Effects of Moisture Adsorption on the Head Rice Yields of Long-Grain Rough Rice

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ABSTRACT

THE head rice (whole kernel) yield of long-grain rough rice ranging from 7.6 to 19.2% initial moisture content was determined after subjecting the rice to moisture adsorption conditions. The conditions ranged from those representing severe moisture adsorption environments—soaking in water, misting with water, equilibrating to a 95% relative humidity environment—to less severe methods created by mixing low and high moisture content rice in proportions of 3:1, 1:1, and 1:3. All methods showed significant reduction in head rice yield when the moisture content at which remoistening was initiated was lower than 13%. Remoistening of rice at a moisture content above 16% had no discernable effect on head rice yields. Head rice yields lower than 2% were produced by severe moisture adsorption treatments when rice at 7.6% moisture content was remoistened. The effects of the moisture adsorption treatments on head rice yields were accurately described by a two-parameter, sigmoid equation commonly used to present adsorption and desorption isotherms in cereal grains.

INTRODUCTION

The value of rice is directly determined by milling quality, which is determined in large part by the head rice yield (whole kernel yield). The term 'head rice' denotes milled rice which is comprised of kernels which are three-fourths kernel or more in length (Anonymous, 1983). The economic importance of maintaining high head rice yields is critical during drying, storage and milling operations, as indicated by Sharma and Kunze (1982) and Wright and Warnock (1983).

Many theories and speculations exist as to why the rice kernel fissures. Fissuring usually results in broken kernels when rice is milled. Low moisture content kernels will fissure due to moisture adsorption, which is caused by a variety of conditions that can exist during both on-farm and commercial drying and storage. Such moisture adsorption conditions can exist when kernels are exposed to high relative humidity environments, such as those that could exist in the upper layers of a deep bed drier, or during aeration with high relative humidity air. Such conditions also exist when high and low moisture kernels

are directly mixed, as is often purposely done at commercial elevators, or in on-farm facilities in which stirring augers are used.

REVIEW OF LITERATURE

Many researchers have cited evidence that moisture adsorption causes fissures in rice kernels both before and after harvest. Stahel (1935) indicated that the percentage of whole grains in field rice began to decline at an average field moisture content of 17 to 20%* with 14% being the critical point at which moisture adsorption produced fissures. Stahel stated that this was caused by exposure to a high moisture environment, not by rapid sun drying. Stahel cited the work of Kondo and Okamura (1930) who found that as rough rice dried, fissuring occurred at a faster and more extensive rate upon moistening. McDonald (1967) further supported these findings and showed that the differences in moisture content of the kernels on a panicle could vary as much as 10 percentage points. Thus, the driest kernels on a panicle could reach a critically low moisture content that could result in fissuring when exposed to high relative humidity air conditions during normal 24 h periods during maturation. Kunze and Prasad (1978) showed that in rice harvested at an average of 29.4% moisture content (MC), 14 out of 60 kernels selected from the driest panicles in a lot were fissured.

Moisture adsorption during storage and processing of rice has also been shown to cause fissures. Kunze and Hall (1965) conducted a study in which six varieties of brown rice samples were equilibrated at an initial temperature and relative humidity and then subjected to a higher relative humidity at the same temperature using saturated salt solutions. Results were recorded in terms of crack counts in samples of 50 grains. The study showed that cracks were produced in all low-moisture kernels exposed to large relative humidity increases. Chen and Kunze (1983) conducted a similar study in which rough rice of two long-grain varieties, Brazos and Labelle, at 8.6 and 10.7% MC was equilibrated to various relative humidity and temperature conditions in an environmental chamber. Head rice yields were not reduced when the 10.7% MC rice was remoistened until an environmental relative humidity of 92% was used. For the 8.6% MC rice, head rice yields decreased when either variety was exposed to relative humidities higher than 64%.

Another approach to creating a moisture adsorption environment was reported by Kunze and Prasad (1978) in which 50-kernel samples of rough and brown rice at 10 to 12% MC were subjected to a high relative humidity environment by placing the samples on top of high

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*All references to moisture content are on a wet basis.

