Effects of Controlled Ambient Aeration on Rice Quality During On-Farm Storage

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ABSTRACT

Rice (*Oryza sativa* L., 'Cypress') quality is highly dependent on its handling; hence, new storage treatments must be analyzed for their impact on rice quality. Rough rice from the 2000 season was harvested, dried, and stored in six farm-scale bins. Three of the bins were aerated with a thermostatically activated controller, and three were aerated under traditional methods. Rice was sampled periodically over 12 weeks, and quality parameters were analyzed. The effects of bin sample position (spatial), bin sample depth, aeration treatment, and storage duration were investigated for their impact on rice quality factors: moisture content, head rice yield, pasting properties, and water absorption. For both aeration treatments at most sampling durations, rice sampled from the center of the bins had significantly lower head rice yield than that sampled from the north and south areas. Overall, moisture contents were not significantly affected by sampling position, although, in some specific sampling time and aeration treatment combinations, significant variation was noticed for moisture content as a function of sampling position. Sample depth within the bin did not cause any changes in the values of the rice properties. Throughout the storage duration, the physicochemical properties of the rice treated with controlled aeration were consistent with the trends of the rice treated with manual aeration. Storage duration significantly influenced ($P < 0.05$) water absorption, peak viscosity, head rice yield (HRY), and moisture content, with all but moisture content increasing over the storage duration. In contrast, the moisture content of the grain slightly decreased over the storage period.

Previous research has shown that the physicochemical properties of rice (*Oryza sativa L.*) are dependent on storage conditions and storage duration. These changes during storage are known as aging. As rice ages, both head rice yield and water absorption ratio increase (Villareal et al 1976). Additionally, changes in grain hardness, volume expansion, and pasting properties have been reported (Sajwan et al 1989; Dhaliwal et al 1990; Hamaker et al 1993, Pearce et al 2001). According to Perez and Juliano (1982), these changes are most significant within the first three months of storage.

Several studies have described the changes that occur in rough rice during storage within a laboratory setting (Perdon et al 1997; Daniels et al 1998). In these studies, rice was held in settings with controlled temperature and relative humidity. Even with closely controlled environments, the physical property response of the rice was difficult to predict. The general trends that were verifiable include 1) head rice yield (HRY) typically increased over the first two to three months of storage, then decreased; 2) pasting properties typically increased over the first three months, then decreased; and 3) water absorption slightly increased over the first month of storage, then held steady. The conditions encountered in farm-scale storage, however, are very unpredictable. Within each bin, small "microenvironments" develop in different spatial areas and grain depths. Very little work has been published that examines how this phenomenon affects functional properties of rice during storage. Processors consistently report that rice milling quality of a given lot is unpredictable, not only from year to year, but also from day to day.

Aeration is the process of blowing ambient air through grain masses for the purpose of cooling and conditioning grain (Bala et al 1990). Aeration can cause changes in the temperature and moisture content of the stored grain as "aeration fronts" pass through the grain. Ambient air conditions significantly affect the grain conditions. There are two main methods in which a rice processor may choose to aerate. Manual aeration requires the storage manager to operate fans with subjective discretion, depending on the manager's experience and ability to monitor weather conditions to determine proper aeration times. Typically, a storage manager will aerate rice when the ambient air conditions are within 10°C of that of the rice and when the humidity is sufficiently low that rehydration will not occur. The manager will operate aeration fans for several hours per week as necessary. Conversely, controlled aeration involves the utilization of a controller that monitors ambient air conditions and activates the aeration process at conditions that will optimize the cooling and conditioning process. Controlled aeration can be used as part of an integrated pest management system to control insect infestations within stored grain because the grain may be rapidly cooled to temperatures below those at which insects can survive.

Consequently, our study was part of an overall research project aimed at determining the effects of on-farm storage conditions on rice quality. Our specific objectives were to determine the effect of aeration treatment, rice depth in a bin, spatial position of rice in a bin, and storage duration on the physicochemical properties of farm-stored rice.

MATERIALS AND METHODS

Rice Storage

Rice (cv. Cypress), harvested in September of 2000, from the Arkansas Department of Corrections Farm near Grady, AR, was used for the study. The rice was dried to 12–14% moisture content (MC), from an initial harvest MC of 20%, by the farm manager using conventional bin drying methods (dried at ≈32.2°C [90°F] for two to three days depending on the harvest MC of the rice). All of the rice was dried in three bins (of the six used). When the first batch of rice was dried, it was transferred to three storage bins at the same site. Then, another batch (three bins) was dried and prepared for storage. All of the bins (GSI, Assumption, IL) were located on the Department of Corrections Farm.

