Processing Characteristics of Long-Grain Rice Grown Under Sprinkler or Flood Irrigation[1]

K. J. MUNDY,[2] J. S. GODBER,[2] S. M. DABNEY,[3] and R. RAO[2]

Cereal Chem. 66(1):42–46

ABSTRACT

Processing quality characteristics of three different long-grain rice cultivars (CICA-8, Labelle, Lemont) grown under three water management regimes (flood, sprinkle when soil matrix potential [SMP] was less than −0.2 bar, sprinkle when SMP was less than −0.5 bar) were tested. Brown rice yields varied between cultivars but were not affected by water management. Milling yields were higher in flooded rice than sprinkler-irrigated rice, but effects within cultivars were variable. Total milled yields were higher for Labelle and Lemont than for CICA-8. Amylose content, which ranged between 26.6 and 29.7%, was not affected by cultivar or water management. Amylograms indicated that CICA-8 had higher viscosity values, less breakdown, and greater setback than Labelle and Lemont. CICA-8 was judged to have lower sensory quality in a rice pudding for the attributes of texture, moisture, and acceptability. There was no overall effect of water management on sensory attributes, but sprinkler-irrigated Labelle was judged higher than flood-irrigated Labelle for the attributes of texture and consistency.

Rice (*Oryza sativa* L.), as the staple food for over half of the world's population, has many diverse uses and is consumed in many forms. Modern technologies including the development of water control schemes; application of fertilizer, herbicides, insecticides and fungicides; introduction of new cultivars; and improvement of cultural practices have increased the number of alternatives available to farmers (Lu and Chang 1980). The quality of the grain obtained from innovative production practices should be evaluated for its suitability for specific end uses in commercial applications and for consumer preferences.

Flooding has been the traditional agronomic approach to rice cultivation in low land areas. Optimizing water use efficiency is an important goal (Lu 1971). Traditional methods of flood irrigation and water distribution through open canals incur water losses through seepage and/or evaporation. Research in Arkansas (Ferguson and Gilmore 1979) and Texas (McCauley et al 1985) indicated that considerably less water is used by sprinkler-irrigated rice than by rice grown under flooded culture, although a variable response of several rice cultivars was found.

It is important that the suitability of different cultivars produced under different production and processing conditions for specific end uses be understood. Rice cultivars and grain types have specific milling, cooking, eating, and processing characteristics. The quality associated with each of these characteristics is ultimately the measure of the suitability for the production of the desired product. Milling quality is evaluated by considering whole-grain (head rice) yield, total milled yield, and milling uniformity. Factors that affect the milling quality include foreign material, chalky and immature grain content, variety, grain type, growing conditions, harvesting, drying and storage techniques. Overall quality factors such as grain appearance, size and shape, milling quality, and degree of milling do not predict cooking or eating quality, however. In the United States during the 1950s, an agronomically superior long-grain cultivar was developed and released for commercial production that later proved to be completely unacceptable for traditional long-grain cooking and processing (Webb 1980).

Monitoring food quality is currently a well-recognized component of improved food production practices. The test of cooked rice is best verified by the measurement of its eating quality. Standard sensory evaluation has been used to evaluate the cooked rice characteristics of aroma, flavor or taste, tenderness or hardness, cohesiveness or stickiness, appearance, and whiteness or color. Sensory analysis of cooked rice has been described by Batcher et al (1957) and reviewed by del Mundo (1979). Sensory tests alone have not been able to explain the fundamental differences of kernel stability, textural quality, and mouth feel. Instrumental and chemical indices have been found to be more sensitive in the analysis of certain aspects of grain quality.

The measurement of amylose content is probably the most important test used to predict grain cooking and processing quality. It has been found to correlate negatively with alkali-spreading value, gel consistency, and stickiness of cooked rice, and positively with amylograph peak viscosity, setback, and consistency values and with hardness of cooked rice (Juliano 1985). Amylography has been used widely to characterize starch slurries in industrial applications and to differentiate grain types (Shuey and Tipples 1982). The various measurements that can be obtained from an amylograph have been described by Merca and Juliano (1981). Many factors such as aging, storage conditions, protein content, and amylose content affect peak viscosity. Breakdown viscosity and setback have been correlated with amylose content. Cooperative tests between laboratories have shown differences for amylography among rice flour samples, but slight variations in the methodology did not significantly change the viscosity values (Whistler et al 1984).

