Prediction of Rice Sensory Texture Attributes from a Single Compression Test, Multivariate Regression, and a Stepwise Model Optimization Method

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ABSTRACT: Sensory texture characteristics of cooked rice (92 samples) were predicted using a compression test and a novel multivariate analysis method (that is, Partial Least Squares Regression optimized by a stepwise method). 11 sensory texture characteristics were evaluated via a trained descriptive panel, and 14 instrumental parameters from a compression test were used in combination with Partial Least Squares Regression to evaluate predictive models for each of the sensory attributes studied.

Among the texture attributes evaluated by the panel, 7 (cohesion of bolus, adhesion to lips, hardness, cohesiveness of mass, roughness of mass, toothpull, and toothpack) were satisfactorily predicted after the optimization by the stepwise method (optimized Rcal > 0.6).

Key Words: rice, texture, sensory evaluation, compression test

Introduction

COOKED RICE TEXTURE HAS BEEN SHOWN TO GOVERN THE acceptance of rice by consumers when consumed as whole grain (Okabe 1979). Texture has been defined as a multidimensional characteristic that only humans can perceive, define, and measure (Szczesniak 1987). As such, descriptive analysis is a useful tool for characterizing texture properties of cooked rice. However, the cost associated with training and maintaining a descriptive panel has prompted many researchers to evaluate less costly and less time-consuming approaches. The evaluation of texture properties involving the use of instruments specifically designed for the evaluation of the physical characteristics of food is a common practice in the food industry. The 2 approaches, sensorial and instrumental, are often explored simultaneously; the aim being to evaluate correlations between the 2 methods (Szczesniak 1968) to potentially derive an instrumental method capable of predicting the sensory characteristics of a food on a routine basis.

Many researchers have studied the instrumental evaluation of cooked rice texture, and several instrumental methods have been examined. At present, 1 of the most popular and reliable instrumental methods involves the use of an Ottawa extrusion cell (Meullenet and others 1998; Juliano and others 1984). The dimensions of the traditional Ottawa cell require rather large quantities (that is, around 100 g of milled rice) of rice for evaluation. In many instances, rice breeders cultivate small experimental plots, and the small amounts of rice yielded do not allow for such instrumental testing. As a result, there is a need for developing instrumental methods that correlate highly with sensory properties and are less demanding on sample quantities. Compression tests, which require smaller sample sizes, performed between flat plates have been described by several researchers (Juliano and others 1981, 1984; Okabe 1979; Szczesniak and Hall 1974). Juliano and others (1984) demonstrated that an instrumental method utilizing small sample sizes (that is, a few kernels) was less reliable than a test performed on bulk samples. However, the successful development of a technique requiring only a few kernels to be performed would be invaluable to rice-breeding programs to quickly and inexpensively assess texture characteristics of cooked rice.

The objectives of this study were (1) to evaluate the suitability of an instrumental compression test requiring small rice samples suitable for predicting cooked rice texture characteristics and (2) to evaluate the use of Partial Least Regression for developing predictive models of specific texture attributes.

Materials and Methods

Rice samples

All varieties were harvested in 1998 from the University of Arkansas Rice Research and Extension Center in Stuttgart, Ark., U.S.A. Harvest moisture contents of the rice varieties were between 17% and 19% (wet base). The rice was immediately cleaned using a Carter-Day Dockage Tester (Carter-Day Co., Minneapolis, Minn., U.S.A.). It was then placed in plastic, airtight buckets, and stored at −10 °C for approximately 2 wk. The rice was then dried using a Parameter Control Generator Unit in a laboratory scale dryer at 43.3 °C and 38.2% RH for 75 min.

The 1st sample set (75 samples) included only 3 rice varieties (that is, Drew (D), Bengal (B), and Kaybonnet (K)) and constituted samples involved in drying and storage studies conducted by the University of Arkansas Rice Processing Program. Drew and Bengal samples were dried under low-temperature conditions (43.3 °C, 38.2% RH, 9.5% EMC, 75 min), while Kaybonnet was dried under both low-temperature conditions (KL) and high-temperature conditions (KH) (60.0 °C, 16.9% RH, 5.8% EMC, 20 min). Drew and Kaybonnet are 2 long-grain rice varieties, while Bengal is a medium-grain variety.

