EFFECT OF MOISTURE CONTENT ON MILLING OF ROUGH RICE STORED FOR SHORT PERIODS OF TIME

BY

FAUSTO MEJIA-MARTINEZ

B.S., Universidad Autonoma de Santo Domingo, Santo Domingo, Republica Dominicana (1975)

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John R. Pedersen

Major Professor

To Santa, my Mother

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INTRODUCTION

Rice (Oryza sativa L.) the staple food of approximately one third of the world population, is usually harvested at 18 to 24% moisture content, wet basis (w.b.). This moisture content is sufficient for changes in the physical, biological and chemical properties of the grain, causing it to lose value and, ultimately, its consumer appeal.

In many countries, especially in tropical areas with high relative humidity and relatively high temperatures, rice is commonly harvested in rainy periods.

For a multitude of reasons freshly harvested rice may be stored, for various lengths of time before it is dried, in a variety of containers, from plastic sacks to relatively sound concrete silos. These conditions can provide an environment suitable for growth of microorganisms, grain respiration and ultimately increase in the internal temperature of the grain mass.

These factors - moisture content, microorganisms, temperature and delay in drying - all interacting, result in deterioration of rough rice.

This study examined how initial moisture content and time of storage affect the quality of milled rice. Emphasis was on monitoring the degree and percentage of discolored kernels and milling yields of rice stored for various short periods of time. Slight increases in the percentage of discolored kernels may reduce the grade of milled rice or its acceptance by the consumers. Reductions in the percentage of head rice yield and total milling yield represent monetary losses (see appendix A, for definitions).

LITERATURE REVIEW

Rice, like other cereal grains, is a biological, hygroscopic material that is subject to cnanges in moisture content and to deterioration in response to changes in environmental conditions. For the purpose of this study deterioration of rice is defined as "loss in marketing quality" of milled rice, and is measured in percentage of discolored kernels, percentage head rice yield and percentage total milling yield.

Factors affecting discoloration of rice

Discoloration of kernels is one of tne more evident signs of rice deterioration. It is associated with the development of fungi (enhanced by grain moisture content and length of storage), elevated temperatures and interaction of these factors as well as biochemical reactions within grain kernels stimulated by high moisture contents and elevated temperatures. Mauron (1981) indicated that discoloration of grains, in general, is dependent on moisture content and temperature as well as duration of heating or reaction time.

Development of Fungi

Moisture content (mc), equilibrium relative humidities (rh), temperature and length of storage, contribute to the development of microorganisms, particularly fungi.

Moisture content of the grain is a critical factor in determining the species of molds which develop. Because of this, fungi growing on or in grains are commonly classified as either field or storage fungi on the basis of their moisture requirements (Christensen and Meronuck, 1986).

Field fungi require moisture contents in equilibrium with relative humidities of 90% or greater in starchy seeds, equivalent to moisture content of 20-22% (wet basis) and above. Storage fungi, which include ten species or so of the genus Aspergillus, several species of the genus Penicillium and species of a few other genera, are adapted to growing in grains whose moisture content is in equilibrium with relative humidities from 65 to 90 percent; that is, moisture contents of about 13.5-20% (Christensen & Meronuck, 1986; Esmay et al, 1979). A moisture content of 14 % has been proposed as the lower limit that permits damaging invasion of sound rice by storage fungi (Alnaji, 1975; Fanse & Christensen, 1966).

On freshly harvested rice the population of storage fungi, mainly species of Aspergillus and Penicillium increases with increased storage periods and is associated with a decrease in field fungi (Christensen and Meronuck, 1986). Invasion of storage fungi and decrease in germination percentage of rice is proportional to increasing moisture content and the increasing length of storage (Mallick and Nandi, 1979; Christensen and Lopez, 1965).

Fanse and Christensen (1966) found that when rough rice relatively free of storage fungi was stored for four months the increase of storage fungi was to a certain extent proportional to the initial moisture content of the grain.

Quitco (1981) observed that in rough rice stored at 24.5% mc, 23.75 percent of grains yielded storage fungi after one week. After two weeks 91.5% had storage fungi, while grains yielding field fungi decreased for the same period of time from 79.0 to 13.34%.

Discoloration of milled rice has been related to certain species of fungi found on rough rice. Black to brownish rice kernels have been associated with Curvularia spp., Aspergillus ochraceus and A. terreus; yellowish-brown kernels with Rhizopus spp.; yellow kernels with Fusarium spp. and A. flavus; while red kernels have been associated with Monascas purpurea (Tullis, 1936; Quitco, 1982a).

Temperature

There is evidence to indicate that high temperatures within a mass of grain, from respiring organisms or other sources, may produce discoloration of milled rice.

Vasan (1980) reported that in rice stored at 23 to 25% mc (90 to 95% rh), the grain-mass temperature increased to 60-65 C. When milled, this rice had highly discolored and off flavored kernels.

Quitco (1982b) sterilized rough rice by two means, finding that when paddy at 23% mc was sterilized with sodium chloride yellowing did not appear, while sterilizing with steam produced yellowing. This is supported by the yellowing of rough rice hydrothermally (high temperature and high moisture) treated to produce parboiled rice.

Biochemical (Maillard type) reactions

Because of high temperatures encountered in storage of rough rice at high moisture contents it has been suggested that a mild form of the parboiling process could be responsible for yellowing (discoloration) of milled rice (Ruiten, 1985). Parboiling is a hydrothermal process in which the crystalline form of starch is changed into an amorphous one, due to irreversible swelling and fusion of starch (Mauron, 1981). Mel'nikov et al. (1982) stated that hydrothermal treatment of normal rice decreased the amounts of certain free amino acids and most sugars, due to their taking part in Maillard reactions and resulted in discoloration of milled rice.

According to Mauron (1981) the first phase in Maillard reactions is a simple condensation process between carbonyl groups of the reducing carbohydrates and free amino groups of amino acids. However this first reaction does not confer any changes in color. The source of reducing sugars in rice may be from the enzymatic conversion of sucrose initiated in the first phase of germination at about 30% mc (Bhattacharya, 1985). The second Maillard phase corresponds to multiple reactions leading to the formation of volatile or soluble substances responsible for aroma and flavor of heated products. The final reactions lead to insoluble brown polymers, melanoidins (Mauron, 1981).

Schroeder (1965) subjected inoculated (with Fusarium chlamydosporium) and non-inoculated samples, after sterilizing, to parboiling and observed that in the non-inoculated samples the total content of amino acids decreased, probably as a result of a chemical reaction with reducing sugars, resulting in a brownish-colored milled rice. Parboiled inoculated samples had no major change in total amino acids, accompanied by an increase in reducing sugars and a noticeable increase in brown to black pigmentation. He concluded that Maillard-type reactions might not be the only cause of change in color as a result of parboiling.

Discoloration during parboiling seems to be a result of non-enzymatic browning of the Maillard type, induced by heat, however, water absorbed during parboiling can dissolve color pigments in the hulls and transport them inward to the endosperm (Bhattacharya, 1985).

Factors affecting milling yields

The interaction of moisture content, temperature, microorganisms and length of storage affect the percentage of head rice yield and total milling recovery, resulting in monetary losses. Quitco (1981) and Chen (1983) found that head rice yield is influenced by the interaction of the moisture content of the grain, the presence of fungi and the length of temporary storage.

In paddy (rough rice) with 23 to 25% moisture content the head rice recovery increased from 80.95 to 84.30% after one-month delay in drying. However head rice recovery in paddy with 20 to 22% moisture decreased from 77.85 to 74.07%, after one-month delay in drying (Quitco, 1981).

De Castro et al. (1980) stated that decreased milling recovery (total milling yield) and head rice yield could be attributed to the deterioration of grain quality during a delay in drying. Losses in dry matter may be responsible for decreases in total milling yield in wet paddy.

The deterioration of rough rice, measured as discolored-milled rice and reduction of head-rice yield, increased with the length of storage (Alnaji, 1975; and Schroeder, 1963).

