Instrumental Assessment of Cooked Rice Texture Characteristics: A Method for Breeders

Jean-Francois Meullenet,[1,2] Elaine T. Champagne,[3] Karen L. Bett,[3] Anna M. McClung,[4] and Domitille Kauffmann[5]

ABSTRACT

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Sensory textural characteristics of cooked rice (61 samples) were predicted using a miniature extrusion cell and the novel data analysis method Spectral Stress Strain Analysis (SSSA). Thirteen sensory texture characteristics evaluated using a trained descriptive panel and stress values from an extrusion test were used in combination with partial least squares regression to evaluate predictive models for each of the sensory attributes studied. Among the textural attributes evaluated by the panel, four (stickiness, hardness, cohesiveness of mass, and uniformity of bite [relative ability of prediction values (RAP) > 0.6, *n* = 61]) could be satisfactorily predicted using an instrumental test and subsequent SSSA. The quality of the models determined varied for the two grain types evaluated. This instrumental method provides a valuable screening tool for rice breeders.

Texture is an important attribute of food acceptance by consumers (Moskowitz and Drake 1972) and, as such, is an important part of cooked rice quality. Sensory analysis techniques, as well as instrumental tests, are useful in the characterization of cooked rice texture. The two approaches are usually explored simultaneously, the aim being to evaluate correlations between the two methods (Szczesniak 1968).

Historically, sensory and processing qualities of rice have been defined in terms of compositional characteristics (e.g., amylose and protein contents) and evaluations of physicochemical properties (e.g., gelatinization and pasting characteristics, alkali spreading value). However, attempts to predict cooked rice textural properties from compositional characteristics are still inadequate (Juliano et al 1984, Rousset et al 1995, Meullenet 1998, Champagne et al 1999). Rapid and accurate instrumental methodologies that relate instrumental measurements to measured sensory texture attributes are needed.

At present, one of the most popular and reliable instrumental methods for predicting cooked rice texture involves the use of an Ottawa extrusion cell (Juliano et al 1981, 1984; Meullenet et al 1998). The dimensions of the Ottawa cell require large quantities (≈100 g) of milled rice for evaluation. In most cases, rice breeders cultivate small experimental plots and the amount of rice produced does not allow for the large quantities required for sensory analyses or instrumental testing using the Ottawa cell. As a result, there is a need to develop an instrumental method that has a high correlation with sensory textural properties and is less demanding of sample quantities. Such an instrumental method would be invaluable to rice breeding programs.

The objectives of this study were to 1) evaluate an instrumental method requiring small quantities of rice that would be suitable for predicting the textural characteristics of cooked rice; and 2) explore the use of multivariate analysis methods such as partial least squares regression for developing predictive models that permit the prediction of sensory textural attributes using instrumental force-deformation spectral data.

MATERIALS AND METHODS

Rice Samples

Samples of short-, medium- and long-grain rice cultivars (*n* = 58) grown in 1996 in Louisiana, Arkansas, Texas, and California were harvested at 20% moisture and dried to 12% moisture (Table I). Milled rice samples (one each) were also obtained from 1996 crops in Taiwan, Korea, and Australia (Table I). After drying, the rices were shipped to the USDA-ARS, Rice Research Unit, Beaumont, TX, where they were stored in closed containers for two to three months at 18°C. One week before sensory analyses, the samples were shelled using a Satake rice machine (model SB, Satake, Houston, TX) and then immediately milled using a laboratory one-pass mill (Satake pearler, model SKD). A milling protocol was established for each grain length type that was determined to be appropriate for producing rice with whiteness values in the targeted 40 ± 2 range considered typical of milled rice. Whiteness was measured using a milling meter (Satake, model MM-1B). Broken grains were removed by standard laboratory-sizing devices composed of indented plates and cylinders. Milled samples were shipped overnight to the USDA, ARS, Southern Regional Research Center, New Orleans, LA. Upon receipt, samples were immediately preweighed into portions for sensory, chemical, and instrumental texture analyses, and stored in 1-quart brown glass jars under a nitrogen headspace at 4°C.

Chemical Analyses

Amylose content was determined in duplicate using the simplified assay method developed by Juliano (1971). Protein content (N × 5.95) was determined in duplicate by the combustion method on a nitrogen determinator (FP-428, Leco, St. Joseph, MI). Alkali spreading value of whole grain milled rice was performed according to Little et al (1958) with modifications. Six grains from each sample were immersed in 50 mL of 1.5% KOH solution overnight at room temperature. Each grain was visually examined the next morning for level of intactness, compared with controls with known scores, and assigned a numerical score (2–7 where 2 = relatively intact and 7 = greatly dispersed). Values from the six grains were averaged to produce one value per sample.

