Determining the Degree of Gelatinization in Parboiled Rice: Comparison of a Subjective and an Objective Method[1]

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Cereal Chem. 70(2):226–230

ABSTRACT

Lemont and Tebonnet long-grain rice samples were parboiled either conventionally or by microwave to different degrees of starch gelatinization. The degree of gelatinization was determined by an objective method (differential scanning calorimetry) and by a subjective rice-grading method that yielded the percentage of translucent kernels in a given sample of parboiled rice. A linear correlation was found between the two methods for both varieties, which suggested that the grading procedure could be used to estimate the degree of gelatinization once a calibration curve was established. In addition, the degree of gelatinization, as determined by differential scanning calorimetry, was compared with head rice yield. The relationship between the two variables was nonlinear, and maximum head rice yield for both Lemont and Tebonnet was achieved when the starch was about 40% gelatinized. Our results indicate that extensive starch gelatinization (extensive parboiling) is not necessary to obtain maximum head rice yields.

Parboiling rice normally consists of soaking rough rice in hot water for several hours until the kernels are saturated, draining the water, steaming the saturated rice for several minutes at or above 100°C to gelatinize the starch, and drying the parboiled product. Compared to raw rice, parboiled rice is harder and gives a higher yield of head rice upon milling (Raghavendra Rao and Juliano 1970). Incomplete parboiling has caused increased kernel breakage upon milling (Subrahmanyan et al 1955, Bhattacharya and Subba Rao 1966). Also, parboiled rice is less sticky after cooking (Kato et al 1983) and requires a longer cooking time than raw rice (Ali and Bhattacharya 1982). These differences between the properties of parboiled and raw rice are due to changes in the starch upon parboiling. The nature of the starch that influences the behavior of parboiled rice is open to question. Raghavendra Rao and Juliano (1970) and Ali and Bhattacharya (1976) believed that many properties of parboiled rice were influenced by starch retrogradation. On the other hand, Priestley (1976a) concluded from X-ray diffraction studies that the presence of an insoluble, helical amylose-lipid complex, not retrogradation, gave parboiled rice its unique characteristics. Mahanta et al (1989) examined parboiled rice starch by X-ray diffraction and differential scanning calorimetry (DSC) and reported that the starch was largely amorphous, with a low degree of crystallinity. They felt that the unique properties of parboiled rice were not due to any form of crystalline starch, such as retrograded or lipid-complexed, but they did not speculate on the exact cause.

Many of the properties of parboiled rice appear to depend on the severity of the parboiling treatment, especially the temperature at which rice is steamed (Bhattacharya 1985). Therefore, the degree of starch gelatinization may be responsible for many of the attributes of parboiled rice. Although degree of starch gelatinization is an important consequence of parboiling, no simple test has been developed to quantify the extent of gelatinization under specific parboiling conditions. Wirakartakusumah (1981) used DSC to measure the degree of gelatinization and the gelatinization temperatures of starch isolated from parboiled rice that had been subjected to different soaking and steaming temperatures. The greatest degree of gelatinization was observed in rice exposed to the highest soaking and steaming temperatures.

DSC can provide an accurate assessment of degree of gelatinization in parboiled rice starch, but it is time-consuming and expensive. Rice processors would like to monitor starch gelatinization using a fast, easy-to-perform test with little or no equipment. Such a test might take advantage of the fact that incomplete parboiling results in partial or surface starch gelatinization. The kernels produced have translucent outer layers and an opaque or white center from the nongelatinized starch. In contrast, completely parboiled rice kernels are translucent. In fact, some rice processors use a subjective evaluation to qualitatively determine the extent of parboiling based on the percentage of translucent kernels found in a given sample of parboiled rice. Although this method can quickly determine whether starch is gelatinized, it cannot quantify the degree of gelatinization nor reflect the occurrence of wasteful over-parboiling.