Ergosterol as a measure of mold activity

Seed germination, visible discoloration, fat acidity and various other indicators are sometimes used as indirect measures of fungal activity. However, such measures may reflect damage from other causes or may change only after extensive fungal growth.

Ergosterol has been considered the predominant sterol component of nearly all fungi and is not a native constituent of grains. Seitz et all. (1977) suggested that ergosterol levels could be an important aid in evaluating the extent of fungal invasion where fungi may have died from unfavorable storage conditions. The ergosterol assay also has the capability of detecting early growth of fungi.

Naewbanij et al. (1986) found a high correlation (r = 0.96) between the ergosterol content and the percentage of damaged kernels in milled rice.

MATERIALS AND METHODS

Rice description

Rice used in the studies reported here was obtained through another research project from Winrock International, Winrock International Institute for Agricultural Development, Petit Jean Mountain, Morrilton, Arkansas. The rice was a long grain variety (New Bonnet) harvested from the 1986 Arkansas crop and had the following properties:

* Test weight:	47.2 lb/bu	
* Moisture content:	12.4 to 12.7%	
* Milling yield:	72.61%	(see appendix A)
* Head rice yield:	83.03%	(see appendix A)
* Agtron color value	73	
* Field fungi:	77% kernels invaded	
* Storage fungi:	no kernels invaded	

Experimental conditions

To determine the effect of high moisture content and short time storage of rice, four moisture contents (14, 18, 22 and 26%) and 6 periods of time (5, 10, 15, 20, 25 and 30 days) were selected.

Moisture adjustment

Since high moisture rice was not available, moisture content of the rice was adjusted to the four levels by tempering 2-kilogram lots of clean rough rice. Distilled water was added to each lot of rice contained in polyethylene bags (doubled for strengtn) and stored at 5 C for 72 hours. Each tempered sample was mixed by shaking several times a day to provide even distribution of the moisture.

Distribution of treatments

Samples were stored from 5 to 30 days in a controlled-atmosphere chamber at 27+2 C and 65+5% relative humidity.

Each tempered lot was divided into two equal samples by use of a riffle divider. Each sample was placed in a 2 liter-capacity vacuum bottle filler (Thermos 18f STRONGLAS filler, King-Seeley Thermos Co., Norwick, Connecticut). For stability and to enhance the insulation, the STRONGLAS fillers were placed in 3 lb-coffee cans and polyuretane used to fill the spaces between the can and the filler. To prevent excessive moisture loss from samples and to prevent an air tight condition within the filler cotton was used to fill the neck space and to support a thermometer.

During preliminary trials and development of method to be used in this research it was found that no discoloration of kernels occurred in rice stored at 18% mc for 5 and 10 days. Rice stored at 22 and 26% mc after 20 and 15 days, respectively was too discolored to provide useful observations. These extremes moisture content and time were not included in the replicated trials. Each treatment had 2 replicates, thus the experiment was based on the study of 34 samples, as follows:

Table 1. Distribution of treatment.

Moisture content (%)	Time (days)					
	5	10	15	20	25	30
14	x	x	x	x	x	x
18	a	a	x	x	x	x
22	x	x	x	x	a	a
26	x	x	x	a	a	a

Combinations of moisture content and time indicated by "a" were not included in tnis study.

Determination of storage effects

To measure the effects of storing rice for various short periods of time at high moisture contents, the following tests were run on each treatment replicate at the beginning of t h e experiment and every 5 days until the storage period for each treatment was completed.

Moisture content

Moisture content was obtained, before and after tempering, after storage and at milling, using a single stage air-oven method as utilized by Sauer, D. B., 1987 (personal communication): approximately 15 grams of sample at 120 C for 24 hours.

Temperature

Glass thermometers (mercury-filled) were placed in each STRONGLAS filler in order to measure the daily temperature in the center of the grain mass. Temperatures were recorded at approximately 5 p.m. daily.

Rice drying for milling

After storage each sample was dried to 12.5 - 13.0% mc for milling. Samples were placed on screen trays (1'x 1') through which air at 65+5% rh and 25+2 C was pulled until the moisture of the rice equilibrated with the humidity of the air. In most cases, this required 36 to 48 hours. A drying plenum was constructed to hold up to six drying trays. The drying plenum was placed in a 30'x 15'x 7' environmental chamber maintained at 25+2 C and 65+5% rh. A centrifugal fan was used to pull air through the rice samples and plenum. During drying moisture content of samples was periodically checked using a Dickey-john GAC II Moisture Tester (Dickey-john Corporation, Auburn, Illinois). Final moisture contents were determined by the air-oven method.

Percentage surface-disinfected kernels yielding fungi

From each replicate, before drying, 100 seeds (two replicates) were plated on MS6T (malt-agar containing 6% sodium chloride and 200 ppm Tergitol NPX), and incubated at 27 C for 5 to 7 days. Each replicate (100 seeds) was plated in three Petri dishes (34, 33 and 33 seeds). Further isolation of non-sporulated mycelium was done on BRE (Brown-rice extract agar) and on PDA (Potato dextrose agar). The BRE extract was prepared as suggested by Burroughs et al (1981): a mixture of brown rice (50 g) and water (1 L) was heated with stirring at 60 C for 1 hr, the mixture filtered, and the filtrate made to volume (1 L). The BRE agar was then prepared using 1.5% purified agar.

The isolated fungi, once identified, were counted and added to the original count on MS6T.

Ergosterol assay

During preliminary trials it was found that no molds developed on rough rice at high moisture content, after 5 to 10 days storage, while the rough rice presented visible signs of deterioration. To determine early fungi invasion (not detected when this rice was plated) the ergosterol content of rough rice treatments was measured. The amount of ergosterol present on rough rice was determined using a HPLC method as utilized in the U.S. Grain Marketing Research Laboratory, Manhattan, Kansas by Seitz and Mohr (unpublished, 1984).

Bulk density

After rough rice samples were dried for milling, the bulk density was determined with a Burrows test-weight apparatus.

Germination

To determine germination percentage, one hundred kernels were placed on a moist paper towel fold, enclosed with aluminum foil and kept at room temperature for 5 to 7 days. Any seed which produced a root or coleoptile was considered to have germinated.

Milling tests

Samples of 1 kg rough rice were dehulled using a McGill laboratory sheller (McGill Inc., Houston, Texas) to obtain brown rice. The McGill sheller was adjusted to dehull 90 to 94% (by weight) of a sample. Then the dehulled rice was polished in a McGill No.2 Miller (Rapsco, Brookshire, Texas). A 802 g weight, placed on the weight lever at 9.5 inches from the saddle center, was removed after 30 seconds of the regular continuous milling time of 60 seconds. This system produced a "reasonably-well-milled" rice (U.S. Standard for Milled Rice, 1983).

* Total milling yield

The amount of rice obtained after milling was weighed for computation of total milling yield (TMY). It was calculated by dividing the weight of milled rice obtained by the weight of rough rice.

$$TMY = WMR/WRR \times 100$$

where:

WMR = weight of milled rice

WRR = weight of rough rice

* Head rice yield

A working subsample of at least 25 g was obtained from the milled rice using a riffle divider (Humboldt Mfg. Co., Chicago, Illinois). To compute the head rice yield (HRY), whole kernels (whole kernels plus those 3/4 long or greater) were separated by hand and the percentage of HRY calculated, as follows:

HRY = WWK/WRS x 100

where:

WWK = weight of whole kernels

WRS = weight of milled rice sample

Discolored kernels

A subsample, at least 25 g, of milled rice was used to determine the percentage (by weight) of discolored kernels, PDK (see Appendix A, for definitions). Discolored kernels were separated by hand according to the interpretative-line transparencies: R-2.0 and R-2.1 (S / J Systems Company, Milwaukee, Wisconsin), approved by the U.S.D.A. in September 1984 and January 1985 respectively.

PDK = WDK/WRS x 100

where:

WDK = weight of discolored kernels

WRS = weight of milled rice sample

Degree of whiteness

As an additional measure of discoloration of the milled rice, a procedure was developed to determine the degree of discoloration of the milled rice sample as a whole.