Sample Preparation for Sensory Evaluations

Portions of rice (600 g) were rinsed three times by covering the rice with cold water and straining to remove excess water. After rinsing, the samples were transferred to preweighed rice cooker insert bowls. Water was added in amounts to give rice-to-water weight ratios appropriate for three different cook types based on amylose content (1:1, 0%; 1:1.4, 10-19%; 1:1.7, 20–25%). These ratios were selected based on test cooking and U.S. and international cooking practices. Rice was presoaked in the cooker insert bowl for 20 min at room temperature and then cooked in a rice cooker-steamer (Panasonic model SR-W10G HP) to completion, as indicated by the automatic shift of the cooker to the warm setting. Rice was held an additional 10 min at the warm setting. The top layer (1 cm) of cooked rice and rice adhering to the sides of the cooker were not presented for tasting. Cooked rice used for evaluation was taken

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[1] Department of Food Science, University of Arkansas, Fayetteville, AR.
[2] Corresponding author. Phone: 501/575 6822. Fax: 501/575 6936. Email: jfmeull@comp.uark.edu
[3] USDA ARS Southern Regional Research Center.
[4] USDA ARS Rice Research Unit.
[5] Ecole Nationale Superieure d'Agronomie Montpellier, France.

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directly from the middle of the pot, transferred to a prewarmed 120°C 2-quart glass bowl and mixed thoroughly while minimizing kernel breakage. Rice samples for panel presentation (≈48 g) were taken using a stainless steel ice cream scoop (size 18), transferred to prewarmed (120°C) 6-oz glass custard cups (Anchor Hocking) insulated by fitted Styrofoam bowls, and covered with 125-mm watch glasses. Cooking of samples was staggered so that samples were evaluated by the panel at 20-min intervals.

Sensory Evaluation Protocol

Eight panelists, previously trained in the principles and concepts of descriptive analysis (Civille and Szczesniak 1973, Civille and Liska 1975, Munoz 1986, Skinner 1988) participated in the study. The lexicon for rice texture used by the panel was based on that developed by Lyon et al (1999) and Goodwin et al (1996) (Fig. 1). The sensory texture profile included 13 sensory attributes that described rice texture at different phases of sensory evaluation, begin-

