Effect of rice storage conditions on the quality of milled rice[1]

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Abstract

To study the effects of moisture content and length of storage on the quality of milled rice, two lots of long grain New Bonnet rough rice with moisture content (m.c.) at 14, 18, 22, and 26% were stored for 5, 10, 15, 20, 25, and 30 days in insulated containers in a chamber maintained at 25°C and 88% relative humidity.

The rough rice stored at 26% m.c. reached a maximum temperature of 63°C in 6 days. When stored at 22% m.c., the maximum temperature reached was 50°C in 17 days, and at 18% m.c. 45°C in 27 days. No temperature increase was observed on rough rice stored at 14% m.c.

The data indicate that rough rice stored at high moisture contents had greater percentages of discoloured kernels, lower milling yield, and lower germination percentage. The percentage of kernels invaded with storage fungi was higher on rough rice stored at high moisture, except at 26% m.c. where the percentage of kernels invaded with storage fungi was almost nil. Such samples had high percentages of kernels invaded with *Thermomyces* sp., a thermophilic fungus.

Introduction

As with any cereal grains, rice is subject to deterioration when not properly stored. The major determinants of storage risk are moisture content, temperature, and time of storage (Christensen and Sauer 1982); Zeleny (1954) stated that moisture content is the most important factor.

Moisture content has an important influence on several aspects of rice quality. Its primary effect is on the keeping properties of rice during storage. Under practical storage conditions moisture is generally the factor most responsible for controlling the rate of deterioration (Webb 1985).

One form of deterioration observed on milled rice is discolouration. Factors such as the development of fungi, elevated temperatures, and biochemical reactions within grain kernels stimulated by high moisture and elevated temperatures have been implicated in rice discolouration (Christensen 1957; Mauron 1981).

In this paper, the discolouration referred to is rice yellowing as defined by interpretive-line slides, R-2.0, heat damage kernels and R-2.1, kernels damaged by heat (S/J Systems Co., Milwaukee, WI) as approved by the USDA in September 1984 and January 1985, respectively.

In rice-growing areas of the world, rice yellowing is a serious problem and is a major determinant of quality and price in milled rice. In rice-grading systems, tolerance levels are established for the presence of yellow kernels (USDA 1989). In Southeast Asia, yellowing of rice is a common post-harvest problem causing financial losses due to downgrading or rejection (Phillips et al. 1988).

There are conflicting reports as to the cause of rice yellowing. Perez and Juliano (1982) stated that yellow rice results from heating of stored unthreshed grain. They speculated that yellowing is caused mainly by fungal respiration at very high humidity. Phillips et al. (1989) found up to 100% yellow grains in wet paddy stored at moisture content greater than 20%. They also stated that it was associated with a high incidence of mould growth and heating of the grain. The involvement of microorganisms on rice yellowing was also reported by Desikachar et al. (1959) and Quitco (1982).

Yap et al. 1990 reported that yellowing of rice can be attained artificially, i.e. without the involvement of microorganisms. In a study of the influences of temperature, water activity and storage atmosphere on the yellowing of milled rice, Gras et al. (1989) suggested non-enzymic browning as the mechanism of yellowing. They further stated that the influences of temperature and water activity were predominant. Bason et al. (1990) made similar observations using rough rice.

In a study on the effect of moisture content on milling of rough rice stored for short periods, Mejia-Martinez (1988) observed that rough rice stored at 14% m.c. over 30 days did not yield discoloured kernels. When stored at 26% m.c., rice milled after 5 days of storage had a distinctly creamy colour (<1% of discoloured kernels), and after 10 days had 95% discoloured kernels. Additionally, he observed that the percentage of kernels yielding fungi decreased drastically at 10 days storage in samples stored at 22% m.c. and no fungi were recovered from samples at 26% m.c. However, the amount of ergosterol in samples at 22% and 26% m.c. increased with time.

This study was conducted to determine the effects of moisture content and length of storage of rough rice on the quality of milled rice.

