Low
Donguin	Korea	M	16.5 ± 0.2	8.3 ± 0.3	6.2 ± 0.0	Low
Kyeema	Australia	L	17.0 ± 0.4	8.3 ± 0.1	4.6 ± 0.1	Intermediate
M204	CA	M	17.5 ± 0.0	7.2 ± 0.1	6.0 ± 0.0	Low
Millin	Australia	M	17.5 ± 0.2	8.1 ± 0.1	6.9 ± 0.1	Low
Amaroo	Australia	M	17.6 ± 0.1	8.0 ± 0.2	7.0 ± 0.0	Low
Ilpoom	Korea	M	17.9 ± 0.2	7.8 ± 0.3	7.0 ± 0.0	Low

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[a] TX = Texas, CA = California, LA = Louisiana, AR = Arkansas.

other group (sensory or instrumental texture). A regression was conducted for each factor that loaded at least one response variable from each group.

RESULTS AND DISCUSSION

Physicochemical Properties

Table I lists the physicochemical property data for the 87 short-, medium-, and long-grain rice samples analyzed in this study. Amylose and protein contents of these nonwaxy cultivars ranged from 10.3 to 24.9% and 5.1 to 11.3%, respectively. All samples had been dried after harvest to ≈12% moisture content. Alkali spreading values ranged from 2.0 to 7.0, indicative of high to low gelatinization temperature types. Rice samples contained typical long-grain cultivars, which cook dry and fluffy and are characterized by relatively high amylose contents and intermediate to high gelatinization temperatures, and typical short- and medium-grain cultivars, which cook moist and clingy and have comparatively low amylose contents and relatively low gelatinization temperatures (Webb 1985). The set also contained samples that were exceptions to the rule. For example, Pelde, CP231, Zena, and Toro 2 are low amylose content (12–13%) types (atypical of long-grain cultivars). Pelde and CP231 are high gelatinization temperature types, and Zena and Toro 2 are low gelatinization temperature types. LA110, IRGA409, El Passo 144, Oryzicola Llamos, Taichung Sen 19, and Doongara are long-grain, high amylose (21–25%) rices that are low gelatinization temperature types.

Principal Factor Analyses

Sensory texture data. Linear correlations among sensory texture data, RVA parameters, and amylose and protein contents were examined by principal factor analysis. Prior to factor analysis, data were subjected to oblique principal component analysis to identify which variables cause collinearity in the correlation matrix. RVA measurements peak and trough were redundant with breakdown and final viscosity, respectively. Therefore, peak and trough data were omitted from factor analysis. Four factors were extracted that explained 90% of data variation (Table II). The majority of variation (51%) was explained by factor 1. RVA measurements setback (0.93), final viscosity (0.85), and breakdown (–0.78) and amylose content (0.89) loaded highest on factor 1. Sensory texture attributes initial starchy coating (–0.59), stickiness (–0.68), and cohesiveness of mass (–0.78) loadings on factor 1 were lower; however, the highest loadings of these attributes was on factor 1. Strong loadings on factor 1 indicate probable linear relationships among these attributes and measurements. A positive relationship between break-