Six bins, 31,000 bu capacity each (12.8 m [42 ft] in diameter and 7 m [23 ft] tall) were filled with ≈20,000 bu of dried rice. Rice in three of the bins was aerated with a thermostatically controlled system (described below), and rice in the three remaining bins was aerated manually according to traditional practices. The fan on each bin (22.4 kW [30 hp], 1,750 rpm, GSI, Assumption, IL) operated at ≈1.3 m^3/min/t (1.2 cfm/bu), based on the amount of rice in the bins. These flow rates are higher than traditional aeration flow rates used in corn and wheat but common in the rice-growing region of the United States

The thermostatically activated aeration controller activated the fans for three bins when the ambient air reached preset conditions. The controllers were set to cool the rice in three cycles. Initially, the thermostat was set to aerate the rice when the ambient air was

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≤23.9°C (75°F). A humidistat prevented rehydration of the rice (aeration at high relative humidity). The equilibrium moisture content values (EMC) of rough rice as a function of temperature and relative humidity were calculated by the modified Henderson equation (ASAE 1997). When the grain temperature equilibrated at ≤23.9°C, the controller was set at 15.5°C (60°F) and 70% rh, and the process was repeated. Finally, the controller was set at 7.2°C (45°F) and 65% rh. Modeling of storage conditions with similar three-cycle aeration plans predicted a successful reduction in grain temperatures compared with traditional methods in corn and wheat (Arthur 1994; Reed and Harner 1998).

The control bins were aerated under the subjective discretion of the farm manager. The manager relies on past experience and instincts to maintain the rice quality. This type of management is practiced often and is difficult to predict or duplicate. In this work, the rice was aerated when the ambient temperature was within 10°C of the rice temperature, and the fans were operated about three hours per week. Thermocouples were distributed in the grain mass to record temperatures at four locations in each bin: north, center, and south locations at 1 m from the top of the grain surface, and in the center at 3 m from the top of the grain surface.

The drying and storage manager dried all of the rice in three bins equipped with a stirrer to aid the drying. After the first batch of rice was finished drying, it was transferred to three bins that were not equipped with stirring devices (these bins were used for controlled aeration). The second batch of rice was loaded into the stirall-equipped bins and dried, it was used for manual aeration. Effects of the stirring devices were expected for some of the rice properties, particularly head rice yield and moisture content.

Rice Sampling

At one-month intervals, for three months, samples were taken from north (N), south (S), and center (C) bin positions at depths of 0.9 m (3 ft) and 2.7 m (9 ft) for a total of six samples per bin. The physicochemical properties of the rice were monitored by evaluating the moisture content, head rice yield, and water absorption and pasting properties.

Physicochemical Property Analyses

Moisture content. The moisture content of the samples was determined using the open air oven method. Duplicate samples were dried for 24 hrs in an open air oven at 130ºC (Jindal and Siebenmorgen, 1987). The moisture content was calculated on a wet basis by taking the mass of water evaporated from the sample and dividing it by the mass of the moist sample.

Head rice yield. Rough rice (150 g) was hulled using a mechanical huller (Satake Engineering, Tokyo, Japan). The brown rice was then milled (McGill #2, Seedburo Equipment, Chicago, IL) to a degree of milling (DOM) of 90 ± 5 determined by a Satake MM1-B meter. The whole kernels were separated from the brokens using a shaker table with 10/64 trays (Grainman Machinery, Miami, FL). The head rice was then weighed, and HRY was calculated as a percentage. Head rice yields were run in duplicate and averaged for each sample.

Water absorption was determined by cooking head rice in excess water and then measuring the change in rice weight (Bhattachayra and Sowbhagya 1971). Modifications to this procedure included placing 20 g of head rice in a wire basket which was then placed in a 250-mL beaker containing 150 mL of water. The beaker was placed in a boiling kettle of water for 20 min (Daniels et al 1998).