Materials and Methods

Rice sample

Two lots of long grain New Bonnet rice used in this study were harvested in September 1991 and obtained directly from the field in Arkansas. Lot 1 from Tojamisa Inc., Craighead County, Arkansas had 19.7% m.c. and a test weight of 44.9 lb per bushel. Lot 2 from L. A. Craig Farms, Craighead County, Arkansas had 20.7% m.c. and a test weight of 45.5 lb per bushel.

For transport, the rice samples were placed in styrofoam containers with dry ice to prevent deterioration and maintain

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the moisture content. Each lot was mixed before the experiment, then samples were taken for determination of moisture content, percentage of germination, percentage of kernels yielding fungi and milling yield. Not all of the rice samples were used at once, so the remaining samples which were at their original moisture content were stored at 5°C.

Experimental conditions

Four moisture contents (14, 18, 22, and 26%) and six storage periods (5, 10, 15, 20, 25, and 30 days) were used. Each moisture was evaluated separately. Rice samples were stored in 2 L capacity thermos bottle fillers (Thermos 18F Stronglas filler, King-Seeley Thermos Co., Norwick, Conn.). Six thermoses were used for each lot of rice; one for termination after 5, 10, 15, 20, 25, and 30 days of storage. A thermocouple was placed within the grain mass and cotton was used to fill the neck space and to support the thermocouple. For stability and to enhance insulation, the Stronglas fillers were placed in metal cans (15.7 cm diameter and 17 cm tall) and polyurethane was used to fill the space between the can and the filler.

Moisture adjustment

Before tempering, approximately 7000 g of each lot of rice was passed through a Carter dockage tester (set for U.S. rice grading) to remove materials other than rice. A preliminary moisture content was determined using a Dickey John GAC II moisture tester. Based on this moisture content, water was added to obtain the required moisture content of the sample. Lots were tempered by placing samples in 60 × 45 cm polybags, adding the required water, mixing thoroughly by shaking and storing at 5°C for 1–2 days to equilibrate. For samples tempered to 26% m.c. half of the amount of water was added during the first day of tempering and the other half was added the second day. After equilibration, the tempered lot was divided into six 1000 g samples using a Boerner divider. Each 1000 g sample was placed in a 2 L capacity thermos bottle.

To obtain 14 and 18% m.c., rough rice samples were air dried at 25 ± 3°C and 60 ± 5% r.h..

Storage and sampling

The thermoses with rice were placed at random in a controlled chamber with 25°C temperature and 88% r.h. and stored for 5, 10, 15, 20, 25, and 30 days. Temperature was recorded daily for each sample using a thermocouple reader. After each storage period, subsamples for determination of moisture content (10–15 g), percentage of kernels invaded with fungi (30 g), ergosterol (20 g), and for percentage of germination (10 g) were taken and stored at 5°C until analysed. The remainder of the sample was dried at 25 ± 3°C and 60 ± 5% r.h. for milling.

Moisture content determination

Except for preliminary moisture tests, moisture content was determined by drying 10–15 g of rough rice at 120°C for 24 hours in a forced-air oven. Moistures were determined before storage, after storage, and after air drying for milling.

Germination

One hundred seeds were placed between moist brown paper towels, wrapped in aluminum foil and incubated at room temperature. Germinated seeds were counted after 3, 5, and 7 days of incubation. Any seed with hypocotyl and coleoptile was counted as germinated.

Fungal invasion

Rough rice kernels were surface disinfected by first rinsing for 5–10 seconds in 95% ethanol then shaking for 1 minute in 2% NaClO (Clorox), and rinsed in sterile distilled water. One hundred seeds were each plated on malt agar (MS6T) containing 6% NaCl and 200 ppm Tergitol NPX (Sigma Chemical Co., St Louis, MO); potato dextrose agar (PDA); and brown rice extract agar (BRE). The BRE was prepared based on the procedure by Naewbanij et al. (1983). Plates were incubated at room temperature for samples stored at 14, 18, and 22% m.c. or at 43°C for samples stored at 22 and 26% m.c.. The number of kernels yielding fungi were counted and identified using a dissecting microscope, 3–10 days after plating. Fungi were identified to genus and species level for *Aspergillus* and to genus level for all other fungi. Unidentified fungi were grown on agar blocks on glass microscope slides incubated in petri plates with moist filter paper.

