

Effects of Postharvest Processing on Texture Profile Analysis of Cooked Rice

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ABSTRACT

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The effects of drying conditions, final moisture content, and degree of milling on the texture of cooked rice varieties, as measured by texture profile analysis, were investigated. Instrumentally measured textural properties were not significantly ($\alpha = 0.05$) affected by drying conditions, with the exception of cohesiveness. Cohesiveness was lower in rice dried at lower temperatures (18°C or ambient) than in that dried at the higher commercial temperatures. Final moisture content and degree of milling significantly ($\alpha = 0.05$) affected textural property values for adhesiveness, cohesiveness, hardness, and springiness; their effects were

interdependent. The effects of deep milling were more pronounced in the rice dried to 15% moisture than that dried to 12%. In general, textural property values for hardness were higher and those for cohesiveness, adhesiveness, and springiness were lower in regular-milled rice dried to 15% moisture than in that dried to 12%. In contrast, hardness values were lower and cohesiveness, adhesiveness, and springiness values were higher in deep-milled rice dried to 15% moisture than in that dried to 12% moisture. Deep milling resulted in rice with lower hardness values and higher cohesiveness, adhesiveness, and springiness values.

World trade developments (GATT, NAFTA) and the “Freedom to Farm” Act are shifting the U.S. rice industry to a market-oriented, global economy. Becoming more market oriented is requiring the industry to have a better understanding of consumer needs for rice with specific sensory and processing qualities and the tools to assess and predict these qualities. Opening of trade with Japan in 1994 has challenged the industry to provide rice to Japan with sensory qualities desired by that market.

U.S. varieties considered to be very similar to Japanese varieties may be subtly different in flavor and texture. These differences may arise from differences in U.S. and Japanese postharvest processing practices. In the U.S., rice is mechanically dried. In Japan, ≈10% is windrow-dried on racks in the field; the remainder is mechanically dried. Rough rice is commonly dried to 12% moisture in the U.S. in contrast to 14–15% in Japan. The impact that these parameters may have on sensory characteristics is not well understood.

To obtain an understanding of the potential impact of postharvest processing conditions on sensory characteristics, a cooperative study involving USDA Agricultural Research Service, industry, university, and international scientists was conducted. The effects of drying conditions, final moisture content, and degree of milling (DOM) on the flavor and texture of U.S. varieties were determined by descriptive sensory analysis and instrumental means. This article reports the effects of these postharvest processing parameters on the texture of cooked rice as measured by texture profile analysis (TPA).

MATERIALS AND METHODS

Rice Samples

Rice from 1994 crops of Bengal (Louisiana [LA], Arkansas [AR], Texas [TX]), Koshihikari (LA, AR, TX, California [CA]),

M-401 (AR, TX, CA), and M-202 (CA) was harvested at 20% moisture. Drying of the varieties was initiated within 24 hr of harvesting and was performed by one of three techniques to obtain rice at 12 and 15% moisture levels: 1) air-drying at 18°C and 40% rh, 2) air-drying at ambient temperatures (26–28°C), and 3) continuous-flow drying with heated air. The continuous-flow drying was on a pilot-scale unit located at Riviana Foods, Inc. (Houston, TX) that simulates commercial dryers. High (60°C), normal (50°C), and low (32°C) commercial drying conditions were used. Following drying, the paddy (rough) rice was stored in closed containers for approximately two to three months in a cool room maintained at 18°C and 40% rh. One week before instrumental testing, the samples were shelled using a Satake Rice Machine model SB and then immediately milled. Regular (light) milling was accomplished using a laboratory Satake One Pass Mill (pearler, model SKD). The first pass was with a 50-g weight in the fifth position; the second pass was with a 50-g weight in the third position. This standard milling protocol was determined to be appropriate for yielding rice with whiteness values in the targeted 40 ± 2 range considered typical of regular-milled rice. Whiteness was measured using a Satake Milling Meter (model MM-1B). Deep milling was performed on 250-g portions of the regular-milled rice using a laboratory Satake Grain Testing Mill (model TM05). Milling conditions were 1 min at 1,250 rpm using a fine mesh abrasive wheel and were appropriate for whiteness values of 49 ± 2 , typical of deep-milled rice. Broken grains were removed with appropriate laboratory sizing devices using standard indented plates and cylinders.