Parboiled rice is harder and less subject to transverse breakage than raw rice, so parboiling has become popular among rice millers because it results in increased head yield. Improved head yield translates into higher profits for the miller because unbroken kernels command a higher price in the marketplace than broken kernels. In addition, parboiled rice commands a higher price than nonparboiled milled rice because some consumers prefer its cooking, flavor, and textural qualities. Priestley (1976b) examined the effectiveness of parboiling in reducing milling breakage in relation to degree of gelatinization. Compared to raw rice, milling breakage in parboiled rice was improved only after the starch was completely gelatinized. However, Itoh and Kawamaura (1991) observed that as the degree of rice starch gelatinization increased from 2 to 60%, the percentage of kernel breakage decreased from 7 to 1% in a linear manner. Improved head rice yield is an important consequence of parboiling, so further clarification of the relationship between head yield and degree of gelatinization appears warranted.

In this study, the use of DSC as an objective method of determining degree of starch gelatinization was examined, and DSC data were correlated with a subjective grading method based on the percentage of translucent kernels. Thus, the subjective method could be established as a quantitative determinant for degree of starch gelatinization in whole kernel rice. The relationship between head rice yield and degree of gelatinization, as measured by DSC, in whole kernels was also evaluated.

MATERIALS AND METHODS

Materials

Rough rice samples of Lemont and Tebonnet long-grain rice were obtained as seed rice (1990 crop) from the Louisiana Agricultural Experiment Station, Rice Research Station, Crowley, LA.

Parboiling Procedures

Microwave parboiling. Microwave parboiling of rice provides precise control of processing variables (Verma et al 1991) and

[1]Presented in part at the AACC 76th Annual Meeting, Seattle, WA, October, 1991.
[2]U.S. Department of Agriculture, ARS, Southern Regional Research Center, New Orleans, LA. Mention of names of companies or commercial products is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the U.S. Department of Agriculture over others not mentioned.
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TABLE I
Processing Conditions for the Microwave-Parboiling Process

Variety Process Intensity	Water Added[a] (g)	Soak Power (kW)	Soak Time (min)	Soak Temp. (°C)	Equil[b] Time (min)	Cook-1 Power (kW)	Cook-1 Time (min)	Cook-1 Temp. (°C)	Cook-2 Power (kW)	Cook-2 Time (min)	Cook-2 Temp. (°C)
Lemont											
Light	1,125	0.45	54	62	54	0.55	45	87	0.45	35	79
Medium	1,125	0.50	60	75	60	0.60	50	88	0.50	40	84
Harsh	1,125	0.55	66	80	66	0.65	55	90	0.55	45	80
Light	1,250	0.45	54	72	54	0.55	45	86	0.45	35	75
Medium	1,250	0.50	60	74	60	0.60	50	86	0.50	40	84
Harsh	1,250	0.55	66	76	66	0.65	55	85	0.55	45	81
Light	1,375	0.45	54	76	54	0.55	45	88	0.45	35	82
Medium	1,375	0.50	60	76	60	0.60	50	89	0.50	40	79
Harsh	1,375	0.55	66	77	66	0.65	55	88	0.55	45	83
Tebonnet											
Light	1,125	0.45	54	73	54	0.55	45	85	0.45	35	86
Medium	1,125	0.50	60	74	60	0.60	50	90	0.50	40	78
Harsh	1,125	0.55	66	78	66	0.65	55	89	0.55	45	86
Light	1,250	0.45	54	70	54	0.55	45	87	0.45	35	79
Medium	1,250	0.50	60	75	60	0.60	50	87	0.50	40	83
Harsh	1,250	0.55	66	76	66	0.65	55	90	0.55	45	88
Light	1,375	0.45	54	57	54	0.55	45	91	0.45	35	83
Medium	1,375	0.50	60	74	60	0.60	50	90	0.50	40	77
Harsh	1,375	0.55	66	77	66	0.65	55	90	0.55	45	84

