Moisture Transfer in Blended Long-grain Rough Rice

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Abstract. *Moisture transfer in mixtures of low- and high-moisture content (MC) rough rice (ranging from 9.5 to 18.0% w.b.) was investigated with a single-kernel moisture tester over a period of 30 days. The intergranular air attained constant relative humidity corresponding to the mean MC of the mixture within a few minutes of mixing. About 90% of the change in the MC of low- and high-MC kernels occurred within first one or two days of mixing even though moisture exchange continued over a period of 30 days. Changes in standard deviation (SD) of MC of the mixture with time, when normalized as a SD ratio, were similar to simulated changes in MCs of low- and high-MC fractions relative to their mean MC. The developed relationships can be used to estimate the MC variation with time in low- and high-MC fractions of mixed rough rice.* ***Keywords.*** *Rough rice, Moisture transfer, Mixing, Single-kernel tester.*

Mixing low- and high-moisture content (MC) rough rice may occur during harvesting and after subsequent drying. Also, rough rice at different moisture levels is sometimes blended to obtain a desired final MC.

Two important points that have emerged from various studies on mixing low- and high-MC grains, other than rough rice, are: 1) the rapid moisture exchange, and 2) the variability in MC of the kernels in a mixture remains for an extended time.

Although the extent of the moisture equilibrating process in mixed grains has been investigated, little is known regarding the rate of moisture transfer and the influence of various fractions of low- and high-MC grain. There is no published study on the extent and rate of moisture transfer in blended rough rice, and the associated role of intergranular air relative humidity (RH).

Objectives

The overall objective was to monitor the MC variability in mixtures of low- and high-MC rough rice with a single-kernel moisture tester and to measure the RH of intergranular air in mixed grain during the equilibrating process. The specific objectives were:

- Study the variability in MC of blended rough rice samples with time with a single-kernel moisture tester.
- Model the changes in MC of low- and high-MC fractions of rough rice with time, when mixed in different proportions, relative to mean MC of the mixture and RH of intergranular air.

Related Studies

Studies have shown that MC variability in mixed grain is higher than that found in unmixed grain at the same mean MC even after extended storage. Since equilibration of moisture in mixed grain of different initial moisture contents (IMCs) involves both sorption and desorption processes, high variability in the MCs of kernels in mixed grain has been attributed to hysteresis effects (Breese, 1955; Hubbard et al., 1957; Day and Nelson, 1965; Young and Nelson, 1967; Henderson, 1970).

Fisher and Jones (1939) reported that when two varieties of wheat at different MCs were mixed, there was a rapid exchange of moisture the first day. They concluded that differences in equilibrium moisture contents (EMCs) of low- and high-MC fractions existed even after storing the mixed grain up to 47 days.

Hart (1964) found that the EMC of grains in mixtures depended on the difference in IMCs of grains, their temperature and kernel size. Also the time required to reach equilibrium was significantly reduced and the variability in EMCs decreased with an increase in mixture temperature.

In a later study, Hart (1967) determined the variation in MCs of individual kernels in a mixture of overdried and undried corn by oven drying at 103° C for 72 h. He found higher variability in the MC of mixed corn than in unmixed corn, and suggested that the variance can be used for detecting mixtures of shelled corn so produced.

Williamson and Woodforde (1971) observed rapid moisture transfer in low- and high-MC wheat during the first day after mixing. The moisture transfer was practically complete within two to three days when IMC differences in the mixture exceeded 14%. They reported a moisture depletion rate of over 0.5%/h for the high MC

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portion of the wheat in the first 12 h after mixing. The RH of the intergranular air reached the equilibrium relative humidity (ERH) value corresponding to the mean MC of the wet and dry wheat samples within 3 min of mixing. They obtained similar results in still and moving air, and under fluctuating temperature conditions.

White et al. (1972) found that the rate of the moisture equilibration process was temperature dependent and the proportions of high- and low-MC corn had little effect on either the moisture transfer rate or the EMC. However, the difference in EMCs in a mixture of corn was reduced with an increase in mixture temperature.

Henderson (1987) reported that the ERHs of barley at the beginning and at the end of a mixing experiment were almost identical within the bounds of an experimental error. Grain mixtures with the same mean MC, but different IMC distributions did not differ in their ERH. It was also reported that dry and wet kernels reached the mean EMC rapidly and 90% of the total moisture exchange occurred within three days in mixtures of one part barley at 7% MC and three parts at 23% MC. The exchange of moisture was more rapid at 20° C than at 10° C, but at both temperatures there was a hysteresis of about 1% MC 28 days after mixing. In addition, it was reported that the ERH of a mixture of dry and wet barley grains was similar to the ERH of unmixed grains of the same mean MC.