Sample Preparation for TPA

Rice samples representing 11 variety-locations were split by location between the USDA, ARS Southern Regional Research Center (SRRC, New Orleans, LA) and USDA, ARS, Richard B. Russell Research Center (RRC, Athens, GA) for TPA, which were conducted concurrently with sensory flavor (Champagne et al 1997) and texture analyses. Based on the randomized complete block design chosen for the sensory analyses, each TPA set contained six rice samples representing all five levels of drying for the same (variety-location, moisture, milling) combination and a blind control (M-202, commercially obtained from CA).

Samples of milled rice were preweighed into 600-g portions and stored in double, Ziploc brand plastic bags (DowBrand, L. P., Indianapolis, IN) at room temperature until sample presentation. The rice was washed, soaked for 20 min, and prepared using a rice-to-water weight of 1:1.3 (Min et al 1994). Rice was cooked in 5-cup Panasonic SR-W10G HP rice cookers to completion, followed by 10-min postcooking (warming) periods. The top 1-cm

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layer of cooked rice and rice adhering to the sides of each cooker were not used. Cooked rice for sampling was taken directly from the middle of each pot, transferred to a prewarmed (120°C) glass bowl, and mixed thoroughly while minimizing kernel breakage. Rice samples (≈48 g) were taken using a size 18 stainless steel ice cream scoop, transferred to prewarmed (120°C) 6-oz glass custard cups (Anchor Hocking) insulated by fitted Styrofoam bowls, and covered with 125-mm watch glasses. One sample was used for the TPA; the remainder were presented to the sensory panel. Cooking of samples was staggered so that samples were analyzed by the panel or texture analyzer at 15-min intervals.

Texture Analyses by TA-XT2 Texture Analyzers

For TPA, both laboratory locations (SRRC and RRC) followed the same protocol using bench-top TA-XT2 Texture Analyzers (Texture Technologies Corp., Scarsdale, NY). A 1-g aliquot of

warm rice from the insulated custard cup was weighed. The sample was arranged in a single-grain layer on the base plate. A compression plate was set at 5 mm above the base. A two-cycle compression, force versus distance program was used to allow the plate to travel 4.9 mm, return, and repeat. Test speed was 1 mm/sec. A 50-mm diameter cylinder plunger was employed. The test was repeated on three replicate samples ($n = 4$). Parameters recorded from the test curves (Fig. 1) were hardness (H1), adhesiveness (A3), cohesiveness (A2/A1), and springiness (D2/D1). The values represent standard calculations of curve attributes of the TPA as described by Bourne (1982) and defined by Munoz et al (1992). A distance (rather than percent) compression test was used for the TPA because of concerns that height or placement of single grains in the 1-g aliquots might unduly influence the sensed contact height that would account for the beginning of the D1 measurement used in percent compression tests. With settings for a constant 5-mm start and a 4.9-mm travel, the rices were compressed to within 0.1 mm of the bottom plate. Gumminess, derived by multiplying hardness by cohesiveness values, will not be addressed in this article. Chewiness (gumminess by springiness) data, which is considered not applicable to rice, will also be omitted.

