

# PREDICTION OF RICE TEXTURE BY SPECTRAL STRESS STRAIN ANALYSIS: A NOVEL TECHNIQUE FOR TREATING INSTRUMENTAL EXTRUSION DATA USED FOR PREDICTING SENSORY TEXTURE PROFILES

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## ABSTRACT

*Sensory texture characteristics of cooked rice for three cultivars (74 samples) were predicted using an extrusion cell and a novel data analysis method (i.e. Spectral Stress Strain Analysis). Eight sensory texture characteristics were evaluated and force values from the instrumental tests were used in combination with Partial Least Squares regression to evaluate predictive models for each of the sensory attributes studied. Relative Ability of Prediction (RAP) values were evaluated for each model; they ranged from 0.06 to 0.85. Satisfactory models are proposed for the two major texture characteristics of cooked rice, namely hardness (RAP=0.85) and stickiness as evaluated by adhesion to lips (RAP=0.76). Other sensory attributes such as roughness of mass (RAP=0.73) and toothpick (RAP=0.81) were also satisfactorily predicted. Sensory attributes such as toothpull (RAP=0.12) and loose particles (RAP=0.06) could not be predicted using the Spectral Stress Strain Analysis.*

## INTRODUCTION

One of the emerging challenges facing the rice industry is to control the overall quality of rice for specific end-use markets. Cooked rice texture has been shown to govern the acceptance of rice by consumers when consumed as whole grain (Okabe 1979). A number of instruments have been employed to measure the texture of cooked rice, including the General Foods Texturometer

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(Szczesniak and Hall 1974; Suzuki 1979; Okabe 1979), the Instron food tester (Perez and Juliano 1979; Perez and Juliano 1981; Juliano *et al.* 1981; Juliano *et al.* 1984), the Tensipresser (Tsuji 1982), the Haake Consistometer (Manohar Kumar *et al.* 1976), and the Texture Analyzer TAXT2 (Champagne *et al.* 1998 and Meullenet *et al.* 1998). In addition to the use of various instruments, different cells, such as flat plates or plungers (Juliano *et al.* 1980; Champagne *et al.* 1998), puncture (Perez *et al.* 1993), the Ottawa Texture Measuring System (Perez and Juliano 1979; Juliano *et al.* 1981; Rousset *et al.* 1995), and the Kramer shear cell (Juliano *et al.* 1980, 1981) are employed. Juliano *et al.* (1981, 1984) summarized and compared some of the methods listed above. They concluded that various instrumental methods gave significantly correlated values for hardness and stickiness, and that the data obtained on bulk samples, instead of individual grains, were more reproducible because of the wide variation of properties among individual grains. These studies aimed to devise a reliable texture test, so that a set of simple indicators of the eating quality could be evolved. More recently, Windham *et al.* (1997) reported that instrumental Texture Profile Analysis was far from fully explaining the variation found in sensory texture data. Much valuable information has been gathered, but the overall objective (i.e., devising a reliable instrumental test to predict rice texture) remains to be achieved.

The amylose content has long been widely recognized as the most important determinant of rice quality (Juliano *et al.* 1965; Juliano 1979), but there are also secondary differences, such as protein content (Windham *et al.* 1997) among varieties having similar amylose contents, that influence rice texture. Because of the current efforts to develop rice varieties with specific eating qualities for international markets, varieties or advanced lines resulting from the breeding programs have shown more homogenous starch properties and other grain characteristics (Khush and Juliano 1985). However, in many instances consumers can still distinguish differences in textural properties among these rice cultivars and consequently express preferences for specific varieties (Perez *et al.* 1993). Thus, it appears that the prediction of rice texture from starch properties alone has become obsolete and the need for a more sensitive method has developed (del Mundo *et al.* 1989). As a result, instrumental methods that can accurately describe textural characteristics of cooked rice are needed.

The objective of this study is not to devise a new instrumental technique or to undermine the existing methods such as those described by Perez *et al.* (1993) or Champagne *et al.* (1998), but rather to investigate an alternative method of analysis (i.e., Spectral Stress Strain Analysis) of data generated using a mechanical extrusion test for assessing rice texture.