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moisture content rice in drying columns. This study showed that the high relative humidity air ahead of the drying front caused fissures in all kernels of both rough and brown rice, especially if the rice in the drying column was above 28% MC. In a study related to cooking characteristics, Desikachar and Subrahamanyan (1961) reported the formation of fissures in milled and parboiled rice due to moisture adsorption.

Another method by which the effects of moisture adsorption have been studied is by direct mixing of high and low moisture content rice. Calderwood (1984) mixed high moisture rough rice varying from 17 to 22% MC with low moisture rice varying from 7 to 12% MC in various proportions. The results indicated that severe reductions in head rice yields did not occur until rice at 8% MC or lower was mixed with rice at 17% MC or higher. Kunze and Prasad (1978) also conducted a mixing study in which sets of 100 kernels of rough, brown and milled rice of five varieties, equilibrated to 33, 43, 53 and 64% relative humidity and 26.7°C, were placed for 48 h in sealed quart containers filled with rough rice equilibrated at 26.7°C and 95% relative humidity. The results showed varietal differences with fissuring being least severe in rough rice. An average of 92% of the rough rice kernels initially equilibrated at 33% relative humidity fissured whereas 2.4% of similar kernels initially equilibrated at 64% relative humidity fissured.

Although research has shown the effects of moisture adsorption, it effects have been quantified primarily in terms of enumerating kernels with fissures. Henderson (1958) reported that fissured kernels do not necessarily break when milled. Research was thus needed to quantify the effects of moisture adsorption in terms of head rice yield, an industry-accepted standard of rice quality as regards breakage of rice.

OBJECTIVES

The objective of this research was to quantify the reduction in head rice yield resulting from moisture adsorption by rough rice. The methods of moisture adsorption were the following:
1. soaking in water;
2. misting with water until condensation occurred;
3. equilibrating in an environment of 95% relative humidity and 30°C (87°F);
4. direct mixing of low and high moisture content rough rice in low to high moisture content proportions of 3:1, 1:1 and 1:3.

PROCEDURE

Rough rice used for this study was a long-grain variety (Tebonnet) which was combine harvested at 24% MC at the Rice Research and Extension Center, Stuttgart, AR, in September, 1985. Immediately after harvest, the rice was cleaned to remove immature kernels and foreign material in an A.T. Farrell Clipper cleaner (Model 2B)†, sacked in plastic bags and stored at 1°C (34°F). The rice was in cold storage approximately 2 months prior to testing.

The effects of moisture adsorption were determined over a range of moisture contents. To attain the various

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

moisture contents, rice was removed from the cooler and shade dried by spreading on a floor. At periodic intervals during drying, representative samples were selected, tested in a Steinlite 400-G moisture meter to determine moisture content, sealed in plastic freezer bags and placed in cold storage. The ambient air conditions inside the laboratory during drying were 24 to 26°C (75 to 79°F) and 55 to 60% relative humidity. The equilibrium moisture content corresponding to these conditions was approximately 12%. Lower moisture content samples were obtained by drying the rice in small lots of about 500 g in a tray drier with air at 38 to 40°C (100 to 104°F) and 25 to 27% relative humidity. These samples were likewise sealed in plastic freezer bags and placed in cold storage. The samples were selected during this overall drying process such that the moisture content of the samples ranged from 8 to 19% at approximately 1% increments. The exact sample moisture contents are shown in Table 1. Prior to remoistening by any method, rice was removed from the cold storage and equilibrated to room temperature while in the plastic storage bags.

The first method of remoistening rice involved soaking 500 g samples at each of the conditioned moisture content levels by immersing the rice into containers of room temperature (22°C) water for 20 h. The moisture content of the rice after soaking was approximately 28 to 30%. After being removed from the water, the samples were drained and simultaneously shade dried to 12.5% MC. The samples were subsequently split in a Boerner divider to obtain representative 125 g samples, hulled in a McGill huller, milled in a McGill #2 miller for 30 s, and size separated using a McGill sizing device with a #12 (4.76 mm (12/64 in.) round holes) screen. All head rice yield determinations were replicated twice with the average yield reported.