Brusewitz (1987) found that blending two samples of corn with different MCs provided a mixture with a MC variability larger than in unblended corn at the same mean MC even after 24 days of storage.

There are no reported studies on moisture transfer rates in blended lots of rough rice. Instead, blending studies in rice have emphasized the changes in milling quality. A reduction in head rice yield may take place when low-MC rough rice is mixed with high MC rough rice due to moisture sorption (Calderwood, 1984; Siebenmorgen and Jindal, 1986).

Recently Nelson and Lawrence (1989) evaluated a crushing-roller type instrument operating on the principle of DC electrical resistance for single-kernel moisture measurement in corn. They indicated that such instrument could be useful in monitoring the increased variability in the MCs of mixed grain lots differing by 2% or more.

EXPERIMENTAL PROCEDURE

SAMPLE PREPARATION

The rough rice used was a long-grain variety 'Tebonnet' that was combine harvested at approximately 20% MC (w.b.) at the Rice Research and Extension Center, Stuttgart, Arkansas, during September 1988 and stored at 1° C for six months. Rough rice was cleaned with a Carter Dockage Tester to remove low density material using a No. 25 screen that had a slot width of 2.39 mm. The cleaned rough rice was then dried slowly to obtain samples at approximately 9, 11, and 14% in a large conditioning chamber using air at a constant temperature of about 25° C and corresponding RHs. Minor variations in the MCs of conditioned rough rice samples were noticed. Mixtures of rough rice were obtained using preselected proportions of the various MC level samples on a weight basis. Thirteen combinations of rough rice mixtures were selected as shown in table 1 so that the mean MC of the mixtures ranged approximately from 11.8 to 16.1%. Individual rough rice samples used in the mixture preparation weighed at least 500 g or more depending upon their respective proportions. The combined samples were thoroughly mixed with a Boerner divider at least three times and sealed in double Ziplock® plastic bags. All rice samples were stored at a room temperature of about 24 ° C.

Table 1. Results of low- and high-MC rough rice mixing experiments*

Test No.	Unmixed Sample MC	Mixture Ratio	Mean MC (% w.b.)	SD of Individual Kernel MCs (% w.b.): Mixed Inital†	Mixed Final‡	Unmixed§
1	(9.6, 18.3)	3:1	11.8	3.43	0.67	0.46
2	(9.7, 11.3, 18.1)	2:2:1	12.0	3.32	0.73	0.47
3	(9.6, 18.3)	2:1	12.5	3.48	0.69	0.48
4	(9.7, 11.3, 18.1)	1:1:1	13.0	3.50	0.79	0.51
5	(17.8, 10.6)	1:2	13.1	2.70	0.75	0.51
6	(11.3, 14.2, 18.1)	3:1:1	13.2	2.24	0.68	0.52
7	(9.3, 11.7, 14.2, 18.1)	1:1:1:1	13.3	2.68	0.65	0.52
8	(11.3, 14.2, 18.1)	2:1:1	13.7	2.20	0.67	0.55
9	(11.0, 17.9)	1:1	14.4	2.80	0.77	0.59
10	(11.3, 14.2, 18.1)	1:2:1	14.4	2.04	0.76	0.59
11	(9.7, 11.3, 18.1)	1:1:3	15.1	3.48	0.80	0.64
12	(11.0, 17.9)	1:2	15.6	2.60	0.82	0.69
13	(9.6, 18.3)	1:3	16.1	2.84	0.84	0.75

* Data are the average of 200 kernels per samplewith three sample replications.
† Measurement made immediately after mixing.
‡ Measurement made after 30 days.
§ Unmixed rough rice at the mean MC of the mixture.

MOISTURE DETERMINATION

The MCs of rough rice samples before and after mixing were determined by drying triplicate 25-g samples in a convection oven at 130° C for 16 h and subsequently corrected to standard MC (Jindal and Siebenmorgen, 1987). A single-kernel moisture tester (Shizuoka Seiki, Model CTR-800A, 1987) was also used after calibration against the bulk-sample oven MC determinations. Immediately after mixing, the MC and SD of the mixed rough rice samples were determined using triplicate, 200 kernel-samples with the single-kernel moisture tester. The procedure was repeated at selected time intervals after mixing except that the rice was mixed thoroughly in the closed plastic bags rather than using a Boerner divider.