After drying, each rice variety was divided into 3 lots to be equilibrated to the final moisture contents of 10%, 12%, and

Table 1—List of samples evaluated from postharvest processing studies

			Storage duration							
variety	MC[a]	ST[b] °C	time 0 (0 week)	time 1 3 weeks	time 2 6 weeks	time 3 12 weeks	time 4 18 weeks	time 5 24 weeks	time 6 30 weeks	time 7 36 weeks
Drew	10	4			*	*		*		*
		21	*		*	*		*		*
		38			*	*		*		*
	12	4			*	*		*		*
		21	*		*	*		*		*
		38			*	*		*		*
	14	4			*	*		*		*
		21	*		*	*		*		*
		38			*	*		*		*
Bengal	10	4								
		21	*							
		38								
	12	4								
		21	*							
		38								
	14	4								
		21	*							
		38								
Kaybonnet high temperature treatment KH	10	4								
		21	*							
		38								
	12	4								
		21	*							
		38								
	14	4								
		21	*							
		38								
Kaybonnet low temperature treatment KL	10	4		*	*				*	
		21	*	*	*				*	
		38		*	*				*	
	12	4		*	*				*	
		21	*	*	*				*	
		38		*	*				*	
	14	4		*	*				*	
		21	*	*	*				*	
		38		*	*				*	

[a] rough rice storage moisture content
[b] rough rice storage temprature (°C)

14%. Equilibration occurred in wooden framed wire-mesh trays (rice layer ½ inch deep) in air-controlled chambers until the target moisture content (mc) was reached. Samples of each variety (Kaybonnet (KL and KH), Drew (D), and Bengal (B)) at each moisture content (10%,12%, and 14%) were again divided into thirds, placed in airtight plastic buckets, and stored at 4, 21, or 38 °C. Samples were evaluated at various stages of storage (0, 3, 6, 12, 24, 30, and 36 wk). However, all samples were not evaluated at all dates. For example, Bengal rice was included in the study only at time 0. A list of the 75 samples evaluated is presented in Table 1.

In addition, 17 cultivars obtained from the same location were used as an additional set of samples. These samples were dried under low-temperature conditions (43.3 °C, 38.2% RH, 9.5% EMC, 75 min), equilibrated to a final moisture content of 12%, and stored at 21 °C for 18 wk. Cultivars and varieties included in this sample set were: 89Y-235, RU9601053, RU9601096, RU961099, STG93M6-104 (that is, 5 cultivars), Arkrose, Baldo, Bengal, Dellrose, Drew, Irga 409, Koshihikari1, Koshihikari2, M202, Nato, S201, and Toro2 (that is, 12 varieties).

Prior to milling, the samples were allowed to equilibrate to room temperature. A McGill sample sheller (husker) was used to remove the hulls, and a McGill No. 2 mill to remove the bran. Samples were milled to a constant degree of milling (DOM = 90). The DOM was measured using a Satake Milling Meter MM-1B. Only head rice was used for sensory and instrumental testing.

Sensory evaluation

Sensory methodology. 11 trained panelists with 3 years of experience in descriptive analysis techniques according to the spectrum methodology (Sensory Spectrum, Chatham, N.J., U.S.A.) evaluated and tested 11 texture attributes of cooked rice. The attributes and their definitions are described in Table 2. The 11 attributes evaluated were tested during 4 evaluation stages. Panelists used paper ballots and numbers between 0 and 15 (Meilgaard and others 1991) with 1 significant digit to quantify sensory scores. References were provided to panelists to use as anchors for specific attributes.

Sample preparation for the sensory evaluation. Rice samples (300 g) were cooked in household rice cookers (National, model SR-W10FN) with a 1:2 rice to water ratio according to methods described by Meullenet and others (1999). Samples were presented at 75±2 °C in preheated glass bowls insulated with Styrofoam cups and covered with watch

Table 2—Vocabulary for sensory texture attributes of cooked rice

TERM	DEFINITION	TECHNIQUE
INITIAL STAGE		
Cohesion Of Bollus	The degree to which the unchewed sample holds or ticks together.	Place ¼ teaspoon of sample in mouth and immediately evaluate how tightly the mass is sticking or holding together. Do not chew or manipulate!
Particle Size	The amount of space the particle takes up in the mouth.	Place sample in center of mouth and evaluate. Do not chew or manipulate!
PARTIAL COMPRESSION STAGE		
Adhesion To Lips	The degree to which the sample adheres to the lips.	Compress sample between lips, release and evaluate the degree to which the product remains on the lips.
FIRST BITE / CHEW		
Hardness	The force required to compress the sample.	Compress or bite through sample one time with molars or incisors.
Cohesiveness	The amount the sample deforms rather than splits apart, cracks or breaks.	Place sample between the molar teeth and compress fully. May also be done with incisors.
CHEWDOWN		
Cohesiveness Of Mass	The amount that the chewed sample holds together.	Chew sample with molar teeth up to 15 times and evaluate. (Loose Mass—Tight Mass)
Macro Roughness Of Mass	The amount of roughness perceived on the surface of the chewed sample. Hint: You are looking for the large lumps, bumps, hills and valleys, etc.	Chew the sample with molars and evaluate the irregularities on the surface of the sample mass.
Toothpull	The force required to separate the jaws during mastication.	Chew sample 2 - 3 times and evaluate.
RESIDUAL		
Residual Film	The amount and degree of residue felt by the tongue when moved over the surface of the mouth.	Swallow the sample and feel the surface of the mouth with the tongue to evaluate.
Toothpack	The amount of product packed into the crowns of your teeth after mastication.	Chew sample 10-15 times, expectorate and feel the surface of the crowns of the teeth to evaluate.
Loose Particles	The amount of particles remaining in and on the surface of the mouth after swallowing.	Chew sample with molars, swallow and evaluate.

