溫濕度變化對碾米品質之影響

Relative Humidity Effect on Milling Quality of Rice

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中　文　摘　要

稻米乃吸濕性之谷物，其含水率隨其環境而變化：環境乾燥，其含水率隨之降低，氣候潮濕，其含水率隨之升高。自稻谷在田間成熟至碾米期間，已乾之谷粒再度受潮之機會甚多，如：田間稻株上已晒乾之谷粒可因夜間露水而受潮；收割時，此等已晒乾之谷粒可因與濕谷混合而受潮；烘乾後之稻谷可因氣候潮濕而受潮，……等。

已乾稻谷在快速吸濕情形下會導致谷粒胴裂，其胴裂程度因吸濕程度而異。已裂之稻谷因有谷壳在外，故視其外表仍似完好，然當經過碾米後，已裂之谷粒多成爲碎米，因而碾米品質爲之降低，故乾谷受潮，胴裂與碾米品質三者互有密切相關。

本試驗是選 Labelle 及 Brazos 品種爲對象，每品種有高低兩種含水率 (11.90 %，9.35 % d. b.)，分別使其曝露於八種不同溫濕度環境：

20°C—64 % RH	30°C—64 % RH
20°C—72 % RH	30°C—72 % RH
20°C—82 % RH	30°C—82 % RH
20°C—92 % RH	30°C—92 % RH

中共四天。四天後置一有空氣調節之試驗室 (23°C ± 2°C，52 %) 三週後始進行同樣之碾米選別過程，其碾米結果如下：

濕度對整粒碾米率 (Head Yield, 下稱整粒率) 之影響：

對較高含水率 (11.90 %，d. b.) 稻谷，僅只 92 % RH 處理影響其整粒率，其餘較低之相對濕度對其不產生影響；但對較低含水率 (9.35 %，d.b.) 之稻谷，則每一種相對濕度處理均有影響，濕度愈高，整粒率愈低，在 92 % RH處理時，整粒率低至 3.8～8.0 %，二品種均是同樣趨勢。

如將稻谷處理前之平衡相對濕度 (Equilibrium Relative Humidity) 與處理時空氣之相對濕度之差異，與碾米率結果比較討論，則可得如下結論：

1.在攝氏 20 至 30 度範圍內，稻谷環境中之相對濕度升高 30 %對較高含水率 (11.90 %，d. b.) 稻谷之整粒率無影響。但若相對濕度升高 40 %，則已生不良影響。

2.在相同溫度範圍內，相對濕度升高 28 %對較低含水率 (9.35%，d. b.) 稻谷之整粒率已生不良影響。濕度再升高，則其整粒率大幅下降。

濕度對碎米比之影響：

碎米比 (Ratio of Brokens) 在本文中是指每樣品中小粒碎米總重與大粒碎米總重之比。

各種處理對較高含水率（11.90 %，d. b.）稻谷之碎米比不生影響，但對較低含水率（9.35 %，d. b.）稻谷之碎米比則具影響，即在 82 % RH 處理時，其碎米比已見升高，而在 92 % RH 處理時，顯著提高。

溫度對整粒率及碎米比之影響：

溫度對較低含水率（9.35 %，d. b.）稻谷之整粒率具確定之影響：30°C 處理之整粒率較 20°C 處理者爲高，其理由可能有二：(1)在 30°C 時稻谷在處理期中吸水較少，導致較輕胴裂，(2)稻谷在較高溫度下具較大之塑性變形（Flow Deformation）能力，因而緩和谷粒內部之應力，減少胴裂。

溫度對較低含水率（9.35 %，d. b.）稻谷之碎米比也具確定影響：30°C 處理者較 20°C 處理者爲低，其可能理由同上。

Introduction

Rice is a hygroscopic grain which adsorbs or desorbs moisture depending on its environment. Though the interest of the grower or processor has been in drying the grain and not in wetting it, there are numerous opportunities for a dried grain to readsorb moisture between the time when it is ripening in the field and before it is milled. Dry grains may pick up moisture from a high relative humidity environment created by other wet grains or by field temperature changes at night. Immediately after threshing, the mixture of high and low moisture grains provides a good environment for the lower moisture grains to readsorb moisture from the interstice environment. In the process of drying with deep-bed dryers, the heated air enters the lower parts of the grain bed and picks up moisture. The drying air then becomes humid warm air. Any low moisture grains ahead of the drying front will readsorb moisture until the drying front reaches them. Dried rough rice a) on the surface in the tops of storage bins, b) in loading or unloading operations, or c) in transport will readsorb moisture if it is exposed to a humid ambient atmosphere.