RELATIVE HUMIDITY MEASUREMENT

A Phys-Chemical RH and temperature measuring probe, which had been calibrated against saturated salt solutions of known vapor pressures, was used to monitor intergranular air conditions. The probe was covered with a protective wire mesh and embedded in the mixed rough rice. The RH of the intergranular air was directly indicated by a digital display. The air was continuously circulated through the grain mass by a peristaltic pump.

Mixtures of low- and high-MC rough rice used for RH determinations were prepared in a separate group and their mean MCs were determined both by the single-kernel moisture tester and the oven method.

SIMULATION OF MOISTURE DESORPTION AND SORPTION IN MIXED ROUGH RICE

The rate of moisture transfer in mixtures of rough rice was estimated by a near-equilibrium simulation model proposed by Thompson (1972). A value of grain dry matter-to-air ratio equal to 0.27 was selected based on preliminary experimental trials. It was assumed, based on analysis of the data, that intergranular air in a mixture of low- and high-MC rough rice had the same temperature and RH as would correspond to the mean MC of the mixture. This resembled a situation in which low- and high-MC grains were exposed separately to a constant RH environment. The following test conditions were assumed for simulating the rates of moisture desorption and sorption in mixed rough rice samples:

Initial moisture content of rice = 9, 12, 15, 18, and 21% w.b.
Air temperature at equilibrium = 15, 25, and 35° C
Air RH at equilibrium = 60, 70, 80, and 90%

Sixty simulated test runs based on the above conditions provided data on the change in MC due to either moisture desorption or sorption in mixed grain for selected durations of 3, 6, 12, 24, and 48 h after mixing of low- and high-MC rough rice samples. The test duration in simulated runs was restricted to a maximum of 48 h in view of the rapid moisture exchange reported in the literature during the first day in mixtures of grains other than rough rice. No hysteresis was assumed in the MCs of rough rice attained as a result of desorption or sorption. The selected combinations of equilibrium air temperature and RH corresponded to EMCs of rough rice approximately in the range from 12 to 17% based on the Chung equation (ASAE, 1988).

RESULTS AND DISCUSSION

All MC measurements made with the single-kernel moisture tester were compared with the oven-method determinations as shown in figure 1. These calibration data showed that MC measurements based on the single-kernel moisture tester and the oven method were linearly related for MCs ranging approximately from 10 to 22%. The regression of single-kernel moisture tester readings on bulk sample oven MC yielded the following equation:

$$Y = -2.47986 + 1.18737X, \quad r^2 = 0.993 \qquad (1)$$

where

Y = bulk sample oven MC (% w.b.)
X = single-kernel moisture tester bulk-sample MC (% w.b.)
r^2 = coefficient of determination

The standard error of estimating bulk-sample oven MC was 0.28 percentage points.

The single-kernel moisture tester provided information on the MC of each kernel, number of kernels tested, mean MC value, and SD of the kernel MCs along with a frequency distribution. Some results on MC determinations by the single-kernel moisture tester are presented in table 1.

The relationship between the mean MC of unmixed rough rice samples and the SD of kernel MCs is shown in figure 2. The SD of kernel MCs increased exponentially with MC. The high SDs above approximately 16% MC indicated a wide variation in kernel MCs and appeared to correspond to ERHs higher than 85%. Hart (1967) reported similar observations when evaluating an electronic instrument for rapid determination of MCs of single corn kernels. Mixing of corn resulted in very wide variations in kernel MCs. Hart attributed these changes in MCs to the characteristic shape of the EMC isotherms in the high RH range.