## MATERIALS AND METHODS

### Samples

Two long-grain rice varieties (Kaybonnet and Cypress) and one medium-grain rice variety (Bengal) were harvested from the University of Arkansas Rice Research and Extension Center in Stuttgart, AR in September 1996 with harvest moisture contents of 19.1, 16.5, and 17.5% (wet base), respectively. The rice was brought immediately to the Biological and Agricultural Engineering lab and cleaned using a Carter-Day Dockage Tester (Carter-Day Co., Minneapolis, MN). It was then placed in plastic, airtight buckets and stored at -10C for approximately one month. The rice was then dried using a Parameter Control Generator Unit in a laboratory scale dryer at 43.3C and 38.2% RH for 75 min (Drying condition A) or at 60C and 16.9% RH for 20 min (Drying condition C). After drying, samples of Cypress, Kaybonnet and Bengal were separated into three lots to be equilibrated to the final moisture contents of 10, 12, and 14%. Equilibration occurred in wooden framed wire-mesh trays (rice layer of ½ in. deep) in air-controlled chambers until the target moisture content (mc) was reached. Samples of each variety at each moisture content (10, 12, and 14%) were again divided into thirds, placed in airtight plastic buckets and stored at 4, 21, or 38C (27 treatments). Samples were evaluated at various stages of storage (i.e. 0, 12, 24 and 36 weeks). However, all samples were not evaluated at all sampling dates because of the limited funding available to perform descriptive analysis. A total of 74 samples were included in the study. A list of samples evaluated is presented in Table 1.

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 testing.

### Sensory Analysis

**Methodology.** Nine panelists trained in descriptive analysis techniques according to the Spectrum methodology (Sensory Spectrum, Chatham, NJ) with three years of experience in descriptive analysis developed a texture lexicon for cooked long and medium grain rice. Four 3-h orientation sessions were necessary for the panel to develop the rice lexicon and test methodology necessary to describe texture characteristics of cooked rice. Eight textural attributes were identified as adequately describing the texture profile of cooked rice for the varieties studied (Table 2). The methodology developed for the evaluation of texture characteristics of cooked rice was organized in four consecutive stages. Adhesiveness to lips was evaluated first as a *surface*

TABLE 1.  
LIST OF SAMPLES EVALUATED

VARIETY	Drying condition	Moisture content (%)	Storage temperature (°C)	Storage duration (week)			
				6	12	24	
KAYBONNET	A	10	4			*	
	A	10	21	*		*	
	A	10	38	*		*	
	A	12	4	*		*	
	A	12	21	*		*	
	A	12	38	*		*	
	A	14	4	*		*	
	A	14	21	*		*	
	A	14	38	*		*	
	C	10	4		*		
	C	10	21		*		
	C	10	38		*		
	C	12	4		*		
	C	12	21		*		
	C	12	38		*		
	C	14	4		*		
	C	14	21		*		
	C	14	38		*		
	CYPRESS	A	10	4	*		*
		A	10	21	*		*
A		10	38	*		*	
A		12	4	*		*	
A		12	21	*		*	
A		12	38	*		*	
A		14	4	*		*	
A		14	21	*		*	
A		14	38	*		*	
C		10	4		*		
C		10	21		*		
C		10	38		*		
C		12	4		*		
C		12	21		*		
C		12	38		*		
C		14	4		*		
C		14	21		*		
C		14	38		*		
BENGAL		A	10	4	m		m
		A	10	21	*		*
	A	10	38	m		*	
	A	12	4	*		*	
	A	12	21	*		m	
	A	12	38	*		*	
	A	14	4	*		*	
	A	14	21	*		*	
	A	14	38	*		m	
	C	10	4		*		
	C	10	21		*		
	C	10	38		*		
	C	12	4		m		
	C	12	21		*		
	C	12	38		*		
	C	14	4		*		
	C	14	21		*		
	C	14	38		*		