TABLE I *(continued)*
Physicochemical Data for Rice Cultivars

Cultivar	Location[a]	Grain Type	% Amylose	% Protein	1.5% Alkali	Gel Type
Langi	Australia	L	18.0 ± 0.0	8.6 ± 0.1	3.8 ± 0.1	Intermediate
Choochung	Korea	M	18.2 ± 0.1	7.6 ± 0.1	6.9 ± 0.1	Low
Illabong	Australia	M	18.4 ± 0.3	8.5 ± 0.1	7.0 ± 0.0	Low
AS 3510	LA	L	20.0 ± 0.2	9.6 ± 0.2	3.5 ± 0.3	Intermediate-high
Cypress	TX	L	20.3 ± 0.1	9.2 ± 0.1	2.0 ± 0.0	High
Cypress	LA	L	21.5 ± 0.2	9.0 ± 0.2	2.7 ± 0.0	Intermediate-high
A301	LA	L	20.6 ± 0.4	9.6 ± 0.4	2.2 ± 0.1	High-intermediate
Lemont	TX	L	20.7 ± 0.1	8.1 ± 0.3	2.0 ± 0.0	High
Labelle	LA	L	20.9 ± 0.0	8.3 ± 0.1	2.4 ± 0.1	High-intermediate
LA110	LA	L	21.2 ± 0.1	9.8 ± 0.5	6.5 ± 0.2	Low
Della	LA	L	21.4 ± 0.2	8.6 ± 0.0	3.1 ± 0.3	Intermediate-high
Bluebonnet	LA	L	21.5 ± 0.2	9.3 ± 0.2	3.4 ± 0.2	Intermediate-high
IR64	TX	L	21.5 ± 0.5	9.2 ± 0.2	2.3 ± 0.1	High-intermediate
Lacassine	LA	L	21.6 ± 0.2	8.3 ± 0.1	2.3 ± 0.0	High-intermediate
Lebonnet	LA	L	21.7 ± 0.2	8.7 ± 0.1	2.3 ± 0.1	High-intermediate
Dellmont	LA	L	21.8 ± 0.1	8.3 ± 0.3	2.3 ± 0.0	High-intermediate
Leah	LA	L	22.3 ± 0.2	8.4 ± 0.1	2.4 ± 0.1	High-intermediate
Kaybonnet	TX	L	21.8 ± 0.0	8.0 ± 0.2	2.1 ± 0.1	High-intermediate
Kaybonnet	AR	L	22.4 ± 0.5	9.3 ± 0.2	2.2 ± 0.2	High-intermediate
Starbonnet	LA	L	21.9 ± 0.1	7.6 ± 0.7	2.6 ± 0.1	Intermediate-high
Tebonnet	LA	L	22.0 ± 0.3	8.7 ± 0.5	2.5 ± 0.0	Intermediate-high
Tebonnet	AR	L	22.3 ± 0.2	7.7 ± 0.3	3.4 ± 0.2	Intermediate-high
Doongara	Australia	L	22.4 ± 0.2	8.1 ± 0.1	5.4 ± 0.4	Intermediate-low
Dawn	LA	L	22.6 ± 0.1	8.1 ± 0.1	2.6 ± 0.3	Intermediate-high
Drew	AR	L	22.7 ± 0.4	8.3 ± 0.5	3.2 ± 0.2	Intermediate-high
L204	CA	L	22.7 ± 0.2	7.0 ± 0.2	3.9 ± 0.2	Intermediate
Bellemont	LA	L	23.0 ± 0.4	8.1 ± 0.1	2.1 ± 0.1	High-intermediate
Oryzicola Llamos	LA	L	23.2 ± 0.1	9.7 ± 0.0	7.0 ± 0.0	Low
Newrex	LA	L	23.5 ± 0.3	9.7 ± 0.3	3.3 ± 0.1	Intermediate-high
Rexmont	AR	L	23.6 ± 0.0	9.1 ± 0.3	2.9 ± 0.1	Intermediate-high
Rexmont	LA	L	23.7 ± 0.1	8.4 ± 0.1	2.7 ± 0.0	Intermediate-high
IRGA409	TX	L	23.8 ± 0.1	9.5 ± 0.0	7.0 ± 0.0	Low
L202	TX	L	24.0 ± 0.1	8.6 ± 0.1	2.0 ± 0.0	High
L202	AR	L	24.1 ± 0.1	8.8 ± 0.1	2.5 ± 0.2	High-intermediate
Guichow	LA	M	24.1 ± 0.0	8.6 ± 0.3	7.0 ± 0.0	Low
A201	CA	L	24.1 ± 0.1	8.1 ± 0.2	4.0 ± 0.0	Intermediate
AB 647	LA	M	24.2 ± 0.1	9.8 ± 0.4	7.0 ± 0.0	Low
Taim	LA	L	24.3 ± 0.5	9.2 ± 0.0	4.0 ± 0.0	Intermediate
Nanking Sel	LA	M	24.5 ± 0.0	9.6 ± 0.4	4.0 ± 0.0	Intermediate
El Passo 144	TX	L	24.5 ± 0.3	9.1 ± 0.4	7.0 ± 0.0	Low
IR72	TX	L	24.5 ± 0.4	7.6 ± 0.1	2.8 ± 0.1	Intermediate-high
L203	CA	L	24.8 ± 0.3	6.5 ± 0.0	3.3 ± 0.2	Intermediate-high
Chui 1	LA	L	24.8 ± 0.1	8.6 ± 0.7	2.6 ± 0.1	Intermediate-high
Dixiebelle	TX	L	24.9 ± 0.1	7.9 ± 0.3	2.3 ± 0.1	High-intermediate
Taichung Sen19	Taiwan	L	24.9 ± 0.1	6.8 ± 0.2	7.0 ± 0.0	Low