[a] Water added to 500 g of rough rice.
[b] Equilibration.

was, therefore, the method of choice to create samples with different degrees of gelatinization. The microwave process is similar to a parboiling process described by Unnikrishnan et al (1982) in which rough rice can be parboiled by soaking in hot water rather than applying steam. The experimental design (Table I) was set up to create nine samples of each variety parboiled to different degrees. Rough rice samples (500 g) from each variety were placed in three different volumes of water (1,125, 1,250, and 1,375 ml). The samples were placed in the chamber of a microwave-vacuum dryer system (Aeroglide, Raleigh, NC) and subjected to the soaking conditions (power, time, and temperature) given in Table I. During the equilibration period, the power to the microwave-vacuum dryer was turned off, and the rice continued to soak in the hot water. After equilibration, microwave power was resumed, and the rough rice was subjected to two separate cooking periods (Table I) to partially gelatinize the starch. At the conclusion of the second cooking step, the rice was removed from the microwave cooker, the water drained, and the samples dried in a thin layer on screens in an air-conditioned lab at 20°C and 60% rh (shade-dried). Moisture values for the samples before drying were 34–44%, wet basis. The severity of the parboiling was designated as light, medium, or harsh, according to soaking and cooking conditions (Table I).

Conventional parboiling. A portion of the original Lemont and Tebonnet rough rice samples was parboiled by a process termed conventional because it involved the steps of hot water soaking, draining the soak water, and, finally, steaming the rough rice. As outlined in Table II, samples (500 g) were soaked in 1,500 ml of water in a steam-jacketed pressure cooker to maintain a temperature of 70°C for 210 min. The rough rice was either allowed to remain in the soak water for 90 min with the steam turned off (equilibrated) and then drained, or the soak water was immediately drained (nonequilibrated). The rice was then steamed in a pressure cooker for 8 min at 121°C and shade-dried.

Subjective Grading of Parboiled Kernels

Replicate samples (approximately 150 g) of microwave-parboiled rough rice were shelled with a McGill sheller (H. T. McGill, Houston, TX). The brown rice was milled to 11–13% degree of milling (weight loss based on brown rice) with a McGill No. 3 mill, according to recognized laboratory methods (U.S. Agricultural Marketing Service 1974). The brown rice was well milled to minimize the dependence of head rice yields on the degree of milling.

TABLE II
Processing Conditions for the Conventional Parboiling Process

Treatment	Time (min)	Temperature (°C)
Soak	210	70
Equilibrate	0 or 90	< 70[a]
Steam	8	121[b]

[a] Allowed to cool during equilibration.
[b] Temperature achieved at 15 psig.

The subjective evaluation, separating the translucent kernels, was performed on a grading table with a dark-blue formica top illuminated from above (approximate height 3 ft) by a set of fluorescent lights. The rice grader used tweezers to handpick only those kernels that were completely translucent. Our rationale was that subjective judgement of how small a white portion in a kernel is acceptable is subject to variation among graders and could result in large variation in the results. Accepting only those kernels that were completely translucent avoided this problem.

Head rice yields were determined on the same milled-rice samples used to evaluate translucent kernels. The grader hand-separated grains that were at least three-quarters intact from those that were not. Yield was calculated as the weight of intact kernels compared to the weight of the microwave-parboiled rough rice used as the starting material.

Objective Evaluation of Parboiled Kernels

A description of the DSC, sample preparation for thermal analysis, development of the thermal curves, and calculation of the gelatinization enthalpy (ΔH) was previously given by Normand and Marshall (1989). For this study, whole kernel samples were subjected to two programmed, consecutive heating and cooling cycles of different durations. Samples were heated from 20 to 110°C at a heating rate of 0.33°C/min, held at 110°C for 5 min, then cooled from 110 to 20°C at a cooling rate of 1°C/min. The cycle was then repeated. Data points were acquired at intervals of 10 sec. Maximum temperature limitations placed on the calorimeter by the manufacturer caused data acquisition to be terminated at 110°C during the heating cycles. No thermal curves were observed during the second heating, so this heating established a baseline for the gelatinization endotherm seen during the first heating. Baseline subtractions were made on all thermal curves and only corrected curves are shown.