A method similar to the first was conducted in which 500 g samples were misted using a plant misting bottle. The samples were spread in a thin layer and misted for approximately 1 min or until condensation formed on the kernels. The samples were placed in plastic freezer bags for 24 h. The rice was then shade dried to 12.5% MC and milled as described above. These two treatments represented the most severe forms of moisture adsorption within the experimental treatments and thus defined the worst conditions for damage due to moisture adsorption.

The third method used in remoistening rice was to place 500 g samples of rough rice at each conditioned moisture content level on 30 cm x 30 cm (1 ft x 1 ft) framed screens in a large environmental chamber. Air in the chamber was maintained at 95% relative humidity and 30°C (86°F). The samples were left in the chamber

TABLE 1. CALCULATED FINAL MOISTURE CONTENTS OF CONDITIONED RICE MIXED WITH 24% MC RICE.

Conditioned moisture content, %	Final moisture content of mixture		
	3:1, %	1:1, %	1:3, %
7.6	11.7	15.8	19.9
8.7	12.5	16.4	20.2
10.0	13.5	17.0	20.5
11.0	14.3	17.5	20.8
11.9	14.9	18.0	21.0
13.1	15.8	18.6	21.3
14.2	16.7	19.1	21.6
15.6	17.7	19.8	21.9
17.0	18.8	20.5	22.3
18.2	19.6	21.1	22.5
19.2	20.4	21.6	22.8

TABLE 2. HEAD RICE YIELD PERCENTAGES* AND (HEAD YIELD RATIOS†) OF MOISTURE ADSORPTION TREATMENTS.

Conditioned moisture content, %	Moisture adsorption treatment					
	Water soaking	Water mist	95% R H, 30 °C air	Direct mixing		
				3:1‡	1:1	1:3
7.6	1.40 (0.02)	1.80 (0.03)	2.28 (0.04)	25.5 (0.43)	20.2 (0.34)	34.8 (0.59)
8.7	6.28 (0.11)	2.30 (0.04)	10.96 (0.19)	37.7 (0.64)	32.8 (0.56)	42.1 (0.72)
10.0	18.2 (0.31)	9.04 (0.15)	38.1 (0.65)	49.7 (0.85)	41.5 (0.71)	50.2 (0.86)
11.0	32.2 (0.55)	15.2 (0.26)	46.7 (0.80)	52.5 (0.89)	50.5 (0.86)	53.6 (0.91)
11.9	43.1 (0.73)	34.84 (0.59)	53.4 (0.91)	54.8 (0.93)	51.4 (0.87)	56.6 (0.96)
13.1	51.0 (0.87)	46.1 (0.79)	55.7 (0.95)	54.8 (0.93)	53.8 (0.92)	58.7 (1.0)
14.2	56.4 (0.96)	51.6 (0.88)	56.6 (0.96)	55.1 (0.94)	55.0 (0.94)	58.7 (1.0)
15.6	55.6 (0.95)	55.9 (0.95)	57.8 (0.98)	55.8 (0.95)	56.2 (0.96)	58.7 (1.0)
17.0	55.6 (0.95)	56.6 (0.96)	57.6 (0.98)	56.9 (0.97)	55.7 (0.95)	58.2 (0.99)
18.2	57.7 (0.98)	58.0 (0.99)	57.1 (0.97)	56.3 (0.96)	55.5 (0.94)	58.4 (0.99)
19.2	57.7 (0.98)	58.4 (0.99)	57.3 (0.98)	55.3 (0.94)	55.8 (0.95)	58.1 (0.99)

*Defined as the weight percentage of cleaned rough rice which remains as whole (three-fourths kernel or more) kernels after complete milling.
†Defined as the head rice yield percentage divided by the control head rice yield percentage of 58.7.
‡Ratio of the weight of conditioned moisture content rice to the weight of rice at 24% MC.

until the rice equilibrated with the environment as determined by equal consecutive sample weight measurements. According to the Chung equation (ASAE, 1984), the moisture content of rough rice in equilibrium with air at 95% relative humidity and 30°C (87°F) is 19.2%.