The objective of this research was to characterize the processing quality of three different cultivars of long-grain rice grown under different water management regimes. The intention was to determine if sprinkler irrigation would have an impact on processing characteristics and if different cultivars responded to sprinkler irrigation differently.

MATERIALS AND METHODS

Samples

Rice cultivars were grown under three water management regimes in Baton Rouge, LA (Dabney and Hoff 1987). One of the water management regimes was conventional flooded culture. The other two regimes were two levels of sprinkler-irrigated upland culture, where sprinkler irrigation was applied when soil matrix potential (SMP) was less than −0.2 bar (sprinkle 2) or when SMP was less than −0.5 bar (sprinkle 5) as measured by tensiometers. A split-plot randomized complete block design was employed with water management as whole plots and cultivars as subplots. The cultivars used were Labelle, Lemont, and CICA-8. After combine harvesting, rice was dried under ambient temperatures to a moisture content (<13%) suitable for storage as measured by a Motomco moisture meter. All samples were stored in a walk-in cold room at 4°C in plastic bags until analyzed.

Hulling and Milling

Samples were stored for at least four months to minimize

[1]Approved for publication by the director of the Louisiana Agricultural Experiment Station as manuscript number 87 21-1636.

[2]Former graduate assistant, assistant professor, and professor, respectively, Food Science Department, Louisiana Agricultural Experiment Station.

[3]Assistant professor, Department of Agronomy, Louisiana Agricultural Experiment Station, Louisiana State University Agricultural Center, Baton Rouge, LA 70803-4200.

differences in aging and were removed from the cold room a minimum of 24 hr before hulling and milling. Samples were hulled using a Satake rice machine (Tokyo, Japan, type THU, class 35A, 1,900 rpm). Brown rice was passed through the machine twice to ensure uniformity and consistency in the brown rice. The weight remaining after the first and second hulling of 500-g samples was determined, and "brown rice yield" was calculated as a percentage of the original sample weight. Brown rice samples (130 g) were then milled with a McGill miller (H. T. McGill, Brookshire, TX) for 60 sec, utilizing a 789-g weight on the miller lever arm. The weight was removed, and the rice was polished for 60 sec, and the white rice weighed. "Milling yield" was then calculated as a percentage of the original brown rice sample weight. "Total milled yield" was calculated as the percentage of white rice recovered from the unhulled rice. Samples were stored in Whirl-Pak bags.

Objective Analysis

Amylograph analysis was conducted using a model VA-lB Visco/Amylo/Graph (C.W. Brabender Instruments, Inc., South Hackensack, NJ) with a 700-cmg sensitivity cartridge. Because of the time constraints associated with amylographic analyses, amylography was conducted on two replications of each treatment. The milled rice was ground using a Mikro-Samplmill hammermill (Mikropul Div. of Slick Corp., Summit, NJ) to an approximate 80-mesh flour. The moisture content was determined by the AACC method (1976).

Amylography was conducted using a modification of the method of Halick and Kelly (1959). A slurry of the rice flour with the water component maintained at 450 g was mixed. A 10% concentration was used for Labelle and Lemont, but several different concentrations were used for CICA-8 because preliminary tests indicated the viscosity scale was exceeded at peak viscosity at the 10% concentration. Each slurry was heated from 30° C at a constant rate of 1.5° C/min to 95° C, held at 95° C for 30 min, and cooled to 50° C at the same constant rate. The gelatinization temperature (GT) was reported as the temperature of the initial increase in viscosity (pasting temperature) minus 3° C (Juliano et al 1964). Breakdown (peak viscosity [P] minus final viscosity at 95° C [H]), setback (viscosity at 50° C [C] minus P) and consistency ($C - H$) were also calculated. The amylose content of the milled rice was determined using the starch-iodine blue colorimetric method described by Juliano (1971).

Sensory Analysis

Sensory quality characteristics of the different treatments were tested using Labelle and CICA-8, grown with either flood or the drier sprinkler (when SMP < -0.5 bar) irrigation treatment. Lemont was excluded from the sensory analysis because of its similarity to Labelle and because only a limited number of treatments could be tested at one time. A locally available rice (Mahatma Extra Long Grain Enriched Rice, Riviana Foods, Inc., Houston, TX) considered to have the desired characteristics was used as a reference. Rice pudding was used as the model for comparison. The puddings were prepared under home kitchen conditions. The pudding formulation was obtained from the Old Fashion Rice Pudding recipe (The Settlement Cookbook, Simon and Shuster, New York). One-cup capacity pyrex custard-cup containers were lightly oiled, and 18.75 g of rice, 18.75 g of sugar, and 180 g of whole milk were added. The ingredients were well mixed; containers were weighed, covered with aluminum foil, and baked in a preheated 163° C electric oven for 90 min. The covers were then removed and the puddings were allowed to "brown" for an additional 30 min. The puddings were removed from the oven, cooled to room temperature, and weighed. Moisture loss during cooking was expressed as a percent of the original weight.