Ergosterol determination

The ergosterol level of the samples was determined using high performance liquid chromatography (HPLC) using the method of Seitz et al. (1979).

Rice drying for milling

After storage, samples were air dried to 12–13% m.c. for milling. Samples were placed on 30 × 30 cm screen trays on a drying plenum located in an environmental chamber at 60 ± 5% r.h. and 25 ± 3°C. Air was pulled through the samples until the moisture of the rice equilibrated with the humidity of the air. Equilibration usually took place at 16–27 hours. Moisture content of the samples was checked periodically using a Dickey-John GAC II moisture tester with final moisture content determined using the air-oven method.

After air drying, the bulk density of the rough rice was determined using a Burrows test-weight apparatus. The samples were then passed through a Carter dockage tester.

Milling tests

Rough rice samples were dehulled using a McGill laboratory sheller (McGill Inc., Houston, Texas) to obtain brown rice. The dial was set at 19 (for long grain rice) to obtain 90–94% dehulled rice (USDA 1989). The dehulled rice was polished using a McGill No. 2 Miller (Rapsco, Brookshire, Texas). An 802 g weight placed on the weight lever at 24.2 cm from the saddle centre was removed after 30 seconds of the regular continuous milling time of 60 seconds.

The total milling yield was calculated by dividing the weight of the milled rice by the weight of the rough rice multiplied by 100.

Head rice consists of unbroken kernels of rice and broken kernels of rice which are at least 3/4 of an unbroken kernel. The percentage head rice yield was calculated by dividing the weight of head rice by the weight of the milled rice sample multiplied by 100.

Discoloured kernels

Discoloured kernels from a 25 g milled rice sample were handpicked and compared with interpretive line slides for rice as approved by the U.S. Federal Grain Inspection Service. R-2.1 (kernels damaged by heat) is defined as any part of whole

or broken kernels of rice which are distinctly discoloured as a result of respiration. R-2.0 (heat damaged kernels) is defined as whole or broken kernels with intensity of discolouration equal to or greater than shown on slide. The percentage of discoloured kernels was determined by dividing the weight of discoloured kernels by the weight of milled rice sample multiplied by 100.

Degree of whiteness

The relative spectral reflectance is another measure of the degree of whiteness of milled rice. A 30 g sample of ground milled rice was placed in an Agtron cup, compacted 35 times and measured in an Agtron M-500 A. Calibration disks 63 and 97 were used to set the Agtron to 0 and 100, respectively. The green mode (546 nm) was used to make the reflectance measurement.

All data were statistically analysed using the SAS (1989) General Linear Model procedure.

Results and Discussion

Temperature

For rice stored at 14% m.c., the temperature remained at 26°C throughout the storage period. When stored at 18% m.c., the maximum temperature reached was 45°C in 27 days and when stored at 22% m.c., the maximum temperature reached was 50°C in 17 days. The rough rice stored at 26% m.c. reached a maximum temperature of 63°C in 6 days (Fig. 1). Except for rice stored at 14% m.c., temperatures declined after reaching the maximum. Milner and Geddes (1946) reported that temperatures in soybeans stored at 25°C and 22% m.c. levelled off at approximately 55°C but then continued to increase after several days due to chemical oxidation. This phenomenon was not observed in this study.

Moisture content

During the storage period, moisture content of rough rice at 14, 18, and 22% remained similar to that at the beginning of storage. However, at 26% the moisture content decreased to approximately 22% after 15 days and remained at that level through 30 days of storage (data not shown).

Germination

Rough rice stored at 14% m.c. had a significantly higher percentage of germinated seeds than at higher moisture contents (Fig. 2). Germination percentages for rough rice stored at 18 and 22% m.c., were not significantly different from each other, except for the initial germination at 22% m.c.. The lower initial percentage germination of 53% at 22% m.c. and 67% at 26% m.c. may be attributed to the dormancy of freshly harvested rice (Perez and Juliano 1981).