m=missing, n= 74 samples

TABLE 2.  
VOCABULARY FOR SENSORY TEXTURE ATTRIBUTES OF COOKED RICE

TERM	DEFINITION	TECHNIQUE	REFERENCE
<b>SURFACE:</b>			
<b>ADHESIVENESS TO LIPS</b>	The degree to which the sample adheres to the lips.	Compress sample between lips, release, and evaluate.	Tomato 0.0 Nougat 4.0 Bread stick 7.5 Pretzel rod 10.0 Rice Krispies <sup>1</sup> 15.0
<b>FIRST BITE:</b>			
<b>HARDNESS</b>	The force required to compress the sample.	Compress or bite through sample once with molars.	Cream cheese 1.0 Egg white 2.5 American yellow cheese 4.5 Beef frankfurter 5.5 Olive 7.0 Peanut 9.5 Almond 11.0 Life Savers <sup>2</sup> 14.5
<b>CHEWDOWN:</b>			
<b>COHESIVENESS OF MASS after 3 and 8 chews</b>	The degree to which the chewed sample holds together.	Chew sample with molar teeth 3 times or 8 times and evaluate.	Licorice 0.0 Carrot 2.0 Mushrooms 4.0 Beef frankfurter 7.5 American yellow cheese 9.0 Brownie 13.0 Canned biscuit dough 15.0
<b>ROUGHNESS OF MASS</b>	The amount of roughness perceived in the chewed sample.	Chew sample with molar teeth 8 times and evaluate.	Unchewed Jello 0.0 Orange peel 3.0 Cooked oatmeal 6.5
<b>TOOTH PULL</b>	The force required to separate the jaws during mastication.	Chew sample up to 3 times and evaluate.	Clam 3.5 Caramel 5.0 Jujubes <sup>1</sup> 15.0
<b>PARTICLE SIZE</b>	The amount of space the particle fills in your mouth.	Place sample in center of mouth and evaluate.	Long-grain rice kernel 0.5 Tic Tac <sup>2</sup> 2.5 M & M (plain) <sup>2</sup> 4.0 Mike & Ikes <sup>2</sup> 6.0 Cherry bite <sup>2</sup> 11.0 Spearmint leaf 13.0 Peppermint patt <sup>2</sup> 20.0
<b>RESIDUAL STAGE</b>			
<b>TOOTHPACK</b>	The amount of product packed into the crows of your teeth after mastication.	Chew sample up to 8 times, expectorate, and feel the surface of the crows of the teeth with tongue.	Captain Crunch <sup>1</sup> 5.0 Heath bars <sup>1</sup> 10.0
<b>LOOSE PARTICLES</b>	The amount of particles remaining in and on the surface of the mouth after swallowing.	Chew sample up to 8 times with molars, swallow and evaluate.	Carrot 10.0

<sup>1</sup> cold cereal, <sup>2</sup> candy

*characteristic* by compressing the sample between dry lips and evaluating the degree to which the samples adhered to the lips. During the *first bite*, hardness was assessed by compressing the sample between molars and evaluating the force required to bite through the sample. Cohesiveness of mass was measured after three and eight chews, and roughness of mass, toothpull and particle size were evaluated during the *chewdown* stage of the evaluation. Finally, toothpack and loose particles were evaluated after expectoration of the product or during the *residual* stage. Sensory scores were given by the panelists using paper ballots and numbers between 0 and 15 (Meilgaard *et al.* 1991). Intensities were assessed by comparison with carefully chosen references anchored on specific attribute scales. A list of such references is provided in Table 2.

**Sample Preparation.** Samples were cooked for 20 min in household steam rice cookers (National, model SR-W10FN) with a 1:2 (vol:vol) rice to water ratio, and immediately mixed and fluffed using a plastic fork. Samples were presented at  $71\text{C} \pm 1$  in preheated glass bowls insulated with Styrofoam cups and covered with watch glasses. Panelists were instructed to monitor temperature during the test using digital thermometers and to complete the evaluation before the temperature of the sample dropped to  $60\text{C} \pm 2$ . The order of sample presentation was randomized across treatments but not across panelists because of limited sample availability and the importance of serving temperature. Nine to twelve samples were presented for texture evaluation at each of the testing sessions. In addition, the samples were evaluated twice by each of the panelists on two separate days. A reference rice sample was presented as a warm-up sample at the beginning of each session. Samples were presented monadically in individual booths featuring incandescent lighting and positive pressure. Panelists were allowed a 10-min break between each sample evaluation and instructed to clean their palate with water.