TABLE I
Physicochemical Results for Rice Cultivars

Cultivar	Location[a]	Grain Type[b]	% Amylose	% Protein	1.5% Alkali	Gel Type[c]
A301	LA	L	20.6 + 0.4	9.6 + 0.4	2.2 + 0.1	HIGH-INT
AS 3510	LA	L	20.0 + 0.2	9.6 + 0.2	3.5 + 0.3	INT-HIGH
Bellemont	LA	L	23.0 + 0.4	8.1 + 0.1	2.1 + 0.1	HIGH-INT
Bluebonnet	LA	L	21.5 + 0.2	9.3 + 0.2	3.4 + 0.2	INT-HIGH
CP231	TX	L	12.3 + 0.3	8.4 + 0.2	2.0 + 0.0	HIGH
Cypress	LA	L	21.5 + 0.2	9.0 + 0.2	2.7 + 0.0	INT-HIGH
Cypress	TX	L	20.3 + 0.1	9.2 + 0.1	2.0 + 0.0	HIGH
Della	LA	L	21.4 + 0.2	8.6 + 0.0	3.1 + 0.3	INT-HIGH
Dixiebelle	TX	L	24.9 + 0.1	7.9 + 0.3	2.3 + 0.1	HIGH-INT
Drew	AR	L	22.7 + 0.4	8.3 + 0.5	3.2 + 0.2	INT-HIGH
El Passo 144	TX	L	24.5 + 0.3	9.1 + 0.4	7.0 + 0.0	LOW
Goolarah	LA	L	14.4 + 0.4	9.1 + 0.2	2.0 + 0.0	HIGH
IR64	TX	L	21.5 + 0.5	9.2 + 0.2	2.3 + 0.1	HIGH-INT
IR72	TX	L	24.5 + 0.4	7.6 + 0.1	2.8 + 0.1	INT-HIGH
IRGA409	TX	L	23.8 + 0.1	9.5 + 0.0	7.0 + 0.0	LOW
Kaybonnet	TX	L	21.8 + 0.0	8.0 + 0.2	2.1 + 0.1	HIGH-INT
Kyeema	LA	L	14.3 + 0.0	8.6 + 0.0	2.0 + 0.0	HIGH
L202	AR	L	24.1 + 0.1	8.8 + 0.1	2.5 + 0.2	HIGH-INT
L203	CA	L	24.8 + 0.3	6.5 + 0.0	3.3 + 0.2	INT-HIGH
LA110	LA	L	21.2 + 0.1	9.8 + 0.5	6.5 + 0.2	LOW
Labelle	LA	L	20.9 + 0.0	8.3 + 0.1	2.4 + 0.1	HIGH-INT
Lacassine	LA	L	21.6 + 0.2	8.3 + 0.1	2.3 + 0.0	HIGH-INT
Leah	LA	L	22.3 + 0.2	8.4 + 0.1	2.4 + 0.1	HIGH-INT
Lebonnet	LA	L	21.7 + 0.2	8.7 + 0.1	2.3 + 0.1	HIGH-INT
Lemont	TX	L	20.7 + 0.1	8.1 + 0.3	2.0 + 0.0	HIGH
Newrex	LA	L	23.5 + 0.3	9.7 + 0.3	3.3 + 0.1	INT-HIGH
Pelde	TX	L	12.2 + 0.2	8.6 + 0.3	2.0 + 0.0	HIGH
Rexmont	AR	L	23.6 + 0.0	9.1 + 0.3	2.9 + 0.1	INT-HIGH
Rexmont	LA	L	23.7 + 0.1	8.4 + 0.1	2.7 + 0.0	INT-HIGH
Starbonnet	LA	L	21.9 + 0.1	7.6 + 0.7	2.6 + 0.1	INT-HIGH
Taichung Sen	Taiwan	L	0.9 + 0.2	11.0 + 0.0	4.9 + 0.2	INT
Taim	LA	L	24.3 + 0.5	9.2 + 0.0	4.0 + 0.0	INT
Zena	TX	L	12.7 + 0.2	8.6 + 0.2	6.0 + 0.0	LOW
AB 647	LA	M	24.2 + 0.1	9.8 + 0.4	7.0 + 0.0	LOW
AB 869	LA	M	12.4 + 0.5	8.3 + 0.1	6.0 + 0.0	LOW
Baldo	LA	M	14.7 + 0.1	9.9 + 0.2	5.4 + 0.4	INT-LOW
Baldo	TX	M	13.1 + 0.3	9.0 + 0.0	6.0 + 0.0	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
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
Calrose 76	TX	M	14.5 + 0.1	7.8 + 0.2	6.0 + 0.0	LOW
Choochung	Korea	M	18.2 + 0.1	7.6 + 0.1	6.9 + 0.1	LOW
Guichow	LA	M	24.1 + 0.0	8.6 + 0.3	7.0 + 0.0	LOW
Illabong	Australia	M	18.4 + 0.3	8.5 + 0.1	7.0 + 0.0	LOW
Kosanbare	LA	M	15.1 + 0.2	7.8 + 0.1	6.0 + 0.0	LOW
Koshihikari	CA	M	16.0 + 0.5	5.2 + 0.1	6.3 + 0.3	LOW
M201	TX	M	10.7 + 0.1	10.9 + 0.2	5.8 + 0.1	LOW-INT
M202	CA	M	14.8 + 0.2	6.8 + 0.1	6.1 + 0.1	LOW
M202	TX	M	10.3 + 0.2	8.4 + 0.1	6.0 + 0.0	LOW
M204	CA	M	17.5 + 0.0	7.2 + 0.1	6.0 + 0.0	LOW
M401	CA	M	17.1 + 0.1	6.2 + 0.2	7.0 + 0.0	LOW
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-INT
Nanking Sel	LA	M	24.5 + 0.0	9.6 + 0.4	4.0 + 0.0	INT
Nato	LA	M	15.8 + 0.2	8.9 + 0.3	5.8 + 0.0	LOW-INT
Pecos	LA	M	15.4 + 0.5	8.3 + 0.1	5.9 + 0.2	LOW-INT
V 4716	LA	M	12.3 + 0.2	9.2 + 0.2	6.0 + 0.0	LOW
Nipponbare	LA	S	16.1 + 0.2	7.6 + 0.0	5.9 + 0.1	LOW-INT
Nortai	LA	S	15.8 + 0.0	7.3 + 0.0	6.0 + 0.0	LOW
S102	CA	S	16.2 + 0.3	7.0 + 0.3	6.0 + 0.0	LOW

[a] TX = Texas, CA = California, LA = Lousiana, AR = Arkansas.
[b] L = long grain, M = medium grain, S = short grain
[c] INT = intermediate gel temperature, LOW = low gel temperature, HIGH = high gel temperature.

ning with the feel of the rice when it was first placed in the mouth and ending with mouthfeel characteristics after the rice was 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 long grain rice grown in California). The standard, presented at the beginning of each session, was used to calibrate the panel. Following 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 lights. Distilled, filtered water (Hydrotech drinking water filtration system) was used to cleanse the mouth between samples. Data acquisition was performed using a computerized ballot system (Compusense, version 1.2, Guelph, Ontario) featuring line scales with marked integers. Sores were recorded using light pens.

Extrusion Cell Design

The extrusion cell used in this study was created in response to the needs of rice breeding programs. Thus, it considers several constraints related to size, price, and the rice quantities necessary for instrumental testing. The cell developed (90 mm long, 20 mm diam.) was made from 0.75-in. PVC compression fitting bored to size and fitted with an extrusion plate of stainless steal mesh (0.5 mm). An extrusion cylinder (19.5 mm diam., 95 mm long) was turned to size from a 1-in. Teflon rod (Fig. 2).