At 18 and 22% m.c., the percentages of germination declined slowly with increased storage period even with the presence of storage fungi. Christensen and Lopez (1965) reported a similar observation on rice stored at 15.5% m.c.. They found that invasion of rice by storage fungi seemed to result in slower loss of germination compared with sorghum, wheat, barley, and maize.

No seeds germinated from rough rice stored at 26% m.c. when stored for 5 days or more.

Fungal invasion

Fungi were usually present on rice samples after all storage periods (Table 1), but the species which developed varied depending on the initial moisture content of rice.

Field fungi

The total field fungi observed was significantly higher for rough rice stored at 14 and 18% than at 22 and 26% m.c.. A similar observation was made by Christensen and Lopez (1965) on Bluebonnet rice. The genera commonly observed were: *Alternaria, Fusarium, Curvularia, Cladosporium, Corynospora, Helminthosporium*, and *Nigrospora*. At 26% m.c., the field fungi isolated were mainly *Fusarium* spp. Del Prado and Christensen (1952) also reported that *Curvularia, Fusarium, Alternaria*, and *Cladosporium* were common field fungi observed on 12 varieties of rice collected from Louisiana and Surinam.

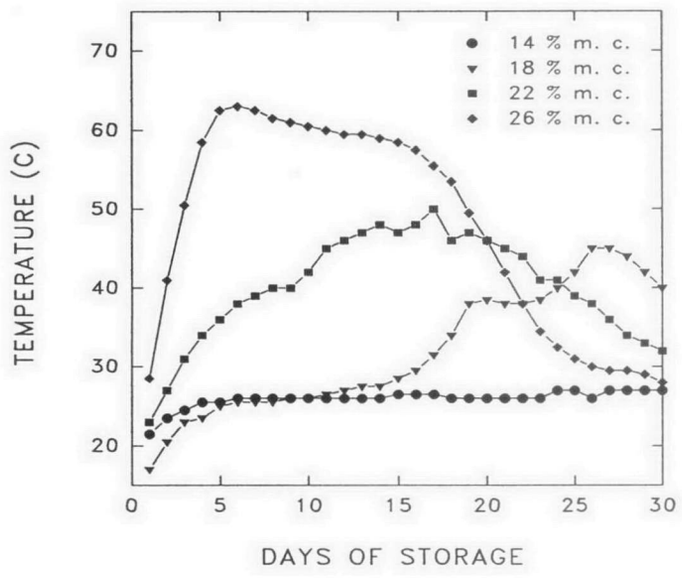

Fig. 1. Daily temperature of rough rice stored for 30 days at 14, 18, 22, and 26% moisture content.

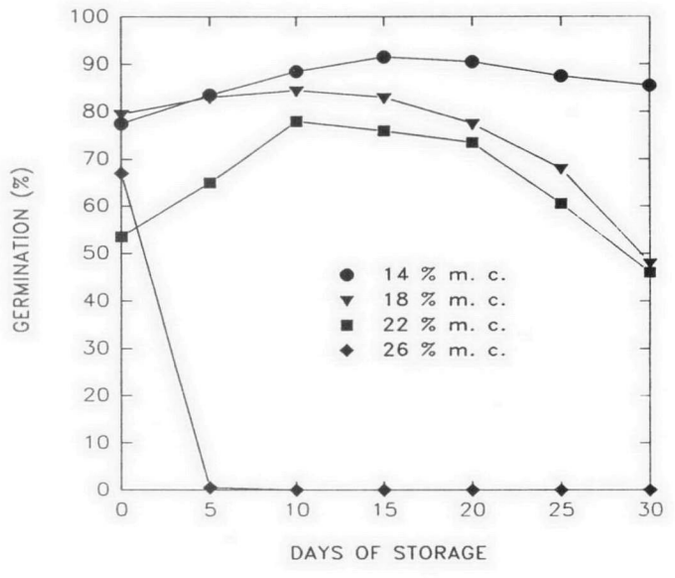

Fig. 2. Germination of rough rice stored for 30 days at 14, 18, 22, and 26% moisture content.