glasses labeled with 3-digit codes. Panelists were instructed to monitor temperature closely during the test and to complete the evaluation before the temperature of the sample dropped to 60 °C (140 °F). Water and soda crackers were provided to panelists to clean their palates between each sample. The serving order was randomized across treatments but not across panelists due to sample availability and importance of sample temperature. Samples were presented 1 at the time to the panelists who sat in individual booths featuring incandescent lighting and positive pressure. Eleven to 15 samples were presented for evaluation at each of the testing sessions. Samples were evaluated twice by the panelists on 2 consecutive testing sessions. At the beginning of each session, a reference rice sample was presented as a warm-up sample.

Instrumental texture analysis

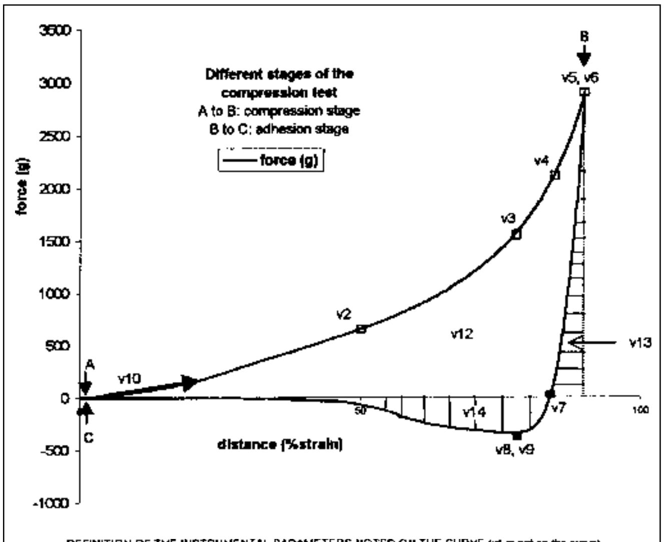
Sample preparation for instrumental analysis. Because temperature greatly influences rice texture (Okabe 1979), it must be very closely monitored so that mechanical testing is accurate and reproducible. Previous work by Meullenet and others (1998) was performed using rinsed cooked rice at room temperature. It was determined (Meullenet and others 1998, 1999) that evaluating cooked rice texture at room temperature did not represent optimal testing conditions and did not closely mimic sensory evaluation protocols. Thus, a cooking protocol similar to that used for sensory testing was developed. However, because the objective of this study was to develop a method for rice breeders who do not have large amounts of sample available, 10 g of milled rice were combined with 17 g of water in a 100-ml beaker and steamed in a rice cooker (National, model SR-W10FN). For uniform and equal absorption of water by all grains, the beaker was placed on a screen inside the rice cooker without direct contact with the heating element. Three hundred and fifty ml of water were added to the rice cooker, and the rice was steamed for 30 min (that is, kept in the covered steamer on "cook" position).

Five kernels of cooked rice were used for each instrumental replication. Since 6 replications were performed for each sample, the beaker containing the cooked rice was kept at a constant temperature in the rice cooker set on the "warm" position. Each rice sample was cooked twice for instrumental evaluation.

Flat plate compression test. The Texture Analyzer (model TA-XT2i, Texture Technologies Corp., Scarsdale, N.Y., U.S.A.) was used to perform the compression test. Five intact rice kernels were placed in a single layer on a clean flat aluminum base. The clearance between the top compression plate (100-mm dia) and the base was set at 5.4 mm. A 5-kg maximum-load load cell was used, and the compression plate traveled for a distance defined to compress the kernels to 90% of their original height. The crosshead pretest speed was set at 2mm/s, while the test speed and the post-test speed were set at 0.5 mm/s. Data were collected using the Texture Expert (version 1.17 Stable Macro System, England). The data acquisition rate was set at 26 points per s. Force in g required to compress the sample was recorded as a function of the distance traveled by the plunger (% of strain), and 6 replications were performed for each sample. An example of a typical curve and the definitions of the calculated instrumental parameters are given in Fig. 1. For this instrumental test, 2 test stages were defined: compression and adhesion. The compression stage was defined as the stage where the flat plate compression contacted 5 rice kernels and traveled until it reached the maximum distance (from A to B, Fig. 1). The adhesion stage of the curve was defined as the stage from the point at which the flat plate started to travel back to its original position (from B to C, Fig. 1) until it returned to the point it first contacted the rice kernels. A macro was written using Texture Expert to calculate 14 instrumental parameters.