Degree of starch gelatinization (%SG) was determined by comparing ΔH for a particular parboiled rice sample (with some starch gelatinization) to its raw rice control (assumed to have no starch gelatinized). Calculations were made using the following equation:

$$\%SG = [1 - (\Delta H_{parb}/\Delta H_{raw})] \times 100 \quad (1)$$

Data Analysis

A linear correlation model was used to evaluate the relationship between specific data sets using a linear regression routine (Sigma Plot, version 4.1, Jandel Scientific, San Rafael, CA). Correlation coefficients (r) for the lines were obtained from Sigma Plot. The levels of significance (P) were obtained for the r values using the Student's t test.

RESULTS

Starch Gelatinization in Parboiled Rice

Thermal curves for microwave and conventionally parboiled Lemont rice are shown in Figure 1. Thermal curves for the Tebonnet variety were similar (data not shown). Severity of microwave parboiling had a pronounced effect on the size of the starch gelatinization endotherm. As the treatment became more severe, the endotherm decreased in size and was shifted to lower temperatures. The thermal data also revealed that conventional parboiling was the harshest of the four treatments and resulted in the smallest endotherm.

After parboiling, a broad, second endotherm appeared on the low-temperature side of the gelatinization endotherm (Fig. 1). This endotherm was present in all but the light parboiled samples and, therefore, was related to treatment severity. The small endotherm might be due to an alteration in the structure of the intact, parboiled kernel resulting from the severity of the parboiling conditions. Marshall (1992) recently observed the development of a low-temperature endotherm in rice. The kernel integrity was disrupted when rice kernels were converted to smaller particle sizes. The low-temperature endotherm became the predominant endotherm as the size of the rice kernel particles decreased. By analogy, disruption of kernel integrity by grinding the parboiled kernels to flour-sized particles would cause the gelatinization endotherm to disappear in favor of the low-temperature endotherm. Figure 2 clearly shows that both endotherms persisted in the flour, and that the thermal profile was not a consequence of kernel integrity.

Shi and Seib (1992) observed that retrograded starches from two waxy rice varieties had melting temperatures 12–27°C below the gelatinization temperatures of the native starches. In our case, the low-temperature endotherm was 30–35°C below the gelatinization temperature in the same sample. Based on the results of Shi and Seib (1992), the low-temperature endotherm may represent retrograded amylopectin formed by cooling of the kernels after parboiling. Because two distinct endotherms are present, the possibility exists that two distinct crystalline forms of the starch (retrograded and native), each with different thermal characteristics, are generated by parboiling. Velupillai (1981) observed the presence of crystalline regions in the centers of parboiled rice kernels using scanning electron microscopy but did not indicate whether more than one type of crystalline structure was seen.

Table III shows the effect of microwave and conventional parboiling on ΔH for Lemont and Tebonnet rice. ΔH values for raw rice are presented for comparison. The large ΔH for Lemont raw rice reflects the absence of starch gelatinization. ΔH values for all the light and some of the medium treated microwave-