Rapid moisture adsorption by dried rice may cause the grains to fissure. A single grain may develop a partial fissure, or perhaps several complete fissures depending on how much and how fast moisture is adsorbed. Therefore, relative humidity changes to which rough rice is subjected should correlate with the subsequent milling quality of the grain.

Fissured grains usually break during shelling (hulling) and milling operations. In general, grain breakage appears to be confined to defective (fissured and immature) kernels. For medium and slender grain varieties, the total breakage observed with a high degree of milling approached the total number of defective grains (Swamy and Bhattacharya, 1980) in the sample.

Objective

The objective of this research was to investigate and analyse the effects on rice quality when rough rice at storage moisture was given a 4-day exposure to a higher relative humidity environment before the samples were shade dried and milled.

Literature Review

Broken grains in a milled rice sample can be related to the variety of paddy, its handling and drying after harvest, and the amount of milling to which it is subjected (Grist, 1975).

A fissure within a rice kernel is a major defect. Fissured grains reduce the head rice yield, because kernels tend to break during shelling and milling operations. Swamy and Bhattacharya (1980) reported that rice grain breakage seemed to originate almost entirely from defective kernels (fissured or immature) for the amount of breakage rarely exceeded the quantity of defective grains. They also stated that in medium and slender varieties, most highly defective grains and many of the single-traverse-cracked grains broke during shelling. The remaining highly defective grains broke during milling.

Kondo and Okamura (1930) reported that 72 percent of rough rice initially at 12.6 percent moisture content fissured when exposed to an ambient environment from 8 a.m. one day to 8 a.m. of the next day. In case of brown rice, 100 percent of the kernels fissured. The fissuring was reported to be due to moisture adsorption during the high relative humidity hours of the night. In the same study they found that the number of fissured kernels was inversely proportional to initial moisture of the grains but proportional to the relative humidity level of the air to which the grains were exposed. A similar observation was made by Stahel (1935). Using an X-ray technique, Henderson (1954) found that many apparently sound kernels contain internal fractures which originate at the center of the kernel and develop along the minor axis toward the outside surface. Different fissure patterns resulting from small humidity increases and from large humidity increases were observed by Kunze and Hall (1965). Only major fissures across the long axis of the grain resulted from small humidity increases. Minor fissures across the long axis at the grain ends preceded the major cracks under large relative humidity increases.

Blending of rough rice at different moisture levels and its subsequent influence on head yield was studied by Calderwood (1979). A severe reduction in head rice resulted from mixing, in a one to one ratio, rice at 8 percent moisture w.b. or lower with rice at 18 percent moisture w.b. or higher.

Fast wetting of the rice grain has a serious effect on milling quality Blakeney and Chesterfield (1976). When relative humidity in the mill room was either below or above the moisture equilibrium of the rice being milled, a decrease of head yield was observed (Autry et al., 1955).

In a study of the causes and characteristics of rice checking, Henderson (1954) suggested that checking resulted from either a moisture or a temperature increase. When the outer portions of the rice kernel take on moisture or increase in temperature, they expand. Since the central portions of a low moisture grain are inelastic, internal pulling apart results in cracks or faults. According to the analysis of Kunze and Choudhury (1972), kernel failure could occur if the compressive stresses at the surface layers developed to the extent that the resulting stresses at the center exceeded the tensile strength of the central portions of the grain. Earle and Ceaglske (1949) found that it is the moisture content of the air and not the temperature that is responsible for the checking of macaroni products.

Drying to storage moisture levels causes few if any fissures in high moisture rough rice, even when grains are dried at the rate of 9.6 percent in one hour, according to Kunze (1979). He concluded that it was the moisture gradient generated within the kernel during drying that caused fissures to develop sometime later. Ban (1971) reported that the fissuring of rough rice grains did not necessarily occur during drying or immediately thereafter.