Statistical analysis

The means of each instrumental parameter for each sample were calculated using proc Means (SAS (version 7.0) Cary, N.C., U.S.A.). Unscrambler (version 6.11b, CAMO, Trondheim, Norway, 1996), a multivariate analysis software, was used to determine predictive models of sensory texture attributes using the 14 instrumental parameters as predictors. Partial Least Squares (option PLS1) Regression was used for predicting each sensory attribute from these parameters. The full cross-validation method was employed to evaluate model robustness. The accuracy of the prediction was expressed using the Root Mean Square Error of Prediction (RMSEP). RMSEP measures the average difference between predicted and measured response values. With the full cross-validation, some samples are kept out of the calibration and used for prediction. This process is repeated until all samples are kept out of the model once. Model validation is a way to test a model and estimate the prediction error for future predictions. The lower the RMSEP calculated, the more accurate the prediction will be. However, the standard deviation of the sensory intensities across all samples for a particular attribute (Stot) has to be considered as well. The ratio of Stot/RMSEP was useful to estimate the relative error made by the prediction model compared with the average difference reported by the panelists between all the samples. This ratio has to be as high as possible to minimize the prediction error.



DEFINITION OF THE INSTRUMENTAL PARAMETERS NOTED ON THE CURVE (v1 is not on the curve)

code	name	description
v1	product height	height of the sample (mm): 5 kernels of rice are placed in a single layer on the base plate
v2	distance 25%	Distance traveled by the plunger (% strain) when the force value is 25% of the maximum positive force
v3	distance 50%	Distance traveled by the plunger (% strain) when the force value is 50% of the maximum positive force
v4	distance 75%	Distance traveled by the plunger (% strain) when the force value is 75% of the maximum positive force
v5	force 100%	Maximum positive force value (g) of the compression test, when the kernels are compressed to 90% of their original height
v6	distance 100%	Distance traveled by the plunger (% strain) when the force value is at its maximum (v5)
v7	distance 0g	Distance traveled by the plunger during the test (% strain), when the force returns to zero during the upward movement of the plate
v8	force -100%	Maximum negative force value (g) during the upward movement of the probe
v9	distance -100%	Distance traveled by the plunger (% strain) at the maximum negative force (v8)
v10	initial gradient	Initial slope of the compression curve when the distance traveled by the plunger is between 0% and 10% strain
v11	A Total	Total area under the curve for positive force values
v12	Area 1	Area under the compression curve for strains between 0 and 90 %
v13	Area 2	A2 = Atotal -A1
v14	Area 3	Area between the X axis and the compression curve for negative forces

Fig. 1—Sample force-distance curve of a compression test for cooked rice

The ratio of Root Square Error of Prediction and Root Square Error of Calibration (RMSEP/RMSEC) was also used as an indication of model robustness. The calibration model was evaluated using all the samples, and RMSEC is the average deviation of the predicted value from the observed sensory intensity. The RMSEC was then compared to the RMSEP calculated by the cross-validation method. A ratio of RMSEP to RMSEC close to 1 indicated a robust model, showing that the removal of a sample from the data did not increase the prediction error.

The correlation coefficient for the calibration (RCal) and the validation (RVal) models were also used to evaluate the quality of both models. RVal was considered to be most important because the validation statistics are most indicative of the future performance of the predictive models developed. The accuracy of the model was described as its faithfulness (that is, how close the measured values were to the actual values) (Camo 1996) and evaluated mostly by the RMSEC/RMSEP, Stot/RMSEP, and the RVal.

The regression coefficients expressed numerically the link between variation in the predictors (that is, instrumental parameters) and variation in the responses (that is, sensory parameters). The prediction of each sensory attribute was most highly influenced by the instrumental parameters with the highest weighted regression coefficients (r).

The concept for this analysis is based on the prediction of sensory texture characteristics from arbitrarily chosen instrumental parameters. Among these parameters, many are probably not useful for the prediction of a given attribute and will create noise in the predictive model. In an attempt to remove variables creating noise in the models, a novel method was used to optimize the original models.

Model optimization

The optimization process was designed to minimize the RMSEP and optimize Rval.

For each sensory attribute, several sets of PLS regression models were evaluated.

First, 1 of the instrumental parameters was systematically kept out of the calculation.

This process was repeated until each 1 of the instrumental parameters was kept out of the model once (that is, a total of

14 models).

Among all the models, the 1 exhibiting the smallest RMSEP was selected (that is, RMSEP minimum and Rval maximum). The RMSEP of this model was then compared to that of the full regression model. If found to be smaller, it was concluded that the instrumental parameter kept out of the calculation was detrimental to the prediction of the sensory attribute. The instrumental parameter was identified and kept out for further optimization.

The same process was repeated (that is, removing 1 instrumental parameter from the predictive model at a time) using the remaining 13 instrumental parameters. The RMSEP of the best model was then compared to that of the best model found for the previous optimization step. If found to be smaller, the process was repeated with the 12 remaining instrumental parameters. These manipulations were repeated until removing a variable from the model caused an increase in RMSEP. An example of model optimization by the stepwise method is given in Table 3.

