Discovery, The Student Journal of Dale Bumpers College of Agricultural, Food and Life Sciences

Volume 1 Article 11

Fall 2000

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Lenjo, Marura and Meullenet, Jean-Francois (2000) "Prediction of Rice Sensory Texture Attributes Using Spectral Stress Strain Analysis and Jack-Knife Model Optimization," *Discovery, The Student Journal of Dale Bumpers College of Agricultural, Food and Life Sciences*. University of Arkansas System Division of Agriculture. 1:*40-46*.
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Prediction of rice sensory texture attributes using spectral stress strain analysis and the jack-knife model optimization method

Marura Lenjo[*] *and Jean-Francois Meullenet*[§]

ABSTRACT

Sensory texture characteristics of cooked rice were predicted using an extrusion test and a novel multivariate analysis method. Eleven sensory texture characteristics were evaluated via a trained descriptive panel and predicted for force/deformation spectra with partial least squares regression. Only four sensory attributes—adhesion to lips (Rcal = 0.83), cohesion of bolus (Rcal = 0.78), cohesiveness (Rcal = 0.69), and hardness (Rcal = 0.72)—were successfully predicted from instrumental measurements.

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INTRODUCTION

Many researchers have studied the instrumental evaluation of cooked rice texture, and a number of instrumental methods have been examined. At present, one of the most popular and reliable instrumental methods involves the use of an Ottawa extrusion cell (Meullenet *et al.*, 1998; Juliano *et al.*, 1981). The dimensions of the traditional Ottawa cell require rather large quantities (i.e., approximately 100 g of milled rice) of rice for evaluation. More recently, a small extrusion cell was designed at the University of Arkansas, and preliminary results have demonstrated the potential of this method for predicting rice texture.

Juliano *et al.* (1984) showed that an instrumental method utilizing small sample sizes was less reliable than tests performed on bulk samples. However, the successful development of a technique requiring a small sample size 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 an experimental extrusion method requiring small samples suitable for predicting cooked rice texture characteristics and (2) to evaluate the use of partial least squares regression (PLSR) for developing predictive models of specific texture attributes.

MATERIALS AND METHODS

Rice Samples

Three rice cultivars were used in the study, and all were harvested from the University of Arkansas Rice Research and Extension Center, Stuttgart, in 1998. Harvest moisture contents of the cultivars were between 17 and 19% (wet base). We studied a total of 102 samples of 'Drew' (D); 'Bengal' (B); and 'Kaybonnet' (K); the samples were taken from rice being used in drying and storage studies conducted by the University of Arkansas Rice Processing Program.

Sensory Evaluation

Sensory Methodology. Eleven trained panelists with 3 years of experience in descriptive analysis techniques according to the spectrum methodology (Sensory Spectrum, Chatham, N.J.) evaluated and intensified 11 texture attributes of cooked rice. Attributes evaluated and definitions are described in Table 1. The attributes evaluated were intensified during four evaluation stages. During the initial stage of the evaluation (i.e., the sample was placed in the mouth but not chewed or manipulated), cohesion of bolus and particles size were evaluated (Table 1). In the second stage (i.e., partial compres-

Meet the Student-Author

Marura Lenjo

I am from Kenya and graduated from high school there. I am majoring in Food Science and plan to graduate in the summer of 2000. I have received several scholarships from the Ozark Food Processors' Association. After graduation, I plan to continue with a graduate degree in Food Science.

I chose this research project because I am particularly interested in sensory science and would like to work in this field in the future. Through this project, I improved my laboratory and research skills greatly. I was also able to experience first-hand working in the area in which I'd like to make my career.

sion), adhesiveness to lips was evaluated by compressing samples between the lips, releasing, and then evaluating the degree to which samples adhered to lips.

Hardness was evaluated after the first bite by compressing or biting through the sample one time with the molars and evaluating the force required to bite through. Cohesiveness was evaluated (i.e., first bite attribute), by placing the sample between the molar teeth, compressing fully, and evaluating the amount the sample deformed rather than split apart, cracked or broke.

Cohesiveness of mass, roughness of mass, and toothpull were evaluated during the chew-down stage. Cohesiveness of mass was assessed by chewing the samples with the molars four or five times and evaluating the degree to which the chewed sample held together. Roughness of mass was evaluated by chewing the sample with the molars eight times and evaluating the amount of roughness perceived in the chewed sample. Toothpull was determined from the force required to separate the jaws during the mastication after chewing the sample three times.

Table 1. Vocabulary for sensory texture attributes of cooked rice.

Attribute	Definition	Technique
	Initial Stage	
Cohesion of bolus	The degree to which the unchewed sample holds or sticks together.	Place 3/4 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. (How big are the particles?)	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 Stage	
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 Stage	
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).
Roughness of mass	The amount of roughness perceived on the surfacethe of the chewed sample. Hint: You are looking for 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 Stage	
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.