### Instrumental Texture Analysis

**Sample Preparation.** A 100 g rice sample was added to 946 mL of boiling water and cooked for 20 min after the water returned to boiling. Okabe (1979) reported that cooked rice texture changes rapidly after cooking. Preliminary experiments conducted in our laboratory also showed that repeatability of instrumental measurements was poor when conducted on warm rice. Consequently, the rice samples were drained immediately after cooking and rinsed for 5 min under cold water. They were then spread on plastic trays, covered with aluminum foil, and stored at 4C until testing (i.e. for 2-3 h). Samples were allowed to equilibrate to room temperature for 30 min before analysis. The two different cooking methods used for the instrumental and sensory evaluation methods do not represent the ideal testing conditions for the purpose of

correlating instrumental data with sensory perception. However, the instrumental data had to be generated using the described cooking method in order to obtain reproducible results. Furthermore, the focus of this study was to develop an instrumental method capable of predicting the sensory perception of texture attributes. Our intention was not to necessarily develop an imitative test reproducing the actual testing conditions of cooked rice using sensory methods.

**Extrusion Test.** A cylindrical extrusion cell (40 mm in diameter and 70 mm deep) was used in conjunction with a Texture Analyzer (model TAXT2i, Texture Technologies, Scarsdale, NY). Preliminary studies in our laboratory and results published by Perez *et al.* (1993), demonstrated the effectiveness of an extrusion cell with 3.2 mm diameter holes. Thirty-five grams of rice, which filled the cell, was placed in the extrusion cell for each test repetition. The cross-head speed was 5 mm/s and total travel of 55 mm. The data were acquired at a rate of 20 points per second via the Texture Expert software. The maximum forces recorded were averaged for the six replications and used for Spectral Stress Strain Analysis.

**Force-deformation Curves Analysis by Spectral Stress Strain Analysis.** Instrumental texture tests have been used to calculate parameters such as maximum load so that correlations can be evaluated with sensory texture attributes. This approach is not always successful and may not be appropriate for samples exhibiting minute texture differences. We hypothesized that the instrumental force deformation curve of any food product could be considered as a spectrum in which each measured force value could be regarded as an individual variable given the same chance to influence the prediction of a particular texture characteristic.

The force-distance curves were treated as spectral data to create an instrumental thumbprint for each of the rice samples evaluated. The concept for this analysis is based on the assumption that texture characteristics may be predicted from the shape of the force-deformation curves rather than from calculated instrumental parameters (e.g. maximum force). In order to perform the Spectral Stress Strain Analysis, the force-deformation curves for each sample were exported from the Texture Expert (Stable Micro Systems, England) to a spreadsheet. Unscrambler (version 6.11, CAMO, Thronheim, Norway), a multivariate analysis software, was used to develop the predictive models for the sensory texture attributes. The 220 instrumental variables extracted from the force deformation curve were used in a Partial Least Squares Regression model (PLS1 option) to predict each of the eight texture attributes evaluated. The random cross validation method was used on centered data. Each instrumental variable was weighted by its respective standard deviation so that each variable was given the same chance to influence the predictive models. Relative Ability

of Prediction (RAP) values, indicators of the quality of predictive models, which take into account the unexplained variation in the sensory data, were calculated as described by Martens and Martens (1986) and Windham *et al.* (1997).