Thirty grams of milled rice were ground in a UDY Cyclone

Sample Mill (UDY Corporation, Fort Collins, Colorado), placed in an Agtron cup, compacted 35 times and measured in the the Agtron M-500 A (Magruson Engineers, Inc. San Jose, California). The 63 and 97 calibration disks were used to set the Agtron to 0 and 100 respectively, and the Green Mode (546 nm) used to make the reflectance measurement.

Samples subjected to different moisture contents, temperatures and lengths of storage, could result in different particle sizes when ground on the UDY mill. It was not known whether the relative spectral reflectance would be affected by possible differences in distribution of particle size within samples. To confirm the validity of the Agtron results, two samples totally different in terms of treatment, were sifted on the Alpine air sifter to obtain four particle size separations. It was determined that changes in relative reflectance between the two samples was not dependent on the particle size distribution (see Appendix B).

RESULTS AND DISCUSSION

Moisture content

Because lots were individually tempered, there were variations between samples. With the exception of two lots at 22% mc, moistures were within 0.4% of the desired at the beginning of storage. The two exceptions were 1.2 and 1.1% over the desired moisture content at the beginning of storage (Table 2).

Moisture contents were expected to decrease during storage since the STRONGLAS fillers were plugged with cotton to allow oxygen to enter and were stored under conditions roughly in equilibrium with 13% mc (27+2 C and 65+5% rh). Samples at 14% mc, decreased less than 0.3% on the average; at 18% mc, the average reduction in moisture content was 1.4%; at 22% mc, 1.6%; and at 26% mc, 2.5%.

After the respective storage periods, lots of rough rice were dried with ambient air at 25 C and 65% rh until samples came to equilibrium with the drying air. At time of milling, moisture contents ranged from 12.3 to 13.1% with an average of 12.7% and standard deviation of 0.2356.

Discolored kernels

Percentage of discolored kernels was determined by

Table 2. Moisture content[1] of rice at different stages of the study.

Moisture content	Days stored	After tempering	After storage	At milling
Initial	-			12.35
14	5	14.18	14.20	12.41
	10	13.94	13.91	12.38
	15	14.23	13.65	12.52
	20	13.81	13.26	12.72
	25	14.05	13.79	12.74
	30	14.04	13.79	12.99
18	15	18.39	16.78	12.62
	20	17.95	16.36	12.87
	25	18.38	17.36	12.96
	30	18.38	17.03	13.01
22	5	23.17	22.24	12.64
	10	22.06	21.20	13.06
	15	22.15	19.89	12.43
	20	23.07	20.70	12.72
26	5	26.36	23.24	12.57
	10	25.82	23.71	12.92
	15	26.13	23.95	12.29

[1]each moisture content is the mean of two replicates and two determinations per replicate.

interpretative line samples (ILS) and compared with relative spectral reflectance measured with the Agtron.

Discolored kernels by ILS

The percentages of discolored kernels for each treatment are shown in Figure 1 and Table 3. Samples at 14% mc had no discolored kernels even after 30 days of storage, suggesting that 14% mc is safe to store rice for short periods of time. This corroborates earlier findings by Fanse and Christensen (1966).

At 18% moisture content no discoloration occurred for the first 15 days of storage, with a gradual increase after 20 days. This may be a direct consequence of increase in temperature and/or in storage fungi (Figure 5 and Table 5). Even though the temperature decreased sharply from 45 C after 25 days it leveled off at about 35 C (Figure 5). This temperature and the increased percentage of A. candidus indicate continued deteriorative activity and could be responsible for the increase to 7.7% discolored kernels at 30 days.

Samples at 22% mc had a gradual increase in discolored kernels for the first 15 days of storage with a sharp increase to 84.9% at 20 days. The temperature reached 61 C after 15 days storage followed by an abrupt decrease to 55 C

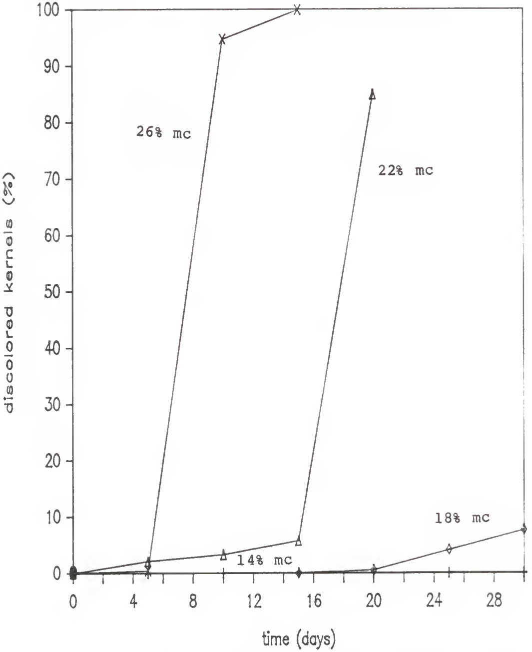


Figure 1. Percentage discolored kernels of milled rice from rough rice stored at four moisture levels for different periods of time.

Table 3. Percentage discolored milled rice kernels[1] from rough rice stored at four moisture levels for different periods of time.

Moisture content	Days stored	Kernels damaged by heat[2]	Heat-damaged kernels[2]	Percentage discolored kernels[2]
Initial	-	0	0	0
14	0	0	0	0
	5	0	0	0
	10	0	0	0
	15	0	0	0
	20	0	0	0
	25	0	0	0
	30	0	0	0
18	0	0	0	0
	15	0	0	0
	20	0.54	0	0.54
	25	4.09	0	4.09
	30	7.65	0	7.65
22	0	0	0	0
	5	2.13	0	2.13
	10	3.29	0	3.29
	15	5.76	0	5.76
	20	71.49	13.38	84.87
26	0	0	0	0
	5[3]	0.45	0	0.45
	10	43.42	51.28	94.70
	15	2.94	96.93	99.87

[1]Discolored = Heat damaged kernels + kernels damaged by heat. [2] averages of two replicates. [3] distinctly creamy color.

at 20 days. A maximum temperature was reached (followed by a sharp decrease) approximately 5 days prior to the increase in percentage discolored kernels.

At 26% mc, samples stored for 5 days had a relatively low percentage of discolored kernels, but the entire sample of rice had a distinctly creamy color. In this case it is suspected that a form of "parboiling" may have occurred, since the moisture content and temperature were favorable for the parboiling process to occur. Bhattacharya (1985), stated that the gelatinization temperature of starch in rice from 26 to 30% mc, varies from 55 to 79 C.

After 10 days storage, 95% of the kernels were discolored. This occurred, as before, after a maximum temperature of 65C (followed by a sharp decrease) had been reached 5 days earlier (Figure 5). The percentage of discolored kernels increased to 100% at 15 days storage as the temperature continued a gradual decline to about 60 C.

At 26% and possibly at 22% moisture contents, the continued high temperatures in the samples suggest some form of deteriorative process even though no mold development was evident (Table 5). Although it was not determined, thermophilic microorganisms or chemical oxidation may have been responsible for the continued high temperatures and kernel discoloration.

Degree of Whiteness/Relative Spectral Reflectance

As an additional measure of discoloration, the relative degree of darkening of the rice was measured using relative spectral reflectance with an Agtron M-500 A.

Although there were no discolored kernels at 14% mc and there was no other visible deterioration, there were slight decreases in relative spectral reflectance values (SRV) over time from 5 to 30 days (Figure 2 and Table 4).

At 18% mc, Agtron color values for specific storage periods were equivalent to those at 14% mc, except at 30 days where there were 7.6% discolored kernels and a slightly lower SRV of 65 (SRV = 67 at 14% mc).

The percentage of discolored kernels appears to have a marked effect on SRV's at 22 and 26% mc, however, the SRV's indicate a decrease in reflectance (or darkening of the rice) due to some additional factor, perhaps a "parboiling" effect.