A temperature change of 34.4°C was shown to be insufficient to cause fissures in brown rice (Kunze and Hall, 1967); even a temperature gradient as large as 96°C did not produce fissures in the grain (Chen and Kunze, 1979). Matthews et al. (1971) subjected long grain rough rice to a combination of time and temperature treatments in hermetically sealed containers to minimize moisture transfer. Duration of heat treatments varied from 2 to 19 hours and temperatures from 60 t0 120°C. Results indicated that heat by itself did not cause fissures in the rice kernel. Studying the effect of warm-temperature sealed-storage after drying on rice cracking, Kato and Yamashita (1979) concluded that for all drying conditions, the higher the immediate storage temperature after drying the less was the subsequent cracking that occurred.

Prasad et al. (1975) found that volumetric expansion of brown rice for 1 percentage point change in moisture is about one hundred times that for 1°C change in temperature. Stresses due to the moisture gradient may therefore be a major cause of fissured grains.

Procedure

Long grain, Labelle, and medium grain, Brazos, rice from the 1978 Texas crop were used. This rice was held in a controlled storage at 12°C and about 67 percent relative humidity. The rice was taken from storage and conditioned for 3 weeks or more in an air-conditioned laboratory room at approximately 23°C and 52 percent relative humidity. All lots were aspirated to remove immature grains, hulls and other light matter. Brown rice kernels were removed by hand so that only mature rough rice kernels remained.

One lot of good long grain rice of about 10 kilograms was divided into two groups (A and B). Another lot of good medium grain rice of the same amount was divided into two groups (C and D). Groups A and C were equilibrated to 9.35 percent moisture content (dry basis, d. b.) in a controlled environmental chamber at 23±1°C, while Groups B and D were equilibrated to 11.90 percent d. b. in a laboratory at ambient air conditions of 23±2°C. The equilibrating process lasted for 3 weeks. This time period was required to essentially attain hygroscopic equilibrium in the new environment (Karon and Adams, 1949).

After equilibration, each of the rice groups (A, B, C, and D) was thoroughly mixed before being stored in sealed bottles. The rough rice was kept in the bottles until it was to be exposed to a higher relative humidity in an environmental chamber. The temperature and relative humidity within the chamber could be automatically controlled within accuracies of ±1°C and ±3%, respectively.

Sixteen samples of approximately 250 grams each were taken from each group and were exposed to eight different temperature-humidity environments. Two samples from each group were subjected to each of the temperature-humidity environments listed below:

20°C (68°F), 64 %	30°C(86°F), 64 %
20°C , 72 %	30°C , 72 %
20°C , 82 %	30°C , 82 %
20°C , 92 %	30°C , 92 %

The environments included conditions which may cause rough rice to fissure and thereby decrease head rice yield.

The environments were produced with a controlled environmental chamber. Test grains were spread into thin layers on screen-bottomed trays in order to permit uniform moisture adsorption. Trays of 560×560 mm (22×22 inches) in size were constructed to hold the samples. The exposure time to each temperature-humidity environment was 4 days. This period allowed the grains to pick up about 96 percent of the moisture that would eventually be adsorbed by the grains if the exposure time were prolonged indefinitely (Breese, 1955). Also this exposure time was used to simulate a similar relative humidity change for low moisture rice in the field.

After the 4-day exposure, the samples were moved to a conditioned air laboratory at approximately 23°C and 52 percent relative humidity for at least another 3 weeks. Then, the rough rice in each sample was divided into two subsamples of approximately 125 grams each. Subsamples were shelled separately with a rubber roll Satake sheller. The resulting brown rice was milled with a McGill No. 2 Miller.

The mill was operated with the weight, which controlled the milling pressure, located at the end of the lever arm. Sorenson et al., (1973) suggested that Labelle samples be milled for 45 seconds and Brazos samples for 60 seconds. The dynamic load (force) imposed by means of the weight on top of the shield of the milling chamber was calculated to be 7 kilograms. Each milled subsample was separated into three fractions with a Hart Uni-Flow Cylinder Tester. The fractions were 1) head rice, 2) large brokens, equivalent to second heads, and 3) small brokens, equivalent to screenings and brewers rice. The sorting procedure developed by Chen (1980) was used. Samples of the sorted rice fractions are shown in Figs. 1 and 2.