The data in figure 2 yielded the following relationship:

$$SD = \exp(0.3259 - 0.2691\ MC + 0.01467\ MC^2)$$
$$r^2 = 0.96 \qquad (2)$$

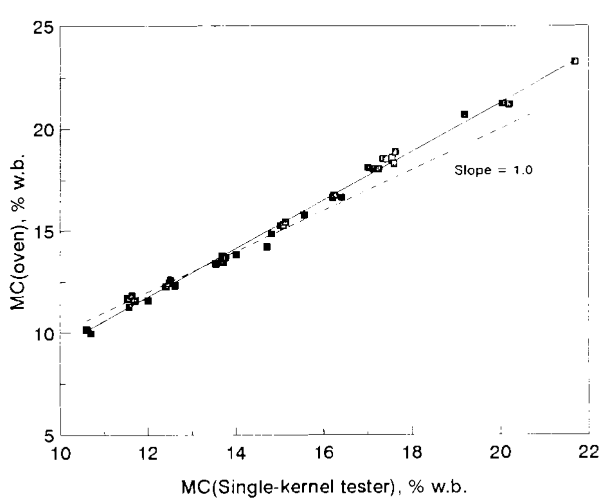

Figure 1–Comparison of rough rice MCs based on bulk sample oven determinations and single-kernel moisture tester measurements.

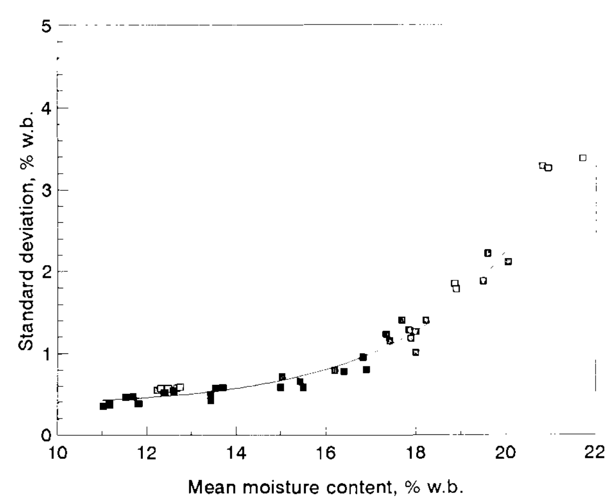

Figure 2–Relationship between SD of individual kernel MCs and mean MC of rough rice determined with the single-kernel moisture tester.

where SD is the SD of kernel MCs (% w.b.) and MC is the mean MC of bulk rough rice (% w.b.).

For unblended rough rice, histograms showing the frequency of occurrence of each kernel MC at 0.5% intervals produced a single mode. However, mixing of low- and high-MC rough rice produced not only a considerably higher SD in kernel MCs in comparison with unmixed rice, but also a number of modes in the histogram representing the mixture components. The bi- or tri-modal nature of the histograms obtained with the single-kernel moisture tester was evident at the start of an experiment depending upon the number of components used to produce the mixture. The SD of a mixed rough rice lot decreased rapidly with time after mixing and then the rate of change slowed considerably. Typical changes over time in the SD of kernel MCs in rough rice mixtures, produced with different proportions of low- and high-MC samples and held at room temperatures of about 24° C, are shown in figure 3.

There were large initial differences in SD of kernel MCs in blended rough rice lots having different proportions of low- and high-MC components. However, the pattern of changes in SD with time appeared to be similar in all samples. It was obvious that the SD of kernel MCs was reduced at a very fast rate during the first day after mixing. The moisture transfer was practically complete within two to three days. Comparison of SD in MCs of rice kernels in unmixed and mixed samples that had been held for about 30 days at room temperature of about 24° C is shown in figure 4. The SD of blended rough rice samples remained higher than the SD of unmixed rough rice having MC similar to the mean MC of the mixture for a long time after mixing. However, the difference in SD of mixed and unmixed rough rice samples appeared to diminish with an increase in the MC of the mixture. For mean MCs of mixed rough rice ranging approximately from 11 to 17%, the SD of mixed rough rice, after equilibrium conditions were met, could be estimated by the following relationship:

$$SD(mix) = SD(eq)(2.59 - 0.09\,MC),\ r^2 = 0.61 \quad (3)$$

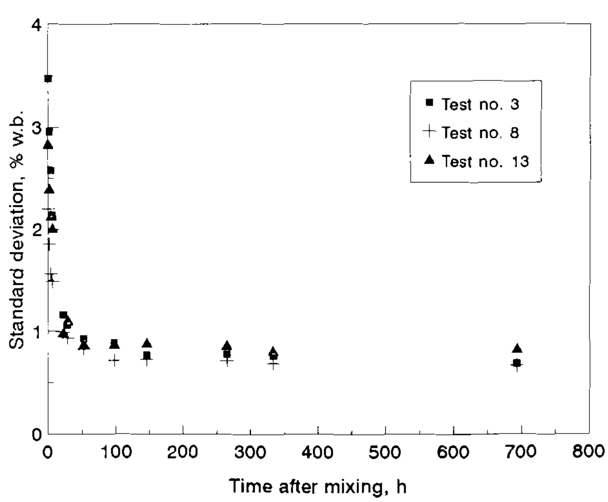

Figure 3–SD of MCs in blended rough rice as a function of time for mixing condition shown in table 1.