A high correlation between percentage discolored kernels and relative spectral reflectance ($r = -0.98$ for 18 and 22% mc; and $r = -0.95$ for 26% mc) suggests that these two measures of discoloration are significantly related. Tnus

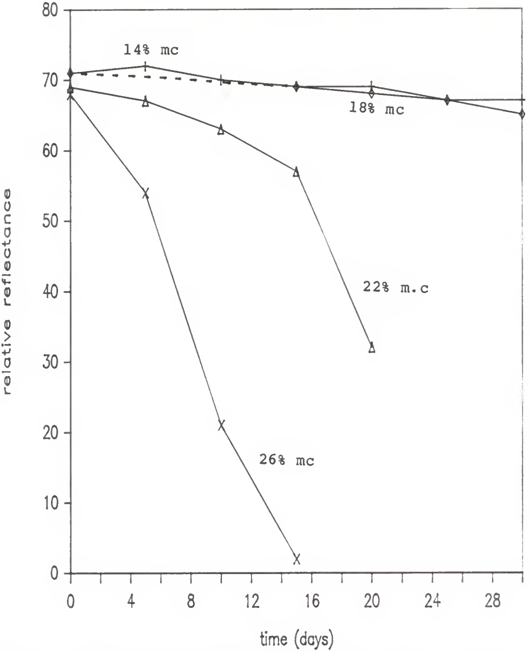


Figure 2. Relative spectral reflectance of rice stored at four moisture levels for different periods of time.

Table 4. Relative spectral reflectance[1] of rice stored stored at four moisture levels for different periods of time.

Moisture content	Days stored	Reflectance[2]
Initial	-	73
14	0	71
	5	72
	10	70
	15	69
	20	69
	25	67
	30	67
18	0	71
	15	69
	20	68
	25	67
	30	65
22	0	69
	5	67
	10	63
	15	57
	20	32
26	0	68
	5	54
	10	21
	15	02

[1]Agtron M-500 A; Green Mode(546 nm); Disks 63 and 97, and mean of two replicates.
[2]Higher the value whiter the color.

the relative spectral reflectance might be used as an index of kernel discoloration.

Milling yields

Total milling yield

Samples milled at the beginning of the storage period had total milling yields (TMY) of 72.6, 71.6, 71.6, and 72.3% respectively at 14, 18, 22 and 26% moisture contents.

Milled rice yield decreased at 14% mc with increased storage time (Figure 3). The cause for this reduction in total milling yield is not known. Although there were no visual signs of deterioration, nor decrease in color value or increase in kernels invaded by fungi, TMY decreased from 72.6 to 69.2% over 30 days storage.

After 15 days storage at 18% mc, TMY decreased to 69.2% and to 66.4% after 30 days. At 22% mc, TMY decreased slightly up to 15 days where it decreased sharply to 64.0% after 20 days storage. This sharp decrease in TMY coincided with the sharp increase in percentage discolored kernels (Figure 1) and decrease in color reflectance (Figure 2).

After 5 days at 26% mc TMY was 69.1% and decreased sharply to 64.1% after 15 days storage. This sharp decrease coincided with the sharp increase in percentage discolored kernels (Figure 1) and decrease in color reflectance

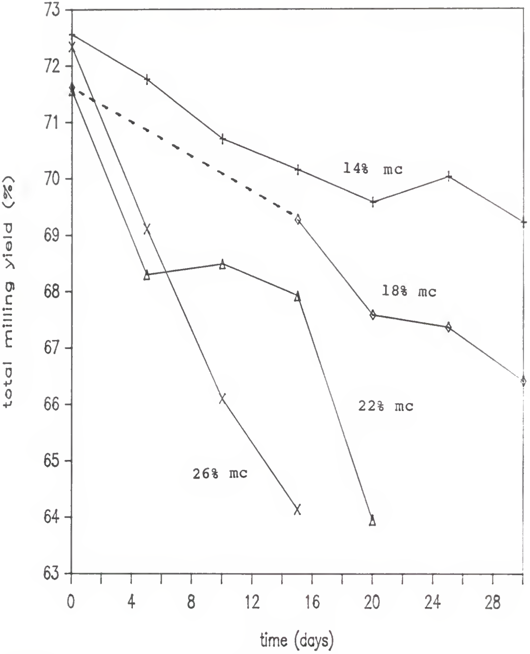


Figure 3. Total milling yield of rice stored at four moisture levels for different periods of time.

(Figure 2).

The decreases in total milling yields are associated with discoloration of rice, which in turn is associated with elevated temperatures. De Castro et al. (1980) stated that the decrease in milling recovery (TMY) is a reflection of the increasing percentage of damaged kernels incurred during the delay in drying the rice. They defined damaged kernels as "whole or broken kernels showing some degree of change, which may be caused by fungi, moisture content and insects".

Head Rice Yield

Although not anticipated, the percentage head rice yield (HRY) after tempering and drying for milling, decreased substantially from an initial 83.0% to 49.6, 46.2 and 65.0% respectively for 18, 22 and 26% mc. At 14% mc, HRY decreased to 80.0% after tempering and drying (Figure 4).

Head rice yield (HRY) at 14% mc varied from 74.5 to 81.3% and did not decrease over a 30 days storage period. At 18% mc HRY was considerably lower. It decreased from 49.6% to 33.4% after 15 days storage, then increased to 41.2, 41.0 and 40.9%, respectively, after 20, 25 and 30 days. At 22% mc HRY decreased from 46.2% to 40.7, 37.9 and 39.9% after 5, 10, and 15 days, respectively, then increased abruptly to 52.8% after 20 days storage. HRY's at 26% mc, in

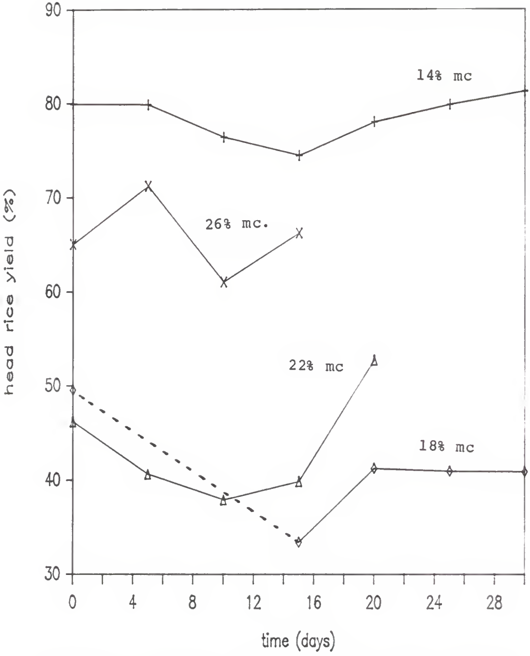


Figure 4. Head rice yield of rice stored at four moisture levels for different periods of time.

general, were erratic but greater than at 18 and 22% mc; 65.0, 71.2, 61.0 and 66.2% at 0, 5, 10, and 15 days, respectively (Figure 4).

Whereas total milling yields (TMY) tended to decrease with increased time in storage and increased moisture content, head rice yields (HRY) remained fairly constant at 14% mc but were considerably lower at 18% and 22% mc. After 20 days storage at 22% mc and at 26% mc HRY's tended to be higher. Increases at these moisture contents coincided with increased temperatures and the occurrence of discolored kernels (Figure 1 and 5) which could indicate a form of annealing or parboiling. Parboiling gelatinizes starch in the rice kernels, reducing the probability of breakage during milling (Bhattacharya, 1985).

Other factors related to discoloration of rice and milling yields

Temperature

There was no change in temperature when samples at 14% mc were stored up to 30 days (Figure 5). At 18% mc there was a gradual increase until 16 days when a rather sharp increase occurred followed by a sharp decrease at 24 days. The temperature appeared to level off at about 35 C.