TABLE I
Analysis of Variance for the Significance of Storage Condition Variables on Physicochemical Properties of Rice

Source	df	Sum of Squares	*F* Ratio	Prob > *F*
Water absorption ratio				
Aeration (A)	1	0.121	3.175	0.077
Position (P)	2	0.038	0.506	0.604
A × P	2	0.450	5.923	0.004
Storage duration (S)	3	3.076	26.964	<0.000
A × S	3	0.109	0.957	0.416
Peak viscosity				
Aeration (A)	1	15,174.708	184.444	<0.000
Position (P)	2	60.846	0.370	0.691
A × P	2	12.013	0.073	0.930
Storage duration (S)	3	1,174.864	4.760	0.004
A × S	3	2,933.702	11.886	<0.000
Moisture content				
Aeration (A)	1	29.311	86.0791	<0.000
Position (P)	2	1.631	2.3949	0.096
A × P	2	7.098	10.4227	<0.000
Storage duration (S)	3	37.525	36.7340	<0.000
A × S	3	18.317	17.9310	<0.000
Head rice yield				
Aeration (A)	1	310.989	41.632	<0.000
Position (P)	2	142.791	9.558	0.000
A × P	2	34.820	2.331	0.102
Storage duration (S)	3	200.765	8.959	<0.000
A × S	3	5.918	0.264	0.851

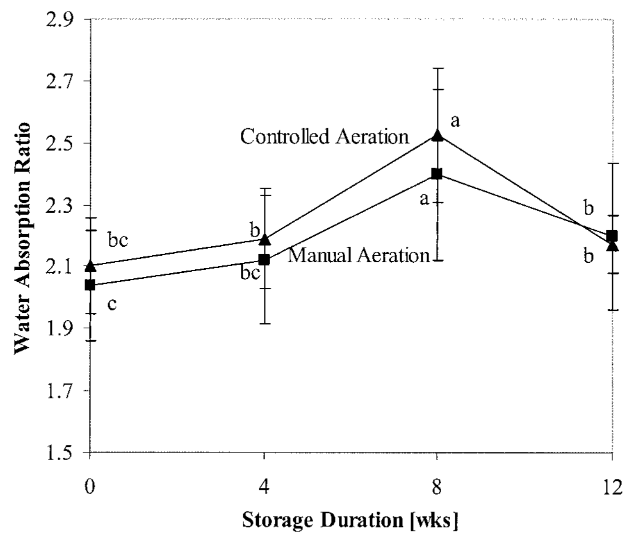

Fig. 1. Water absorption ratio of cooked rice as a function of storage duration for manual aeration and controlled aeration. Error bars show ± standard deviation. Values with the same letter are not significantly different at $P < 0.05$.

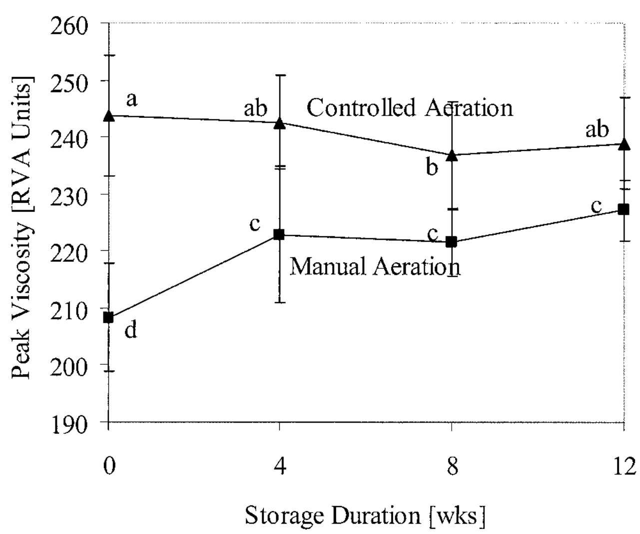

Fig. 2. Peak viscosity values of rice slurries as a function of storage duration for manual aeration and controlled aeration. Error bars show ± standard deviation. Values with the same letter are not significantly different at $P < 0.05$.

After this cooking stage, the rice and the basket were removed and allowed to drain for 10 min; the cooked rice weight was recorded. The water absorption was computed as a ratio of cooked rice weight to the initial rice weight, each sample was run in duplicate and averaged to obtain the water absorption of each sample.

Pasting Properties. Head rice was ground into flour using a Udy cyclone sample mill with a 40-mesh screen (model 1093, Tecator, Hoganas, Sweden). Rice flour (2 g) was heated in a convection oven for 1 hr at 130°C, and the moisture content was determined. After the moisture content was determined, samples were prepared on a 12% moisture basis by adding a given mass of rice flour (depending on its moisture content) to a given volume of water, as directed by Newport Scientific (Warriewood, Australia). Samples were analyzed using the Rapid Visco Analyser (RVA) Series 4 rice analysis procedure. Each sample was run in duplicate and final viscosities were collected and averaged.