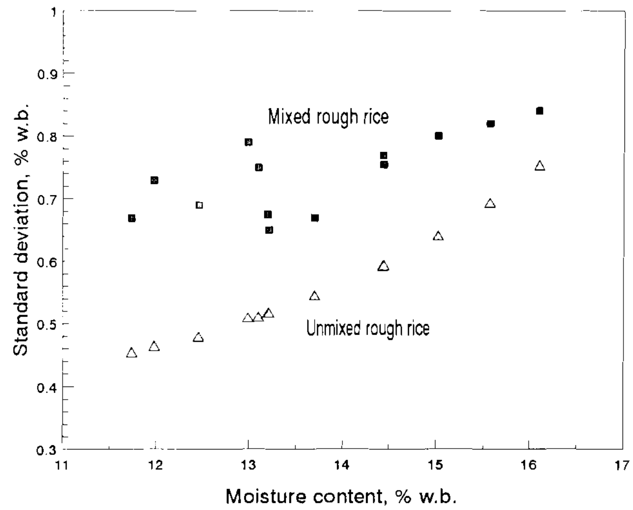

Figure 4–Comparison of SD of MCs in blended rough rice with that of unmixed rough rice at the mean MC of the mixture.

where

SD(mix) = SD in kernel MCs in mixed rice (% w.b.)

SD(eq) = SD in kernel MCs in unmixed rice at the mean MC of mixture (% w.b.)

MC = mean MC of mixture (% w.b.)

The standard error of estimating the SD of kernel MCs in mixed rough rice was 0.04% w.b. Equation 3 did not account for the influence of the proportions of low- and high-MC rough rice used in the mixture and, therefore, the correlation coefficient was not very high. However, equation 3 did provide useful information on the SD in mixed rough rice lots having mean MCs ranging approximately from 11 to 17%, which could be used for detecting lots of blended rough rice. In addition, the increased variability in kernel MCs in mixed lots lasted for an extended time of about 30 days after mixing. These findings are in line with those of Hart (1967) who reported that mixed samples of corn exhibited higher variance in their MCs compared to unmixed samples.

Rapid moisture exchange in the mixtures caused approximately a 90% change in total possible reduction in SD to occur within one to two days. This indicated that a change in SD of kernel MCs with time obviously corresponded to the moisture exchange rate in blended rough rice. However, this did not provide any information on the extent of hysteresis caused by the desorption and sorption of moisture taking place simultaneously in the grain mass.

A standard deviation ratio (SDR) for a mixture of low- and high-MC rough rice was defined as follows:

$$SDR = \frac{SD(t) - SD\ (eq)}{SD(0) - SD\ (eq)} \quad (4)$$

where

SD(t) = SD of MCs in a mixture at time t (% w.b.)

SD(0) = SD of MCs in a mixture at t = 0 (% w.b.)

SD(eq) = SD of MCs in unmixed grain at the mean MC of mixture (% w.b.)

The SD of kernel MCs in the unmixed grain was assumed to be at an equilibrium level and could be directly determined by the single-kernel moisture tester. In contrast, the SD of MCs in mixed rough rice samples was expected to vary from a high initial value to lower values during the period after mixing. Since the values of SD of kernel MCs in a mixture of rough rice are likely to be influenced by the relative proportions of low- and high-MC components, the changes in SD of mixed rough rice were normalized in terms of the SDR.

The computed values of SDR are plotted against time in figure 5 for a period of about two days during which most of the moisture transfer took place. Figure 5 shows that the SDR was reduced by over 50% in less than one-half day. The SDR was further reduced to about 75% after one day and to about 90%, two days after mixing. The relationship between SDR and the duration after mixing was represented by the following equation:

$$SDR = \exp(-0.2018\, t^{0.6048}), r^2 = 0.96 \qquad (5)$$

where SDR is the SDR (decimal) and t is the time after mixing (h).

Equation 5 could be effectively used for estimating the time during which moisture transfer takes place.