Results and Discussion

Prediction of cooked rice texture

Among the texture attributes evaluated by the sensory panel, 7 (that is, cohesion of bolus, adhesion to lips, hardness, cohesiveness of mass, roughness of mass, toothpull, and toothpack) were satisfactory predicted using the compression test and the stepwise method of optimization (optimized Rcal > 0.6).

Cohesion of bolus

Cohesion of bolus was not really well predicted by the full regression model (Rval = 0.57, Table 4). However, results were improved by the stepwise optimization method (Rval = 0.61, Table 5). Furthermore, the optimized model exhibited a RMSEP/RMSEC ratio close to 1, and the ratio of Stot/RMSEP was high (RMSEP/RMSEC = 1.07 and Stot/RMSEP = 3.75, Table 5). Hence, the model was robust, and its relative error was low compared to the standard deviation of the cohesion of bolus intensities across all samples. The RMSEP (−4.18%, Table 5) and RVal (+7.99%, Table 5) for the optimized model were improvements over the values for the full regression model (Table 4). Therefore, the method of optimization employed here allowed a significant improvement of the regression model.

The optimized model was also useful in increasing the weighted regression coefficient for the remaining variables. After removing the variables 1 and 7 (product height and distance maximum traveled by the plunger during the test), which were found to create noise in the model, the prediction was most highly influenced by the maximum negative force value (v8) and the area between the distance axis and the negative part of the compression curve (v14). The regression coefficients need to be discussed as a way to determine what variables are most important. The weighted coefficients for these parameters were negative ($r_8 = -0.18$ and $r_{14} = -0.28$). Since these 2 parameters were evaluated during the adhesion stage of the test, it is not surprising to find a correlation with the cohesion of bolus, which represents an indirect measurement of sample stickiness.

Adhesion to lips

Adhesion to lips was predicted well using all 14 predictive variables (Table 4). Model optimization improved the RMSEP value by 4.97% (Table 5). The correlation coefficient for the

Table 3—An example of model optimisation by stepwise and Partial Least Squares Regression for predicting roughness of mass of cooked rice

Purpose: Improve the results of the full cross validation model using all the instrumental parameters.
RMSEP=0.264 and correlation coefficient for the validation model R VAL = 0.681

step 1: 1 variable kept out of calculation			step 2: 2 variables kept out of calculation			step 3: 3 variables kept out of calculation			step 4 4 variables kept out of calculation			step 5 5 variables kept out of calculation		
	RMSEP	Rval		RMSEP	Rval		RMSEP	Rval		RMSEP	Rval		RMSEP	Rval
*rom1	0.261	0.692	"rom2,1"	0.257	0.704	***"rom2,3,1"***	***0.244***	***0.736***		out			out	
rom2	***0.255***	***0.709***		out			out			out			out	
rom3	0.264	0.682	***"**rom2,3"***	***0.249***	***0.725***		out			out			out	
rom4	0.265	0.681	"rom2,4"	0.250	0.722	"rom2,3,4"	0.258	0.701	"rom2,3,1,4"	0.257	0.702	"rom2,3,1,6,4"	0.257	0.704
rom5	0.264	0.682	"rom2,5"	0.258	0.700	"rom2,3,5"	0.255	0.710	"rom2,3,1,5"	0.254	0.713	"rom2,3,1,6,5"	0.253	0.713
rom6	0.259	0.699	"rom2,6"	0.254	0.711	"rom2,3,6"	0.246	0.731	***"rom2,3,1,6"***	***0.242***	***0.742***		out	
rom7	0.263	0.686	"rom2,7"	0.257	0.703	"rom2,3,7"	0.253	0.714	"rom2,3,1,7"	0.253	0.715	"rom2,3,1,6,7"	0.252	0.717
rom8	0.258	0.702	"rom2,8"	0.257	0.702	"rom2,3,8"	0.252	0.718	"rom2,3,1,8"	0.252	0.718	"rom2,3,1,6,8"	0.252	0.717
rom9	0.265	0.679	"rom2,9"	0.254	0.712	"rom2,3,9"	0.251	0.720	"rom2,3,1,9"	0.254	0.712	"rom2,3,1,6,9"	0.252	0.716
rom10	0.266	0.676	"rom2,10"	0.262	0.691	"rom2,3,10"	0.259	0.697	"rom2,3,1,10"	0.260	0.695	"rom2,3,1,6,10"	0.259	0.697
rom11	0.266	0.679	"rom2,11"	0.265	0.680	"rom2,3,11"	0.263	0.688	"rom2,3,1,11"	0.263	0.686	"rom2,3,1,6,11"	0.262	0.648
rom12	0.264	0.682	"rom2,12"	0.258	0.702	"rom2,3,12"	0.254	0.712	"rom2,3,1,12"	0.253	0.714	"rom2,3,1,6,12"	0.253	0.715
rom13	0.262	0.688	"rom2,13"	0.257	0.704	0.254099	0.255	0.710	"rom2,3,1,13"	0.256	0.706	"rom2,3,1,6,13"	0.253	0.715
rom14	0.262	0.690	"rom2,14"	0.255	0.709	0.254773	0.254	0.711	"rom2,3,1,14"	0.253	0.714	"rom2,3,1,6,14"	0.253	0.714
best without variable 2			best without variables 2 and 3			best without "variables 2,3 and 1"			best without "variables 2,3,1 and 6"			previous model can't be improved		