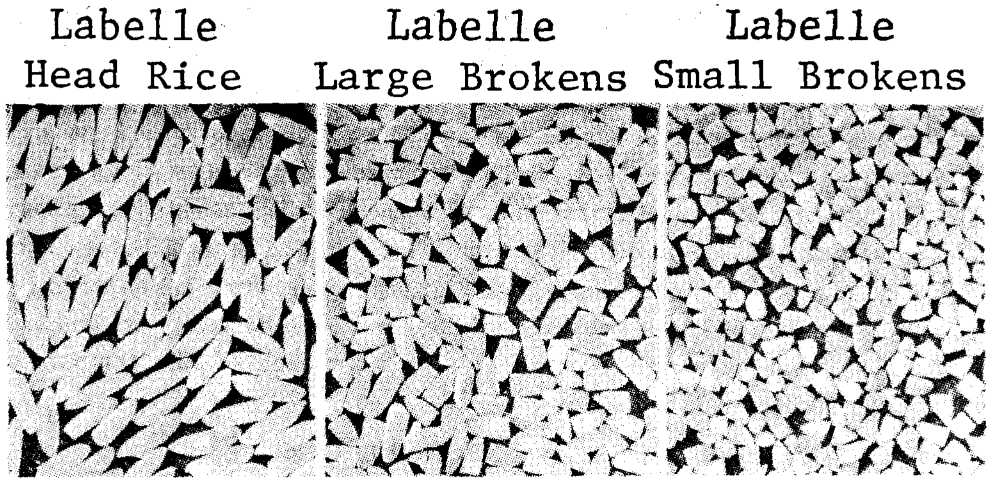


Fig. 1. Milled rice fractions of the Labelle variety sorted by the Hart-Uni-Flow Cylinder Tester.

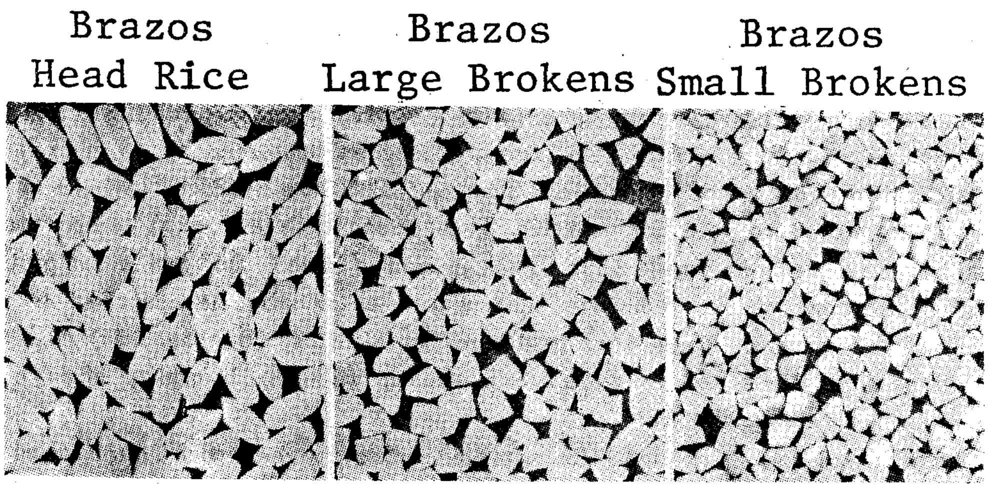


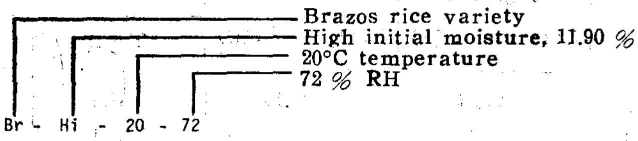
Fig. 2. Milled rice fractions of the Brazos variety sorted by the Hart Uni-Flow Cylinder Tester.

The whole experiment involved two varieties, two moisture contents, two temperatures and four relative humidities, making a total of 32 treatments with four observations nested in each treatment.

Particle sizes, weight and weight percentages of sorted fractions of milled rice which resulted from rough rice subjected to the different treatments were Investigated, compared and analyzed to see if there was any significant difference among the treatments. Four untreated subsamples, two of the long grain and two of the medium grain, were used as controls. They remained in the laboratory at approximately 23°C and 52 percent relative humidity from the beginning of the experiment until they were processed.