The final means of investigating the effects of moisture adsorption was through direct mixing of high and low moisture content rice. Rice from each conditioned moisture content level was directly mixed with high moisture content rice (24%) in a Boerner divider in 3:1 (conditioned MC: 24% MC), 1:1 and 1:3 proportions by weight. The final moisture content values of the mixtures were calculated and are listed in Table 1. The mixed samples were sealed in plastic bags for 72 h at a temperature of approximately 20°C (68°F). The samples were then shade dried to 12.5% MC and milled as in previous methods.

To establish a control for comparison of treatment effects, seven samples of rice at 24% MC were shade dried to 12.5% MC with no subsequent moisture adsorption treatments. The samples were milled in the same manner as above. The milling yield averaged 69.6% while the head rice yield averaged 58.7% with a standard deviation of 0.67%.

RESULTS AND DISCUSSION

The head rice yield percentages attained when rice at each of the conditioned moisture content levels was subjected to the various moisture adsorption treatments are listed in Table 2. For ease of comparison and computational convenience in describing the effects of each moisture adsorption treatment, the head rice yield percentages were normalized by dividing by the control head rice yield of 58.7%. The normalized ratio is termed
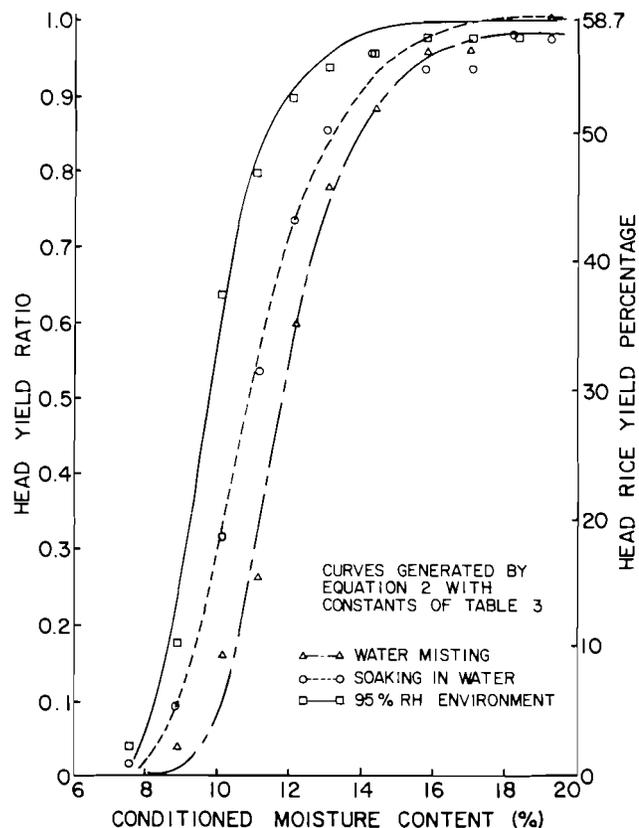
Fig. 1—Effects of high relative humidity and saturated environments on head rice yields.
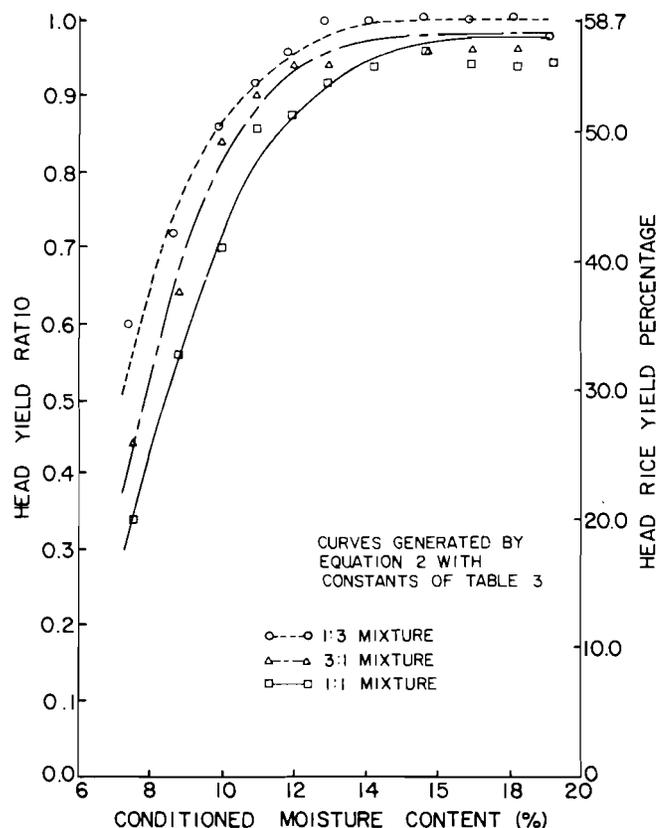
Fig. 2—Effects of mixing low and high moisture content rice on head rice yields.