Sample Preparation for Instrumental Analysis

Because temperature influences rice texture (Okabe 1979), it must be carefully controlled so that instrumental testing is accurate and reproducible. Previous work by Meullenet et al (1998) was performed using rinsed cooked rice at room temperature. However, it was concluded that evaluations performed at room temperature did not represent optimal testing conditions. Thus, a cooking protocol similar to that used for sensory testing was developed. Milled rice (30 g) was rinsed three times by covering the rice with cold water, straining to remove excess water, and then transferring to a 150-mL beaker. Water was added according to amylose content as noted previously, and samples were allowed to presoak for 20 min. For uniform and equal absorption of water by all grains, the beaker was placed on a screen inside a steam rice-cooker to prevent direct contact with the heating element. Water (200 mL) was added in the rice-cooker. Rice was steamed for 30 min. Cooked rice was then thoroughly mixed using a plastic fork before transferring 8.5 g into each of six identical extrusion cells. The filled cells were then quickly returned to the rice cooker and held an additional 10 min at the warm setting to simulate sensory testing conditions. Due to physical constraints such as sample availability and extrusion cell loading time, instrumental testing conditions were not exactly identical to that of the sensory cooking protocol. However, cooking procedure differences were subtle, and instrumental test cooking conditions should be representative of the sensory protocol.

Phases/Attributes[1]	**Definitions**
PHASE I.	*Place 6-7 grains of rice in the mouth behind the front teeth. Press the tongue over the 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 to which grains return to original shape after partial compression with molars.
Cohesiveness	degree to which the grains deform rather than crumble, crack, or break when biting with molars.
Hardness	force required to bite through the sample with the molars.
PHASE III.	*Evaluate during chew.*
Cohesiveness of Mass	maximum degree to which the sample holds together in a mass while chewing.
Chewiness	amount of work to chew the sample.
Uniformity of Bite	uniformity of force throughout bites.
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.

[1] Attributes intensities based on 0-15 scale.

Fig. 1. Sensory descriptive analysis attributes and definitions used to evaluate cooked rice texture.

Instrumental Measurements

Extrusion cells were removed one at a time from the rice-cooker and instrumental testing was performed immediately. Instrumental evaluation was conducted using a texture analyzer (model TA-XT2i, Texture Technologies, Scarsdale, NY) in combination with a 25-kg load cell. The crosshead speed was set at test speed of 2.0 mm/sec for a total distance of 85 mm. Force-distance curves were recorded. A typical force-deformation curve is shown in Fig. 3. The curve can be divided into four sections corresponding to the main stages of the instrumental test (packing, compression, extrusion, and tension). These phases were derived from examining partially extruded samples. For example, the extrusion phase was determined to start from the distance at which the rice kernels are starting to be extruded through the screen and end when the extrusion cylinder started its upward movement.

Statistical Analyses

The six subsamples of the force-distance curve from each sample were compared, and an average force-distance curve was determined. The average force-distance curve was exported to spreadsheet software to extract forces corresponding to specific cylinder travel distances. A force value was assessed for each deformation increment and used as a predictive variable. A multivariate analysis software (Unscrambler, vers. 6.11b, CAMO, Throndheim, Norway) was used to determine predictive models of sensory texture attributes. The concept for this Spectral Stress Strain Analysis (SSSA) is

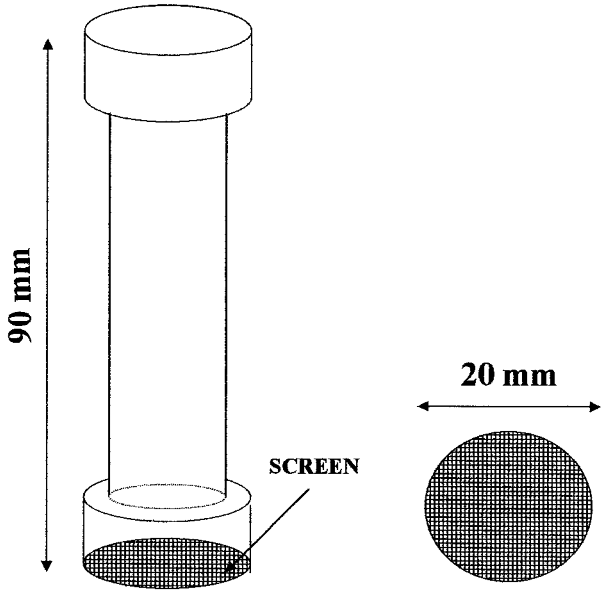

Fig. 2. Experimental extrusion cell.

