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KERNEL MOISTURE CONTENT VARIATION IN EQUILIBRATED RICE SAMPLES

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ABSTRACT

An individual kernel moisture meter and an individual kernel oven drying procedure were used to quantify the kernel-to-kernel moisture content (MC) variation in equilibrated rough rice samples varying in MC from 9 to 37%, w.b. Average, bulk sample MCs were also determined using an oven drying method. No difference ($p < 0.05$) was found in the average MCs measured by the meter at three weeks or three months from the time the samples were conditioned. The average MCs measured by the meter and the individual kernel oven procedure were in close agreement with those determined by the bulk sample oven method. A characteristic response in the standard deviation of the individual kernel MCs measured by the meter was observed for both storage periods. The standard deviation increased exponentially from approximately 0.5% at 10% average MC to 4.5% at 26% MC. The coefficient of variation also increased dramatically with average MC, indicating that the hygroscopic response to MC change of individual rice kernels within a sample is different.

INTRODUCTION

Moisture content (MC) is used perhaps more than any other property in managing rice from harvest throughout milling. Thus, many studies have used MC as a benchmark property in quantifying the effects of various harvest, drying, storage and milling practices. Dilday (1987) showed that the MC at which rice was harvested was a factor in determining its head rice yield. Pertaining to aeration guidelines and recommendations, Banaszek and Siebenmorgen (1990a), Siebenmorgen and Jindal (1986), and Kunze and Prasad (1978) demonstrated that rice below a MC of approximately 14% is susceptible to cracking if allowed to adsorb moisture. Banaszek, et al. (1989), Pominski et al. (1961), and Webb and Calderwood (1977) have shown that the MC at the time of milling can dramatically affect both head rice yield and the degree to which the rice is milled for given laboratory mill settings.

Because of the importance of average MC, the performance and behavior of a bulk rice sample are dependent on the individual kernel MCs comprising the sample. Kocher et al. (1989), Wadsworth and Matthews (1985), Chau and Kunze (1982), and Wadsworth et al. (1982) have indicated that large differences in individual kernel MCs exist throughout maturation and at harvest. Recent work by Nelson and Lawrence (1989) has shown that large variations in MC from kernel to kernel can exist in corn samples in which the kernels were apparently equilibrated, i.e., moisture exchange between the kernel and surrounding air had ceased. Other work in which observations of variability in rice milling yield determinations conducted at the same average MC suggest that some of the variability in results could be due to differences in kernel MC distributions within a sample.

The objectives of this study were to:

- Evaluate the performance of an individual kernel moisture meter; and
- Determine the variability in kernel-to-kernel MCs in "equilibrated" rice samples at various average MC levels.

MATERIALS AND METHODS

SINGLE-KERNEL MOISTURE METER

The moisture meter used in this study was a Shizuoka Seiki Co.*, Model CTR-800A. The meter is capable of measuring the MC of individual kernels of rice, wheat and barley. The meter operates on the principle of measuring the dc conductance of kernels as they individually pass between crushing-roller electrodes. The output of the meter includes the MC of each kernel, the average MC of the sample and the standard deviation of the individual kernel MCs. Complete specifications and operating instructions are available from Shizuoka Seiki (1987). The crushing action of the CTR-800A is destructive from the standpoint of using the measured sample for subsequent tests requiring whole kernels.

EXPERIMENTAL PROCEDURE

Rough rice of a long-grain variety, "Newbonnet", which had been stored in bulk at 18% MC (wet basis) for approximately one year at 1° C was used for testing. Sixteen 500-g samples were either dried or wetted to attain a MC range from 9 to 37%. Samples were dried by exposing thin layers on screen trays to ambient air conditions (approximately 20° C). Samples were wetted by spraying calculated amounts of water to known masses of rice as it was being tumbled in a plastic bag. After the drying and wetting processes, each sample was sealed in a

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*Mention of a commercial name does not imply endorsement by the University of Arkansas.

zip-lock plastic bag to allow kernel MC equilibration. To promote equilibration, the contents of the bags were frequently mixed without breaking the seal of the bag.