the "head yield ratio" and can vary from 0 to 1. The values of this ratio are listed in parentheses in Table 2.

The effects of the various moisture adsorption treatments on head rice yields are illustrated in Figs. 1

and 2. Dramatic reductions in head rice yields occurred as a result of moisture adsorption by low moisture content rice. Head rice yields of 1.40, 1.80 and 2.28% were produced as a result of remoistening 7.6% moisture content rice by water soaking, misting, or exposure to a 95% relative humidity atmosphere, respectively (Table 2). This indicates that under severe moisture adsorption conditions, practically all kernels were adequately fissured to break when milled. This result is supported by Kunze and Hall (1965) who reported that fissures were counted in all kernels of brown rice initially at 8.3% MC that were exposed to a 75% relative humidity environment.

Fig. 1 indicates that the repsonses to the severe moisture adsorption treatments followed similar patterns with a sharp decline in head rice yields beginning when rice in the range of 14 to 16% MC was remoistened. Stahel (1935) reported that the critical moisture content at which moisture adsorption caused cracks in kernels was 14%.

Head rice yield reductions also occurred when rice in the range of 7.6 to 14% MC was mixed with the 24% MC rice (Fig. 2). The mixing treatment effects were similar to those of the severe moisture adsorption treatments. It is indicated in Fig. 2 that the 1:1 mixture caused greatest head rice yield reductions while the 1:3 mixture caused the least reduction among the mixing treatments. It is postulated that the 1:3 mixture was least damaging due to the fact that only 25% of the rice mixture experienced severe moisture adsorption conditions. The 1:1 mixture, however, had half the mixture exposed to high moisture conditions. The 3:1 mixture had the greatest percentage of conditioned rice exposed to moisture adsorption, yet due to the small fraction of high moisture content rice, moisture adsorption conditions were not as severe as in the 1:1 mixture (Table 1).

The results of the mixing treatments are more extreme than those of Calderwood (1984). Calderwood showed that mixing high moisture content rice at 22% with low moisture content rice at 12, 10 and 8% in 1:1 ratios produced no head rice yield reductions in the 12% case and 4 and 6.5 percentage point reductions for the 10 and 8% cases, respectively. The comparable curve for the 1:1 mixture shown in Fig. 2 indicates that much more severe head rice yield reductions were measured in this study. A head rice yield of 20.2%, representing a reduction of 38.5 percentage points, was produced as a result of mixing rice at 7.6% MC with rice at 24% MC in a 1:1 mixture. Higher moisture content "wet rice" as well as varietal differences between this study and Calderwood's could account for some of this more severe head rice yield reduction measured in this study. Calderwood showed varietal variation among the long-grain varieties, Labelle and Lebonnet.