based on the prediction of sensory texture characteristics from the shape of the force-deformation curves rather than on the calculation of instrumental parameters such as maximum force or total work (Fig. 3). Partial least squares regression (option PLS1) was used for predicting sensory attributes from force-distance curve. When only one sensory attribute is modeled, the PLS algorithm is noniterative (PLS1). The full cross-validation method was employed to evaluate model robustness. The accuracy of the model was expressed using the root mean square error of prediction (RMSEP). To compare the predictive ability of the calibration models, relative ability of prediction values (RAP) as described by Martens and Martens (1986) were calculated for each sensory attribute as:

$$\mathrm{RAP} = (S^2_{\mathrm{tot}} - \mathrm{RMSEP}^2)/(S^2_{\mathrm{tot}} - S^2_{\mathrm{ref}}) \qquad (1)$$

where S_{tot} is the standard deviation of a sensory attribute and S_{ref} is the standard error of the reference method (sensory evaluation) indicating the uncertainty of the analysis due to panelist. S_{ref} is defined for a sensory attribute as:

$$S_{\mathrm{ref}} = (\mathrm{MSE} / (P \times R))^{0.5} \qquad (2)$$

where MSE is the mean square error derived from two-way analysis of variance with samples and panelists, and P and R represent the number of panelists and replications, respectively.

RESULTS AND DISCUSSION

Physicochemical Properties

Physicochemical data for the 61 short-, medium-, and long-grain samples are listed in Table I. Amylose and protein contents of the nonwaxy cultivars ranged from 10.3 to 24.9% and 5.2 to 11.0%, respectively. The amylose content of Taichung Sen was very low (0.9%), typical of a waxy cultivar, and protein content was high (11%). Alkali-spreading values were 2.0–7.0, indicative of high to low gelatinization temperature types.

This set of rice samples contained both typical and atypical short-, medium-, and long-grain cultivars. Typical long-grain cultivars are dry and fluffy when cooked and are characterized by relatively high amylose content and intermediate to high gelatinization temperatures. In contrast, typical short- and medium-grain cultivars are moist and clingy when cooked and have comparatively low amylose content and relatively low gelatinization temperatures (Webb 1985). Atypical cultivars were also present in the sample set. For example, Pelde, CP231, and Zena had low amylose contents (12–13%) atypical of long-grain cultivars; Pelde and CP231 are high-gelatinization-temperature types, while Zena is a low-gelatinization-temperature type. L110 and IRGA409 are long-grain, high-amylose (21–25%) low-gelatinization-temperature rices. Atypical of a waxy cultivar, Taichung Sen is an intermediate-gelatinization-temperature type and had cooked textural properties similar to a cultivar with high amylose.

Prediction of Cooked Rice Texture

Results from descriptive sensory evaluation show that the largest ranges of scores (data not shown) between the 61 rice samples were reported for stickiness, hardness, cohesiveness of mass, and uniformity of bite. It is for these attributes that the greatest differences between samples were reported. It is, in general, difficult to predict sensory textural differences from an instrumental test when samples exhibit small or no differences for a particular sensory attribute. This observation for the sensory data may exlain some of the poor results obtained for some of the attributes evaluated in this study.

Among the texture attributes evaluated by the panel, stickiness, hardness, cohesiveness of mass and uniformity of bite (RAP > 0.6) were satisfactorily predicted using an instrumental test and subsequent SSSA. Predictive models were evaluated for short-, medium-, and long-grain cultivars combined (Table II) as well as for specific gelatinization temperature types. The segregation of samples into either low-to-intermediate (Table III) and intermediate-to-high (Table IV) gelatinization temperature was performed in an attempt to improve on the models obtained using all samples combined.

Stickiness was relatively well predicted (RAP = 0.76, Table II) using the miniature extrusion test in combination with SSSA. This result was expected for two reasons. First, the extrusion test was performed using warm cooked rice, using cooking methods similar to those used for sensory evaluation. In previous studies by Meullenet et al (1998), rice was rinsed and kept cold (4°C) before measuring texture and it was reported that the prediction of rice stickiness was unreliable using an instrumental extrusion test. A possible explanation for the reliable prediction of rice stickiness in the present study is that the starch leaching from individual rice kernels was not rinsed after cooking. For an estimation of the average error of prediction expressed in sensory units, RMSEP = 0.51 (Table II), which was roughly one-half of a unit on the 15 point scale used by the panel. This is an extremely encouraging result as sensory panel data standard deviations are usually within this range. Analyses performed on low-to-intermediate and intermediate-to-high gelatinization temperature rices as separate groups showed