The initial intent of the study was to compare average MCs measured by the CTR-800A with those obtained by an oven method. As such, after three weeks of equilibration in the plastic bags, the individual kernel MCs of six, randomly selected, 200-kernel subsamples of each of the sixteen, 500-g samples were measured with the CTR-800A meter. The MCs of two, 25-g subsamples (approximately 1250 kernels) of each 500-g sample were determined by drying the subsamples for 24 h at 130° C in a heated air convection oven. Results of these initial tests showed large ranges of kernel MCs within a sample. This suggested that complete equilibration may not have occurred and prompted a more in-depth investigation. The procedure conducted at three weeks using the CTR-800A was repeated three months after samples were conditioned. In addition, 50-kernel subsamples were randomly selected from eight of the 500-g samples, and the MC of each of these kernels was determined by using an oven procedure described below. The eight 500-g samples from which the 50-kernel subsamples were chosen were selected from samples in the 11 to 27% MC range, which represents the typical MC measurement range encountered in rough rice. The individual kernel oven MC determination consisted of placing each of the 50 kernels in separate 12.7-mm copper tubing caps and drying in an oven at 130° C for 16 h. Each kernel was weighed before and after drying using a digital balance, accurate to 0.01 mg. This procedure was replicated three times, i.e., three, 50-kernel subsamples were taken from each of the eight 500-g samples selected for testing in this part of the experiment.

The process of randomly selecting kernels from a bulk sample for the individual kernel oven test resulted in the selection of some kernels which were not completely filled or were in some other way non-representative of sound kernels. These kernels, as well as errors in weighing the kernels during this part of the test, caused apparent outliers in the individual kernel oven data. To account for these extremes in MC measurement, Chauvenet's criterion (Holman, 1978) was applied to systematically determine if dubious kernel MCs should be eliminated. For the case of having 50 MC values for each test set of the individual kernel oven test, Chauvenet's criterion states that deviations from the mean MC value of more than 2.57 standard deviations can be considered as outliers. This criterion was applied to all the 50-kernel oven test sets. After applying Chauvenet's criterion once to the data sets, a new mean and standard deviation were computed. Of the 1200 kernels (50 kernels/test × 8 average MC levels × 3 reps) tested in the individual kernel oven tests, 41 MC values were eliminated based on this criterion. Because of the set clearance between the rollers of the CTR-800A, extremely small kernels generally pass through the machine without a reading being detected. Thus, it was deemed unnecessary to apply this criterion to the MC values produced by the meter.

Results and Discussion

Comparison of Average MCs

For most applications of moisture meters, the bulk average moisture content is of interest. Table 1 summarizes the bulk average moisture content values determined after three weeks and three months of equilibration. These data are illustrated in figure 1. The data indicate little difference between CTR-800A average MCs for a given sample at either the three-week or three month test time. The following regression equation was applied to each set of average MCs measured with the CTR-800A:

$$y = a * x + b \quad (1)$$

TABLE 1. Average moisture content (% w.b.) values determined after two periods of equilibration

	Three Weeks		Three Months	
Sample	Oven*	CTR-800A†	CTR-800A†	Oven‡
1	10.50 (0.20)§	10.43 (0.05)	11.10 (0.09)	
2	11.24 (0.11)	11.52 (0.04)	11.87 (0.05)	11.12 (0.51)
3	13.18 (0.03)	13.40 (0.00)	13.43 (0.05)	13.28 (0.10)
4	15.50 (0.03)	15.73 (0.05)	15.47 (0.08)	14.85 (0.58)
5	17.58 (0.14)	17.12 (0.08)	16.87 (0.12)	16.87 (0.29)
6	18.86 (0.03)	18.02 (0.04)	17.95 (0.11)	18.43 (0.41)
7	20.64 (0.00)	18.90 (0.14)	18.88 (0.04)	19.21 (0.38)
8	22.32 (0.17)	20.17 (0.22)	20.87 (0.19)	
9	24.46 (0.03)	22.48 (0.26)	23.82 (0.26)	23.82 (0.36)
10	26.54 (0.20)	25.65 (0.32)	27.28 (0.29)	25.37 (0.69)
11	28.68 (0.00)	27.58 (0.47)	29.28 (0.26)	
12	31.00 (0.34)	29.90 (0.27)	31.47 (0.20)	
13	32.88 (0.06)	31.87 (0.75)	31.90 (0.49)	
14	34.24 (0.23)	32.95 (0.21)	33.10 (0.22)	
15	35.86 (0.48)	33.27 (0.23)	35.35 (0.19)	
16	37.34 (0.03)	34.20 (0.76)	35.22 (0.20)	

* Mean of two moisture contents determined by drying 25-g samples in an oven at 130 ° C for 24 h.