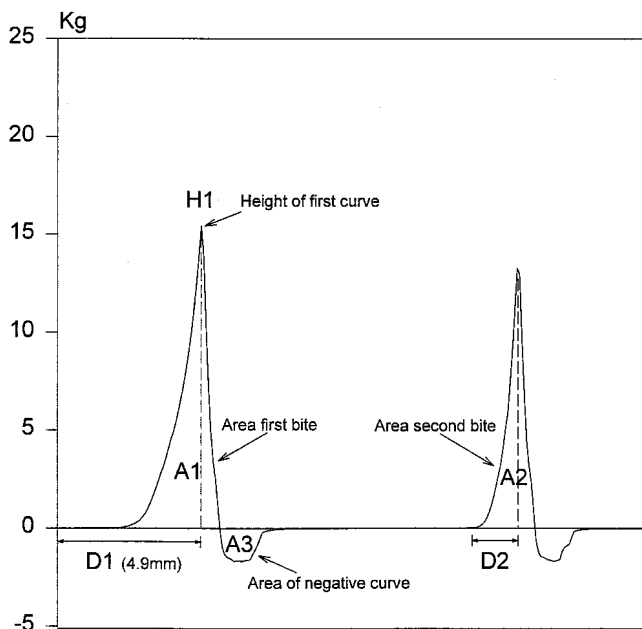


Fig. 1. Typical texture profile analysis curve. Test parameters: force-distance test, compression plate set at 5 mm to travel 4.9 mm at 1 mm/sec. Attributes noted on the curves: H1, hardness (kg) measurement of force at the peak of the first curve; A1, area under the first curve; A2, area under the second curve; A2/A1, cohesiveness, ratio of area under the curves A2/A1; A3, adhesiveness, area of the negative force curve, representing the work to separate the plunger from the sample on the upstroke after the first curve; D2/D1, springiness, ratio of D2 to D1, where D1 is the total distance (4.9 mm in this study) traveled by the plunger on the downstroke and D2 is distance traveled on the downstroke by the plunger from the point of sample contact to end of the downstroke.

Statistical Analyses

Analyses of variance (ANOVA) were conducted for the purpose of examining the effects of processing conditions on each textural attribute. Both full-factorial ANOVA and one-way ANOVA were conducted for each attribute for data pooled from RRC and SRRC and grouped by 1) laboratory, variety, location; 2) laboratory, variety; and 3) laboratory. The full-factorial ANOVA allowed identification of significant interactions. The one-way ANOVA allowed least significant difference (LSD) comparisons of each drying-moisture-milling combination. There was a sufficient amount of rice available of each variety-location to allow for only a single independent preparation for sensory analyses and TPA. Hence, the four repeated measurements on each rice sample were averaged to represent each sample. Estimates of error variability required to conduct ANOVA, typically obtained from the measure of variability among replicate samples, were obtained by assuming the variability associated with the highest order interaction term in the data group to be an appropriate estimate. For data grouped by laboratory, variety, and location, the highest order interaction (dry by moist by milling) was of interest. In this case, a half-normal plot analysis (Milliken and Johnson 1989) was conducted to obtain an estimate of the error variability. Method precision as an indication of laboratory consistency was calculated for the blind control samples, which were the only replicated samples. The precision of the SRRC and RRC laboratories was statistically similar for the textural properties, except for adhesiveness. Significant differences are reported for $\alpha = 0.05$, unless otherwise noted in the text.

TABLE I
Effects of Drying Conditions on Instrumental Cohesiveness Values^a

Rice	Air-Drying			Commercial	
	18°C	Ambient	Low (32°C)	Normal (50°C)	High (60°C)
All samples combined	0.612a	0.608a	0.618b	0.619b	0.619b
Regular-milled	0.603a	0.595a	0.612b	0.615b	0.613b
Deep-milled	0.621a	0.621a	0.624a	0.624a	0.625a
Regular-milled, 15% moisture	0.596a	0.596a	0.613b	0.615b	0.615b
Bengal (AR) ^b	0.585a	0.582a	0.603b	0.595b	0.615c
Regular-milled, 12% moisture	0.575ab	0.591bc	0.601c	0.599c	0.616d
Regular-milled, 15% moisture	0.576a	0.579ab	0.613c	0.592b	0.596bc
Deep-milled, 12% moisture	0.590ab	0.584a	0.595ab	0.600b	0.600b
Deep-milled, 15% moisture	0.597b	0.573a	0.603b	0.589b	0.648c

^a Means followed by the same letter in the same row are not significantly different ($\alpha = 0.05$).

^b Arkansas (AR).