Toothpack, loose particles, and residual film were evaluated last in the residual stage after swallowing. Toothpack was evaluated from the amount of the sample packed into the crowns after mastication. The loose particles were assessed from the amount of particles remaining on the surface of the mouth. Residual film was assessed by evaluating the amount of residue felt by the tongue when moved over the surface of the mouth.

Panelists used paper ballots and a rating between 0 and 15 (Meilgaard et al., 1991) with one significant digit to intensify 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, Tehran, Iran) with a 1:2 rice-to-water ratio according to methods described by Meullenet et al. (1999). Samples were presented at 75 ± 2°C in preheated glass bowls insulated with polystyrene cups and covered with watch glasses labeled with three-digit codes. Panelists were instructed to monitor temperature closely during the test and to complete the evaluation before the temperature of the sample reached 60ºC. Water and soda crackers were provided to panelists to clean their palate between each sample. Serving order was randomized across treatments but not across panelists because of sample availability and the importance of the temperature of the sample. Samples were presented one at a time to the panelists, who sat in individual booths featuring incandescent lighting and positive pressure. Eleven to fifteen samples were presented for evaluation at each of the testing sessions. Samples were evaluated twice by panelists on two consecutive testing sessions. At the beginning of each session, a reference rice sample was presented as a warm-up sample.

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 et al. (1998) used rinsed cooked rice at room temperature. It was determined (Meullenet et al., 1998; Meullenet et al., 1999) that cooked rice texture evaluated at room temperature does not represent optimal testing conditions and does 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 was combined with 17 g of water in a 100-ml beaker and cooked in a rice cooker under steam conditions. 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 fifty milliliters of water was added to the cooker, and the rice was steamed for 30 minutes (i.e., covered steamer on “cook” position).

Extrusion Cell Design. The extrusion cell used in this study was created in response to the needs of a rice-breeding program. Therefore, it considers several constraints related to its size, price, and the rice quantities necessary for instrumental testing. The cell developed (90 mm in length and 20 mm in diameter) was made from a 3/4-in. PVC (polyvinyl chloride) compression fitting bored to size and fitted with an extrusion plate consisting of a stainless steel mesh (0.5-mm mesh). An extrusion cylinder (19.5 mm in diameter and 95 mm in length) was turned to size from a 1-in. Teflon rod (Fig. 1).

Instrumental Measurements. Extrusion cells were removed one at a time from the rice cooker, and instrumental testing was performed immediately. The instrumental evaluation was carried out using a texture analyzer (Texture Technologies, model TA-XT2i, Scarsdale, N.Y.) in combination with a 25-kg load cell. The crosshead speed was set at a test speed of 2 mm/second for a total distance of 85 mm. Force-distance curves were recorded. A typical force deformation curve is shown in Fig. 2. The curve can be divided into four sections corresponding to the main stages of the instrumental test: packing, compression, extrusion, and tension (Fig. 2).

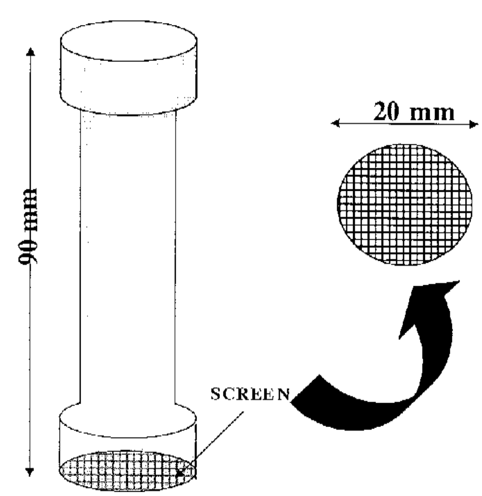

Figure 1. Plastic extrusion cell used to evaluate texture of cooked rice.

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 began to be extruded through the screen and to 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 an Excel spreadsheet to extract forces corresponding to specific cylinder travel distances. A force value was assessed for each deformation increment and was used as a predictive variable. Unscrambler (version 7.5, CAMO, Throndheim, Norway, 1996), a multivariate analysis software, was used to determine predictive models of sensory texture attributes. The concept for this analysis—Spectral Stress Strain Analysis (SSSA)—is 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. 2). Partial least squares regression (option PLS1) was used for predicting sensory attributes from force-distance data. The full cross-validation method was used to evaluate the robustness of the model. The accuracy of the model was expressed using the root mean square error of prediction (RMSEP). The jack-knife model optimization method was used to remove instrumental variables creating "noise" in the model.