## RESULTS AND DISCUSSION

Pearson's correlations between the eight sensory attributes evaluated in this study and the maximum load from the instrumental test were evaluated. Table 3 shows that the maximum load from the instrumental extrusion test used in this study does not adequately predict cooked rice hardness ( $R=0.36$ ) or any of the other sensory attributes discussed here ( $R<0.46$ ). However, the results presented here do not agree with previous data by Perez *et al.* (1993); they reported a high correlation ( $R=0.94$ ) between extrusion maximum force and sensory hardness. The much lower correlation reported in the present study could be due to the fact that the overall differences between samples (only three varieties) may have been smaller than those of the samples used by Perez *et al.* (i.e. 15 varieties). In addition, correlation coefficients using 74 samples will usually be lower than if 15 samples are used. We feel that the poor results obtained in the present study justify the development of an alternative data analysis method for assessing cooked rice texture using an extrusion cell.

Adhesion to lips was relatively accurately predicted using Spectral Stress Strain Analysis (SSSA) (Table 4). The Relative Ability of Prediction (RAP=0.76) value is high enough to feel confident with the prediction of rice adhesion to lips in samples exhibiting relatively small differences. Furthermore, the Root Mean Square Error of Prediction (RMSEP=0.46), an indicator of the average error of prediction expressed in sensory units, was less than half a point on the 15 cm scale used for sensory testing. In addition, the RAP reported here (RAP=0.76) is much greater than that reported by Meullenet *et al.* (1998) (RAP=0.21). In our previous studies, a set of five instrumental parameters was used to predict individual texture attributes. That more conventional method of analysis showed that predicting texture of rice samples exhibiting small overall differences was a difficult task. The results obtained in the present study demonstrate the potential of SSSA for predicting rice adhesion to lips. Hardness was well predicted (RAP=0.85) using SSSA (Table 4). The RAP value reported is much improved over values reported earlier (RAP=0.52) by Meullenet *et al.* (1998). The average error of prediction (RMSEP=0.20) was extremely small, demonstrating the ability of SSSA to provide reliable prediction of cooked kernel hardness. Cohesiveness of mass evaluated after 3 chews ( $COM_3$ ) was not well predicted by SSSA (RAP=0.16, RMSEP=1.19, Table 4). This result is in agreement with results previously reported by Meullenet *et al.* (1998), demonstrating that this sensory texture attribute is difficult to predict using the

TABLE 3.  
 PEARSON'S CORRELATION COEFFICIENTS BETWEEN SENSORY TEXTURE ATTRIBUTES OF COOKED RICE AND  
 INSTRUMENTAL MAXIMUM LOAD

	data range (min-max)	Adlip	Hard	Com 1	Com 2	Rough	Tpull	Size	Tpack	Loose	Max load
Adhesion to lips	8.1-12.7	1.00									
Hardness	3.1-5.7	-0.44	1.00								
Cohesiveness of mass 1	3.5-8.3	0.37	-0.23	1.00							
Cohesiveness of mass 2	3.1-6.4	0.41	-0.37	-0.24	1.00						
Cohesiveness of mass	5.5-7.0	-0.45	0.80	-0.32	-0.33	1.00					
Toothpull	1.3-3.6	0.31	-0.16	-0.46	0.79	-0.17	1.00				
Particle size	0.7-1.4	0.02	0.33	-0.07	-0.28	0.31	-0.16	1.00			
Toothpack	0.8-2.8	0.48	-0.58	-0.28	0.59	-0.54	0.60	-0.02	1.00		
Loose particles	1.9-4.7	-0.44	0.28	-0.78	0.08	0.39	0.21	0.05	0.10	1.00	
Maximum load (Kg)	7.9-21.5	0.01	0.36	0.16	-0.19	0.38	-0.13	0.45	-0.25	-0.15	1.00

n=74

TABLE 4.  
MODELING RESULTS FROM SPECTRAL STRESS-STRAIN ANALYSIS (SSSA)

Attribute	Range of sensory data (min-max)	R <sup>1</sup>	# of PCs <sup>2</sup>	RMSEP <sup>3</sup>	RAP <sup>4</sup>
Adhesion to lips	8.1-12.7	0.77	5	0.46	0.76
Hardness	3.1-5.7	0.81	3	0.19	0.85
Cohesiveness of mass after 8 chews	3.1-6.4	0.61	4	0.44	0.57
Particle size	0.7-1.4	0.59	4	0.07	0.52
Roughness of mass	5.5-7.0	0.66	4	0.19	0.73
Toothpack	0.8-2.8	0.67	4	0.15	0.81
Toothpull	1.3-3.6	0.44	2	0.27	0.12
Loose particles	1.9-4.7	0.31	1	0.22	0.06