† Mean of the average moisture contents of six, 200-kernel samples with moisture content of each kernel determined by a Shizuoka Seiki CTR-800A moisture meter.

‡ Mean of the average moisture contents of three, 50-kernel samples with moisture content of each kernel determined by drying in an oven at 130 ° C for 16 h.

§ Values in parentheses are the standard deviation of replicates comprising the average.

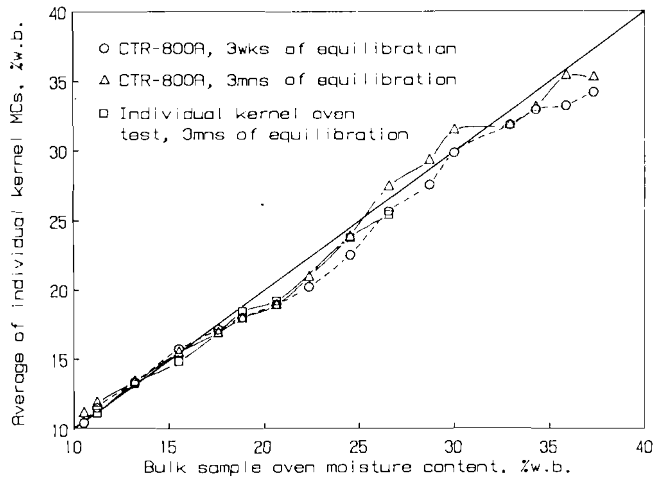

Figure 1–Comparison of average MCs determined after three weeks and three months of equilibration using a Shizuoka Seiki CTR-800A moisture meter to those measured with an individual kernel oven method and a bulk sample oven method.

where

y = CTR-800A average MC (% w.b.),
x = three-week bulk sample oven MC (% w.b.),
a,b= statistical constants.

An F-test for testing the equality of two regression lines, described by Neter and Wasserman (1974), showed no statistical difference in the two CTR-800A regression lines at a 5% level of significance. This indicates that, according to the CTR-800A measurements, the average MCs of the samples had not changed over the storage time between tests. This observation is illustrated in figure 1 which indicates that the three-week and three-month CTR-800A readings below approximately 21% were especially close.

The data from the CTR-800A also agreed well with the bulk sample oven MC determinations, especially for MCs less than approximately 18%. The average difference in readings between the two methods (including the meter data at both storage periods) was 0.83 percentage points, while for MCs less than 18% the difference was 0.35 percentage points. The meter data followed similar trends both at the three-week and three-month test times in regard to the bulk sample oven data. As shown in figure 1, the trends were not consistent as to over- or under-predicting MC in comparison to the bulk sample oven data over the entire range of MCs tested.

The average MC measured by the individual kernel oven drying procedure closely followed the trends of the CTR-800A (fig. 1) and large differences (over one percentage point) from the bulk sample oven data occurred only above 19% MC. The USDA (1971) procedure for determining MC, which involves grinding samples, recommends a two-stage drying process for high MC samples. The trends in the data query the accuracy of the bulk sample oven MC method used for high MC rough rice, although the average difference between the individual kernel oven drying method and the bulk sample oven method was only 0.66 percentage points over the 11 to 26% range with the average difference being 0.40 percentage points for MCs less than 19%. The average difference between the individual kernel oven drying results and the CTR800A readings (including the meter results at both storage periods) was 0.52 percentage points.

Table 1 shows the standard deviations among replicates of the average MC values of each measurement method at the two test times. The standard deviation of the CTR-800A readings was lower in all cases than that of the individual kernel oven method and was comparable to the bulk sample oven method. Under approximately 18% MC, the standard deviation of the CTR-800A average MCs was generally less than 0.10 percentage points, indicating a desirable repeatability of meter readings.

Variation of Kernel MC

Associated with each MC value determined by averaging individual kernel MCs is the standard deviation of the individual kernel MCs. Table 2 lists the average of the individual kernel MC standard deviations for each measurement method/equilibration time period combination. Figure 2 illustrates these data, indicating the trend of increasing standard deviation as average sample MC increases, up to approximately 27%. This trend was common to the meter individual kernel MC standard deviations at both three weeks and three months with the response being especially close for average MCs less than 20%.