Test Code

A code was developed to represent the different conditions for the milling quality tests. The grain varieties, Labelle or Brazos, are represented by Lb or Br, respectively. Initial moisture contents are represented by Hi for 11.90 percent d. b. samples and Lo for 9.35 percent d. b. samples. The temperatures and the relative humidities in the environmental chamber are represented by the last two numbers, respectively. The example given below is self-explanatory.



Results and Discussion

Head Yield

The data in Table 1 are the milling results of all samples from both varieties subjected to the temperature-humidity treatments. The reader should note that there was a difference of 9.3 percentage points in the initial quality (head rice) of the two varieties. Each value in the table is an average of four replications. Analysis of variance were performed on all the data with a digital computer and the Statistical Analysis System (SAS). The same analysis was also applied to each relative humidity level. The results of the analysis of variance indicate that 1) the initial moisture content, 2) the relative humidity and 3) the temperature all significantly affected the head rice yield.

Temperature Effect

The data were grouped for analyses according to each relative humidity. The experiment showed that temperature level had an obvious and consistent effect on the head yield for the low moisture samples. The head yields were higher at 30°C than at 20°C for every level of relative humidity and for both varieties, Fig 3. The average difference was about 5 percentage points for any given relative humidity exposure. The reason could be that the grain took up less total mositure during conditioning in the environmental chamber at higher temperature for a given relative humidity. For example, in a 4 day conditioning period, the low moisture Labelle rough rice samples took up 4.29 grams of water per 100 grams of dry matter at 20°C and 64 percent RH, while similar rice samples took up only 3.69 grams of water at 30°C and 64 percent RH. The smaller moisture adsorption then caused less damage to the grain. Also, the reason could be that at higher temperature, the grain had more capacity for flow and deformation within the kernel structure. The stresses caused by the moisture gradient were more readily released, thus causing less damage to the grain (Kato and Yamashita, 1979). Faster moisture adsorption at higher temperature should have had an adverse effect on the head yield. However, no adverse effects were observed. This was possibly because the adverse effects, if any, for higher temperature were overridden by the favorable effects mentioned above.

Table 1. Milling results from different temperature and relative humidity treatments of rough rice. Each value is the average of four replications.

Treatment	Rough Rice Sample Wt. (g)	Brown Rice Sample Wt. (g)	Milling Yields %		Ratio of Brokens
			Total	Head	
Lb-Hi-20-64	121.54	96.14	68.8	58.3	0.42
Lb-Hi-20-72	123.42	98.49	69.4	58.8	0.42
Lb-Hi-20-82	122.80	96.77	68.3	57.0	0.45
Lb-Hi-20-92	128.19	101.53	68.8	54.5	0.42
Lb-Hi-30-64	127.25	100.27	68.9	58.4	0.44
Lb-Hi-30-72	122.12	96.47	69.0	58.6	0.45
Lb-Hi-30-82	127.62	101.59	69.2	58.0	0.44
Lb-Hi-30-92	124.00	97.96	68.6	54.5	0.44
Lb-Lo-20-64	128.49	101.25	68.0	55.3	0.40
Lb-Lo-20-72	125.95	99.00	68.4	50.6	0.42
Lb-Lo-20-82	121.54	92.98	66.8	23.7	0.44
Lb-Lo-20-92	129.72	101.57	68.3	3.8	0.60
Lb-Lo-30-64	130.47	103.07	68.1	56.0	0.39
Lb-Lo-30-72	124.92	98.44	68.3	52.8	0.40
Lb-Lo-30-82	128.54	101.68	68.5	32.7	0.43
Lb-Lo-30-92	125.31	98.49	68.6	7.6	0.48
Lb-Control	130.63	106.07	70.9	59.8	0.42
Br-Hi-20-64	124.60	101.42	72.4	54.5	0.06
Br-Hi-20-72	122.54	99.75	72.2	53.6	0.06
Br-Hi-20-82	121.89	98.85	71.7	52.3	0.06
Br-Hi-20-92	126.89	103.03	71.9	43.4	0.06
Br-Hi-30-64	127.13	103.36	72.1	52.3	0.05
Br-Hi-30-72	123.14	100.11	72.2	51.8	0.05
Br-Hi-30-82	125.01	101.26	71.3	51.0	0.06
Br-Hi.30-92	123.19	100.28	72.0	44.0	0.05
Br-Lo-20-64	127.31	103.25	72.0	47.7	0.05
Br-Lo-20-72	125.79	102.39	71.9	36.1	0.06
Br-Lo-20-82	132.37	107.22	71.5	16.2	0.10
Br-Lo-20-92	130.37	105.60	70.0	4.0	0.22
Br-Lo-30-64	130.38	105.87	72.1	51.0	0.06
Br-Lo-30-72	125.47	101.88	71.9	43.5	0.05
Br-Lo-30-82	128.22	104.11	71.8	25.1	0.08
Br-Lo-30-92	125.35	101.78	71.0	8.3	0.19
Br-Control	131.38	106.42	71.2	50.5	0.06