RESULTS AND DISCUSSION

Effects of Drying Conditions on Textural Properties

Rough rice samples were dried to 12 and 15% moisture contents under five different conditions ranging from mild (air-drying at 18°C, 40% rh) to harsh (commercial drying at 60°C). The only textural property significantly affected by drying was cohesiveness for combined rice samples (data for all varieties, locations, moisture contents, and DOM combined). Cohesiveness values were significantly lower for rice dried at 18°C or ambient temperature (26–28°C) than those for rice dried at higher temperatures (Table I).

The effect of drying conditions on textural properties was statistically similar for samples dried to 12 or 15% moisture. The effect of drying conditions on textural properties was also statistically similar for regular- and deep-milled rice samples, with the exception of cohesiveness. Differences in the measured values of this property between drying levels in the regular-milled rice was generally larger than those of the deep-milled rice, as shown in Table I. The drying by moisture by milling interaction effect was also statistically significant for cohesiveness. Comparisons of textural property values at each DOM-moisture level combination showed cohesiveness was significantly higher ($\alpha = 0.10$) in regular-milled, 15% moisture rice dried at temperatures above ambient compared to those dried at 18°C or ambient temperature (Table I). No significant differences were observed among cohesiveness values at other DOM-moisture level combinations.

Examination of data for individual varieties grown at specific locations indicated that drying conditions did not significantly affect textural property values, with the exception of cohesiveness for Bengal (AR) (Table I). Cohesiveness was significantly higher in Bengal (AR) dried at temperatures above ambient compared to those dried at 18°C or ambient temperature. No significant drying by moisture, drying by milling, or drying by milling by moisture interaction effects were observed for Bengal (AR).

Higher cohesiveness values at temperatures above ambient may be explained by rice being more likely to develop fine, hair-line fissures following drying at the higher rates of commercial drying than following slower drying at ambient or lower temperatures

(Ban 1971, Kunze 1979, Mossman 1986). These fissures allow water to be more readily absorbed during cooking, yielding rice that tends to be more cohesive.

Effects of Final Moisture Content on Textural Properties

The moisture content (12 or 15%) to which the rice was dried significantly affected adhesiveness, cohesiveness, hardness, and springiness. The effects of moisture content on the values of these textural properties were dependent on the DOM, as shown in Table II. Regular-milled rice dried to 15% moisture had larger hardness values when compared to that dried to 12% moisture. In contrast, hardness values were smaller in deep-milled rice dried to 15% moisture content. Adhesiveness values were smaller in regular-milled rice dried to 15 versus 12% and larger in deep-milled rice dried to the higher moisture content. Cohesiveness and springiness values were smaller at the higher moisture content in both regular- and deep-milled rice.

Rice dried to 15% moisture will fissure to a lesser extent than that dried to 12% moisture. Rhind (1962) suggests that a change in the physical behavior of rice starch occurs at 15% moisture content, and this change of state is a factor in fissuring. When the moisture content of white rice is $\approx 15\%$, the grains do not crack when immersed in water (Satake 1989). However, according to Satake, if the moisture content is $< 14\%$, fissures in the rice will result in instantaneous cracking when immersed. Paste exudes out of the cracks during cooking and the grains become soft. Thus, rice dried to 15% moisture is expected to be harder and less springy, cohesive, and adhesive than that dried to 12%.

Deep milling decreases protein content by $\approx 0.5\%$ (Champagne et al 1996). Rices low in protein have been shown to be more tender and cohesive than those high in protein (Primo et al 1962, Onate et al 1964, Juliano et al 1965). Yanase et al (1984) observed that protein content is inversely related to adhesiveness.

The results of this investigation agree with these observations, with two exceptions. DOM did not affect adhesiveness and springiness in rice dried to 12% moisture. Therefore, in deep-milled rice, the apparent effects of moisture on these properties are confounded by milling, as indicated in Table II.

TABLE II
Instrumental Textural Properties Exhibiting a Significant ($\alpha = 0.05$) Moisture \times Milling Interaction Effect

	Regular-Milled			Deep-Milled		
	15% Moisture	12% Moisture	Difference ^a	15% Moisture	12% Moisture	Difference ^a
Adhesiveness (A3)	-2.147	-2.080	-0.067	-1.932	-2.081	0.149
Cohesiveness (A2/A1)	0.607	0.609	-0.002	0.615	0.630	-0.015
Hardness (kg)	17.619	17.359	0.26	16.225	17.177	-0.952
Springiness (D2/D1)	0.311	0.342	-0.031	0.326	0.341	-0.015

^a Difference between values for 15 and 12% moisture rice.