<sup>1</sup>R is the correlation coefficient between observed and predicted validation scores

<sup>2</sup>Number of principal components chosen according to the residual variance plot to avoid overfitting

<sup>3</sup>Root Mean Square Error of Prediction expressed in sensory units

<sup>4</sup>Relative Ability of Prediction =  $(S_{tot}^2 - RMSEP^2) / (S_{tot}^2 - S_{ref}^2)$  where:

$S_{tot}$  = standard deviation of the sensory intensities across all samples for a particular attribute

$S_{ref} = (MSE/P \cdot R)$

MSE = mean square error derived from a two way analysis of variance

extrusion test used in this study. Results reported for cohesiveness of mass evaluated after 8 chews (RAP=0.57, RMSEP=0.44) showed that the prediction of this sensory attribute is not entirely satisfactory (Table 4). The RAP reported by Meullenet *et al.* (1998) for the same attribute was similar (RAP=0.60) to that reported here, illustrating that SSSA did not improve upon predictive models determined using more conventional methods of data analysis. Roughness of mass was well predicted by SSSA (RAP=0.73, RMSEP=0.19, Table 4). This is a surprising result since no significant predictive model was reported in previous studies by Meullenet *et al.* (1998). The RMSEP is small enough for accurately predicting roughness of mass in cooked rice. Toothpack was satisfactorily predicted using SSSA (RAP=0.81, RMSEP=0.14, Table 4) thus improving upon the prediction models previously determined by Meullenet *et al.* (1998). Meullenet *et al.* (1998) reported satisfactory predictive models for the texture attribute toothpull (RAP=0.73). Surprisingly, SSSA was found to poorly predict toothpull (RAP=0.12, Table 4). This result shows that SSSA may not always be a method of choice for predicting individual sensory attributes. The predictive model for particle size (RAP=0.52, Table 4) improved upon the model proposed by Meullenet *et al.* (1998). However, the RAP is not large enough to accurately predict particle size. This may be a result of the small spread of intensities observed for this attribute among the samples evaluated.

The attribute loose particles was poorly predicted using SSSA ( $RAP=0.06$ ) as previously reported by Meullenet *et al.* (1998). It is not surprising that predicting the amount of residual particles after swallowing might be an impossible task since the sensory evaluation of this attribute occurs after extensive mastication and expectoration of the rice sample.

Following is an explanation of the models developed using SSSA in the current study. The techniques used here (i.e., Partial Least Squares Regression) rely strictly on statistics. Conventional instrumental methods such as the Texture profile Analysis (Bourne 1978; Champagne *et al.* 1998) provide some rationale for deciding what instrumental parameters should be related to particular sensory attributes. As a result, when relying solely on advanced statistical methods, one needs to be able to justify the models proposed. The analysis of weighted regression coefficients provides information fundamental to the justification of these multivariate models. Figures 1 and 2 are graphical representations of the weighted regression coefficients for each of the 220 variables used for predicting the sensory attributes adhesion to lips and hardness, respectively. The weighted regression coefficients were chosen so that the relative importance of each predictive variable, regardless of their magnitude, could be investigated. In addition, a sample force deformation curve was superimposed so that the portions of the force deformation curve most important in predicting adhesion to lips could be identified. Four separate phases (i.e. contact, compaction, yielding and shearing) were identified in the force deformation curves. The contact phase represents roughly the first 8-10mm of travel by the extrusion cell cylinder. The compaction phase (i.e., next 22-25mm of travel by the extrusion cylinder) is the phase of the test during which rice kernels are pressed against each other and rearrange themselves to form a more compact mass. The yielding phase is a short phase (i.e., 5 to 10 mm of travel) and represents the stage of the test during which there is rapid increase in the stress sustained by the sample, just before it yields to extrusion. Finally, the shearing phase represents the phase during which the sample is extruded through the extrusion plate. In Fig. 1, the regression coefficients for the contact phase are mostly negative, showing that the more sticky rice samples may be more loosely packed in the cell than less sticky samples. At the beginning of the compaction phase, regression coefficients are large and positive. It is possible that more sticky rice kernels offer more resistance to packing and sliding between individual kernels. During the second half of the compaction phase, there is no more sliding between kernels and the mass is now being compacted. The correlation coefficient reported between adhesion to lips and hardness ( $r=-0.44$ ) shows that stickier samples were, as a general rule, less hard than less sticky samples. At this stage of the test, the less sticky rice samples (also the firmer samples) offer more resistance than stickier samples. Regression coefficients for the next phase, the yielding phase, are mostly positive. We hypothesize that more sticky rice