RESULTS AND DISCUSSION

The use of instrumental data for predicting sensory texture attributes of rice was proven feasible for a number of the sensory attributes studied. The removal of sample outliers or statistically insignificant predictive variables allowed the optimization of the model.

Cohesion of bolus was reasonably well-predicted (Rcal = 0.71, Table 2). The optimization of the model resulted in a significant improvement of the model statistics. The correlation coefficient (0.78, Table 3) for the optimized model was slightly higher than that of the full model. Correspondingly, the root mean square error of calibration (RMSEC) of the optimized model was slightly lower (0.43, Table 3) than that of the full model (RMSEC = 0.52, Table 2). The optimized model was well-validated (Rval = 0.72, Table 3), with a reasonably low RMSEP of 0.49.

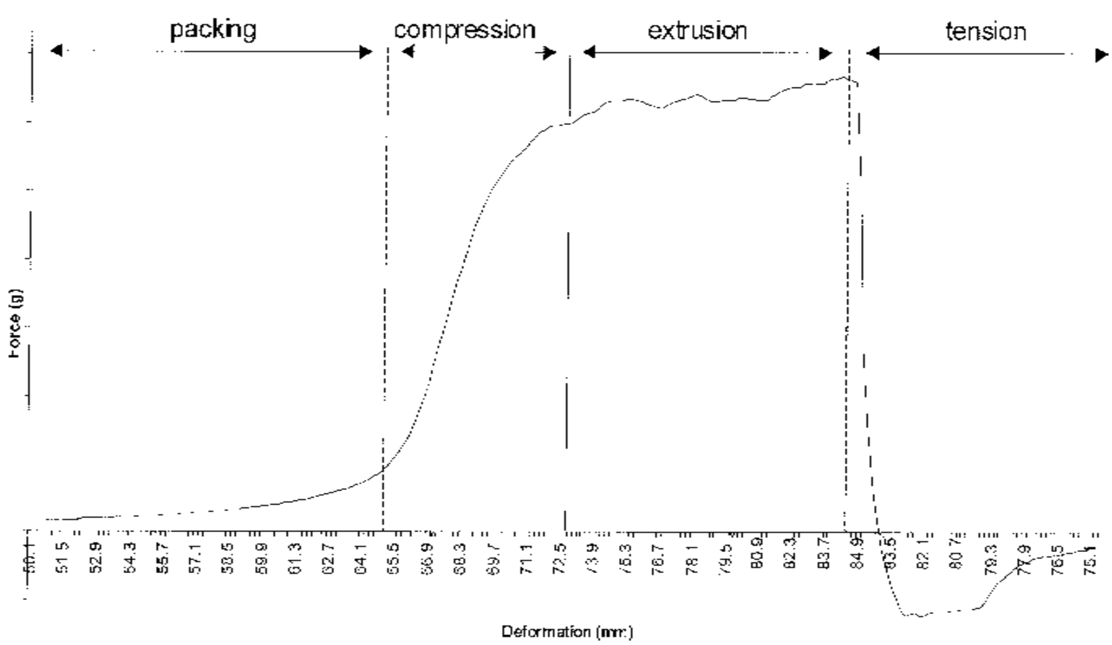

Figure 2. Results of the spectral stress strain analysis used to determine predictive models of the sensory texture attributes.

Particle size was poorly predicted (Rcal = 0.30, Table 2). Optimization of the model resulted in only a slight improvement of the correlation coefficient (Rcal = 0.46, Table 3). However, the relationship between particle size and instrumental data is too weak to hope to accurately predict this attribute.

Adhesion to lips was well-predicted (Tables 2 and 3). All samples were used in the calculation of the final model. To optimize the results, only the significant predictive variables were used. (i.e., jack-knifing). The correlation coefficient for the full model (0.75, Table 2) was found to be high. Correspondingly, the RMSEC was relatively low (0.57, Table 2). The optimized model was significantly improved (Rcal = 0.83, Table 3) and validated well (Rval = 0.76, RMSEP = 0.67, Table 3).

Hardness was well-predicted, with a relatively high correlation coefficient of 0.69 (Table 2) for the full model and correspondingly a low RMSEC of 0.28 (Table 2). The model was optimized by removal of insignificant predictive variables and sample outliers. The optimized model had a correlation coefficient of 0.72 (Table 3), which was a slight improvement over that of the full model. This model was well-validated (Rval = 0.69, RMSEP = 0.28, Table 3).

The full model for cohesiveness had a fairly low correlation coefficient (0.44, Table 2). However, the RMSEC was fairly low (0.29). An attempt to optimize the model by removal of statistically insignificant variables resulted in poorer model statistics. As a result, the model was optimized by removal of sample outliers, which resulted in a significant improvement in the model statistics. The correlation coefficient (0.69, Table 3) was close to satisfactory, with a corresponding low RMSEC of 0.17 (Table 3). This model was well-validated using the full cross-validation method (Rval = 0.61,Table 3). The RMSEP of the optimized model was much lower than that of the full model (RMSEP = 0.19, Table 3).