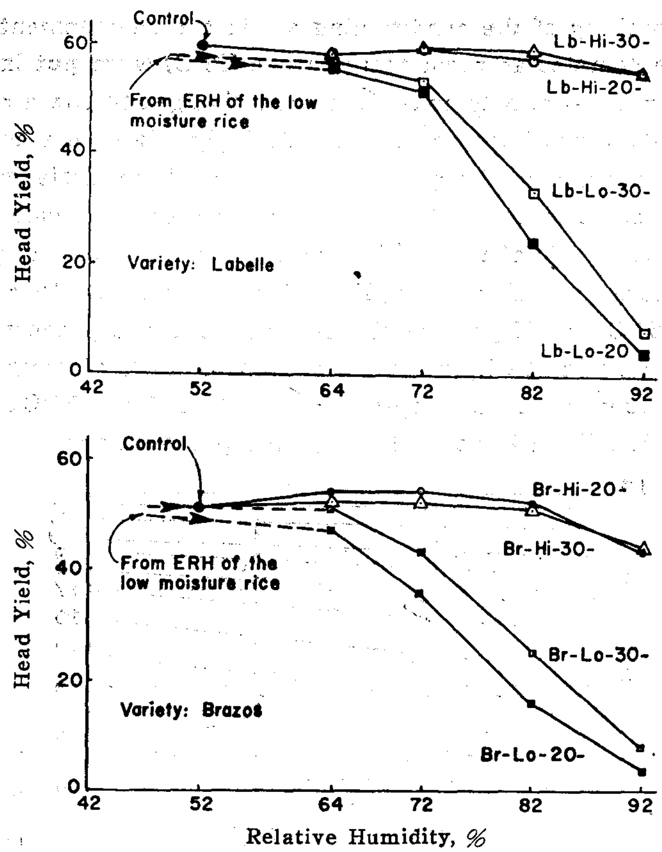


Fig. 3. Relative humidity and temperature effects on head yield for the indicated variety.

For the high moisture samples, the effects of temperature level on head yield were small and inconsistent. This indicates that the tests were probably run at conditions where head rice yield was beginning to be affected. The effects were generally small because the environmental changes, both at 20°C or 30°C apparently did not produce moisture gradients great enough within the grains to cause serious damage. The inconsistent or irregular results also may be due to random errors which were accumulated through the conditioning and milling process.

Initial Moisture and Relative Humidity Effects

For high initial moisture samples, there was no significant decrease in head yield in either variety until the exposure was to a 92 percent relative humidity. For samples with low initial moisture, the head yields already started to drop when either variety was exposed to a 64 percent relative humidity. For exposures to higher relative humidity environments, the head yields for both varieties dropped abruptly and were reduced to just a few percentage points at 92 percent relative humidity.

The above results also can be stated in terms of relative humidity changes between the equilibrium relative humidity of the rice samples before exposure to the relative humidity of the conditioning air in the environmental chamber.

When the rice samples at room temperature (23°C) were put into the environmental chamber, the grain temperature soon changed to the air temperature in the chamber. This was because of the relatively high heat conductivity of the grain. As a consequence the grain samples picked up little moisture from the environment before being equilibrated with the chamber temperature. Hence, most of the moisture change should have occurred while the grain was at a constant temperature. For example, when a high moisture sample was conditioned to a 20°C and 64 percent RH environment. the process followed the A-C-D lines as shown in the hygroscopic equilibria chart of rough rice, Fig. 4. Likewise, when a low moisture sample was conditioned to a 30°C and 92 percent RH environment, it followed the B-N-H-I-J-K-L process lines.