The individual kernel oven MC tests were performed to check the validity of the variability in kernel MCs as indicated by the CTR-800A meter. The standard deviations of the individual kernel oven MC determinations generally followed the trends of the meter. However, the individual kernel oven standard deviations were greater than those measured by the meter for average MCs less than 20%. It is speculated that the inherent errors associated with weighing individual kernels prior to and after oven drying, especially with the small mass changes associated with the lower MCs during drying, account for this.

The variability in individual kernel MCs within a sample can be illustrated by frequency distributions as shown in figure 3. Figure 3 displays the frequency distributions for the CTR-800A meter data and the individual kernel oven method for a low MC sample (bulk sample oven MC of 11.24%) and a high MC sample (bulk sample oven MC of 24.26%). The concentration of kernel MCs about the mean for the 11.24% MC sample illustrates the MC composition of a relatively dry sample. Conversely, the frequency distribution at 24.26% MC indicates much less concentration and thus greater variability in kernel MCs about the mean with a higher MC sample.

A characteristic response in the standard deviation of the individual kernel moisture contents was observed (fig. 2). In general, this standard deviation increased exponentially from approximately 0.5% at 10% average MC to 4.5% at 26% average MC. Some increase in standard deviation would be expected because of the increased average MC level. However, Table 2 indicates that the coefficient of variation was much greater at high MCs than at low MC levels. Thus, the increase in variability with MC level was more than that which would be expected due to higher average MC levels.

Nelson and Lawrence (1989) used a Shizuoka Seiki CTR-800 individual kernel moisture meter in corn. They used 20-kernel samples from lots ranging in average MC from 12 to 30%. Their results showed that the standard deviation of the samples increased from 0.47% at 12.4% average MC to 2.50% at 30.4% average MC when using the standard, rough-rice calibration provided with the meter. After applying a calibration procedure, verification trials using 20-kernel samples from lots ranging from 12.2 to 25.8% average MC showed standard deviations from a low of 0.32% at 12.6% average MC to a high of 1.87% at 23.3% average MC. The trends in standard deviation as reported by Nelson and Lawrence were similar to those shown in figure 2 in that standard deviation generally increased as average moisture content increased.

TABLE 2. Average standard deviations (% w.b.) of individual kernel moisture contents determined after two periods of equilibration

	Three Weeks	Three Months	
Sample #	CTR-800A*	CTR-800A*	Oven†
1	0.57 (5.4)‡	0.37 (3.5)	
2	0.60 (5.3)	0.37 (3.3)	1.94 (17.3)
3	0.50 (3.8)	0.44 (3.3)	1.02 (7.7)
4	0.67 (4.3)	0.70 (4.5)	1.95 (12.6)
5	0.81 (4.6)	0.81 (4.6)	1.67 (9.5)
6	1.12 (5.9)	1.07 (5.7)	1.35 (7.2)
7	1.45 (7.0)	1.80 (8.7)	1.55 (7.5)
8	2.02 (9.1)	3.32 (14.9)	
9	3.05 (12.5)	3.65 (14.9)	1.73 (7.1)
10	4.63 (17.4)	4.42 (16.7)	3.53 (13.3)
11	4.47 (15.6)	3.20 (11.2)	
12	4.14 (13.4)	2.99 (9.6)	
13	3.48 (10.6)	3.31 (10.1)	
14	3.30 (9.6)	3.27 (9.6)	
15	2.96 (8.3)	2.32 (6.5)	
16	2.55 (6.8)	3.63 (9.7)	

* Mean of the standard deviations of individual kernel moisture contents of six, 200-kernel samples.
† Mean of the standard deviations of individual kernel mositure contents of three, 50-kernel samples.
‡ Values in parentheses are the coefficients of variation (%), calculated by dividing the standard deviation by the associated bulk sample oven MC from Table 1.