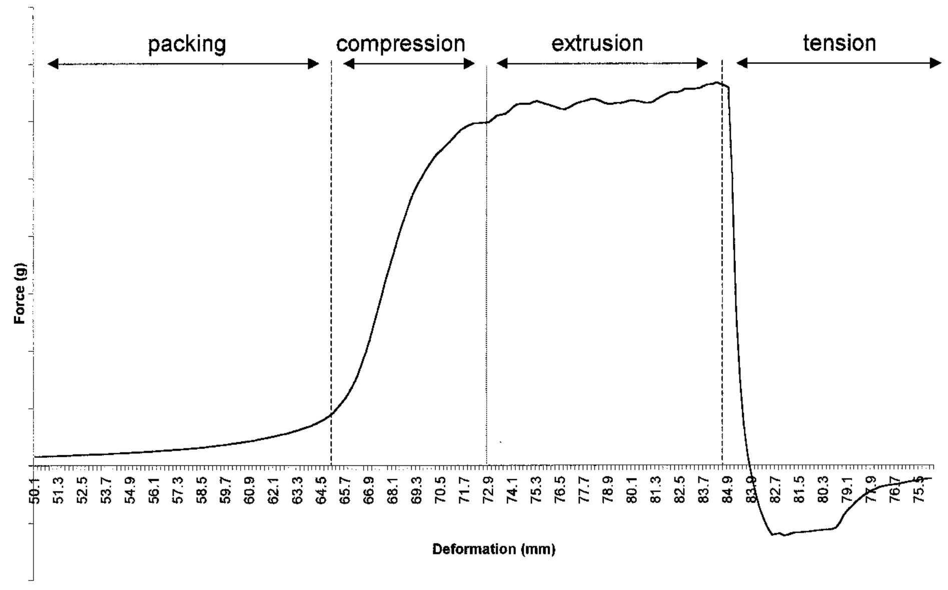

Fig. 3. Typical sample extrusion curve and related test phases.

that predictive models were more accurate for the intermediate-to-high gel temperature samples (RAP = 0.78, RMSEP = 0.51) (Table IV) than for low-to-intermediate gel temperature samples (RAP = 0.58, RMSEP = 0.69) (Table III). This result is surprising because more variation in sensory stickiness scores was observed, and average panel unreliability as measured by S_{ref} was lower for the low-to-intermediate gel temperature samples.

Hardness is the most commonly evaluated sensory attribute using instrumental tests. The instrumental test performed in this study using the miniature extrusion cell showed promising results (RAP = 0.69, n = 61) (Table II). This is a significant improvement over the RAP reported by Meullenet et al (1998) using a standard back extrusion cell (RAP = 0.52) and may be due to the differences in cooking methods used by the two studies. In the study by Meullenet et al (1998), hardness was evaluated on room-temperature rice a few hours after cooking. During storage, starch retrogradation may occur at different rates in different cultivars, rendering instrumental data unrepresentative of sensory assessments. The RAP reported in our study is high enough to allow discrimination between samples exhibiting minute differences for this sensory characteristic. Furthermore, the average prediction error (RMSEP = 0.34) (Table II) was very low. Analyses performed on the low-to-intermediate and intermediate-to-high gel temperature as separate groups showed slightly better results for the intermediate-to-high gel temperature samples (RAP = 0.90, RMSEP = 0.31) (Table IV).

Cohesiveness of mass is defined as the degree to which the sample holds together in a mass when chewed. The sensory definition implies that the perception of this attribute is related to the mass cohesion after the sample has been compressed and sheared. Thus, the sensory definition is in accordance with the instrumental test principle that extrusion is a combination of compression and shearing as used in this study. Cooked rice cohesiveness of mass sensory scores were relatively well predicted by the instrumental data (RAP = 0.62, RMSEP = 0.54) (Table II). These results were similar to those reported by Meullenet et al (1998). Models calculated for the two gel temperature types were better for the low-to-intermediate gel samples (RAP = 0.76, RMSEP = 0.47) (Table III). This result is not surprising because the variation in sensory intensities was larger in the low-to-intermediate gel temperature samples (S_{tot} = 0.78, Table III) than in the intermediate-to-high gel temperature samples (S_{tot} = 0.70, Table IV).

Uniformity of bite was reasonably well predicted by the instrumental data (RAP = 0.69, RMSEP = 0.37) (Table II). Results also showed a higher RAP for the low-to-intermediate gel temperature (RAP = 0.79, Table III) than for the intermediate-to-high gel temperature samples (RAP = 0.66, Table IV). Both the panel variability (S_{ref} = 0.33) and average prediction error (RMSEP = 0.36) were lower for the low-to-intermediate gel temperature samples.

Although other attributes showed promising results when the model was generated, the models did not validate well using the full cross-validation method. Use of such predictive models would not yield reliable results for attributes such as initial starch coating (R_{cal} = 0.72), springiness (R_{cal} = 0.67), and cohesiveness (R_{cal} = 0.74) (Table II). Slickness, roughness, chewiness, moisture absorption, residual loose particles, and toothpacking intensities were not well predicted by the extrusion test used in this study. Sensory estimation of residual particles present in the mouth after swallowing did not exhibit a large range of scores; sensory scores were 3.5–4.6 on a 15-point scale. To a lesser extent, the same was observed for roughness and slickness. In general, the sensory attributes exhibiting a large range of scores were those best predicted by instrumental SSSA.