At 22 and 26% mc there were sharp increases after 2 days of storage. At 26% mc a maximum of 65 C was reacned in just

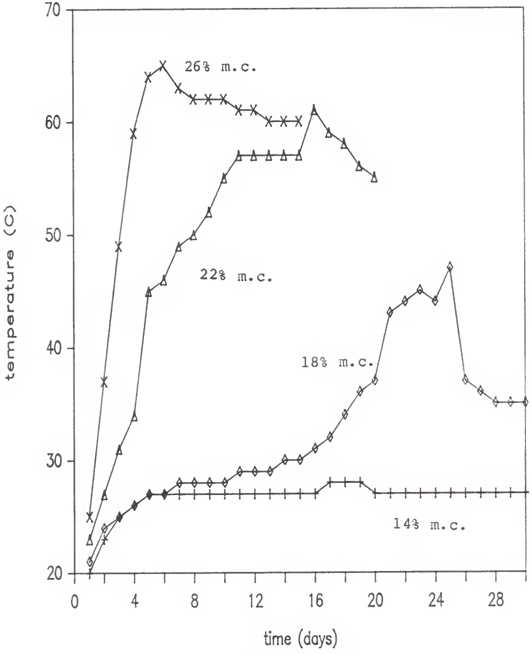


Figure 5. Daily temperature of rough rice stored at four moisture levels for different periods of time.

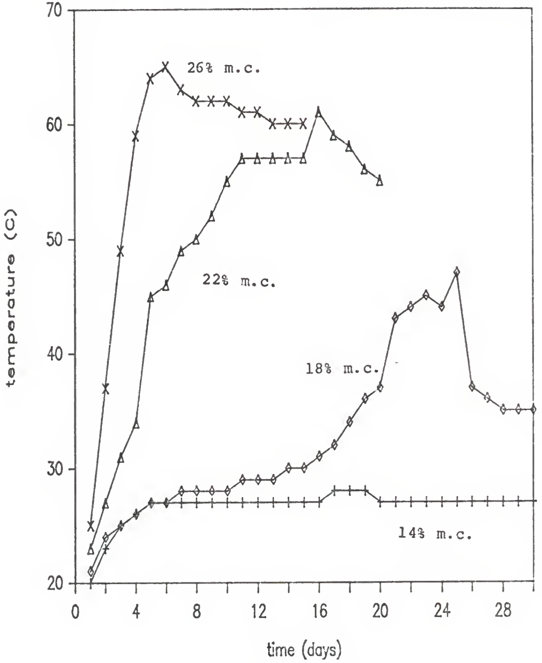


Figure 5. Daily temperature of rough rice stored at four moisture levels for different periods of time.

storage fungi (Figure 8).

Although respiration itself was not studied, respiratory activity of both field and storage fungi probably initiated an increase in temperature which then induced other (thermophilic) respiratory activity, especially under the storage conditions reported here.

Daily temperatures for 18, 22 and 26% mc decreased after 24, 16 and 5 days, respectively (Figure 5). At 22 and 26% mc the percentage discolored kernels increased 5 days after the peak temperatures. Even though the temperatures gradually decreased they still remained near that required for Maillard-type discoloration of rice (Juliano, 1972). At 18% mc, temperatures were not, according to Juliano (1972), high enough for Maillard-type discoloration, however, 4 and 8% of the kernels were discolored after 25 and 30 days, respectively.

Degree-days above 27 C (temperature at which samples were stored) were determined for samples at 18, 22 and 26% mc (Figure 6). Degree-days correlated with percent discolored kernels was found to be high at 18, 22 and 26% mc; r = 0.97, r = 0.82 and r = 0.85, respectively. Figure 7 suggests that 110 days-degree at 26% mc and about 280 days-degree at 22% mc would produce 5% discolored kernels. The

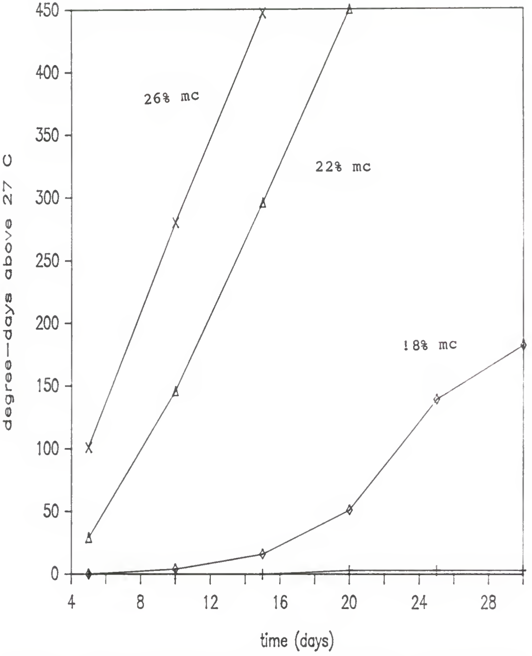


Figure 6. Degree-days above 27 C of rough rice stored at four moisture levels for different periods of time.

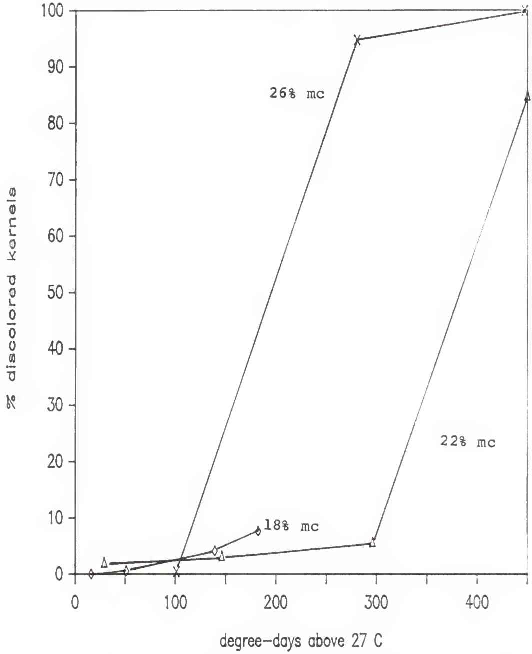


Figure 7. Degree-days above 27 C vs percent discolored kernels of milled rice stored at four moisture levels for different periods of time.

relationship between day-degrees and discolored kernels is very similar to that of time and discolored kernels (Figure 1) at these moisture contents.

At 18% mc, 150 day-degrees resulted in 5% discolored kernels. This was less than that required at 22% mc, where as the time required to produce 5% discolored kernels was greater than that at 22% mc. This would tend to indicate that discoloration of kernels may occur at lower temperatures when these temperatures are extended over longer periods of time. The day-degree relationship with discolored kernels requires further study.

Microorganisms

The percentage of surface-disinfected kernels invaded by fungi at 14% mc remained constant over the 30 days storage and were primarily field fungi (Table 5).

At 18% moisture content, there was a sharp increase in storage fungi, primarily Aspergillus glaucus, Aspergillus candidus and Penicillium spp. This increase in storage fungi was accompanied by a reduction in field fungi. After 15 days storage, 100% of the kernels were invaded, with the percentage invaded by field fungi decreasing and those invaded by storage fungi increasing with length of the storage period.

Table 5. Surface-disinfected rough rice kernels(%)1 yielding fungi when stored at four moisture levels for different periods of time.

Moisture content	Days stored	Field fungi	A.g.	A.f.	A.c.	Pen.	Total
Initial	-	77	0	0	0	0	77
14	5	78	1	0	0	0	78
	10	77	1	0	0	0	77
	15	78	0	0	1	1	80
	20	80	1	1	0	0	82
	25	73	2	0	8	1	84
	30	76	1	0	1	0	78
18	15	57	27	0	10	21	98
	20	38	34	0	23	35	100
	25	5	46	1	74	15	100
	30	2	31	1	87	8	100
22	5	80	0	6	3	12	97
	10	29	4	1	6	0	40
	15	30	3	0	0	0	33
	20	0	0	0	0	0	0
26	5	0	2	0	0	0	2
	10	0	0	0	0	0	0
	15	0	0	0	0	0	0

A.g. = *Aspergillus glaucus*, A.f. = *A. flavus*,
A.c. = *A. candidus*, Pen = *Penicillium spp*.
1average of two replicates.