TABLE III
Instrumental Textural Properties of Varieties Grown in Specific Locations That Were Significantly Affected ($\alpha = 0.10$) by Final Moisture Content

Variety-Location ^a	Property ^{b,c}	Regular-Milled			Deep-Milled		
		15% Moisture	12% Moisture	Difference ^d	15% Moisture	12% Moisture	Difference ^d
Bengal (AR)	Springiness	0.319	0.371	-0.052	0.311	0.354	-0.043
Koshihikari (AR)	Hardness	17.233	15.176	2.057	15.345	14.677	0.668
Koshihikari (LA)	Springiness*	0.385	0.353	0.032	0.299	0.371	-0.072
Koshihikari (CA)	Adhesiveness*	-1.866	-1.779	-0.087	-1.471	-1.704	0.233
M-202 (CA)	Cohesiveness*	0.590	0.581	0.009	0.593	0.639	-0.046
	Hardness*	15.575	14.848	0.727	13.922	16.316	-2.394
M-401 (TX)	Adhesiveness	-1.934	-1.669	-0.265	-1.944	-2.277	0.333
M-401 (CA)	Adhesiveness*	-2.092	-2.073	-0.019	-1.920	-2.360	0.440
	Springiness*	0.329	0.300	0.029	0.233	0.296	-0.063

^a Arkansas (AR), Louisiana (LA), California (CA), Texas (TX).

^b Measured properties as defined in Fig. 1.

^c Asterisks denote a significant ($\alpha = 0.10$) moisture \times milling interaction effect.

^d Difference between values for 15 and 12% moisture rice.

The effects of final moisture content on textural properties were dependent on variety and location. Drying the rice to 15% final moisture content versus 12% did not significantly ($\alpha = 0.10$) affect the textural property values for Bengal (LA), Bengal (TX), M-401 (AR) and Koshihikari (TX). Final moisture content significantly ($\alpha = 0.10$) affected textural property values for Bengal (AR), Koshihikari (AR), Koshihikari (LA), Koshihikari (CA), M-202 (CA), M-401 (TX), and M-401 (CA). Table III lists the effects of drying the rice to 15% moisture versus 12% moisture on textural property values for regular- and deep-milled rice. The effects of moisture content were dependent on DOM for some properties, as noted by asterisks. Drying to 15% moisture as compared to 12% moisture decreased adhesiveness in regular-milled Koshihikari (CA), M-401 (TX), and M-401 (CA). The opposite effect was observed with these varieties when deep milled. Hardness was higher in regular-milled Koshihikari (AR) and M-202 (CA) dried to the higher moisture content. Deep-milled M-202 (CA) dried to 15% moisture was not as hard as that dried to 12%. The hardness of deep-milled Koshihikari (AR) dried to 15% moisture was higher than that dried to 12% moisture, but the magnitude of the difference was smaller than that of the regular-milled 15% and 12% moisture Koshihikari (AR). These effects of moisture content on hardness values in the deep-milled rices can be explained by the milling effect being larger for rice dried to 15% moisture than to 12% moisture, as discussed above. Springiness was lower in regular- and deep-milled Bengal (AR) and deep-milled Koshihikari (LA) and M-401 (CA) that were dried to the higher moisture content. Higher springiness in regular-milled Koshihikari (LA) and M-401 (CA) at 15% moisture is explained by opposing moisture-milling effects. No significant ($\alpha = 0.10$) moisture by drying or moisture by drying by milling interaction effects were observed for the variety-location data.