Correlation Between Sensory Attributes and Force-Deformation Curve

Some portions of the force-deformation curves were identified as important in the prediction of several sensory attributes. Figure 4 is a graphical representation of weighted regression coefficients for each of the instrumental variables used. The regression coeffici-

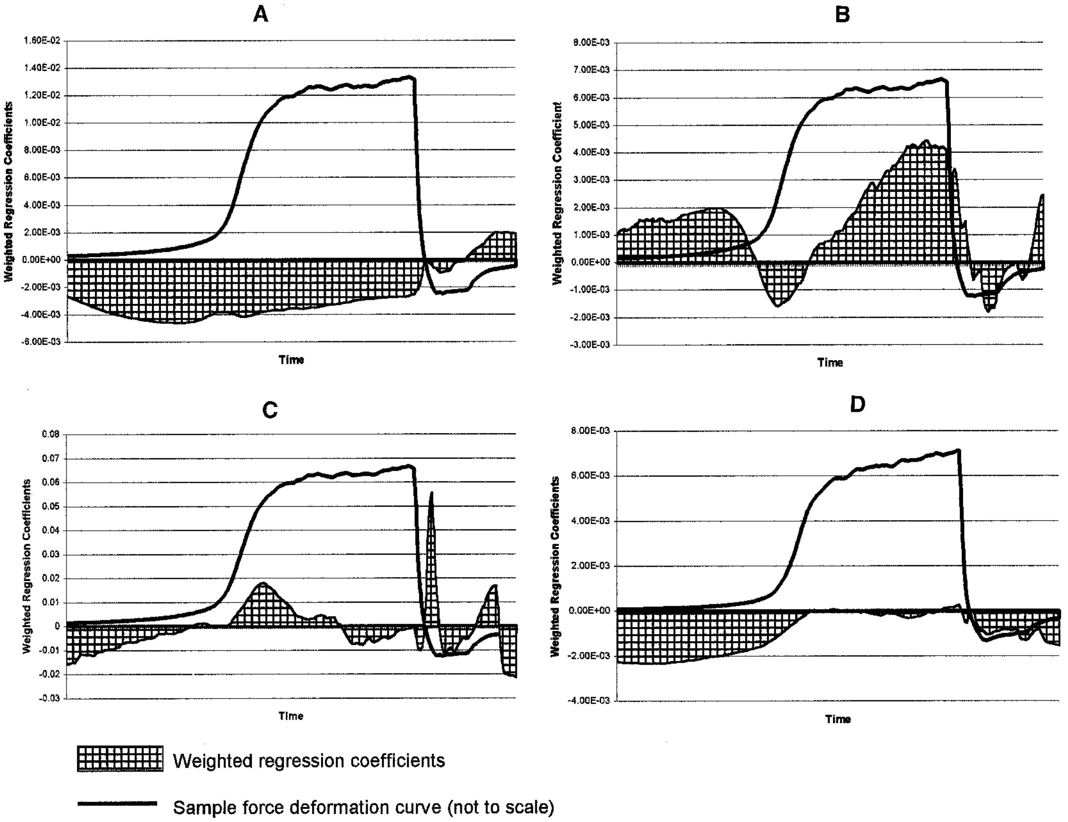

Fig. 4. Weighted regression coefficients, corresponding force-deformation curve for stickiness (**A**), hardness (**B**), cohesiveness of mass (**C**), and uniformity of bite (**D**)

ents were graphed in weighted form so that the relative importance (regardless of the magnitude of the force response) of each instrumental variable could be assessed. For example, models evaluated for stickiness (Fig. 4A) show that the entire portion of the curve corresponding to the down-travel of the probe is important to the prediction of this attribute. In particular, the initial compression of the sample was identified as critical for the prediction of rice stickiness. This observation is not surprising because it corresponds to the portion of the test during which the rice kernels stick together. Hardness (Fig. 4B) was especially correlated with the extrusion portion of the curve (shearing of individual kernels). Cohesiveness of mass (Fig. 4C) showed a more complex pattern of regression coefficients. However, it appeared that the tension part of the extrusion test was most important in determining cohesiveness of mass. Uniformity of bite (Fig. 4D) was highly correlated with the first and last portions of the curve (packing and tension).

CONCLUSIONS

The use of a miniature extrusion cell in combination with multivariate analysis techniques showed a satisfactory prediction of four main sensory attributes of cooked rice texture (stickiness, hardness, cohesiveness of mass, and uniformity of bite). In the instrumental force-deformation spectra used for modeling sensory perception, portions of the curve were identified as important to the prediction of the textural attributes. This method should allow rice breeders to make routine assessments of rice texture quality based on defined sensory criteria. This instrumental test provides rice breeders a tool for selecting rice cultivars suited for cultivation in the United States based on sensory texture characteristics.