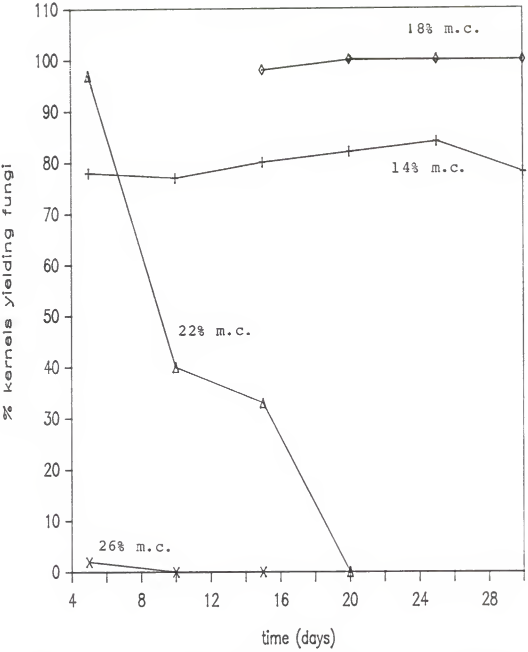


Figure 8. Surface-disinfected rough rice kernels yielding fungi when stored at four moisture for different periods of time.

At 22% mc moisture the percentage of kernels yielding fungi decreased from 97% to 0 at 20 days; while at 26% mc only 2% were invaded by A. glaucus at 5 days storage (Table 5). The decreased percentages of kernels invaded with fungi coincided with temperatures in excess of 60 C (Figure 5). This corroborated earlier findings reported by Christensen and Meronuck (1986).

The major species of field fungi identified at the different levels of moisture are presented in Appendix H.

Ergosterol Content

Ergosterol contents of rice stored at each moisture content and storage period were determined to confirm the presence of fungi in samples. (Appendix G). The percent of kernels yielding fungi decreased drastically at 10 days storage in samples at 22% mc while no fungi developed on samples at 26% moisture (Table 5). Despite this, the amount of ergosterol found in samples at 22 and 26% mc increased with time. Based on this finding, the procedure utilized for ergosterol determination was checked. It was discovered that a deviation was made during the "digestion" of the samples.

Ergosterol contents were rerun again using the remainder of samples of rice at 18, 22 and 26% mc. Although the values obtained in the second analysis were considerably

Table 6. Ergosterol content[1] of rough rice stored at 18, 22 and 26% moisture contents for different periods of time.

Moisture content	Days stored	Ergosterol (ppm)
18	20	3.34
	25	7.96
	30	13.99
22	5	7.89
	10	9.93
	20	58.95
26	5	6.62
	10	18.47

[1]means of two replicates

lower than those in the first, they did follow the same pattern (Table 6). Even though observed fungal invasion decreased for samples at 22% mc and no fungi developed on samples at 26% mc, the amount of ergosterol increased. It was suspected that the increased ergosterol might be a result of microorganisms not detected on seeds plated at 27 C (Meronuck, R. A. and Sauer, D. B. Personal communication. Nov 23, 1987). Samples at 22 and 26% mc were plated on PDA and incubated at 40 C to determine if thermophilic microorganisms were present. At least one species of the *Mucorales* group was found on seeds plated. Isolates from seeds plated on PDA and incubated at 40 C were inoculated on PDA and incubated at 27 and 40 C. While some *Mucorales* did grow on plates at 40 C none grew at 27 C when incubated for 6 days. This may explain the increased ergosterol originally found in samples at 22 and 26% moisture content (Table 6) and the fact that the temperature remained over 55 C. This discrepancy requires additional research.

CONCLUSIONS

The following conclusions are based on the results of this research.

1. The safe storage time, in terms of discolored rice kernels (less than 5%), for re-wetted rough rice is 10 days for 22% moisture content and 20 for 18% moisture content. At 26% mc, although there were no distinctly discolored kernels - at 5 days storage - the milled rice presented a distinctly creamy color that might reduce its consumer acceptance. Rough rice stored for 30 days at 14% mc did not result in discolored kernels of milled rice.

2. Based on the high correlation (r = -0.95 to -0.98) found between relative spectral reflectance and percentage discolored kernels, a color value of 67 could be considered an acceptable level of darkening of rice flour, corresponding to less than 5% discolored milled rice.

3. Storage of rough rice at moisture contents of 18 - 26% mc resulted in decreases in total milling yield (milling recovery). This decrease is greater at higher moisture contents and longer storage periods.

4. Tempering (re-wetting) and drying for milling considerably reduced head rice yields of samples prior to

storage. At 14% mc, head rice yield did not decrease over 30 days storage. HRY's were greater at 26% mc than 18% and 22% mc. At 22% mc HRY's tended t recover at 20 days storage.

5. Further research is necessary to investigate the relationship between mold development and ergosterol levels in heating rough rice and between degree-days and discolored kernels.

REFERENCES CITED

ALNAJI, L.K. 1975. Control of microorganisms during rice storage. Master of Science Thesis. Department of Grain Science and Industry, Kansas State University, Kansas, USA. p 23, 50.

BHATTACHARYA, K.R. 1985. Parboiling of Rice, IN Rice Chemistry and Technology. Published by AACC, St. Paul, Minnesota. Second Edition. p 289-348.

BURROUGHS, R.; SEITZ, L., AND CHUNG, D. S. 1981. Holding Rough Rice for testing. Kansas State University, Manhattan, Kansas. Paper presented at The 1981 Grains Post-Harvested Workshop. Manila Philippines. p 7.

CHEN Y. L. 1983. Effect of Environmental Changes on Rice Yield and particle size of Broken kernels. Cereal Chem. 60(3):238-241.

CHRISTENSEN, C. M., and LOPEZ, L. C. 1965. Relation of Moisture Content and Length of Storage to changes in the Microflora and Germination Percentage of rough Rice. Phytopathology 55:953-956.

CHRISTENSEN, C. M., and MERONUCK, R. A. 1986 Quality Maintenance in Stored Grains and Seeds. University of Minnesota Press, Minneapolis. p 7, 19-39.

DE CASTRO, R. E. ; ANDALES, S. C.; and PADUA, D. B. 1980. Field trials of pre-drying handling systems. Paper presented in the Proceeding of the 3rd Annual workshop on Grain Post-harvest Technology, Malaysia, 29-31 Jan. p 17.

ESMAY, M., SOEMANGAT, E. and PHILLIPS, A. 1979. Rice postproduction technology in the tropics. Published for the East-west Center by the University Press of Hawaii, Honolulu. p 80.

FANSE, H. A., and CHRISTENSEN, C. M. 1966. Invasion by Fungi of Rice Stored at Moisture Contents of 13.5 to 15.5%. Phytopathology, 56:1162-1164.

JULIANO, B. 1972. The Rice Cariopsis and its Cmposition, IN Rice Chemistry and Technology by The American Association of Cereal Chemistry. St. Paul, Minnesota. First Edition. p 16-74.

MALLICK, A. K. and NANDI, B. 1979. Role of moisture content in deterioration of rough rice in storage. Seed Science and Technology, 7:423-429.

MAURON, J. 1981. The Maillard reaction in Food; a Critical Review from the Nutritional Standpoint, IN Maillard Reactions in Food. Published by Pergamon Press. Great Britain. First Edition. p 5-35.

MEL'NIKOV, E. M., et al. 1982. Comparative characteristics of rice turning yellow during storage and yellowing hydrothermal treatment. (Rum., sum. in English). Pishcheraya Tekhnologiys No. 3. p 55-57.

NAEWBANIJ, M.; SEIB, P.A.; CHUNG, D.S.; SEITZ, L.M., and DEYOE, C.W. 1986. Ergosterol versus Dry matter loss as quality indicator for high rough rice during holding. Cereal Chem. 63(4):315-320.

QUITCO, R. T. 1981. Paddy deterioration from procurement to storage. The National Post-harvest Institute for Research and Extension (NAPHIRE). Technical Bulletin No. 2. Philippines. p 11.

QUITCO, R. T. 1982a. Studies on Fungal Infection and Heating on Paddy. Documentation of the GASGA-Seminar: Paddy Deterioration in the Humid Tropics, Philippines, Oct. 1982. p 52-56.