Effect of DOM on Textural Properties

The DOM significantly affected textural property values for adhesiveness, cohesiveness, hardness, and springiness. The effect of DOM on the value of textural properties was dependent on moisture level (Table IV). The differences between values for adhesiveness, hardness, and springiness for deep- and regular-milled rice were larger for rice dried to 15% than 12%; the difference was smaller for cohesiveness. As discussed earlier, hardness decreased and cohesiveness increased with deep-milling. Adhesiveness and springiness were higher in deep-milled, 15% moisture rice than in regular-milled, 15% moisture rice. Deep-milling did not affect their values in rice dried to 12% moisture.

The effects of DOM were dependent on variety and location, as were the effects of final moisture content. Deep- versus regular-milling the rice did not significantly ($\alpha = 0.10$) affect the textural property values for Bengal (TX), Koshihikari (AR), and Koshihikari (LA). The DOM significantly ($\alpha = 0.10$) affected textural property values for Bengal (AR), Bengal (LA), Koshihikari (TX), Koshihikari (CA), M-202 (CA), M-401 (AR), M-401 (TX) and M-401 (CA). Table V lists the effects of deep- versus regular-milling on textural property values for rice by variety-location dried to 12 and 15% moisture. The effects of DOM were dependent on moisture content for some properties, as noted by asterisks. Hardness values were lower in deep-milled rice than in regular-milled rice for Bengal (AR), Bengal (LA), Koshihikari (CA), and M-401 (AR) dried to 12 and 15% moisture levels. Hardness was also lower in deep-milled M-202 (CA) dried to 15% moisture. However, deep-milled M-202 (CA) dried to 12% moisture had higher hardness values. Springiness values were lower in deep-milled than in regular-milled Koshihikari (TX), Koshihikari (CA), and M-401 (CA) at both moisture levels. Cohesiveness was higher in deep-milled Koshihikari (TX) and M-401 (CA) at both mois-

TABLE IV
Textural Properties Exhibiting a Significant ($\alpha = 0.05$) Milling x Moisture Interaction Effect

Property ^a	12% Moisture			15% Moisture		
	Deep-Milled	Regular-Milled	Difference ^b	Deep-Milled	Regular-Milled	Difference ^b
Adhesiveness	-2.081	-2.080	-0.001	-1.932	-2.147	0.215
Cohesiveness	0.630	0.609	0.021	0.615	0.607	0.008
Hardness	17.177	17.359	-0.182	16.225	17.619	-1.394
Springiness	0.341	0.342	-0.001	0.326	0.311	0.015

^a Measured properties as defined in Fig. 1.

^b Difference between values for deep- and regular-milled rice.

TABLE V
Textural Properties of Varieties Grown in Specific Locations That Were Significantly Affected ($\alpha = 0.10$) by Degree of Milling

Variety-Location ^a	Property ^{b,c}	12% Moisture			15% Moisture		
		Deep-Milled	Regular-Milled	Difference ^d	Deep-Milled	Regular-Milled	Difference ^d
Bengal (AR)	Adhesiveness	-2.105	-2.157	0.052	-1.739	-2.183	0.444
	Hardness	15.274	16.651	-1.377	15.142	15.617	-0.475
Bengal (LA)	Hardness	19.028	19.888	-0.860	18.168	19.642	-1.474
Koshihikari (TX)	Cohesiveness	0.649	0.612	0.037	0.646	0.621	0.025
	Springiness	0.338	0.390	-0.052	0.299	0.391	-0.092
Koshihikari (CA)	Adhesiveness*	-1.704	-1.779	0.075	-1.471	-1.866	0.395
	Cohesiveness	0.607	0.624	-0.017	0.602	0.608	-0.006
	Hardness	15.069	16.716	-1.647	15.163	16.504	-1.341
	Springiness	0.289	0.306	-0.017	0.298	0.319	-0.021
M-202 (CA)	Cohesiveness*	0.639	0.581	0.058	0.593	0.595	-0.002
	Hardness*	16.316	14.848	1.468	13.922	15.575	-1.653
M-401 (AR)	Hardness	15.312	15.650	-0.338	14.686	16.767	-2.081
M-401 (TX)	Cohesiveness	0.676	0.682	-0.006	0.655	0.609	0.046
M-401 (CA)	Adhesiveness*	-2.360	-2.073	-0.287	-1.920	-2.092	0.172
	Cohesiveness	0.621	0.606	0.015	0.608	0.600	0.008
	Springiness*	0.296	0.300	-0.004	0.233	0.329	-0.096

^a Arkansas (AR), Louisiana (LA), California (CA), Texas (TX).