The economic impact of the moisture adsorption effects observed in this study can be exemplified by noting that if rice at a typical storage moisture content of 12% is equilibrated to a 95% relative humidity and 30°C condition, head rice yield reductions of 4 percentage points could occur. This corresponds to a price reduction of approximately $0.30 per cwt, based on the 1984 average dockage rate of $0.075 per cwt per percentage point of head rice yield reduction (Fryar et al., 1986). Often rice is inadvertently over-dried to moisture contents below 12%, which could lead to more severe losses if remoistened. For example, remoistening 11%

MC rice with 95% relative humidity and 30°C air could cause head rice yield reductions of 12 percentage points based on the data of Table 2. This reduction would result in a dockage of $0.90 per cwt.

Chung and Pfost (1967) developed the following two-parameter isotherm equation for cereal grains and their products based on thermodynamic relations:

$$\ln \frac{(P)}{(P_o)} = \frac{-A}{RT} \cdot \exp(-B \cdot MC) \quad \dots\dots\dots\dots\dots \quad [1]$$

where,

P/P_o = ratio of water vapor partial pressure to saturation pressure at temperature, T

A,B = constants

T = absolute temperature

MC = moisture content

R = universal gas constant

Chung and Pfost showed that this equation described experimental adsorption and desorption data accurately. Although adsorption isotherms were not measured in the study reported herein, the effects of moisture adsorption, in terms of head rice yield, were measured. The sigmoid form of the adsorption isotherms reported by Chung and Pfost is of the same form as the curves of Fig. 1. By noting that the temperature in this study was essentially constant, the analagous form of equation [1] for the variables of this study is:

$$\ln (HYR) = -A \cdot \exp(-B \cdot MC) \quad \dots\dots\dots\dots\dots \quad [2]$$

where,

HYR = head yield ratio, decimal basis

MC = moisture content, decimal wet basis

The constants of this head yield ratio equation were determining using a non-linear fitting routine (Procnlin) available through the statistical package, SAS (1985). The constants and coefficients of multiple determination for each treatment are shown in Table 3. All moisture adsorption treatment effects are shown to be accurately described by the head yield ratio equation as indicated by coefficients of determination exceeding 0.95. Thus the results of this fitting routine show that the form of the relationship between damage caused by moisture adsorption (head rice yield reduction) and conditioned moisture content of the rice follows the same, sigmoid form of relation as does that of the moisture adsorption isotherms reported by Chung and Pfost (1967). Constants from Table 3 were used in equation [2] to generate the curves of Fig. 1 and 2.

The results depicted in Figs. 1 and 2 indicate that the amount of damage resulting from moisture adsorption was related to the moisture content level as described by

TABLE 3. REGRESSION RESULTS OF FITTING THE HEAD YIELD RATIO EQUATION (EQUATION 2) TO TREATMENT EFFECTS.

| Moisture adsorption treatment | Constants | | Standard deviations | | Coefficients of determination |
	A	B	s(A)	s(B)	r^2
soaking in water	637	63.6	230	3.37	0.996
water mist	2135	68.7	1391	5.40	0.992
95% RH, 30 °C	3549	88.8	1900	5.57	0.994
3:1 mixture	57	55.9	29	6.01	0.956
1:1 mixture	37	47.1	13	3.79	0.974
1:3 mixture	35	54.6	10	3.42	0.987

equation [2]. Since the medium creating the mositure adsorption condition was the same within a treatment for all samples at the various moisture contents, the vapor pressure differences between the rice adsorbing moisture and the surrounding medium was directly determined by the sample rice moisture content. Since Kunze and Hall (1967) have shown that rice can be remoistened without damage if the environmental relative humidity is gradually increased, it appears that damage is related to vapor pressure differential.

CONCLUSIONS

All methods of moisture adsorption caused severe reductions in head rice yields when the moisture content at which remoistening was initiated was below 13%. The methods which produced the greatest head rice yield reductions were those of exposure to high relative humidity or saturated environments, in which sharp declines in head rice yields occurred when rice at 14 to 16% MC was remoistened. Head rice yields lower than 2% were measured when rice at 7.6% was exposed to severe moisture adsorption conditions.