[a] TX = Texas, CA = California, LA = Louisiana, AR = Arkansas.

down and stickiness has been reported (Tani et al 1969). A negative relationship of amylose with breakdown and positive relationships with amylographic final viscosity and setback also have been reported (Juliano 1964a, Juliano and Pascual 1980).

Factor 2 explained 20% of data variation. Sensory texture attributes springiness (0.73) and hardness (0.74) loaded high on factor 2. Chewiness (0.56), toothpacking (0.41), residual loose particles (0.38), cohesiveness (0.37), moisture absorption (–0.38), and uniformity of bite (–0.51) exhibited their highest loading on factor 2, but the values of these attributes were relatively low. No RVA measurements loaded high on factor 2.

Protein content (0.65) and RVA measurements pasting temperature (0.55) and slickness (–0.66) loaded highest on factor 3, which explained 10% of data variation. Factor 4, which explained 9% of data variation, had the highest loadings for peaktime (0.69) and roughness (0.50).

TPA data. Linear correlations among instrumental TPA data, RVA measurements, and amylose and protein contents also were examined by principal factor analysis. Four factors were extracted that explained 89% of data variation (Table III). Factor 1 represented the majority of variation at 48%. The only measurements that exhibited their highest loading on factor 1 were TPA attributes gumminess (0.87), hardness (0.82), resilience (0.78), and cohesiveness (0.60). Loadings of RVA measurements on factor 1 were very low (0.06–0.12).

Factor 2 explained an additional 21% of data variation. RVA measurements setback (0.82), final viscosity (0.71), breakdown (–0.60), and pasting temperature (0.58) had their highest loadings on factor 2. The only TPA attribute to have its highest loading on factor 2 was adhesiveness (0.74). Amylose (0.75) also loaded high on factor 2. Protein loading on factor 2 was low (0.35) but was the highest loading of this measurement on a factor.

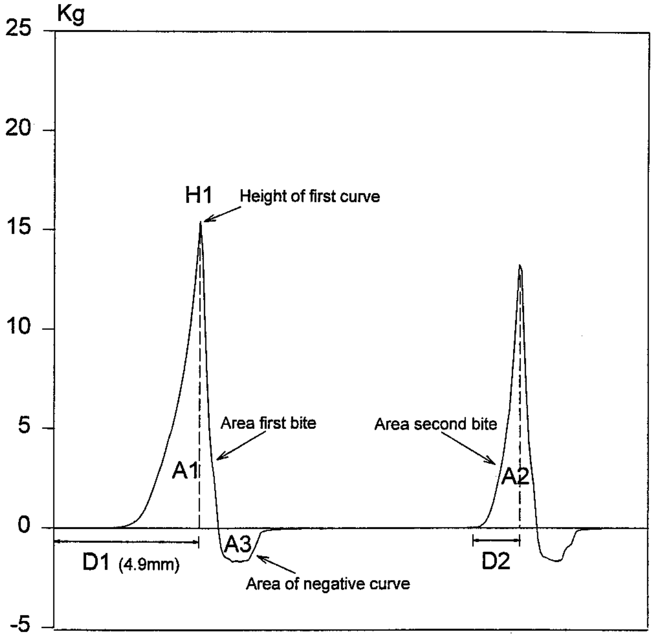

Fig. 2. Typical texture profile analysis (TPA) curve of 1-g rice samples. TPA text parameters: force-distance test, compression plate set at 5 mm to travel 4.9 mm at 1 mm/sec. Attributes on curves: H1, hardness (kg), measurement of force at peak of first curve; A1, area under first curve; A2, area under second curve; A4, measured from first data point to first probe reversal point; A5, measured from first probe reversal point to point where force returns to zero; A2/A1, cohesiveness, ratio of area under curves A2/A1; A3, adhesiveness, area of negative force curve, representing work to separate plunger from sample on upstroke after first curve; D2/D1, springiness, ratio of D2 to D1, where D1 is total distance (4.9 mm) traveled by plunger on downstroke and D2 is distance traveled on downstroke by plunger from point of sample contact to end of downstroke.