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Erratum

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Instrumental Assessment of Cooked Rice Texture Characteristics: A Method for Breeders

Jean-Francois Meullenet, Elaine T. Champagne, Karen L. Bett, Anna M. McClung, and Domitille Kauffmann

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The following tables should have been included with the text:

TABLE II

Model Statistics for Predicting Individual Sensory Attributes from Spectral Stress Strain Analysis Using All Samples (*n* = 61)

	MSE[a]	S_{tot}[b]	S_{ref}[c]	RMSEP[d]	RAP[e]	R_{cal}[f]
Phase I						
Initial starch coating	0.62	0.58	0.21	0.44	0.49	0.72
Slickness	1.85	0.77	0.37	0.74	0.10	0.39
Roughness	1.38	0.61	0.32	0.54	0.31	0.27
Stickiness	1.59	0.85	0.34	0.51	0.76	0.77
Phase II						
Springiness	0.88	0.44	0.26	0.40	0.28	0.67
Cohesiveness	1.29	0.55	0.31	0.44	0.53	0.74
Hardness	0.79	0.49	0.24	0.34	0.69	0.81
Phase III						
Cohesiveness of mass	1.50	0.76	0.33	0.54	0.62	0.71
Chewiness	0.50	0.34	0.19	0.35	–0.07	0.38
Uniformity of bite	1.64	0.41	0.35	0.37	0.69	0.73
Moisture absorption	0.86	0.41	0.25	0.36	0.37	0.50
Phase IV						
Residual particles	0.39	0.21	0.17	0.21	–0.03	0.18
Toothpacking	0.94	0.36	0.26	0.35	0.08	0.33

[a] Mean square error derived from a two-way analysis of variance.
[b] Standard deviation of the sensory intensities across all samples for a particular attribute.
[c] Standard error of the reference method.
[d] Root mean square error of prediction.
[e] Relative ability of prediction values.
[f] Regression coefficient for the calibration model.

TABLE III

Model Statistics for Predicting Individual Sensory Attributes from Spectral Stress Strain Analysis Using Low-to-Intermediate Gel Temperature Samples (*n* = 28)

	MSE[a]	S_{tot}[b]	S_{ref}[c]	RMSEP[d]	RAP[e]	R_{cal}[f]
Phase I						
Initial starch coating	0.63	0.54	0.22	0.47	0.29	0.59
Slickness	1.80	0.75	0.37	0.67	0.27	0.38
Roughness	1.36	0.67	0.32	0.65	0.08	0.35
Stickiness	1.41	0.99	0.32	0.69	0.58	0.71
Phase II						
Springiness	0.82	0.42	0.25	0.38	0.28	0.85
Cohesiveness	1.28	0.53	0.31	0.40	0.65	0.86
Hardness	0.70	0.45	0.23	0.33	0.62	0.66
Phase III						
Cohesiveness of mass	1.35	0.78	0.32	0.47	0.76	0.69
Chewiness	0.42	0.25	0.18	0.26	–0.16	0.24
Uniformity of bite	1.48	0.45	0.33	0.36	0.79	0.63
Moisture absorption	0.81	0.34	0.25	0.33	0.12	0.48
Phase IV						
Residual particles	0.39	0.21	0.17	0.19	0.54	0.81
Toothpacking	0.89	0.41	0.26	0.37	0.31	0.57

[a] Mean square error derived from a two-way analysis of variance.
[b] Standard deviation of the sensory intensities across all samples for a particular attribute.
[c] Standard error of the reference method.
[d] Root mean square error of prediction.
[e] Relative ability of prediction values.
[f] Regression coefficient for the calibration model.

TABLE IV

Model Statistics for Predicting Individual Sensory Attributes from Spectral Stress Strain Analysis Using Intermediate-to-High Gel Temperature Samples (n = 33)

	MSE[a]	S_{tot}[b]	S_{ref}[c]	RMSEP[d]	RAP[e]	R_{cal}[f]
Phase I						
Initial starch coating	0.58	0.58	0.21	0.43	0.51	0.74
Slickness	1.72	0.51	0.37	0.53	–0.16	0.30
Roughness	1.41	0.63	0.33	0.64	–0.06	0.40
Stickiness	1.67	0.87	0.36	0.51	0.79	0.82
Phase II						
Springiness	0.95	0.47	0.27	0.44	0.19	0.54
Cohesiveness	1.16	0.56	0.30	0.59	–0.13	0.33
Hardness	0.90	0.57	0.26	0.31	0.90	0.76
Phase III						
Cohesiveness of mass	1.47	0.70	0.34	0.54	0.53	0.70
Chewiness	0.55	0.39	0.21	0.33	0.37	0.63
Uniformity of bite	1.75	0.45	0.37	0.40	0.66	0.57
Moisture absorption	0.92	0.47	0.27	0.37	0.55	0.67
Phase IV						
Residual particles	0.38	0.21	0.17	0.24	–0.70	0.26
Toothpacking	0.96	0.32	0.27	0.32	–0.13	0.56

[a] Mean square error derived from a two way analysis of variance.

[b] Standard deviation of the sensory intensities across all samples for a particular attribute.

[c] Standard error of the reference method.

[d] Root mean square error of prediction.

[e] Relative ability of prediction values.

[f] Regression coefficient for the calibration model.