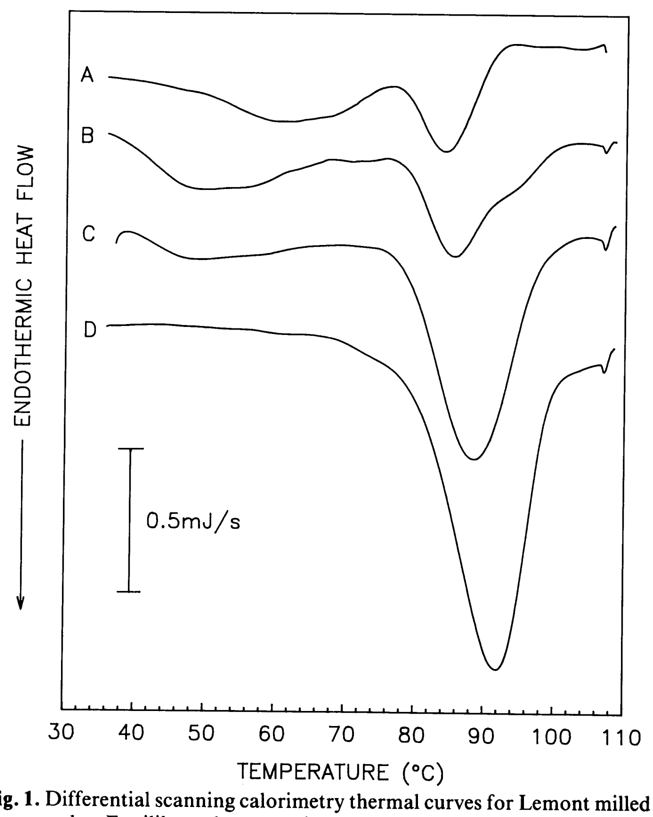

Fig. 1. Differential scanning calorimetry thermal curves for Lemont milled rice samples. Equilibrated, conventionally parboiled (A); microwave parboiled, 1,125 ml of water added (B–D); harsh, medium, and light treatment, respectively. The heating rate of the calorimeter was 0.33°C/min, and the water content of all samples was 70% (w/w).

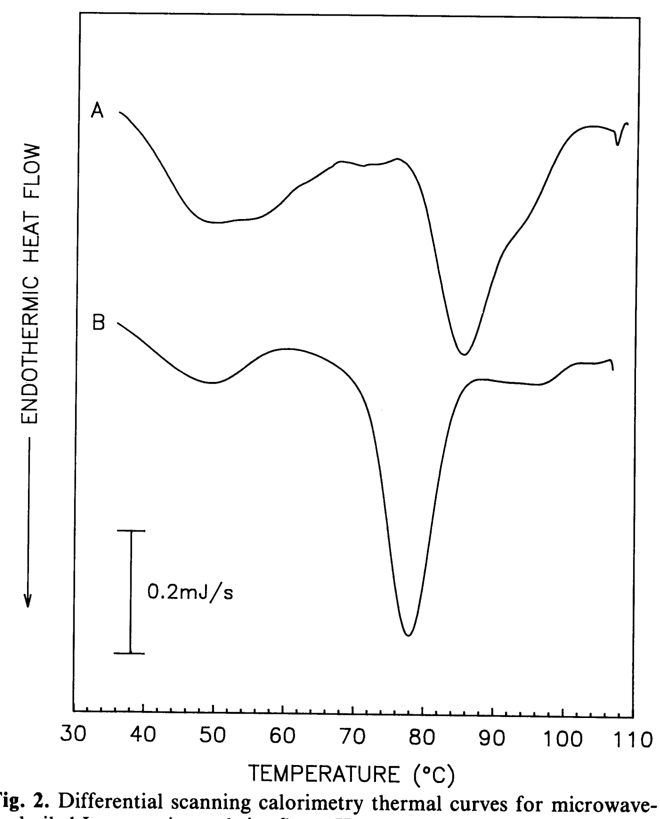

Fig. 2. Differential scanning calorimetry thermal curves for microwave-parboiled Lemont rice and rice flour. Harsh treatment, 1,125 ml of water added (A); sample from A ground to a flour (B). The heating rate of the calorimeter was 0.33°C/min, and the water content of the samples was 70% (w/w).

parboiled samples were the same as, or close to, the value for the raw rice. This indicates little, if any, gelatinized starch in these samples. ΔH for Tebonnet raw rice was somewhat smaller than ΔH for three of the microwave-parboiled samples. Based on these ΔH values, we assumed no starch gelatinization occurred in any of the three samples. However, it is possible that some starch annealing may have occurred in this variety without starch gelatinization. Krueger et al (1987) showed an increase in the ΔH of corn starch annealed under subgelatinization process conditions.