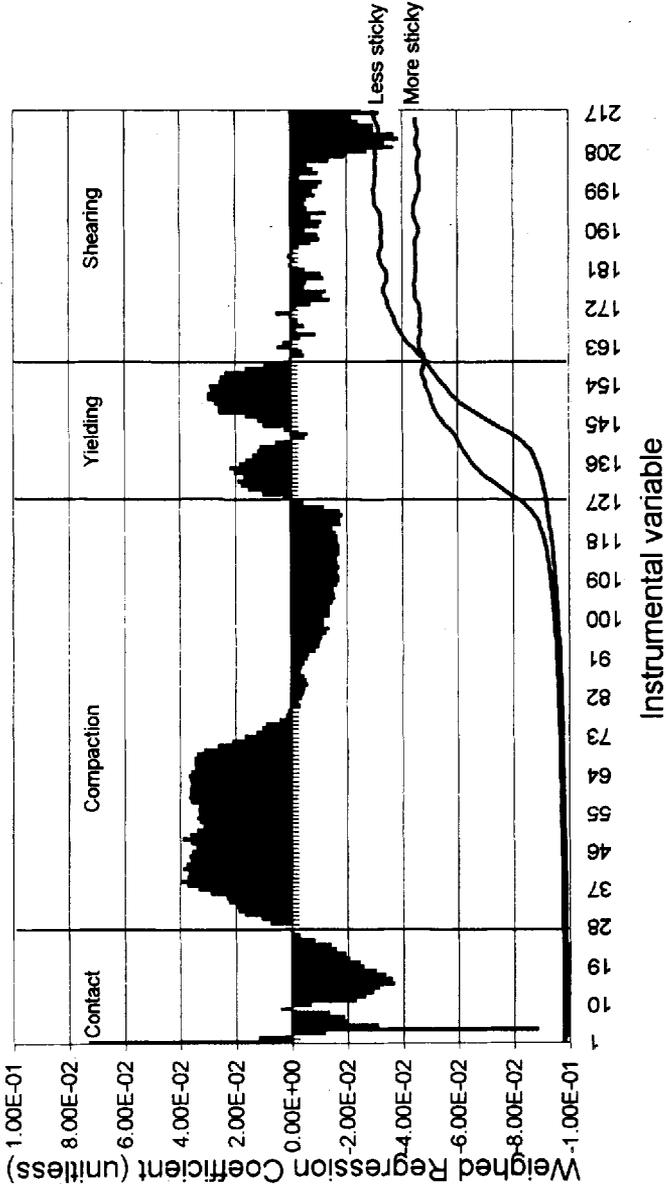


FIG. 1. WEIGHTED REGRESSION COEFFICIENTS AND SAMPLE FORCE DEFORMATION CURVES FOR THE ADHESION TO LIPS SPECTRAL STRESS STRAIN MODEL