Sensory evaluations for moisture, consistency, texture, and overall acceptability of the pudding samples were done on the day of preparation. A laboratory panel of eight judges selected from the Food Science Department of Louisiana State University was used. During training sessions, agreement was reached on term and characteristic definitions. An evaluation sheet for each sample consisted of four horizontal hedonic scales 12.7 cm long. Each characteristic was anchored with appropriate terminology at the beginning and end of the scale. Scores were measured to the nearest 0.25 cm and converted to numeric values. Each of the four treatments (CICA-8 flood, CICA-8 sprinkle 5, Labelle flood, Labelle sprinkle 5) were sampled six times over four days.

Statistical Analyses

The Statistical Analysis System (SAS Institute 1985) was used to compute analysis of variance. Significant differences between means were tested by the least significant difference test. Because the experimental design of the milling portion of the experiment employed a split-plot design, four different LSDs were calculated to account for differences in the error term as described by Cochran and Cox (1957).

RESULTS

Milling

Brown rice milling yields (Table I) were significantly lower ($P \leq 0.05$) for CICA-8 than the other cultivars tested. The main effect of water management did not significantly influence mean brown rice milling yields at the 0.05 level of probability. However, ANOVA analysis indicated a highly significant ($P \leq 0.01$) interaction between water management and cultivar. When yields of individual cultivars were considered, CICA-8 and Labelle had a significantly ($P \leq 0.05$) lower yield at the driest water management level compared with rice grown under flooded culture. Labelle also had a significantly ($P \leq 0.05$) lower yield at the driest water management level versus the intermediate water management level.

CICA-8 had the highest ($P \leq 0.05$) milled rice yields, whereas Lemont had the lowest (Table II). Flooded rice had significantly ($P \leq 0.05$) greater milled yield than either sprinkler treatment; however, the drier of the sprinkler treatments had a higher ($P \leq 0.05$) milled yield than the wetter sprinkler treatment. As with brown rice yields, Labelle milled yields were significantly reduced by sprinkler irrigation. In contrast, there was no effect due to water management treatment on the CICA-8 and Lemont rices.

Lemont rice produced a significantly ($P \leq 0.05$) higher total yield than CICA-8, but there were no differences between Lemont

TABLE I
Brown Rice Yield (%)

	Water Management			
Cultivar	**Flood**	**Sprinkle 2**	**Sprinkle 5**	**Mean[a]**
Labelle	75.8	76.9	69.4	74.0
Lemont	78.8	73.3	77.4	76.6
CICA-8	73.4	69.3	64.8	69.1
Mean[a]	75.7	73.1	70.5	···

[a] Least significant differences (LSD) for separation of water management means = 5.4 ($n = 12$); LSD for separation of cultivar means = 4.2 ($n = 12$); LSD for separation of means within the same water management level = 7.3 ($n = 4$); and LSD for separation of means regardless of management level = 8.0 ($n = 4$). All are significant at $P \leq 0.05$.

TABLE II
Milled Rice Yield (%)

	Water Management			
Cultivar	**Flood**	**Sprinkle 2**	**Sprinkle 5**	**Mean[a]**
Labelle	88.5	84.5	86.0	86.4
Lemont	89.1	87.8	88.9	88.6
CICA-8	90.6	89.7	89.5	89.9
Mean[a]	89.4	87.4	88.1	···

[a] LSD for separation of water management means = 1.02 ($n = 12$); LSD for separation of cultivar means = 0.97 ($n = 12$); LSD for separation of means within the same water management level = 1.67 ($n = 4$); and LSD for separation of means regardless of management level = 1.70 ($n = 4$). All are significant at $P \leq 0.05$.

and Labelle nor between CICA-8 and Labelle (Table III). Furthermore, Lemont had higher ($P \leqslant 0.05$) yields than either CICA-8 or Labelle with the driest sprinkler treatment, but there were no differences between cultivars at the other two water management levels. Flooded rice had significantly ($P \leqslant 0.05$) higher total yields than either sprinkler treatment, with no difference between sprinkler treatments. Total yields for Lemont and CICA-8 were unaffected by water treatment, but there was a significant reduction ($P \leqslant 0.05$) in total yield at the drier sprinkler treatment versus the flooded treatment for Labelle.