Conventionally parboiled rice had the smallest ΔH values in both varieties (Table III). Therefore, in our study, conventional parboiling resulted in greater starch gelatinization than microwave parboiling did. No difference in starch gelatinization was observed between equilibrated and nonequilibrated samples.

Comparison of Subjective and Objective Methods of Measuring Degree of Gelatinization

Figure 3 shows the relationship between %SG and percent translucent kernels (%TK) obtained by microwave parboiling for Lemont and Tebonnet rice and also the linear correlation model used to examine the relationship between the data sets. The r values were significant ($P < 0.01$). Apparently, the two rice varieties can be represented by straight lines with different slopes and intercepts. This demonstrates the importance of adjusting parboiling conditions for each rice variety. The %SG in microwave-parboiled rice can be directly estimated from a measurement of %TK by employing the appropriate linear equation.

Figure 4 represents the relationship between head rice yield and %SG as determined by DSC. Both Lemont and Tebonnet gave similar curves. The relationship was nonlinear as head rice yield rapidly increased with relatively small changes in %SG. Head rice yield appeared to reach a maximum at about 40% gelatinization for both varieties and remained at maximum yield up to 70% gelatinization.

DISCUSSION

Two methods of assessing starch gelatinization in microwave-parboiled rice and their relationship were examined. A subjective method relies on a human rice grader to separate translucent, milled kernels from those containing white centers. White centers signify incomplete starch gelatinization because the ordered, crystalline structure of the ungelatinized starch reflects light off the surface of the ungelatinized granules, rendering them opaque to the eye. In any given population, a certain percentage of parboiled kernels are completely translucent, and the remainder have white centers of different sizes. Therefore, we would expect a population with a large percentage of translucent kernels to have a high degree of gelatinization, and vice versa, but the assessment would only be qualitative. In the objective method, DSC quantitatively determines the amount of ungelatinized starch remaining after parboiling. By a simple calculation (equation 1), we can determine %SG in a given parboiled sample.

DSC can directly determine %SG not only in parboiled rice but also in any whole kernel rice, treated or untreated (Normand and Marshall 1989, Marshall et al 1990). However, in a processing facility, routine measurement of %SG by DSC would be time-consuming, require a skilled instrument operator, and involve a large initial outlay of funds to purchase the instrument. Alternatively, the subjective evaluation method would be fast, require easily taught skills, need no instrumentation, and be readily adaptable to a processing operation. Our results indicate that the subjective method shows promise as a means to quantify %SG in microwave-parboiled rice (Fig 3). For the subjective evaluation to be successful, a calibration equation may have to be developed for each specific rice variety evaluated.

The DSC technique is the basis for the subjective grading method that was developed to estimate %SG. Wirakartakusumah (1981) used DSC to record gelatinization parameters in parboiled rice, but gelatinization was observed in isolated starch preparations, not in whole kernel rice. Normand and Marshall (1989) showed significant differences in gelatinization parameters of whole kernels and those of rice flour. Therefore, using whole kernels would provide a more accurate assessment of starch gelatinization.