*rom1: PLSR for roughness of mass using all the instrumental parameters except the instrumental variable number 1
"**rom2,3: PLSR for roughness of mass using all the instrumental parameters except the instrumental variables number 2 and 3"
Cells in bold show the best model compared to the best model from the previous optimization step

validation model was the highest (Rval = 0.84, Table 5), RMSEP/RMSEC (1.05, Table 5) was really close to 1, and Stot/RMSEP was relatively high (4.02, Table 5). The model was robust enough, and the prediction was mainly influenced by 3 instrumental parameters: the product height ($r_1 = 0.44$, Table 5), the distance traveled by the plunger at the maximum negative force ($r_9 = -0.25$, Table 5), and the negative area under the curve ($r_{14} = -0.84$, Table 5). The influence of the sample height shows that the rice samples exhibiting higher adhesion to lips also featured a plumper kernel. This is not surprising since stickier rice kernels, such as medium-grain cultivars, are also usually thicker. The 2 other instrumental parameters involved in the prediction of adhesion to lips were indicative of the adhesion stage of the compression test (Fig. 1, from B to C), a result expected for this sensory attribute. The optimized model was reduced to a total of 10 instrumental variables (Table 5).

Hardness

Hardness is the most commonly evaluated sensory attribute using instrumental tests.

It was also well predicted by the optimized model (Rval = 0.76, Table 5) using all the variables except the maximum negative force value. The most important instrumental parameters were found to be the negative area under the curve ($r_{14} = 0.21$, Table 5) and the initial force gradient or modulus ($r_{10} = 0.14$, Table 5). The latter relationship was expected because the force required to compress a hard sample increases faster than the force required to compress a less hard sample, resulting in a higher initial gradient. This result is in agreement with data reported by Meullenet and others (1998) that demonstrated that the hardness of the cooked rice was most highly correlated with initial slope.

The RMSEP from the full regression model was improved by the stepwise method (−5.08%, Table 5), and the RMSEP/RMSEC ratio was the lowest of all the 7 sensory attributes suitably evaluated (RMSEP/RMSEC = 1.04, Table 5). In addition, the Stot/RMSEP ratio (3.29, Table 5) was also high enough to conclude that the optimized predictive model of hardness has an acceptable prediction ability.

Cohesiveness of mass

Cohesiveness of mass was also 1 of the sensory attributes well predicted by the compression test data. Indeed, the performance indicators for the optimized model described a suitable predictive model. Rval (0.74, Table 5) was reasonably high. The RMSEP/RMSEC ratio (1.04, Table 5) was close to 1, and the Stot/RMSEP ratio (3.84, Table 5) was acceptable. The prediction of cohesiveness of mass was most highly influence by the negative area ($r_{14} = -0.31$, Table 5) and the maximum nega-

Table 4—Full regression model statistics for predicting individual sensory attributes