Cohesiveness of mass was not extremely well-predicted. The correlation coefficient for the full model (Rcal = 0.55, Table 2) was relatively low. Optimization of the model by removal of one sample outlier and of the statistically insignificant variables resulted in slightly improved model statistics (Rcal = 0.58, Table 3). However, the optimized model was not well-validated (Rval = 0.46, Table 3).

Roughness of mass was fairly well-predicted. Attempts at optimizing the model resulted in poorer model statistics. The correlation coefficient for the full model (0.62, Table 2) was moderately high, with a correspondingly low RMSEC (0.26, Table 2). The full model validated well, with a low RMSEP of 0.28 (Table 2).

Toothpull was also moderately well-predicted by instrumental texture data (Rcal = 0.56, RMSEC = 0.19, Table 2). Model optimization was performed by removing two sample outliers, which resulted in improved model statistics (Rcal = 0.60, RMSEC = 0.18, Table 3). The optimized model did not validate well (Rval = 0.46, Table 3), but the RMSEP remained low (RMSEP = 0.20, Table 3).

Table 2. Full predictive model statistics of rice sensory texture attributes.

	Rcal[z]	RMSEC[y]	Rval[x]	RMSEP[w]
Cohesion of bolus	0.71	0.52	0.64	0.57
Particle size	0.30	0.07	0.22	0.07
Adhesion to lips	0.75	0.68	0.68	0.75
Cohesiveness	0.44	0.29	0.33	0.31
Hardness	0.69	0.28	0.58	0.32
Cohesiveness of mass	0.55	0.46	0.42	0.51
Roughness of mass	0.62	0.26	0.53	0.28
Toothpull	0.56	0.19	0.47	0.20
Residual film	0.12	0.19	-0.10	0.20
Toothpack	0.59	0.22	0.47	0.25
Loose particles	0.32	0.35	0.19	0.36

[z] Rcal = calibration model correlation coefficient.
[y] RMSEC = root mean square error of calibration.
[x] Rval = full cross validation—correlation coefficient.
[w] RMSEP = root mean square error of prediction.

Table 3. Optimized (jack-knifed) predictive model statistics of rice sensory texture attributes.

	Rcal[z]	RMSEC[y]	Rval[x]	RMSEP[w]
Cohesion of bolus	0.78	0.43	0.72	0.49
Particle size	0.46	0.06	0.42	0.06
Adhesion to lips	0.83	0.57	0.76	0.67
Hardness	0.72	0.27	0.69	0.28
Cohesiveness	0.69	0.17	0.61	0.19
Cohesiveness of mass	0.58	0.46	0.46	0.50
Roughness of mass	0.51	0.28	0.47	0.29
Toothpull	0.60	0.18	0.46	0.20
Residual film	0.32	0.19	0.27	0.19
Toothpack	0.60	0.22	0.44	0.25
Loose particles	0.18	0.36	0.08	0.36

[z] Rcal = calibration model correlation coefficient.
[y] RMSEC = root mean square error of calibration.
[x] Rval = full cross validation—correlation coefficient.
[w] RMSEP = root mean square error of prediction.

Residual film was poorly predicted (Rcal = 0.12, Table 2). Model optimization resulted in a slight improvement, but the correlation coefficient remained unsatisfactorily low (0.32, Table 3).

Toothpack was not very well-predicted from the instrumental texture data (Rcal = 0.59, Table 2). However, the full model's RMSEC was low (0.22, Table 2). Model optimization was performed by removing statistically insignificant variables and one sample outlier. This optimization resulted in only a slight improvement of the correlation coefficient (0.60, RMSEC = 0.22, Table 3). However, the optimized model did not validate well (Rval = 0.44, Table 3).

The attribute of loose particles was poorly predicted and had a low correlation coefficient of 0.32 (Table 2). An attempt to optimize the model resulted only in a lower correlation coefficient (0.18, Table 3).

In summary, the use of an extrusion test in combination with multivariate analysis techniques and the jackknife optimization method allowed the satisfactory prediction of adhesion to lips, cohesion of bolus, cohesiveness of mass, and hardness. These attributes are of utmost importance to the quality of rice texture, as they are related to the two most important qualities of rice—stickiness and hardness. Although this method might be less accurate in predicting sensory texture characteristics of cooked rice than other commonly used instrumental tests are, it has the advantage of being less demanding on rice sample quantities necessary to perform the test. This feature may be of special interest to rice breeders.

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