Relative Humidity of Intergranular Air in Mixed Rice

Equilibrium moisture contents (EMCs) were computed by the Chung equation using the experimental RH data of intergranular air in mixed rough rice samples at about 24 °C. Figure 6 shows the relative comparison of mean MCs of mixed rough rice samples determined by the standard oven method against the estimated EMC values. There was a linear relationship between the EMC estimated by the Chung equation and the mean MC of the mixture. However, the Chung equation overpredicted the mean MC of the mixture perhaps due to the different experimental conditions. The differences between the experimental and estimated MCs increased up to about 3% with an increase in the sample MC from approximately 10 to 18%. In practice, the RH probe could be calibrated for determining the mixture MC based on the RH and temperature of the intergranular air.

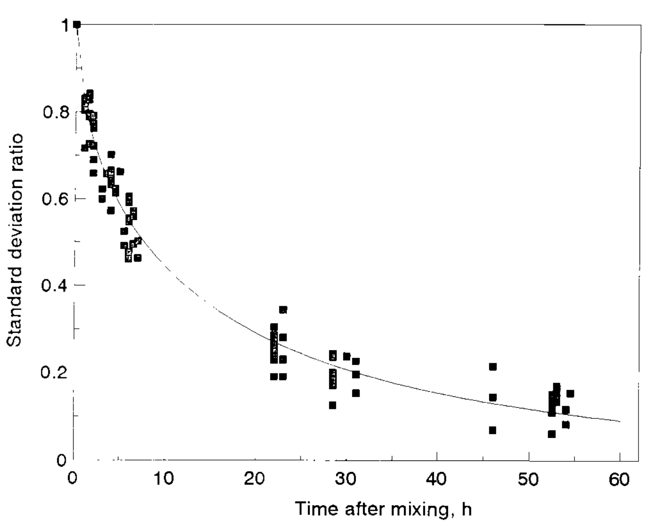

Figure 5–The SD ratio of blended rough rice as a function of time.

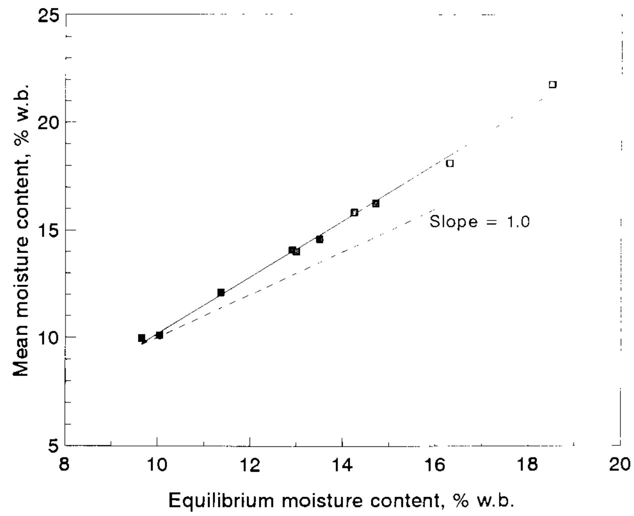

Figure 6–Relationship between mean MC of blended rough rice and EMC estimated by the Chung equation.

Intergranular air RH measurements in mixed rough rice samples showed that reasonably constant readings with mean fluctuation less than ±1 to 2% were obtained 10 to 15 min after mixing. The RH stabilized more quickly either by the movement of grains inside the closed container induced by shaking or by increasing the flow of circulating air. Similar results on ERH and moisture transfer have been reported by Williamson and Woodforde (1971) in wheat, and by Henderson (1987) in barley. Minor fluctuations in room temperature ranging from 1 to 2° C caused the ERH of the mixture to change accordingly. An increase in room temperature resulted in a corresponding increase in ERH and this trend was reversed with the lowering of room temperature.

Simulated Moisture Transfer in Mixed Rough Rice

The RH and MC data indicated that moisture transfer in mixtures of low- and high-MC kernels took place through an atmosphere of constant temperature and RH corresponding to the mean MC of the mixture. Therefore, it could be hypothesized that the moisture transfer rate between low- and high-MC components relative to the mean MC depends upon the proportions of the mixture. Since the intergranular air conditions remained constant shortly after mixing, the net rates of moisture transfer of low- and high-MC components also remained equal. However, the corresponding rates of MC change in each component would be different, depending upon the relative mass of each component. In a grain mixture, the fraction constituting the lower weight proportion will always undergo maximum change in its MC, and thus will be subjected to higher rates of moisture content change. Thus, in general, moisture transfer in blended grain is influenced by the proportions of low- and high-MC kernels, and the temperature and RH of the intergranular air corresponding to the mean MC of the mixture.