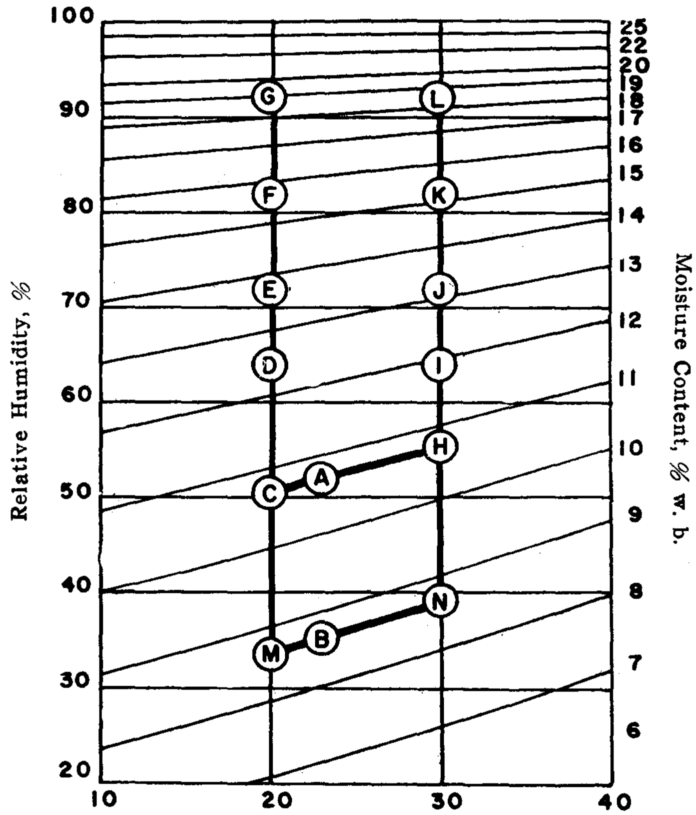


Fig. 4. The hygroscopic equilibria chart for rough rice, on which the initial rice conditions, the environmental settings and the conditioning processes to which th rice samples were subjected are shown.

Initial conditions of samples at the two moisture levels are represented by A and B. Postulated transient conditions are C, H, M and N. Conditions set in the environmental chamber were D, E, F, G, I, J, K and L.

Conditions set in the environmental chamber caused the samples to move along the lines of D, E, F and G at 20°C and along I, J, K and L at 30°C.

The relative humidities at points C, H, M and N are 50, 55, 33 and 39 percent, respectively. Therefore, for the high moisture rice samples which were conditioned in the environmental chamber at 20°C, the relative humidity increases imposed on the rice were 14, 22, 32 and 42 percentage points for the four relative humidity settings, respectively. For similar rice samples conditioned at 30°C, the RH increases were 9, 18, 28 and 38 percentage points. Similarly, for the low moisture samples conditioned at 20°C, the RH increases imposed on the rice were 31, 39, 49 and 59 percentage points for the four RH settings, respectively. And for similar rice samples conditioned at 30°C, the RH increases were 25, 33, 43 and 53 percentage points.

Comparing the foregoing statement with the head yield results it seems proper to conclude that for high moisture (11.90 % d. b., or 10.70 % w. b.) samples, a relative humidity increase of 28 percentage points at temperatures between 20 and 30°C would have little if any affect on head yield, but a RH increase of 38 percentage points would have a definite affect on head yield. An average reduction of six percentage points in head yield was observed. For the low moisture (9.35 % d. b. or 8.55 % w. b.) samples, a RH increase as small as 31 percentage points within the same temperature range caused a loss of about four percentage points in head rice yield. Greater relative humidity increases caused much greater losses in head yield.

Thus, the results show that relative humidity changes in the environment had a definite effect on the head rice yield; and drier rice was more subject to head yield losses. The results are consistent with observations made by Kondo and Okamura (1930), Stahel (1935), Kunze and Hall (1965) and Calderwood (1979).

Ratio of Brokens

Ratio of brokens was defined as the weight ratio of the small rice fragments to the large fragments in a milled rice sample. The ratios resulting from the milling quality tests for different treatments for both varieties are shown in Table 1.