QUITCO, R.T. 1982b. Fungi as the cause of yellowing and other discoloration of rice. Paper presented at The Regional Grains Post-Harvest Workshop. Jan. 1982. Thailand. p 9.

RUITEN, H.T.L. 1985. Rice Milling: An overview, IN Rice Chemistry and Technology by The American Association of Cereal Chemistry, St.Paul, Minnesota. Second Edition. p 352

SEITZ, L.M.; MOHR, H.E.; BURROUGHS, R., and SAUER, D.B. 1977. Ergosterol as and indicator of Fungal Invasion in grains. Cereal Chem. 54(6):1207-1217.

SCHROEDER, H. W. 1965. Fungus deterioration of rice: Effects of fungus infection on free aminoacids and reducing sugars in white and parboiled rice. Cereal Chem. 42(6):539-545.

SCHROEDER, H. W. 1963. Orange Stain, a Storage Disease of Rice Caused by Penicillium puberulum. Phytopathology, 53:843-845.

TULLIS, E. C. 1936. Fungi isolated from discolored rice kernels. United States Department of Agriculture, Washington, D. C. Technical Bulletin No. 540. p 11.

United States Standards for Rice, Revised July 1983. Federal Grain Inspection Service, United States Department of Agriculture, Washington. D.C.

VASAN, B. S. 1980. Handling of high moisture paddy during wet season-a practical approach to the existing problem. Bulletin of Grain Technology. 18(3):232-233.

APPENDICES

Appendix A

Definitions of terms

According to the United States Standards for Rice, 1983, Heat-damaged kernels and Damaged kernels are defined as:

Damaged kernels: Whole or broken kernels of rice which are distinctly discolored or damaged by heat, water, insects or any other means, and parboiled kernels in non-parboiled rice. "Heat-damaged kernels" shall not function as damaged kernels.

Heat-damaged kernels: Whole or broken kernels of rice which are materially discolored and damaged as a result of heating and parboiled kernels in parboiled rice which are as dark as, or darker in color than, the interpretative line for heat-damaged kernels

For the purpose of this research:

Discolored kernels: was the "summation of heat-damaged kernels and kernels damaged by heat".

Total milling yield: was the quantity of whole and broken kernels of rice combined that are produced in the reasonable well milling or rough rice.

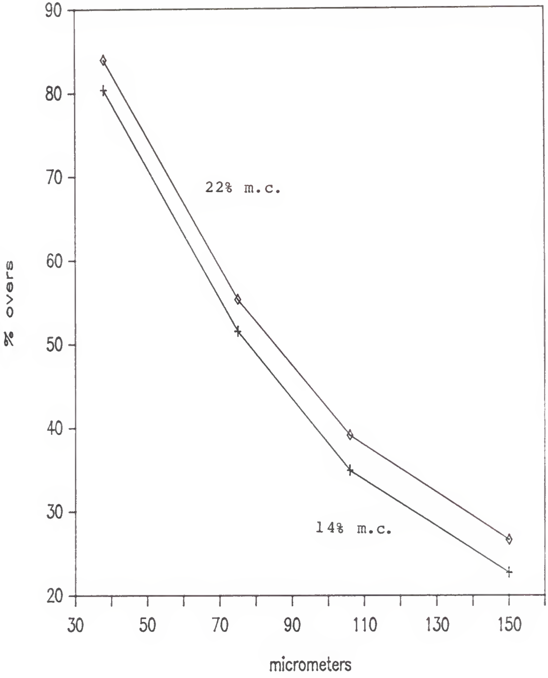
Head rice yield: was the quantity of unbroken kernels of rice and broken kernels of rice which are at least three-fourth of an unbroken kernel.

Appendix B: Brief study regarding the effect of particle size on the color values of rice at sstored at 14 and 22% moisture contents for 20 days.

B-1. Comparison of overs (%)[1] for two samples of rice stored at 14 and 22% mc for 20 days.

Sieve openings (micrometers)	Moisture Content (%)	
	14	22
38	80.4	84.0
75	51.5	55.3
106	34.9	39.1
150	22.7	26.6

[1]mean of two replicates and three determinations per replicate.



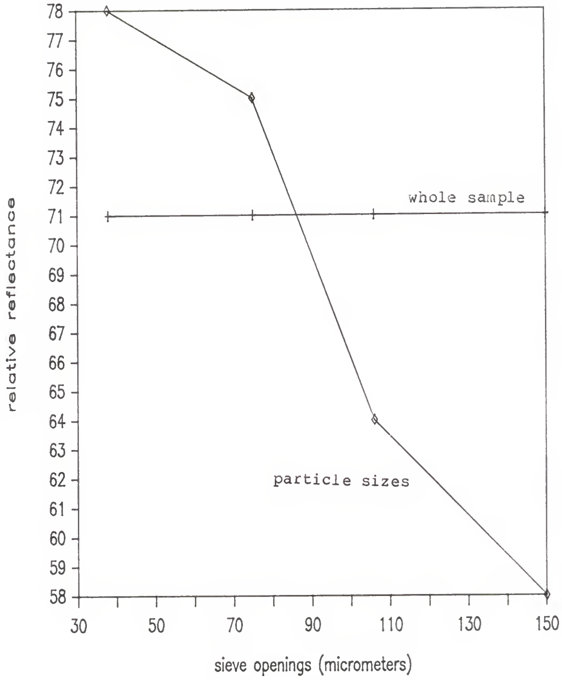
B-2. Comparison of overs (%) for two samples of rice stored at 14 and 22% mc stored for 20 days.

B-3. Means overs percentage[1] for two samples of rough rice stored at 14 and 22% mc 20 days.

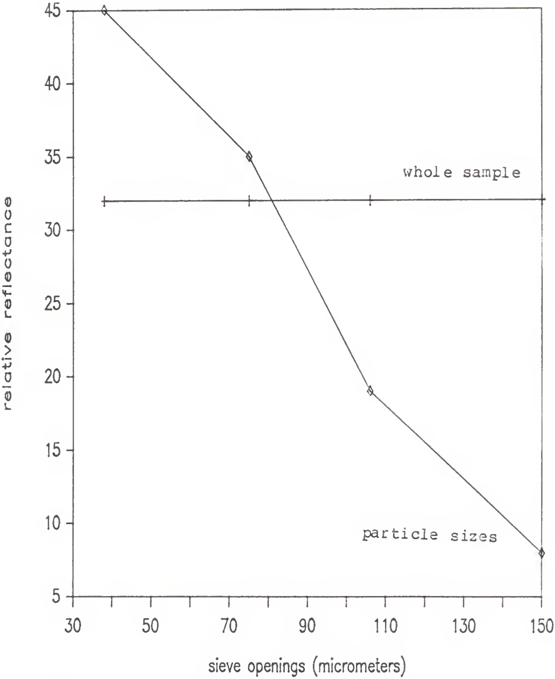
Moisture content	Mean % overs	St Dv	T value	Levels of sig.
14	47.3750	24.9810	-0.2202	0.8330
22	52.2500	24.7939	-0.2202	0.8330

We accept the Null Hypothesis = means are equal. The Ho = equal variances is also accepted, at $p = 0.9904$.

[1]mean of two replicates and 3 determination per replicate.



B-4. Comparison of reflectance/color for different particle sizes of rice stored at 14% mc for 20 days.



B-5. Comparison of reflectance/color for different particle sizes of rice stored at 22% mc for 20 days.