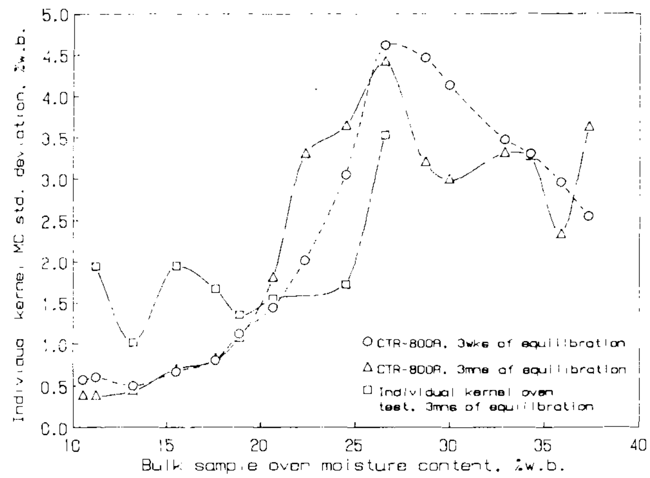

Figure 2–Average individual kernel MC standard deviations determined from MC data taken after three weeks and three months of equilibration using a Shizuoka Seiki CTR-800A moisture meter and an individual kernel oven method.

The dramatic increase in standard deviation with average MC (fig. 2 and Table 2) and the associated non-constant coefficient of variation (Table 2) suggests that the hygroscopic response to MC change of rice kernels within a given sample is different. If the hygroscopic behavior were the same for all kernels as MC changed, there would not be a difference in the coefficient of variation as the average MC level changed. The low kernel MC variability at low average MCs compared to the relatively high kernel MC variability at higher average MCs in figure 2 suggests that kernels in a sample will dry or wet to different "equilibrium" MCs (recall that the MC lots were created by drying or wetting rice from an initial MC level of 18%). This observation is supported by Banaszek and Siebenmorgen (1990b), who showed that bulk samples of rough rice at initial MCs from 9 to 15% did not increase to a common, asymptotic equilibrium MC value when exposed to a moisture sorbing environment. The cause of this varying hygroscopic behavior is hypothesized to be due in part to varying kernel maturities when the rice was harvested. Kocher et. al. (1989) showed a large, non-normal variation in kernel MCs that dramatically changed throughout the harvest season. Because of the variability in kernel MCs at harvest, an associated variability in kernel hygroscopic behavior would also be expected.

Conclusions

Average MCs measured by a Shizuoka Seiki CTR-800A individual kernel moisture meter were in close agreement with those measured by a bulk sample oven method, with the average difference in readings between the two methods being 0.83 percentage points. For average MCs less than 18%, the difference was 0.35 percentage points. No difference ($p < 0.05$) in meter MCs was found when measuring MCs after three weeks or three months of conditioning to achieve equilibration of samples. Average MCs determined by an individual kernel oven drying procedure were in close agreement with the CTR-800A results, with the average difference between readings between the two methods being 0.52 percentage points.

A characteristic response in the standard deviation of the individual kernel MCs measured by the CTR-800A