Objective Analysis

Amylose content, which ranged between 26.7 and 29.7% dry weight (Table IV), was not influenced by either cultivar or water management treatment. Typical amylograms for each cultivar are depicted in Figure 1. Labelle and Lemont had similar and slightly lower pasting temperatures (73.6 and 73.5° C) than did CICA-8 (74.8° C). When GT was determined from the amylogram, all three cultivars would be classified as intermediate (70–74° C) types. Peak viscosity was higher for Lemont than Labelle. Lemont also had greater viscosity throughout the amylography. Peak viscosity for CICA-8 at a 10% slurry concentration exceeded the amylograph scale and would have been higher than that of Lemont at an equal concentration (Fig. 2). The greatest difference between cultivars

TABLE III
Total Yield (%)

Cultivar	Water Management: Flood	Sprinkle 2	Sprinkle 5	Mean[a]
Labelle	67.6	65.1	59.6	64.1
Lemont	69.9	63.8	68.5	67.5
CICA-8	66.5	62.7	58.0	62.4
Mean[a]	67.8	63.9	62.0	...

[a] LSD for separation of water management means = 4.8 ($n = 12$); LSD for separation of cultivar means = 4.3 ($n = 12$); LSD for separation of means within the same water management level = 7.5 ($n = 4$); and LSD for separation of means regardless of management level = 7.8 ($n = 4$). All are significant at $P \leqslant 0.05$.

TABLE IV
Amylose Content[a] (% dry weight)

Treatment	Cultivar: Labelle	Lemont	CICA-8	Means
Flood	26.68	29.55	29.63	28.76
Sprinkle 2	28.47	28.10	28.74	28.43
Sprinkle 5	28.08	27.94	27.87	28.23
Means	27.79	28.40	28.85	...

[a] LSD = 1.9 ($n = 6$); $P \geqslant 0.05$.

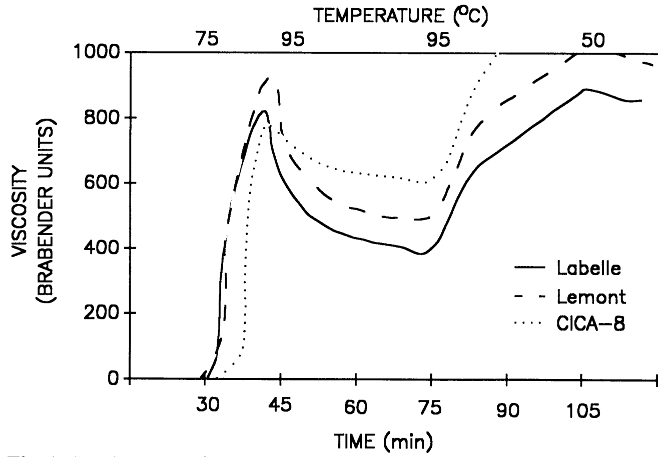

Fig. 1. Amylograms of Labelle, Lemont, and CICA-8 with flood irrigation. Slurry concentration was 10% for Labelle and Lemont and 9% for CICA-8.

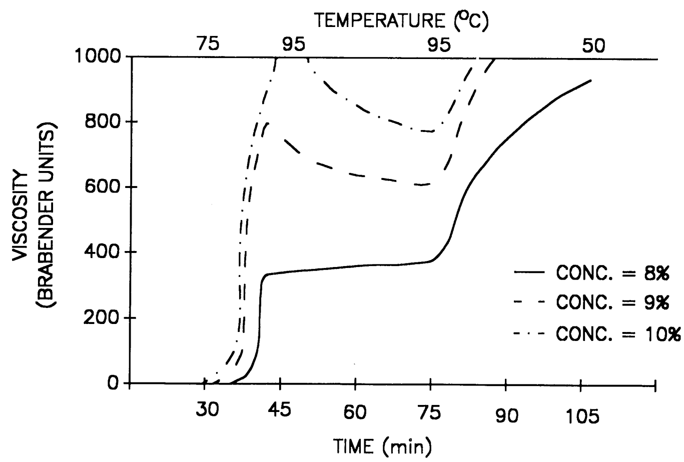

Fig. 2. Amylograms of CICA-8 with flood irrigation at 8, 9, and 10% slurry concentrations.