Springiness (0.94) and chewiness (0.77) had their highest loadings on factor 3, which represented an additional 11% of data variation. No RVA measurements loaded on this factor. Factor 4 explained 9% of data variation. Peaktime was the only measurement to have its highest loading on this factor.

Stepwise Multiple Regression Analyses

RVA measurements versus sensory texture or TPA attributes with the strongest linear correlations, as indicated by factor loadings, were subjected to stepwise multiple regression analyses to determine how well RVA measurements predicted cooked rice texture.

Sensory texture data. Table IV shows the multiple regression analysis results for predicting cohesiveness of mass, stickiness, initial starchy coating, slickness, cohesiveness, and hardness from RVA measurements. Setback explained most of the variance attributed to the models describing cohesiveness of mass (47%), stickiness (33%),

TABLE II
Principal Factor Analysis of Sensory Texture Data, Rapid Visco Analyser (RVA) Measurements, and Amylose and Protein Contents[a]

Variable	Factor 1	Factor 2	Factor 3	Factor 4
Chemical composition				
Amylose	**0.89**	0.05	0.27	–0.11
Protein	0.28	0.09	**0.65**	0.09
Sensory texture				
Initial starchy coating	**–0.59**	0.01	–0.56	–0.19
Slickness	–0.34	0.05	**–0.66**	0.13
Roughness	0.04	0.01	0.35	**0.50**
Stickiness	**–0.68**	–0.11	–0.48	0.00
Springiness	0.30	**0.73**	–0.09	–0.02
Cohesiveness	–0.25	**0.37**	–0.26	0.20
Hardness	0.54	**0.74**	0.16	0.19
Cohesiveness of mass	**–0.78**	–0.15	–0.32	0.16
Chewiness	0.00	**0.56**	–0.11	0.36
Uniformity of bite	–0.37	**–0.51**	–0.06	–0.21
Moisture absorption	**–0.43**	–0.38	–0.13	0.18
Residual loose particle	–0.05	**0.38**	0.12	0.08
Toothpacking	–0.29	**0.41**	–0.21	–0.05
RVA measurement				
Pasting temp.	0.40	–0.16	**0.55**	–0.31
Peaktime	0.11	0.23	–0.17	**0.69**
Final viscosity	**0.85**	0.12	0.41	0.13
Breakdown	**–0.78**	–0.22	–0.12	–0.33
Setback	**0.93**	0.03	0.42	–0.01
% Variation explained (total = 90%)	51	20	10	9

[a] Bold values indicate highest load for each variable.

TABLE III
Principal Factor Analysis of Instrumental Texture Data, Rapid Visco Analyser (RVA) Measurements, and Amylose and Protein Contents[a]

Variable	Factor 1	Factor 2	Factor 3	Factor 4
Chemical composition				
Amylose	0.12	**0.75**	–0.03	–0.10
Protein	–0.14	**0.35**	0.11	0.05
Instrumental texture				
Adhesiveness	–0.10	**0.74**	0.09	–0.16
Resilience	**0.78**	–0.02	0.06	–0.26
Hardness	**0.82**	0.02	–0.01	0.13
Cohesiveness	**0.60**	–0.09	0.00	–0.45
Gumminess	**0.87**	0.01	–0.02	0.01
Springiness	–0.11	0.03	**0.94**	0.05
Chewiness	0.30	0.04	**0.77**	0.01
RVA measurement				
Pasting temp.	–0.12	**0.58**	–0.01	–0.40
Peaktime	–0.06	–0.05	0.05	**0.74**
Final viscosity	0.11	**0.71**	–0.03	0.13
Breakdown	–0.09	**–0.60**	0.03	–0.39
Setback	0.08	**0.82**	–0.03	–0.02
% Variation explained (total = 89%)	48	21	11	9

[a] Bold values indicate highest load for each variable.

and initial starchy coating (31%). The full, multiple regression models explained 56, 45, and 40% of the variation in cohesiveness of mass, stickiness, and initial starchy coating, respectively. Most of the variance attributed to the models describing slickness (14%) and cohesiveness (8%) was explained by pasting temperature. Only 22 and 12% of the variation in slickness and cohesiveness, respectively, were explained by the full models. Breakdown (22%) explained most of the variance in the model for hardness; the full model explained 26% of the variation.