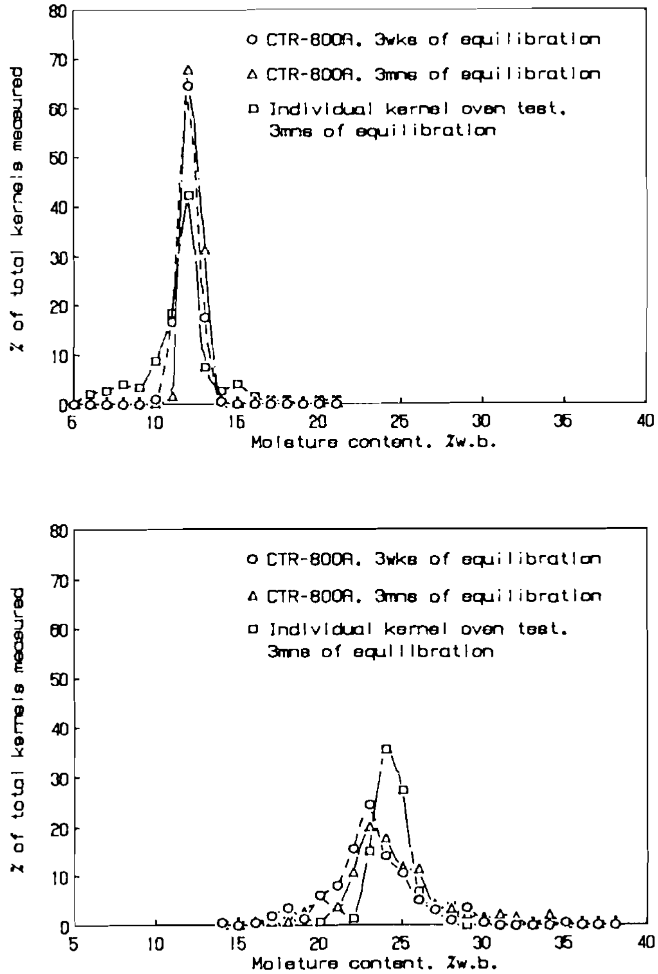

Figure 3–Individual kernel MC frequency distributions for a low and high MC sample as measured after three weeks and three months of equilibration using a Shizuoka Seiki CTR-800A moisture meter and an individual kernel oven method.

meter was observed for both the three week and three month time period. The standard deviation increased exponentially from approximately 0.5% at 10% average MC to 4.5% at 26% average MC. The coefficient of variation also increased dramatically with average MC, indicating that the hygroscopic response to MC change of individual rice kernels within a sample is different.

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REFERENCES

Banaszek, M.M. and T.J. Siebenmorgen. 1990a. Head rice yield reduction rates caused by moisture adsorption. *Transactions of the ASAE* 33(4): 1263-1269.

———. 1990b. Adsorption equilibrium moisture contents of long-grain rough rice. *Transactions of the ASAE* 33(1): 247-252.

Banaszek, M.M., T.J. Siebenmorgen and R.N. Sharp. 1989. Effects of moisture content at milling on head rice yield and degree of milling. *Arkansas Farm Research* 38(2): 15.

Chau, N.N. and O.R. Kunze. 1982. Moisture content variation among harvested rice grains. *Transactions of the ASAE* 25(4): 1037-1040.

Dilday, R.H. 1987. Influence of threshing cylinder speed and grain moisture at harvest on milling yield of rice. *Proceedings of the Arkansas Academy of Science* 41: 35-37.

Holman, J.P. 1978. *Experimental Methods for Engineers*, 3rd ed. New York: McGraw-Hill, Inc.

Kocher, M.F., T.J. Siebenmorgen, R.J. Norman and B.R. Wells. 1989. Rice kernel moisture content variation at harvest. *Transactions of the ASAE* 33(2): 541-548.

Kunze, O.R. and S. Prasad. 1978. Grain fissuring potentials in harvesting and drying of rice. *Transactions of the ASAE* 21(2): 361-366.

Nelson, S.O. and K.C. Lawrence. 1989. Evaluation of a crushing-roller conductance instrument for single-kernel corn moisture measurement. *Transactions of the ASAE* 32(2): 737-743.

Neter, J. and W. Wasserman. 1974. *Applied Linear Statistical Models*. Homewood, IL: Richard D. Irwin, Inc.

Pominski, J., T. Wasserman, E.F. Schultz, Jr. and J.J. Spadaro. 1961. Increasing laboratory head and total yields of rough rice by milling at low moisture levels. *Rice Journal* 64(10): 11-15.

Shizuoka Seiki Co., Ltd. 1987. Instruction manual for Shizuoka's single kernel moisture tester, Model CTR-800 and CTR-800A. 4-1 Yamana, Fukuroi, Shizuoka, Japan 437.

Siebenmorgen, T.J. and V.K. Jindal. 1986. Effects of moisture adsorption on the head rice yields of long-grain rough rice. *Transactions of the ASAE* 29(6): 1767-1771.

USDA. 1971. Oven methods for determining moisture content of grain and related agricultural commodities, Ch. 12. Equipment Manual, GR Instruction 916-6. Consumer and Marketing Service, Grains Division, Hyattsville, MD.

Wadsworth, J.I. and J. Matthews. 1985. Milling yields and moisture distribution in rough rice. *Transactions of the ASAE* 28(4): 1346-1352.

Wadsworth, J.I., J. Matthews and J.J. Spadaro. 1982. Moisture content variation in freshly harvested rice associated with kernel thickness. *Transactions of the ASAE* 25(4): 1127-1130.

Webb, B.D. and D.L. Calderwood. 1977. Relationship of moisture content to degree of milling in rice. *Cereal Foods World* 22: 484.