C. Milling tests[1] of rough rice stored stored at four moisture levels for different periods of time.

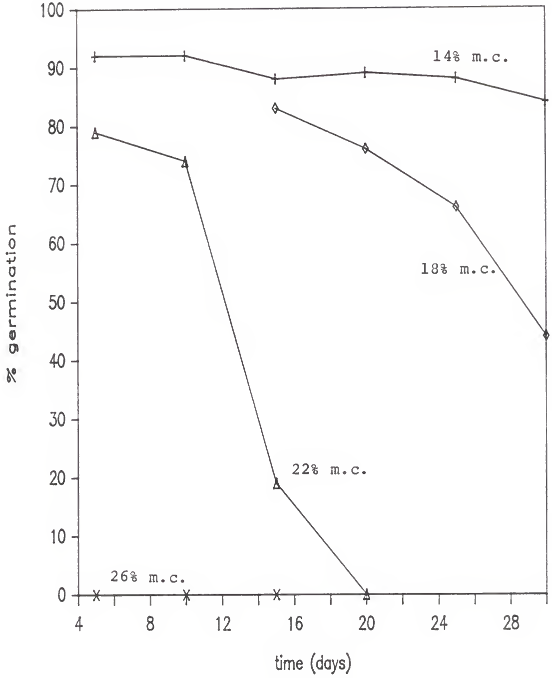
Moisture content	Days stored	Total milling yield (%)	Hulls (%)	Bran (%)	Head rice yield (%)
Initial	-	72.61	18.28	9.11	83.03
14	0	72.56	17.61	9.83	79.95
	5	71.76	18.64	9.60	79.89
	10	70.70	20.35	8.95	76.40
	15	70.15	18.35	11.50	74.45
	20	69.58	20.51	9.91	78.02
	25	70.03	20.49	9.48	79.88
	30	69.22	20.57	10.21	81.32
18	0	71.62	18.14	10.24	49.56
	15	69.23	19.94	10.79	33.41
	20	67.58	21.16	11.26	41.27
	25	67.36	21.28	11.36	40.95
	30	66.41	21.30	12.29	40.92
22	0	71.57	18.24	10.19	46.21
	5	68.30	21.22	10.48	40.66
	10	68.49	21.80	9.71	37.93
	15	67.92	22.44	9.64	39.87
	20	63.95	26.04	10.01	52.75
26	0	72.34	18.03	9.63	65.04
	5	69.11	21.94	8.95	71.23
	10	66.10	20.43	13.47	61.04
	15	64.14	23.25	12.61	66.23

[1]mean of two replicates. Bran % determined by difference.

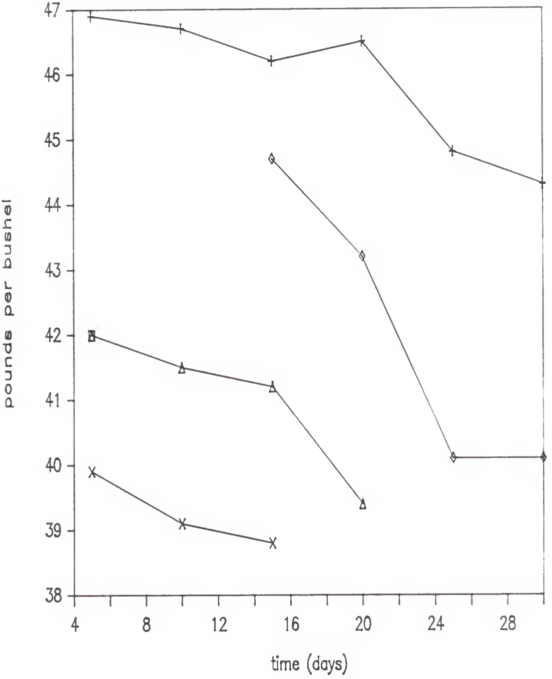
D-1. Percentage of germination of rough rice stored at four moisture levels for different periods of time.

Moisture content	Days stored	Germination[1] (%)
Initial	-	92
14	5	92
	10	92
	15	88
	20	89
	25	88
	30	84
18	15	83
	20	76
	25	66
	30	44
22	5	79
	10	74
	15	19
	20	0
26	5	0
	10	0
	15	0

[1]mean of two replicates



D-2. Germination percentage of rough rice stored at four moisture levels for different periods of time.



E-1. Test weight of rough rice stored at four moisture levels for different periods of time.

E-2. Test weight of rough rice stored at four moisture levels for different periods of time

Moisture content	Days stored	Bulk density[1] (lb/bu)
Initial	-	47.2
14	5	46.9
	10	46.7
	15	46.2
	20	45.5
	25	44.8
	30	44.3
18	15	44.7
	20	43.2
	25	40.1
	30	40.1
22	5	42.0
	10	41.5
	15	41.2
	20	39.4
26	5	39.9
	10	39.1
	15	38.8

[1]determined after drying and mean of two replicates.

G. Ergosterol content[1] of rough rice stored at four moisture levels for different periods of time.

Moisture content	Days stored	Ergosterol (ppm)
Initial	-	2.16
14	5	1.62
	10	1.45
	15	1.28
	20	1.46
	25	1.34
	30	1.95
18	15	7.04
	20	7.09
	25	29.42
	30	30.76
22	5	20.69
	10	29.66
	15	57.46
	20	184.58
26	5	14.64
	10	49.94
	15	109.73

[1]mean of two replicates

H. Major species of field fungi on rough rice stored at four moisture levels for different periods of time.

Moisture content (%)	Days stored	Field fungi species
Initial	-	Alternaria, Helminthosporium.
14	05	Alternaria, Sphaeropsiles (Phoma).
	10	Alternaria, Helminthosporium, Curvularia.
	15	Alternaria, Helminth.
	20	Alternaria, Helminth.
	25	Non-sporulated white mycelium (NSWM).
	30	NSWM, Alternaria.
18	15	Alternaria, Helminth.
	20	Alternaria, Helminth.
	25, 30	No growth.
22	05	Fusarium, Alternaria.
	10	Mucorales (Syncephalastrum), Fusarium, Curvularia.
	15, 20	No growth.
26	5, 10, 15	No growth.

EFFECT OF MOISTURE CONTENT ON MILLING OF ROUGH RICE STORED FOR SHORT PERIODS OF TIME

BY

FAUSTO MEJIA-MARTINEZ

B.S., Universidad Autonoma de Santo Domingo, Santo Domingo, Republica Dominicana (1975)

AN ABSTRACT OF A THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Grain Science & Industry

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1988

ABSTRACT

Long grain rough rice at 14, 18, 22 and 26% moisture content was stored for 5, 10, 15, 20, 25 and 30 days to determine how moisture content and length of storage affected the quality of milled rice. Insulated containers (STRONGLAS-fillers) were used to simulate bulk storage.

To obtain milled rice with less than 5% discolored kernels (determined by USDA interpretative line transparencies) rough rice was stored for 10 days at 22% mc and 20 days at 18% mc. At 26% mc, rice milled after 5 days storage had a distinct creamy color (less than 1% discolored kernels) and after 10 days, 95% discolored kernels. Rough rice stored at 14% mc over 30 days did not result in discolored kernels. Discoloration was also determined by relative spectral reflectance.

Rice temperatures increased within the insulated storage containers and had a distinct effect on percentage discolored kernels. Rough rice stored at 26% mc reached a maximum temperature of 65 C in 5 days and at 10 days had 95% discolored kernels. At 22% mc, a maximum of 61 C was reached at 15 days and resulted in 85% discolored kernels at 20 days. At 18% mc a maximum temperature of 46 C was reached at 25 days and had only 8% discolored kernels at 30 days.

Temperatures did not increase in rice stored at 14% mc.

Total milling yield (TMY) decreased only slightly over 30 days for rice stored at 14% mc. TMY's were lower, respectively, for rice stored at 18, 22 and 26% mc and tended to decrease with increased time of storage. Head rice yields (HRY) were greatest at 14% mc and remained about the same over 30 days storage. HRY's were lowest at 18, 22, and 26% mc were reduced considerably by tempering and drying for milling and tended to increase at higher moisture contents.

The degree of microbial activity in samples (determined by plating) remained constant at 14% mc with approximately 77% kernels invaded with field fungi. At 18% mc, 100% of the kernels were invaded. The percentage invaded by field fungi decreased and those invaded by storage fungi increased. At 22% mc, the percentage kernels invaded by both field and storage fungi decreased from 97% at 5 days to 0 at 20 days. No fungi were detected by plating in 26% mc rice stored for 5, 10 or 15 days.