The data show that:

1. The high moisture samples were not affected by any relative humidity change as far as the ratio of brokens was concerned. However, the low moisture samples were significantly affected. The ratio of brokens for both varieties was slightly affected at the 82 percent relative humidity exposure and was overwhelmingly affected at the 92 percent exposure, Fig. 5. Thus, comparing with the relative humidity effect on head rice yield, the ratio of brokens seems less sensitive to relative humidity changes. For example, at the 82 percent exposure, the head yield was reduced from 59.8 percent for the control to 28.2 percent (average of 23.7 and 32.7) for the low moisture Labelle samples. But the ratio of brokens remained at about 0.44, compared to 0.42 for the control samples.

2. The ratios were generally higher for 20°C treatments than for 30°C treatments. This was possibly because at 20°C the rice samples took up more moisture than at 30°C for a given relative humidity.

Less moisture adsorbed by rice samples at 30°C could have caused fewer small particles to develop in the milled rice samples. More flow deformation at higher temperature also may have helped to prevent the production of small particles.

3. The ratio of brokens for Labelle was generally much higher than the ratio for Brazos. This could have been caused by 1) the long grain having more fissures across its long dimension, thereby causing the kernel to break up into more smaller particles because of its smaller diameter and 2) the separating procedure which was the same for both varieties. The ratio change was of more interest than the value of the ratio itself.

The ratio of brokens results are consistent with the work of Kunze and Hall (1965), who stated that under small humidity changes, the cracks which developed were large (major) and extended over the grain cross section, In cases of large humidity changes, the impending damage by major cracks was often preceded by small cracks near the grain tips. Kunze (1977) implied that those small cracks near the grain tips may be the source for the many small kernel fragments often found in milled rice samples.

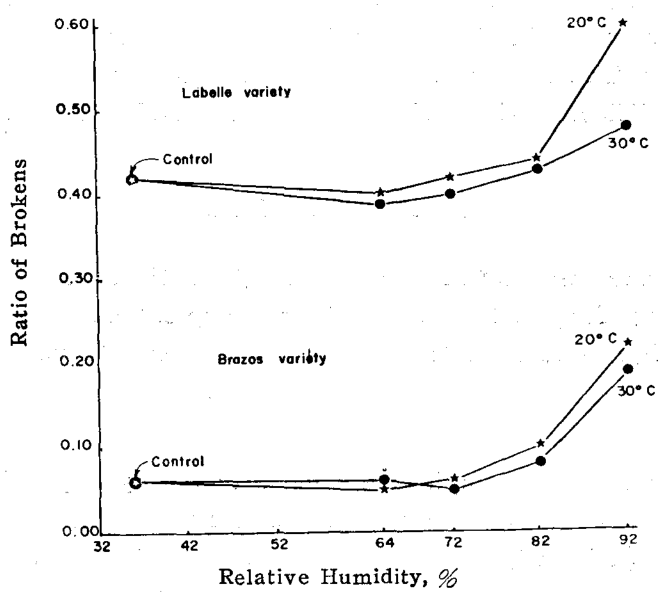


Fig. 5. Effects of relative humidity exposures at indicated temperatures on the ratio of brokens for low moisture rice samples of the indicated variety.

Summary and Conclusions

1. For the high moisture (11.90 %, d. b.) samples, in the temperature range of 20 to 30°C, a relative humidity increase of 38 percentage points affected the head

yield of the grain, while for the low moisture (9.35%, d. b.) samples, a relative humidity increase of 31 percentage points already caused significant loss in head yield in the same temperature range. As relative humidity increases were made larger, the head yields decreased rapidly.

2. Head yields of the low moisture rough rice samples of both Labelle and Brazos varieties were lower at 20°C than that at 30°C after individual grain samples were subjected for 4 days to each of eight temperature-humidity conditions (two temperatures and four relative humidities) in an environmental chamber.

3. The weight ratio of the small brokens to the large brokens in a milled rice sample was less responsive to environmental changes than was the head yield, but it showed a definite increase when low moisture grain was exposed to high relative humidity conditions.

4. The low moisture samples already showed a decreased head yield when they were exposed to only a 64 percent relative humidity environment. Therefore, it is advisable not to dry grain beyond its highest safe storage moisture, which is around 12.5 percent w. b.

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