The change in MCs of low- and high-MC components in a mixture were normalized in terms of a moisture ratio (MR) computed relative to the mean MC of the mixture as follows:

$$MR = \frac{MC(t) - MC(eq)}{MC(0) - MC(eq)} \quad (6)$$

where

MC(t) = MC of rough rice at time t (% w.b.)
MC(0) = MC of rough rice at t = 0 (% w.b.)
MC(eq) = mean MC of mixed rough rice (% w.b.)

Since the mean MC of the mixture was distinctly related to the ERH and temperature of the intergranular air (fig. 6), the EMC of rough rice was estimated by the Chung equation (ASAE, 1988) for estimating moisture desorption and sorption in a grain mixture under constant air conditions. An exponential model of the form presented by Page (1949) provided a good statistical fit to each of the 60 simulated tests as follows:

$$MR = \exp(-k\,t^{0.6875}) \quad (7)$$

$$k = 0.2551 - 0.22884\,RH + 0.0016\,T\,RH, \quad r^2 = 0.974 \quad (8)$$

where

MR = moisture ratio (decimal)
k = moisture transfer constant ($1/h^{0.6875}$)
T = air temperature (°C)
RH = air relative humidity (decimal)
t = time of exposure (h)

Equation 7 applied both to desorption and sorption of moisture in rough rice, and was used to calculate the changes in low- and high-MC components in the mixture with time.

Model Applicability

The applicability of the developed model (eq. 7) for estimating the moisture transfer in blended rough rice was checked by direct comparison between experimental and predicted changes in the MCs of low- and high-MC rough rice fractions with time when exposed to constant air temperature and RH in a large conditioning unit. Figure 7 shows a typical comparison between experimental and predicted moisture desorption and sorption curves for rough rice samples with IMCs of 18.7 and 9.4%, respectively, under equilibrium air conditions of 25° C and 75% RH. The predicted and experimental moisture contents were very close showing differences of less than 0.5% on the average.

The moisture transfer model (eq. 7) appeared to provide reasonable predictions of moisture sorption and desorption in low- and high-MC rough rice, respectively, when exposed to constant air conditions. These results indicated that moisture transfer in mixed grain took place relative to the equilibrium conditions (temperature and RH) of the intergranular air corresponding to the mean MC of the mixture.

Figure 8 presents a relative comparison of the changes in SDR and MR with time in the mixtures of rough rice. The values of SDR were estimated from equation 5 at a mean MC of about 13.7%, which represented the average of all rough rice mixtures used in this study. Correspondingly, the values of MR were computed for a mean MC of 13.7%, which corresponds to the surrounding air ERH of about 65% at a room temperature of about 24° C based on the Chung equation. The changes in SDR and MR with time in mixed rough rice as shown in figure 8 followed essentially the same pattern confirming that changes in MCs and their SDs indeed are closely related.

The SDR indicates a change in SD of MCs of both low- and high-Moisture components at any given time in mixed rough rice relative to the initial maximum SD and it thus indirectly represents an overall change in MC variability with time after mixing. The MR, on the other hand, accounts for the collective change in MC of both low- and high-moisture components subjected to simultaneous sorption and desorption. Interestingly, the respective rates of change in SDR and MR appeared to be almost identical despite the differences in the two approaches. However, the plots of SDR and MR with time may deviate from each

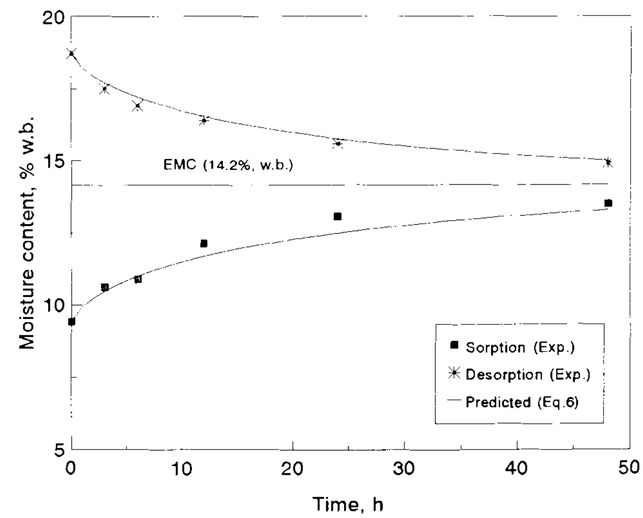

Figure 7–Comparison of experimental and predicted MCs of rough rice during moisture desorption and sorption tests.