Table V shows the effect of including amylose and protein contents as variables in the multiple regression analyses. Inclusion of these variables had little effect on the amount of variance attributed to the models describing sensory attributes. Setback still explained 33 and 31% of the variation in stickiness and initial starchy coating, respectively. However, most of the variance (48%) in the model for cohesiveness of mass was explained by amylose; setback was not included as a variable. Most of the variance (21%) in the model for slickness was explained by protein; pasting temperature explained only 5% of the variance. Pasting temperature still explained 8% of the variance in cohesiveness; protein was not included as a variable. Breakdown (22%) still explained most of the variance in hardness when amylose and protein were included as variables in the analysis. Amylose explained 8% of the variance; the contribution of protein to the model was small.

TPA data. Table VI shows the multiple regression analysis results for predicting adhesiveness using RVA measurements. Setback explained most of the variance (38%) attributed to the model describing adhesiveness. The full model explained 48% of the variation in adhesiveness. Table VI also shows the effect of including amylose and protein as variables. Amylose and protein explained 50 and 2%, respectively, of the total variance (58%) attributed to the model. Only 1% of the variance attributed to the model was explained by setback.

Exception-to-the-rule samples. The exception-to-the-rule samples that cook atypically of their amylose content or gelatinization temperature types were excluded from the data set to determine whether their exclusion would improve the accuracy of RVA measurements in predicting cooked rice texture. The ability of the full models to predict sensory and instrumental texture attributes improved slightly, as indicated by increased r^2 values (0.01–0.08).

Correlations of amylose and protein contents to combined texture attributes and RVA measurements. Because amylose is considered the single most important determinant of cooked rice texture, amylose was modeled as a combination of texture attributes and RVA measurements. As shown in Table VII, sensory attributes cohesiveness of mass and stickiness explained 53% of the model variance for amylose; most of the variance was explained by cohesiveness of mass (47%). The model describing amylose in terms of TPA attributes was stronger than that described by sensory attributes. TPA attributes adhesiveness (50%), hardness (9%), and cohesiveness (6%) explained model variance. The direct correlation between amylose and hardness was $r = 0.45$ (data not shown). In comparison, Ohtsubo et al (1990) reported a correlation of amylose to texturometer adhesiveness and hardness of $r = 0.28–0.33$ and 0.46–0.69, respectively, for a set of 29 samples with amylose contents in the range of 13.3–16.6%. Reported correlations of measurements of Instron hardness to amylose have a range of $r = 0.53–0.87$ (Perez and Juliano 1979, Ohtsubo et al 1990).

The model for protein content in terms of sensory attributes was weak ($r^2 = 0.29$); slickness (21%), roughness (4%), and stickiness (4%) explained the variance (Table VII). Combined TPA attributes correlated more poorly with protein with the model explaining only 9% of the variance.

Table VIII shows the ability of combined RVA measurements to predict amylose and protein contents. RVA measurements explained

TABLE IV
Multiple Regression Analysis for Predicting Sensory Texture Attributes from Rapid Visco Analyser (RVA) Measurements[a]

Dependent Variable Variable	Model r^2	F	$P > F$
Cohesiveness of mass			
Setback	0.47	154.49	0.0001
Pasting temp. × peaktime	0.51	11.39	0.0009
Setback × setback	0.53	8.05	0.0051
Pasting temp.	0.55	3.87	0.0507
Pasting temp. × pasting temp.	0.56	5.20	0.0239
Stickiness			
Setback	0.33	84.74	0.0001
Breakdown × pasting temp.	0.37	8.94	0.0032
Setback × setback	0.42	15.22	0.0001
Setback × pasting temp.	0.43	4.83	0.0293
Final viscosity	0.45	4.42	0.0371
Initial starchy coating			
Setback	0.31	76.01	0.0001
Setback × final viscosity	0.34	7.23	0.0079
Breakdown × pasting temp.	0.36	5.66	0.0185
Pasting temp. × pasting temp.	0.39	7.75	0.0060
Setback × pasting temp.	0.40	4.03	0.0462
Slickness			
Pasting temp.	0.14	27.14	0.0001
Setback	0.17	7.13	0.0083
Final viscosity × pasting temp.	0.22	9.20	0.0028
Cohesiveness			
Pasting temp.	0.08	14.75	0.0002
Setback	0.10	3.88	0.0504
Pasting temp. × pasting temp.	0.12	4.50	0.0354
Hardness			
Breakdown	0.22	47.47	0.0001
Setback × breakdown	0.26	8.81	0.0034

[a] Variables entered into model consecutively as listed; model r^2 is cumulative with addition of each variable.