Model statistics	cohesion of bollus	particles size	adhesion to lips	hardness	cohesiveness	cohesiveness of mass	roughness of mass	toothpull	toothpack	loose particles	residual film
RMSEC [1]	0.53	0.13	0.67	0.25	0.28	0.43	0.25	0.19	0.23	0.30	0.25
RMSEP [2]	0.59	0.14	0.74	0.27	0.29	0.46	0.26	0.21	0.25	0.33	0.27
RMSEP/RMSEC	1.11	1.01	1.11	1.09	1.05	1.07	1.05	1.09	1.10	1.11	1.08
Stot [3]	2.11	0.92	2.83	0.84	1.07	1.72	1.38	0.47	1.28	1.00	0.83
Stot/RMSEP	1.21	1.01	1.77	1.55	1.15	1.44	1.37	1.26	1.21	1.10	1.15
RCal [4]	0.67	0.36	0.86	0.80	0.56	0.76	0.72	0.68	0.66	0.57	0.59
R Val [5]	0.57	0.19	0.82	0.76	0.49	0.72	0.68	0.61	0.56	0.43	0.49
number of PCs [6]	3.00	2.00	3.00	4.00	2.00	2.00	2.00	3.00	3.00	3.00	2.00
	Weighted regression coefficient (r) for each instrumental variables used in the final model										
v1 product height	0.03	0.02	0.36	0.06	0.02	0.07	-0.05	0.04	0.10	0.05	0.11
v2 distance 25%	0.00	-0.02	-0.08	-0.05	-0.07	-0.10	-0.04	-0.08	-0.05	0.03	-0.05
v3 distance 50%	0.02	-0.01	-0.07	-0.10	0.00	-0.04	-0.04	-0.03	-0.03	0.00	-0.03
v4 distance 75%	0.01	-0.01	-0.10	-0.11	0.00	-0.04	-0.04	-0.04	-0.05	0.00	-0.05
v5 force 100%	-0.09	0.01	-0.14	0.09	-0.05	-0.10	0.03	-0.03	-0.02	0.07	-0.01
v6 distance 100%	-0.11	-0.01	0.10	-0.01	-0.01	-0.04	-0.01	-0.01	0.03	-0.07	-0.01
v7 distance 0g	0.03	0.00	0.14	0.03	0.04	0.09	-0.05	0.03	0.03	0.00	-0.01
v8 force -100%	-0.17	0.01	-0.35	-0.06	-0.05	-0.14	0.03	-0.06	-0.07	0.02	-0.07
v9 distance -100%	-0.11	0.01	-0.22	-0.02	0.00	-0.09	-0.02	-0.03	-0.05	0.02	-0.06
v10 gradient initial	0.03	0.01	0.05	0.13	0.05	0.10	0.03	0.06	0.04	-0.05	0.04
v11 total area	-0.10	0.01	-0.19	0.03	-0.04	-0.10	0.04	-0.09	-0.01	0.06	-0.01
v12 area1	-0.08	0.00	-0.18	0.04	-0.06	-0.12	0.03	-0.03	-0.01	0.06	-0.03
v13 small area 2	-0.10	0.01	-0.19	0.02	-0.03	0.10	0.04	-0.04	-0.01	0.06	-0.01
v14 negative area	-0.28	0.02	-0.62	0.21	-0.09	-0.29	0.05	-0.02	0.11	0.08	-0.09

[1] RMSEC: root mean square error of calibration
[2] RMSEP: root mean square error of prediction
[3] Standard deviation of the sensory intensities across all samples for a particular attribute
[4] Correlation coefficient for the calibration
[5] Correlation coefficient for the validation
[6] number of principal components in the model

tive force value ($r_8 = -0.16$, Table 5). These 2 parameters were also highly correlated with cohesion of the bolus. It was foreseeable that these 2 sensory attributes would be influenced by the same instrumental parameters. The only major difference between the 2 models was that the cohesion of bolus model included the distance traveled by the plunger when the force value is at its maximum ($r_6 = -0.10$, Table 5), while the cohesiveness of mass model included the maximum distance traveled by the plunger during the test ($r_7 = 0.11$, Table 5).

Roughness of mass

The correlation coefficient for the validation of the optimized model was adequate (Rval = 0.74, Table 5). It was improved during optimization (8.83%, Table 5) over the full regression model (Table 4). The RMSEP was also decreased by 8.44% (Table 5). Moreover, as for all the other models, the ratio RMSEP/RMSEC was close to 1 (0.99, Table 5), and Stot/RMSEP was somewhat high (4.35, Table 5). The prediction of roughness of mass was shown to be influenced by the negative area under the curve (r_{11} = 0.11, Table 5) and the initial gradient (r_{10} = 0.08, Table 5). The most influential instrumental parameters were the same as for hardness. Unfortunately, these observations could not be related to the sensory definition of roughness of mass.

Toothpull

Toothpull showed slightly more disappointing results than the other sensory attributes (Rval = 0.63, RMSEP/RMSEC = 1.06, and Stot/RMSEP = 3.43, Table 5). However, the model was robust, and its relative error of prediction was low. The regression coefficients for the 11 predictive variables were all lower than 0.09 and did not allow the identification of the most influential instrumental variables.

Toothpack

From previous research conducted at the University of Arkansas (Meullenet and others 1998, 1999), it was expected to find the prediction model for toothpack to be acceptable. Unfortunately, toothpack was predicted with moderate accuracy even after the optimization process (Rval = 0.59, Table 5). However, the RMSEP/RMSEC ratio was close to 1