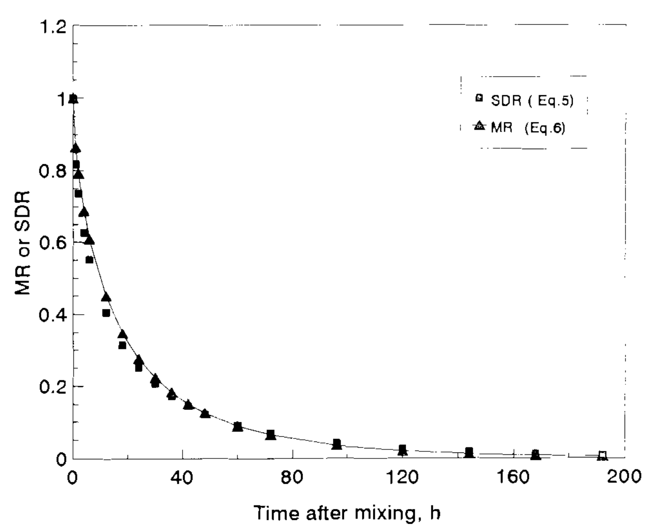

Figure 8–Relative comparison of changes in SD ratio and moisture ratio with time in blended rough rice.

other under experimental conditions other than those used in the present study. The relationship between SDR and time given by equation 5 applies only to the 'Tebonnet' rough rice variety. Further experimental work may be necessary to check for the possible influences of growing seasons and rice varieties on the relationship between MC and SD determined by a single-kernel moisture tester.

Summary and Conclusions

In this study, the changes in MC and the SD of kernel MCs with time were investigated in blended rough rice. Low- and high-MC rough rice having MCs ranging from approximately 9.5 to 18% w.b. were mixed in different proportions to produce mean MCs ranging from 11.8 to 16.1% w.b. Mixed rough rice samples were tested for the SD of the kernel MCs at selected time intervals over a period of 30 days at a temperature of about 24° C under room conditions using a single-kernel moisture tester. A concept of SDR was introduced to indicate an overall change in SD of low- and high-MC rough rice in a mixture relative to the SD of unmixed rough rice at the same mean MC. The changes in MCs due to sorption and desorption were estimated based on an equilibrium simulation model and were normalized relative to the mean MC of the mixture in the form of the MR (eq. 7), assuming no hysteresis effects. A comparison of the plots of SDR and MR with time for average test conditions revealed almost identical changes taking place simultaneously, and thus validated the hypothesis that moisture exchange in mixtures of low- and high-MC rough rice takes place through an atmosphere of constant RH corresponding to the mean MC of the mixture. The following are the main conclusions of this study:

- The variability of individual kernel MCs in a mixed rough rice sample changed rapidly after mixing, indicating an exponential decrease in variability over time after mixing. Also, the final SD values remained always higher than the corresponding values in the original samples even after a time of 30 days following mixing.
- The changes in SD of the MCs of individual grains can be normalized in the form of a SDR which appears to vary with time in a unique manner for blended rough rice having varying mass proportions of different MC samples. The SDR can be effectively used to detect the blending of rough rice lots having different MCs at least for 30 days, and more importantly to monitor the rate of moisture transfer in blended rough rice with a single-kernel moisture tester.
- Moisture transfer in blended rough rice takes place at a constant RH corresponding to the weighted mean MC of the mixture. For a given mean MC of the mixed rough rice, a change in grain temperature may result in either an increase or decrease in the RH and thus affect the moisture transfer rate. In a closed environment, the moisture sorption and desorption rates remained constant as indicated by the constant level of the ERH maintained throughout the experimentation.
- It was possible to simulate the moisture transfer resulting from sorption and desorption simultaneously in mixed rough rice containing low- and high-MC grains and to express the simulation results in the form of a MR as a function of exposure time, temperature, and RH.
- There were distinct similarities between the variation of SDR and MR with time indicating that changes in both MC and SD took place simultaneously and in an almost identical manner. The developed relationship for MR could be used to estimate the MC variation with time in mixed rough rice, whereas the relationship for SDR could enable the direct monitoring of moisture transfer for practical applications.

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