TABLE V
Multiple Regression Analysis for Predicting Sensory Texture Attributes from Rapid Visco Analyser (RVA) Measurements and Amylose and Protein Contents[a]

Dependent Variable Variable	Model r^2	F	$P > F$
Cohesiveness of mass			
Amylose	0.48	155.45	0.0001
Final viscosity	0.54	20.65	0.0001
Breakdown × protein	0.56	10.25	0.0016
Stickiness			
Setback	0.33	83.14	0.0001
Breakdown × pasting temp.	0.36	8.93	0.0032
Setback × setback	0.42	15.25	0.0001
Final viscosity × protein	0.45	8.80	0.0035
Final viscosity × amylose	0.49	15.08	0.0001
Initial starchy coating			
Setback	0.31	74.58	0.0001
Setback × final viscosity	0.33	7.05	0.0087
Breakdown × pasting temp.	0.36	5.57	0.0194
Final viscosity × protein	0.38	7.24	0.0079
Final viscosity × breakdown	0.41	7.90	0.0055
Pasting temp. × amylose	0.43	4.43	0.0369
Slickness			
Protein	0.21	46.11	0.0001
Pasting temp.	0.26	9.65	0.0022
Pasting temp. × protein	0.30	11.32	0.0010
Cohesiveness			
Pasting temp.	0.08	14.66	0.0002
Hardness			
Breakdown	0.22	47.13	0.0001
Amylose × amylose	0.30	18.63	0.0001
Breakdown × protein	0.32	4.83	0.0293
Amylose × protein	0.33	3.98	0.0476

[a] Variables entered into model consecutively as listed; model r^2 is cumulative with addition of each variable.

90% of model variance for amylose, with setback (71%) explaining most of the variance. The correlation of amylose with setback (r = 0.84) was higher than was reported in an earlier RVA study (r = 0.64) (Delwiche et al 1996). The model for protein using RVA measurements was not as strong. The total model for protein explained 41% of the variance; most of the variance was attributed to pasting temperature (15%).

CONCLUSIONS

Although amylose content is considered the most important determinant of cooked rice texture, this constituent falls short as a predictor, because cultivars with similar amylose contents may differ in textural properties. Thus, amylography is used as one of a battery of tests, in addition to measuring amylose content, to improve differentiation of cultivars. The intent of our study was to determine how well amylography conducted using an RVA serves as a predictor of cooked rice texture, as a stand-alone tool and in combination with amylose contents. We concluded that none of the cooked rice textural attributes, whether measured by descriptive analysis or instrumental TPA, were linearly modeled with high accuracy by RVA. Sensory texture attributes cohesiveness of mass, stickiness, and initial starchy coating and TPA attribute adhesiveness had the strongest correlations with RVA measurements. Setback explained most of the variance attributed to models describing these attributes; the strongest correlation (r = 0.69) was with cohesiveness of mass. Inclusion of amylose content in regression analyses did not strengthen models. Exclusion of samples that cook atypically of their amylose content or gelatinization temperature types did not improve the accuracy of RVA measurements in predicting cooked rice texture.

TABLE VI
Multiple Regression Analysis for Predicting Instrumental Adhesiveness from Rapid Visco Analyser (RVA) Measurements With and Without Amylose and Protein Contents Included[a]

Dependent Variable Variable	Model r^2	F	$P > F$
Adhesiveness: model without amylose and protein			
Setback	0.38	105.52	0.0001
Breakdown	0.43	12.63	0.0005
Pasting temp.	0.48	15.97	0.0001
Adhesiveness: model with amylose and protein			
Amylose	0.50	165.25	0.0001
Breakdown × amylose	0.53	13.04	0.0004
Protein	0.55	6.29	0.0131
Setback	0.56	4.21	0.0417
Setback × pasting temp.	0.58	6.19	0.0139

[a] Variables entered into model consecutively as listed; model r^2 is cumulative with addition of each variable.