Because the relationship between head rice yield and %SG is

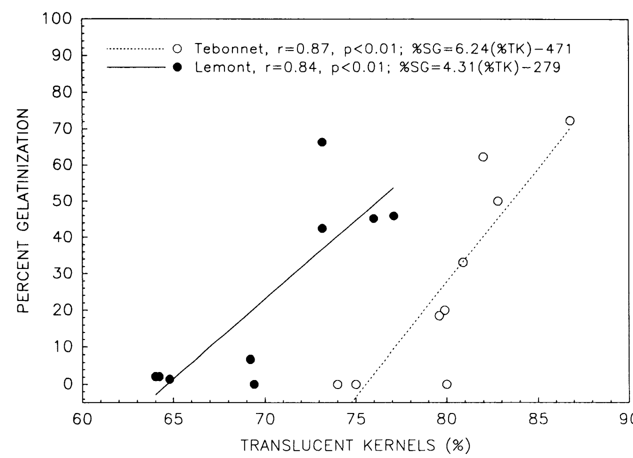

Fig. 3. The relationship between percent starch gelatinization (%SG) and percent translucent kernels (%TK) for microwave-parboiled Lemont and Tebonnet rice showing the correlation coefficients (r), levels of significance (p) and the linear regression equations. Least-squares linear regression analysis performed on the data set from each variety.

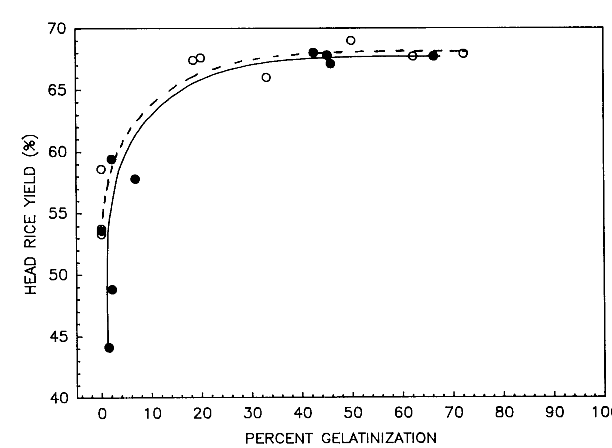

Fig. 4. The relationship between head rice yield and percent starch gelatinization for microwave-parboiled Lemont (●) and Tebonnet (○) rice.

TABLE III
The Effect of Parboiling on Gelatinization Enthalpy (ΔH)[a] in Lemont and Tebonnet Rice

Treatment	Process Intensity	ΔH (J/g) Lemont	Tebonnet
Raw rice	. . .	14.6 ± 0.4	13.0 ± 0.4
Microwave	Light	14.4 ± 0.1	10.6 ± 0.3
(1,125 ml of	Medium	8.4 ± 0.6	8.7 ± 1.7
water added)	Harsh	4.9 ± 1.2	4.9 ± 1.7
	Light	14.3 ± 0.5	14. 0 ± 0.1
(1,250 ml of	Medium	14.3 ± 0.3	6.5 ± 1.8
water added)	Harsh	8.2 ± 1.9	3.6 ± 1.3
	Light	14.6 ± 0.4	14.4 ± 0.1
(1,375 ml of	Medium	13.6 ± 0.4	13.6 ± 1.1
water added)	Harsh	8.0 ± 0.8	10.4 ± 0.5
Conventional	Equilibrated	2.2 ± 0.1	2.4 ± 0.1
	Nonequilibrated	2.1 ± 0.2	2.5 ± 0.2

[a] Means ± SEM for 2–4 determinations.

not linear (Fig. 4), DSC cannot directly estimate head rice yield. However, head rice yield reached a maximum at approximately 40% gelatinization. Results of this study do not support the observations of either Itoh and Kawamura (1991) or Priestly (1976b) that were noted earlier. One reason for parboiling rice is to minimize kernel breakage during milling. Our results show that achieving maximum gelatinization during parboiling is not necessary for achieving minimum kernel breakage. This concept appears valid for at least two varieties of long-grain rice. Although we have emphasized milling yield versus degree of parboiling, flavor and textural qualities of partially gelatinized parboiled rice would also have to be considered to ascertain whether this product could be sold to consumers.

ACKNOWLEDGMENTS

We wish to thank Glenn Johnson and Myra Lewis for acquisition of the DSC data and Cheryl Mosley for determination of head yield and percent translucent kernels.

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[Received June 10, 1992. Accepted October 23, 1992.]