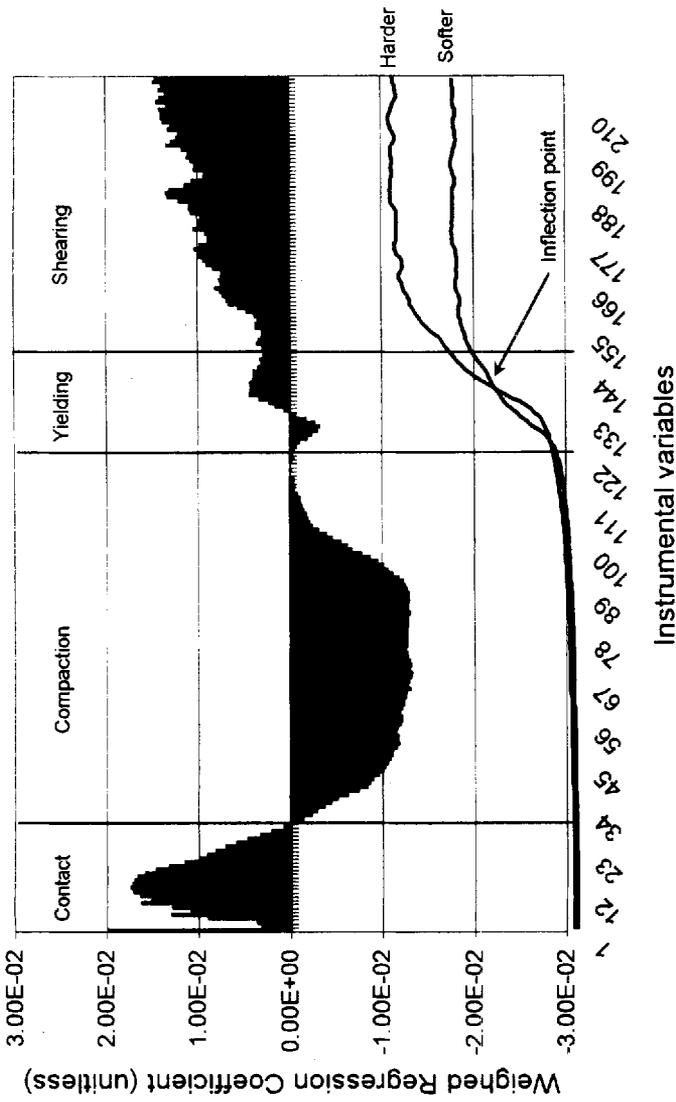


FIG. 2. WEIGHTED REGRESSION COEFFICIENTS AND SAMPLE FORCE DEFORMATION CURVES FOR THE HARDNESS SPECTRAL STRESS STRAIN MODEL

samples (i.e. also less firm) start the extrusion process sooner than the firmer and less sticky samples, explaining the fact that the stresses for stickier rice samples are higher at this stage of the extrusion test. In Fig. 2, the regression coefficients for the contact phase were found to be positive, indicating that harder samples offer more resistance to compression and may be more tightly packed at the beginning of the test. All regression coefficients for the compaction phase are negative. The firmer kernels, also the less sticky kernels, offer less resistance to the rearrangement of individual kernels. During the yielding phase, a change in the sign of the regression coefficients can be observed. We interpret this as a more rapid build up of energy in the firmer rice kernel mass prior to extrusion. For the shearing phase, all regression coefficients are positive, demonstrating that the stress or load necessary for extruding a sample is larger for firmer rice. The interpretation of the force deformation curves and the corresponding regression coefficients represent only the authors' interpretation of the data. However, the interpretation of such models (i.e. SSSA) should be seen in future use of this type of methodology as an important part of justifying and validating the proposed models.

## CONCLUSIONS

Overall, Spectral Stress Strain Analysis showed potential for predicting rice texture characteristics from an instrumental extrusion test. It offered significant prediction improvements over more conventional modeling techniques as reported by Meullenet *et al.* (1998). SSSA is providing a truly new approach to relating instrumental measurements of texture to sensory intensities. The results presented here demonstrate the potential of this new approach for predicting individual sensory texture attributes even for samples exhibiting small overall texture differences. More fundamental work is needed to explain the underlying reason for the success of this data analysis method. The involvement of particular sections of the force in the prediction of sensory texture attributes needs to be further investigated. The samples used in this study represented three cultivars only. Before models of this sort can reliably be used in the rice industry, there will need to be more extensive studies conducted including samples with a more diverse genome.

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