TABLE VII
Multiple Regression Analysis for Determining Correlation Between Amylose and Protein Contents and Combined Sensory or Instrumental Texture Profile (TPA) Analyses Attributes[a]

Dependent Variable Variable	Model r^2	F	$P > F$
Amylose: model with combined sensory attributes			
Cohesiveness of mass	0.47	151.21	0.0001
Stickiness	0.53	22.04	0.0001
Amylose: model with combined TPA attributes			
Adhesiveness	0.50	168.45	0.0001
Hardness	0.59	35.89	0.0001
Cohesiveness	0.65	26.60	0.0001
Protein: model with combined sensory attributes			
Slickness	0.21	46.11	0.0001
Roughness	0.25	8.25	0.0046
Stickiness	0.29	7.93	0.0055
Protein: model with combined TPA attributes			
Adhesiveness	0.07	13.15	0.0004
Cohesiveness	0.09	4.03	0.0464

[a] Variables entered into model consecutively as listed; model r^2 is cumulative with addition of each variable.

Ascertaining how well amylose predicts cooked rice texture is difficult based on prior studies (e.g., Juliano et al 1965, Perez and Juliano 1979, Sowbhagya et al 1987, Del Mundo et al 1989, Ohtsubo et al 1990, Perez et al 1993, Kawamura et al 1996). Interpretation and comparison of results among these studies is difficult because an array of different sensory evaluation methods (e.g., preference, difference tests) using the mouth or fingers were used, and the sensory textural attributes measured were not defined or uniformly defined. Additionally, texture evaluations in these studies were limited to properties such as firmness or tenderness, stickiness, and adhesiveness that fall short in capturing the complexity of rice texture. In our study, we were able to better assess rice texture in its entirety using descriptive sensory analysis, which is an analytical, objective methodology. Using this methodology, trained panelists identified 13 sensory attributes that described rice texture at different phases of sensory evaluation, beginning with the feel of the rice when it was first placed in the mouth and ending with mouthfeel characteristics after the rice was swallowed. Correlation of the intensities of the 13 textural attributes with amylose produced a model with r^2 = 0.53; cohesiveness of mass (47%) and stickiness (6%) explained variance.

The model describing amylose as a combination of TPA measurements was stronger (r^2 = 0.65) than the model with combined sensory attributes. Adhesiveness (50%), hardness (9%), and cohesiveness (6%) explained model variance.

There are few reports relating protein content and cooked rice texture (Primo et al 1962, Onate et al 1964, Juliano et al 1965). In our study, the impact of protein content on cooked rice texture appeared to be minor. Protein content was weakly, negatively correlated to slickness and stickiness and weakly, positively correlated to roughness. When protein content was included in the model explaining sensory texture using RVA measurements, it replaced pasting temperature in describing slickness. The model, however, was weak.

TABLE VIII
Multiple Regression Analysis for Determining Correlation Between Amylose and Protein Contents and Rapid Visco Analyser (RVA) Measurements[a]

Dependent Variable Variable	Model r^2	F	$P > F$
Amylose: model with combined RVA measurements			
Setback	0.71	406.39	0.0001
Setback × setback	0.83	118.79	0.0001
Breakdown	0.86	70.79	0.0001
Final viscosity	0.88	26.71	0.0001
Pasting temp. × pasting temp.	0.89	15.47	0.0001
Final viscosity × final viscosity	0.90	15.13	0.0001
Breakdown × pasting temp.	0.90	7.79	0.0059
Protein: Model with combined RVA measurements			
Pasting temp.	0.15	28.90	0.0001
Final viscosity × peaktime	0.18	7.77	0.0059
Final viscosity × final viscosity	0.23	11.06	0.0011
Final viscosity	0.31	19.51	0.0001
Setback	0.35	8.31	0.0045
Final viscosity × breakdown	0.36	3.74	0.0547
Final viscosity × pasting temp.	0.37	2.59	0.1094
Pasting temp. × peaktime	0.38	2.71	0.1018
Pasting temp. × pasting temp.	0.39	3.75	0.0545
Setback × peaktime	0.41	4.00	0.0469

[a] Variables entered into model consecutively as listed; model r^2 is cumulative with addition of each variable.

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