Storage fungi

When stored at 14% m.c. only 1% of the kernels were invaded by *Aspergillus glaucus* after 20, 25, and 30 days of storage. Rough rice stored at 18% and at 22% m.c. had the highest percentage of *Aspergillus* and *Penicillium* species. Generally, the percentage of storage moulds observed increased with storage time. The species commonly present were: *Aspergillus glaucus*, *A. candidus*, *A. flavus*, *A. niger*, *A. ochraceus*, *A. versicolor*, *A. fumigatus*, *A. ustus*, and *Penicillium* spp. Most of these species are associated with stored grains that are heating (Christensen and Meronuck 1986).

At 26% m.c., *A. fumigatus* was the principal *Aspergillus* species observed and it decreased with increased storage period. Visually, however, such samples showed advanced deterioration.

The low percentages of most fungi in rough rice stored at 26% m.c. may be attributed to heating within the grain mass. Figure 1 shows a temperature of 63°C after 5 days of storage. This temperature is too high for most fungi to survive (Cooney and Emerson 1964). However, after the maximum temperature was reached, *Thermomyces* sp., a thermophilic fungus, was increasingly observed (Table 1). A greater percentage of the kernels also yielded yeasts.

The presence of fungi on the rice samples was confirmed by determining the amount of ergosterol (Table 1). Seitz et al. (1979) reported that ergosterol determination is an important aid in evaluating the extent of fungal invasion on grain samples where fungi are difficult to detect due to unfavourable conditions. Mejia-Martinez (1988) reported ergosterol in rice stored at 26% m.c., but plated rice samples were not incubated at 43°C to detect the thermophilic fungus, *Thermomyces* sp.

The other fungal genera observed in this experiment were *Rhizopus* sp. and *Mucor* sp. For rice stored at 22% m.c., *Mucor* sp. was commonly observed after all storage periods.

Milling and head rice yield

Rough rice stored at 14 and 18% m.c. had significantly higher milling yields compared with those stored at 22 and 26%. Rice stored at 26% m.c. had the lowest milling yield which also decreased with storage period (Fig. 3).

The percentage head rice yield generally decreased with storage time, but there were no significant differences due to moisture content.

Discoloured kernels

Based on the interpretive line slides, rough rice stored at 26% m.c. had a significantly higher percentage of discoloured kernels than at 22%. There were no discoloured kernels observed on rice stored at 14 or 18% m.c. (Fig. 4). At 18% m.c., however, the milled rice appeared slightly grey instead of white. In addition, some yellow kernels were observed after 25 and 30 days of storage, but the intensity was not as great as that on the line slide. This change in appearance was reflected in the reduction of relative spectral reflectance readings at 18% m.c. obtained with the Agtron. Relative spectral readings were also significantly affected by moisture content. This observation indicates that Agtron may provide an objective measure of rice discolouration. Milled rice obtained from rough rice stored at 14% m.c. in all storage periods was not discoloured.

The percentage of discoloured kernels was high when rough rice was stored with high initial moisture content. Rough rice stored at 26% m.c. attained the highest temperature (63°C) in 5 days; and percentage of discoloured kernels reached 83% in 10 days. Although the temperature declined after 5 days, the percentage of discoloured kernels increased throughout the storage period.

Conclusion

Our results indicate that discolouration of milled rice was greatly affected by the initial moisture content of rough rice during storage.

High moisture content stimulated the growth of fungi which in turn elevated the temperature in a thermally insulated environment. High temperature appeared to determine the species

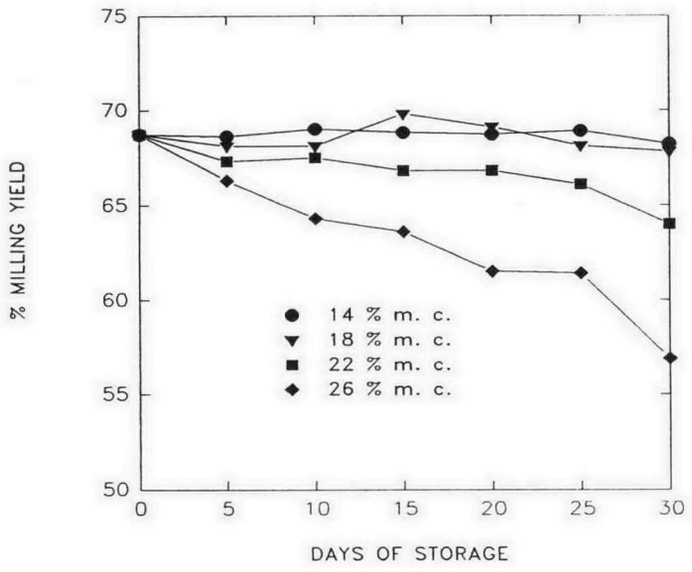

Fig. 3. Milling yield of rough rice stored for 30 days at 14, 18, 22, and 26% moisture content.