Mixing of low and high moisture content rice produced head rice yield reductions that were not as drastic as those of the more severe moisture adsorption environments. Sharp declines in head rice yields did not occur until rice at below 12 to 14% MC was mixed with 24% MC rice.

Remoistening rough rice from a moisture content above approximately 16% had no discernable effect on head rice yields. It appears that a critical moisture content exists in the range of 14 to 16% such that remoistening of rice below this moisture content will cause reductions in head rice yields.

The effects of moisture adsorption on the head rice yields of rough rice were shown to closely follow the sigmoid form of relation used for describing moisture adsorption and desorption isotherms in cereal grains.

References

1. Anonymous, United States Department of Agriculture. 1983. United States Standards for Rice. Federal Grain Inspection Service. Washington, D.C. Rev. 1983.

2. ASAE. 1984. ASAE Standard—Standards, Engineering Practices and Data adopted by the American Society of Agricultural Engineers. ASAE, St. Joseph, MI.

3. Calderwood, D. L. 1984. Milling yield of rough rice blended at different moisture contents. TRANSACTIONS of the ASAE 27(1):248-249, 254.

4. Chen, Y. L. and O. R. Kunze. 1983. Effect of environmental changes on rice yield and particle size of broken kernels. Cereal Chemistry. 60(3):238-241.

5. Chung, D. S. and H. B. Pfost. 1967. Adsorption and desorption of water vapor by cereal grains and their products. TRANSACTIONS of the ASAE. 10(4):549-556.

6. Desikachar, H. S. R. and R. Subrahmanyan. 1961. The formation of cracks in rice during wetting and its effect on the cooking characteristics of the cereal. Cereal Chemistry 38(4):356-364.

7. Fryar, E. O., L. O. Prsch, S. H. Holder, N. P. Tugwell. 1986. The economics of controlling peak in Arkansas rice. Arkansas Farm Researach. May-June 35(3):7. University of Arkansas, Fayetteville.

8. Henderson, S. M. 1958. The causes and characteristics of rice checking. Rice Journal 57(5):16, 18.

9. Kondo. M. and T. Okamura. 1930. Der durch die feuchtig-keitszunahme verusachte querriss (Doware) des reiskornes. Ohara Inst. f. Landw. Forsch. Ber. 24:163-171.

10. Kunze, O. R. and C. W. Hall. 1965. Relative humidity changes that cause brown rice to crack. TRANSACTIONS of the ASAE 8(3):396-399, 405.

11. Kunze, O. R. and C. W. Hall. 1967. Moisture adsorption characteristics of brown rice. TRANSACTIONS of the ASAE 10(4):448-450, 453.

12. Kunze, O. R. and S. Prasad. 1978. Grain Fissuring Potentials in Harvesting and Drying of Rice. TRANSACTIONS of the ASAE 21(2):361-366.

13. McDonald, D. J. 1967. 'Suncracking' in rice, some factors influencing its development and the effects of cracking on milling quality of the grain. Unpublished MS Thesis. The University of Sydney, Sydney, N. S. W., Australia. Quoted by Kunze and Prasad. 1978.

14. SAS Institute Inc. 1985. SAS User's Guide: Statistics, version 5 ed., Cary, NC: SAS Institute Inc. 1290 pp.

15. Sharma, A. D. and O. R. Kunze. 1982. Post-drying fissure developments in rough rice. TRANSACTIONS of the ASAE 25(2):465-474.

16. Stahel, G. 1935. Breaking of rice in milling in relation to the condition of the paddy. Tropical Agriculture. XII(10):255-261.

17. Wright, R. E., and W. K. Warnock. 1983. Effects of temperature and vapor pressure on rice milling quality. ASAE Paper No. 83-3513, ASAE, St. Jospeh, MI 49085.