^b Measured properties as defined in Fig. 1.

^c Asterisks denote a significant ($\alpha = 0.10$) moisture x milling interaction effect.

^d Difference between values for deep- and regular-milled rice.

ture levels, M-202 (CA) at 12% moisture, and M-401 (TX) at 15% moisture. Cohesiveness was lower in deep-milled Koshihikari (CA) at both moisture levels. Deep-milling resulted in higher adhesiveness in Bengal (AR) and Koshihikari (CA) with 12 and 15% moisture contents. Adhesiveness was also higher in deep-milled M-401 (CA) when dried to 15% moisture; at the lower moisture content this textural property was lower with deep-milling. The trends described above for the combined rice samples were followed for the specific rice varieties-locations, with a few exceptions. The exceptions can be explained by opposing moisture effects, the magnitude of which is suspected to depend on the extent of fissuring occurring in the rice.

CONCLUSIONS

Studies cited in the literature have focused on assessing textural properties of different rice varieties and relating differences in texture with amylose, protein, moisture and fat contents, alkali spreading value, amylographic gelatinization and paste viscosity characteristics, and water uptake capacity (Okabe 1979, Juliano and Pascual 1980, Juliano 1985, Sowbhagya et al 1987, Ebata et al 1989, Mundo et al 1989). Limited research has addressed the influences of growing location (Choi et al 1994a,b), fertilizer application (Yanase et al 1984, Ohtsubo et al 1993), DOM of brown rice (Roberts 1979, Yanase et al 1985, Piggott et al 1991), and storage conditions (Okabe 1979, Perez and Juliano 1981, Tsugita et al 1983, Chun et al 1991, Ohtsubo et al 1993, Chrastil 1994) on textural characteristics. No studies were found in the literature concerning the effects of drying conditions, final moisture content, and DOM (white rice) on cooked rice texture to allow comparisons with the results obtained here.

In this investigation, differences in textural property values measured, although statistically significant, were small. Correlation of these data with textural data obtained by descriptive sensory analyses will allow the determination of which textural parameters are noticeably affected by postharvest processing conditions. Later articles will report the results of the sensory texture study and the correlation of the instrumental and sensory data.

Instrumentally measured textural properties were not affected by drying conditions, with the exception of cohesiveness. Cohesiveness was lower in rice dried at lower temperatures (18°C or ambient) than that dried at the higher commercial temperatures. Bengal (AR) was the only rice in which cohesiveness measurements were significantly affected by drying conditions. The slower, more gradual drying at 18°C or ambient would be beneficial in minimizing the occurrence of fissuring.

Final moisture content and DOM significantly affected all of the textural properties measured. The effects of moisture and milling on textural property values were interdependent. The effects of deep-milling were more pronounced in the rice dried to 15% moisture than that dried to 12%. The magnitude of the moisture effect possibly depended on the extent of fissuring and differed with variety and location. In general, drying to 15% moisture content instead of 12% would minimize fissuring and cracking upon submersion in water. The cooked rice would tend to be firmer and less adhesive, cohesive, and springy. This would help avoid problems with the cooked rice being too soft and mushy (Satake 1989). Conversely, deep milling would lend to a rice that would cook soft and be more adhesive, cohesive, and springy.

The varietal-location dependence of the effects of final moisture content and DOM on textural properties needs to be considered by industry in order to optimize postharvest handling for yielding rice with specific textural properties for designated markets. Traditional drying and milling methods may need to be altered for optimization. For example, if a U.S. rice variety cooks too hard for the Japanese palate, deep milling may be useful for yielding a softer rice. Deep milling would also yield a whiter rice. Visually,

the rice may then be more appealing to Japanese consumers, who also consider whiteness to be an important, desirable attribute.

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