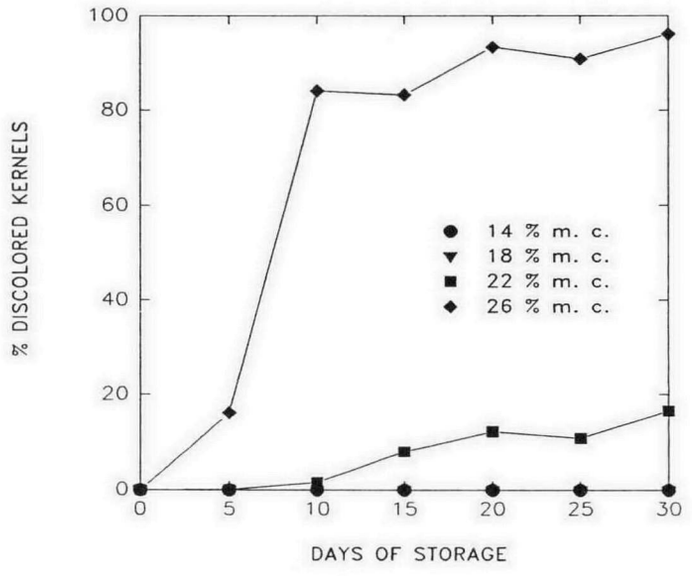

Fig. 4. Milling yield of rough rice stored for 30 days at 14, 18, 22, and 26% moisture content.

Table 1. Mould invasion and ergosterol level of rough rice stored for 30 days at 14, 18, 22, and 26% moisture content (m.c.).

m.c.	Time	Kernels invaded (%)[b]	Total percent[a] invaded by				Ergosterol (ppm)
			Field fungi[c]	Storage fungi[d]	*Thermomyces* sp.	Yeast	
	Initial	100	261	0	0	0	7.02
14	5	100	249	0	0	0	5.00
14	10	100	269	0	0	0	4.03
14	15	100	259	0	0	0	3.17
14	20	100	227	1	0	0	3.50
14	25	99	279	1	0	0	3.33
14	30	97	213	1	1	0	3.98
18	5	100	235	0	0	0	5.52
18	10	100	219	22	0	0	5.58
18	15	100	258	43	0	0	5.13
18	20	100	253	58	0	0	8.77
18	25	100	110	103	1	0	12.58
18	30	98	29	123	6	0	20.87
22	5	100	160	3	0	0	8.42
22	10	100	188	23	0	0	46.47
22	15	71	28	50	0	2	34.39
22	20	83	29	39	0	2	24.82
22	25	76	15	69	1	4	25.90
22	30	97	87	42	0	0	61.94
26	5	100	1	15	81	36	47.77
26	10	100	15	1	77	77	47.02
26	15	100	15	2	86	58	87.32
26	20	100	26	0	97	48	152.97
26	25	100	0	9	90	90	155.87
26	30	100	0	3	74	83	153.30

[a]Sum of the percentages of all species observed in 100 kernels.
[b]100 minus non invaded kernels.
[c]Include the genus *Alternaria, Curvularia, Cladosporium, Corynospora, Fusarium, Helminthosporium,* and *Nigrospora.*
[d]Include *Aspergillus glaucus, A. candidus, A. flavus, A. niger, A. ochraceus, A. versicolor, A. fumigatus, A. ustus,* and *Penicillium* spp.

of fungi which remained active. The conditions generated by the fungi resulted in decreased germination, low milling yield, and high percentage of discoloured kernels.

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