TABLE V
Amylograph Values of Rice Cultivars Grown Under Different Water Management Regimes

Variety Treatment	Pasting Temperature (° C)	Peak Viscosity (P) (BU)	Final Viscosity[a] (H) (BU)	Viscosity[b] (C) (BU)	Breakdown ($P-H$) (BU)	Setback ($C-P$) (BU)	Relative Breakdown[c]
Labelle (10% slurry)							
Flood	73.5	875	435	940	440	65	0.87
Sprinkle 2[d]	73.5	880	435	925	445	45	0.91
Sprinkle 5[e]	73.9	800	405	910	395	110	0.78
Mean	73.6	855	425	925	425	75	
Lemont (10% slurry)							
Flood	73.2	955	480	1,000*[f]	475	45*	0.91*
Sprinkle 2	73.5	840	450	985	390	145	0.73
Sprinkle 5	73.9	825	425	940	400	115	0.78
Mean	73.5	875	455	975*	415	100*	
CICA-8 (9% slurry)							
Flood	74.3	745	600	1,000*	145	255*	0.36*
Sprinkle 2	76.5	600	515	1,000*	85	400*	0.18*
Sprinkle 5	73.5	620	535	1,000*	85	380*	0.18*
Mean	74.8	655	550	1,000*	105	350*	

[a] Final viscosity at 95° C.
[b] Viscosity at 50° C.
[c] Breakdown/(breakdown + setback).
[d] When soil matrix potential < −0.2 bar.
[e] When soil matrix potential < −0.5 bar.
[f] An asterisk indicates that the value is understated because viscosity exceeded the chart maximum.

appears to be with CICA-8 during the cooling phase. CICA-8 had less breakdown (P − H, 105 Brabender units [BU]) than Labelle and Lemont (425 and 415 BU, respectively, Table V). Water irrigation treatment had little influence on the overall shape of the curve within cultivar. Sprinkler-irrigated rice showed lower values for *P*, *H*, breakdown, and setback. Peak viscosity also appeared to be slightly higher for rice grown under flood irrigation than under sprinkler irrigation (Table V).

Sensory Analysis

Labelle had greater ($P \leq 0.05$) sensory quality than CICA-8 for texture, moisture, and acceptability (Table VI). Although there was no overall sensory effect due to water management, sprinkler-irrigated Labelle rice was rated better than flood Labelle rice for the attributes of texture and consistency. There was no difference for CICA-8 rice due to water management treatment for any sensory attribute.

TABLE VI
Sensory Analysis of CICA-8 and Labelle Grown Under Different Water Management Regimes

Variable	LSD	CICA-8 Sprinkle	CICA-8 Flood	Labelle Sprinkle	Labelle Flood
Texture	0.43	2.74 a[a]	2.90 a	4.17 c	3.65 b
Moisture	0.47	2.69 a	2.99 a	4.19 b	3.72 b
Consistency	0.54	2.77 a	2.68 a	3.19 b	2.51 a
Acceptability	0.45	2.42 a	2.59 a	3.39 b	3.25 b

[a] Means ($n = 48$) within rows followed by different letters are significantly different ($P \leq 0.05$) $n = 4$ (where 5 is desirable, 1 is undesirable).

DISCUSSION

Brown rice yield may be influenced by many different factors including grain type, cultivar, growing conditions, harvesting method, and drying conditions (Webb 1985). Cultivar differences occurred since CICA-8 had lower brown rice yield than the other two cultivars tested. It is possible that the lower yield for CICA-8 was due to a longer growing season in Louisiana (Dabney and Hoff 1987) that subjected it to a different set of environmental conditions during ripening. There were no overall differences in brown rice yield due to water management regime, although individual decreases in yields related to sprinkler irrigation treatments occurred for both CICA-8 and Labelle. This result indicates a need for consideration of cultivar differences with respect to water management decisions.