Table 5—Optimized model statistics for predicting individual sensory attributes

Model statistics	cohesion of bollus	particles size	adhesion to lips	hardness	cohesiveness	cohesiveness of mass	roughness of mass	toothpull	toothpack	loose particles	residual film
RMSEC [1]	0.52	0.13	0.67	0.25	0.28	0.43	0.24	0.19	0.23	0.30	0.25
RMSEP [2]	0.56	0.14	0.70	0.26	0.29	0.45	0.24	0.20	0.25	0.32	0.26
%improvement RMSEP*	4.18	2.35	4.97	5.08	1.10	3.21	8.44	2.80	1.97	4.54	5.12
RMSEP/RMSEC	1.07	1.07	1.05	1.04	1.04	1.04	0.99	1.06	1.07	1.07	1.02
Stot/RMSEP [3]	3.75	3.53	4.02	3.29	3.66	3.84	4.35	3.43	5.17	4.55	4.06
RCal [4]	0.67	0.42	0.86	0.80	0.55	0.76	0.74	0.68	0.65	0.57	0.58
R Val [5]	0.61	0.27	0.84	0.76	0.51	0.74	0.74	0.63	0.59	0.49	0.56
%improvement Rval*	7.99	43.78	2.34	0.49	4.79	2.93	8.83	3.75	3.97	14.96	13.41
number of PCs [6]	2	4	2	4	2	2	2	2	3	3	2
Weighted regression coefficient (r) for each instrumental variables used in the final model											
v1 product height		0.03	0.44	0.06	0.02			0.04	0.12	0.08	0.13
v2 distance 25%	0.00			-0.02	-0.07	-0.09		-0.08			
v3 distance 50%	0.03	-0.05	-0.03	-0.09	0.00	-0.03					
v4 distance 75%	0.01	-0.04	-0.08	-0.11	0.00	-0.03	-0.06	-0.04	-0.14		-0.17
v5 force 100%	-0.10		-0.07	0.09	-0.05	-0.10	0.03		-0.07	0.10	-0.01
v6 distance 100%	-0.10			-0.01						-0.06	
v7 distance 0g		0.03	0.17	0.03	0.04	0.11	-0.05	0.03		0.03	
v8 force -100%	-0.18				-0.05	-0.16	0.07	-0.06	-0.06		-0.06
v9 distance -100%	-0.08	0.03	-0.25	-0.03	-0.02	-0.08	0.00	-0.03			
v10 gradient initial	0.03			0.14	0.05	0.10	0.08	0.06	0.05		
v11 total area	-0.11	0.02	0.14	0.02	-0.04	-0.10	0.05	-0.03		0.07	0.01
v12 area1	-0.10	-0.01	-0.12	0.05	-0.06	-0.13	0.02	-0.05		0.07	-0.03
v13 small area 2	-0.11	0.03	-0.14	0.02	-0.03	0.09	0.06	-0.03			0.02
v14 negative area	-0.28	0.03	-0.84	0.21	-0.09	-0.31	0.11	-0.09	-0.12	0.13	-0.09
variables number	10	9	10	13	13	12	10	11	6	6	8

[1] RMSEC: root mean square error of calibration

[2] RMSEP: root mean square error of prediction

*

[3] Stot: Standard deviation of the sensory intensities across all samples for a particular attribute

[4] Correlation coefficient for the calibration

[5] Correlation coefficient for the validation

[6] number of principal components in the model

% improvement represent RMSEP decreasing and Rval increasing between the full regression model and the optimized model

(1.07, Table 5), and the Stot/RMSEP ratio was the highest of all the optimized models (5.17, Table 5). Model optimization increased the correlation coefficient for the validation model by 3.97% (Table 5). The optimized model featured only 6 variables. The predictive model was influenced mostly by the negative area ($r_{14} = -0.12$, Table 5) and the product height ($r_1 = 0.12$, Table 5).

Others

No significant correlation (Rcal < 0.6) between sensory attributes and instrumental parameters were reported for particles size, cohesiveness, loose particles, and residual film.

Discussion

IN ORDER TO COMPLETELY APPRECIATE THE PERFORMANCE OF the compression test and evaluate its ability to predict cooked rice texture attributes, it would be necessary to compare the results obtained here with a test performed on bulk samples (Juliano and others 1981). Even if this was not done on this set of samples, Meullenet and others (1999) reported testing a similar set of samples using a rice extrusion test. The calculated RMSEPs were, in general, smaller than those reported in the present study. This result could be due to the performances of the 2 different tests or to other factors such as the amount of variation reported for the sample sets.

However, the results presented here for adhesion to lips (that is, an indicator of rice stickiness and 1 of the most important texture characteristics of rice) were improved (Rval = 0.84) over those reported using the extrusion test (RVal = 0.77). This result is not surprising since the extrusion test was performed using only the downward movement of the extrusion piston, while the compression test considered instrumental parameters calculated in tension. This reasoning is strengthened by the fact that the model for adhesion to lips was most affected by the maximum negative force (v8) and the negative area under the curve (v14).

Conclusions

THE USE OF A COMPRESSION TEST IN COMBINATION WITH multivariate analysis techniques and the stepwise optimization method allowed the satisfactory prediction of 7 main sensory attributes of cooked rice texture (cohesion of bolus, adhesion to lips, hardness, cohesiveness of mass, roughness of mass, toothpull, and toothpack). The compression test has some limitations because it uses few kernels that may not be representative of the distribution of kernel properties. Juliano and others (1981) also reported that both instrument methods gave significantly correlated values for some sensory attributes (that is, hardness and stickiness), but data obtained on bulk instead of individual grains were more reproducible.

Although the method presented here might be less reproducible than extrusion tests and its prediction error could be slightly higher, it has the important advantage of being less demanding on rice sample quantities. Consequently, this test could be used in rice-breeding programs to rapidly, accurately, and inexpensively assess texture of cooked rice in a manner that adequately reflects several key sensory attributes.

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MS 20000230

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