Milling yield is related to grain characteristics such as size, shape, and hardness because of the dependence on intergrain interaction during the milling procedure. In normal commercial operations, milling machine settings are adjusted to remove a certain percentage of the brown rice by weight, i.e., 10%. In this research the milling machine settings were adjusted during a preliminary experiment to remove approximately 10% of a randomly chosen set of brown rice samples. The initial settings were then maintained throughout this experiment. The fact that CICA-8 had higher yields than Lemont and Labelle may have been related to differences in grain size and shape. Flooded rice consistently had higher milled rice yield than sprinkler-irrigated rice. One factor that may have contributed to this difference was a reduced grain size for sprinkler-irrigated rice (Dabney and Hoff 1987). With reduced grain size, sprinkler-irrigated rice would have had greater exposed surface area per unit of weight during the milling procedure, which could have resulted in higher milling losses. It is also possible that the hardness of the rice was affected by the process of wetting and rewetting that occurred in the sprinkler-irrigated treatment. Although there were definite trends in milling effects due to treatment and cultivar that may be valuable to millers, in a commercial enterprise these differences would be minimized through the proper adjustment of the milling machinery.

The mean total yield of the flooded rice in this experiment (67.8%) was slightly higher than the figure of 65.6% reported to be the average milling yields for long-grain rice grown in the southern United States (Webb 1985). The mean yield for sprinkler-irrigated rice (63.0%) was slightly lower than this average.

Objective Analysis

Amylograms of the rice cultivars in this study were typical of rice flour slurries (Juliano 1985). There were distinct differences in curve behavior between the cultivars (see Fig. 1). Cultivar differences in amylograph curves were first reported by Halick and Kelly (1959). Lemont and Labelle had similarly shaped curves at 10% (dry weight) slurry concentration. CICA-8 amylograms were generated from a 9% slurry concentration, because at a 10% concentration the curves exceeded the scale at peak viscosity (Fig. 2). A 9% slurry concentration generated a curve where peak viscosity remained on the scale; however, the curve still exceeded the scale during the cooling phase. This would lower the calculated values for setback ($C - P$) and consistency ($C - H$), which are calculated with the viscosity value, *C*, obtained when the paste is cooled to 50° C (Table V).

Viscosity is known to be affected by many factors such as aging or storage of the sample, protein and amylose content, and concentration of the slurry. The amylose content (percent dry basis) of the three long-grain cultivars tested ranged from 26.6 to 29.7% (Table V). Although the method used to determine amylose content may underestimate amylose content of high-amylose samples (Juliano 1971), the values determined in this study were still sufficiently high to classify all cultivars as having high-amylose content (>25%). Although CICA-8 had slightly higher (not significant) amylose content, the much higher *C* values of CICA-8 (higher viscosity when cooled to 50° C) could not be explained on the basis of amylose content. This response may be due to a difference in the hot-water-insoluble amylose content among cultivars, which has been shown to be a key parameter and indicator of quality by Bhattacharya et al (1978). They proposed three different classes of high-amylose-content rices with varied percentages of insoluble amylose (>15%, 12.5–15%, <12.5%). It was found that relative breakdown (BD_r = breakdown/[breakdown + setback]) increased with decreasing insoluble amylose. From this relationship, it could be speculated that CICA-8 would have a higher insoluble amylose content than Labelle or Lemont, as BD_r values (Table V) ranged from <0.18 to 0.36 for CICA-8 compared with Lemont (0.73–0.91) and Labelle (0.78–0.91).

Sensory Analysis

Labelle was considered more acceptable from a sensory standpoint than CICA-8. The reasons for this difference in acceptability may be related to objective parameters. It has been well established that amylose content is an important determinant of rice quality (Juliano 1968, 1979) and is probably the most objective index of the texture of cooked rice. Although there were only small differences in total amylose content, inferences made with regard to hot-water-insoluble amylose may help explain the sensory differences that were observed between CICA-8 and Labelle. Bhattacharya et al (1978) found that stickiness and consistency of cooked rice were correlated with the three classes of varied hot-water-insoluble amylose; they obtained higher stickiness and lower consistency values as it decreased. Taste panel scores indicated that Labelle was more desirable than CICA-8 for texture. Desirability was related to a stickier texture. Consistency, although not different between cultivars overall, was lower for the Labelle flooded treatment. These results are consistent with the theory that Labelle had lower hot-water-insoluble amylose than CICA-8.

CONCLUSIONS

Milling quality, as related by various measurements of milling yield, was influenced by cultivar. A consistent interaction between cultivar and water management for milling parameters was obtained. These results suggest that expectations for milling yields should be related to cultivar differences as well as the possibility that cultivars may be affected differently by water management levels.

While brown rice and milling yields tended to be slightly reduced, sprinkler irrigation did not significantly alter the other quality factors evaluated in this study. This study thus provides some reassurance to processors that if sprinkler-irrigation culture is adopted by rice growers in the southeastern United States, the rice produced will not need special handling or processing.

LITERATURE CITED

AMERICAN ASSOCIATION OF CEREAL CHEMISTS. 1976. Approved Methods of the AACC. Method 44-20, approved April 1961. The Association: St. Paul, MN.

BATCHER, O. M., DEARY, P. A., and DAWSON, E. H. 1957. Cooking quality of 26 varieties of milled white rice. Cereal Chem. 34:277-285.

BHATTACHARYA, K. R., SOWBHAGYA, C. M., and INDUDHARA SWAMY, Y. M. 1978. Importance of insoluble amylose as a determinant of rice quality. J. Sci. Food Agric. 19:359.

COCHRAN, W. G., and COX, G. M. 1957. Experimental Designs, 2nd ed. John Wiley & Sons: New York.

DABNEY, S. M., and HOFF, B. J. 1987. Influence of water management on growth and yield of no-till planted rice. Crop Sci. (In press)

DEL MUNDO, A. M. 1979. Sensory assessment of cooked milled rice. Pages 313-325 in: Proc. Wksp. on Chem. Aspects of Rice Grain Quality. Int. Rice Res. Inst.: Los Baños, Laguna, Philippines.

FERGUSON, J. A., and GIILMRE, J. T. 1979. Water and nitrogen relations of sprinkler irrigated rice. Arkansas Farm Res. 27:2.

HALICK, J. V., and KELLY, V. J. 1959. Gelatinization and pasting characteristics of rice varieties as related to cooking behavior. Cereal Chem. 36:91.

JULIANO, B. O. 1968. Relation of some properties of rice starch and protein to eating quality preferences for milled rice in Asia. Getreide Mehl Brot 18:82.

JULIANO, B. O. 1971. A simplified assay for milled-rice amylose. Cereal Sci. Today 16:334-40.

JULIANO, B. O. 1979. The chemical basis of rice grain quality. Page 69 in: Proc. Wksp. on Chem. Aspects of Rice Grain Quality. Int. Rice Res. Inst.: Los Baños, Laguna, Philippines.

JULIANO, B. O. 1985. Criteria and tests for rice grain qualities. Page 443 in: Rice Chemistry and Technology. B. O. Juliano, ed. Am. Assoc. Cereal Chem.: St. Paul, MN.

JULIANO, B. O., BAUTISTA, G. M., LUGAY, J. D., and REYERS, A. C. 1964. Studies on the physio-chemical properties of rice. J. Agric. Food Chem. 12:131-38.

LU, J. J. 1971. The demand for United States rice: An economic-geographic analysis. Ph.D. dissertation. University of Washington, Seattle.

LU, J. J., and CHANG, T. T. 1980. Rice in its temporal and spatial perspectives. In: Rice: Production and Utilization. B. S. Luh, ed. Avi Publ. Co.: Westport, CT.

McCAULEY, G. N., HOSSNER, L. R., and NESMITH D. M. 1985. Sprinkler irrigation as an energy and water saving approach to rice production and management of riceland pests. Rep. TR-134. Texas Water Resources Institute: College Station, TX. 225 p.

MERCA, F. E., and JULIANO, B. O. 1981. Physicochemical properties of starch of intermediate-amylose and waxy rices differing in grain quality. Staerke 33:253.

SAS INSTITUTE. 1985. SAS/STAT guide for personal computers, version 6 edition. SAS Institute, Cary, N.C.

SHUEY, W. C., and TIPPLES, K. H. 1982. The Amylograph Handbook. Am. Assoc. Cereal Chem., St. Paul, MN.

WEBB, B. D. 1980. Rice quality and grades. In: Rice: Production and Utilization. B. S. Luh, ed. Avi Publ. Co.: Westport, CT.

WEBB, B. D. 1985. Criteria of rice quality in the United States. Page 403 in: Rice Chemistry and Technology. B. O. Juliano, ed. Am. Assoc. Cereal Chem.: St. Paul, MN.

WHISTLER, R. L., BeMILLER, J. N., and PASCHALL, E. F. 1984. Starch Chemistry and Technology. Academic Press: New York.

[Received January 19, 1988. Revision received September 6, 1988. Accepted September 14, 1988.]