Statistical Analysis

Analysis of variance (ANOVA) was performed using JMP (SAS Institute, Cary, NC), to first determine whether the storage variables contributed significantly ($P = 0.05$) to changes in MC, HRY, water absorption ratio (WAR), and peak viscosity. Student's *t*-test was used to compare means of each treatment for each variable. The trends among the different treatments were examined and compared to determine the effects of the two different aeration treatments.

RESULTS AND DISCUSSION

Based on the ANOVA results (Table I) for the rough rice, the storage duration contributes significantly to changes in MC, HRY, WAR, and peak viscosity. These results are consistent with results reported by others (Villareal et al 1976; Perdon et al 1997; Daniels et al 1998; Indudhara Swamy et al 1978), which showed that pasting properties, HRY, and WAR of rice changed with storage duration. In addition, aeration treatment significantly influenced MC, HRY, and peak viscosity. Sampling depth did not significantly influence physicochemical properties. Therefore, in subsequent analyses, sample depth values were used as repeated measures. Sampling location (spatial, not depth) within a bin contributed to significant differences in HRY, and the combination of sampling position and aeration treatment led to significant differences in MC and WAR.

The water absorption ratio for rice as a function of storage duration is shown for both aeration treatments in Fig. 1. In both cases, the ratio increased during the first two months of storage and then dropped slightly. These results are similar to those reported by Perdon et al (1997) that showed a general increase over a three-month storage period before seeing a decrease. The means separation shows the significant effects of storage duration and reinforces the similarity of the values generated by the two aeration treatments.

The peak viscosity of the rice flour slurries changed very little during storage, though the effect was statistically significant (Fig. 2). This is consistent with results of Perdon et al (1997) and others, which also demonstrated a general increase in peak viscosity as storage duration increased; however, the increase in this study was not as sharp. Peak viscosity of pastes prepared from the manually aerated rice were significantly lower ($P < 0.05$) than the peak viscosity of the pastes prepared from the controller-aerated rice.

Storage duration caused significant differences in the MC of the rice. However, the overall effect was unique in each aeration treatment (Fig. 3). Rice in the bins that were manually aerated was not

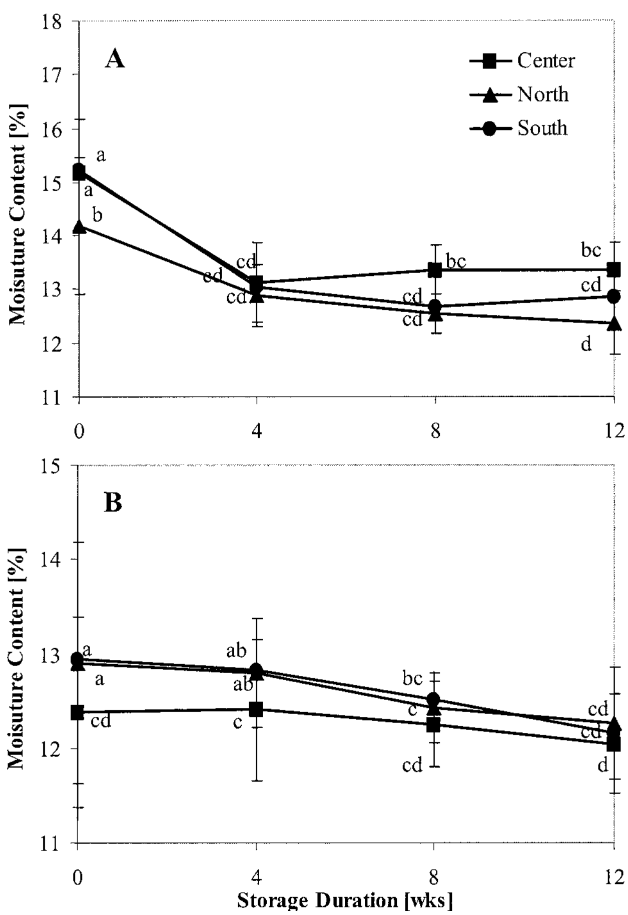

Fig. 3. Moisture content (MC) of rough rice as a function of storage duration and bin sample location for manual aeration (**A**) and controlled aeration (**B**). Average standard deviation was 0.27%. Values with the same letter in each graph are not significantly different at $P < 0.05$.

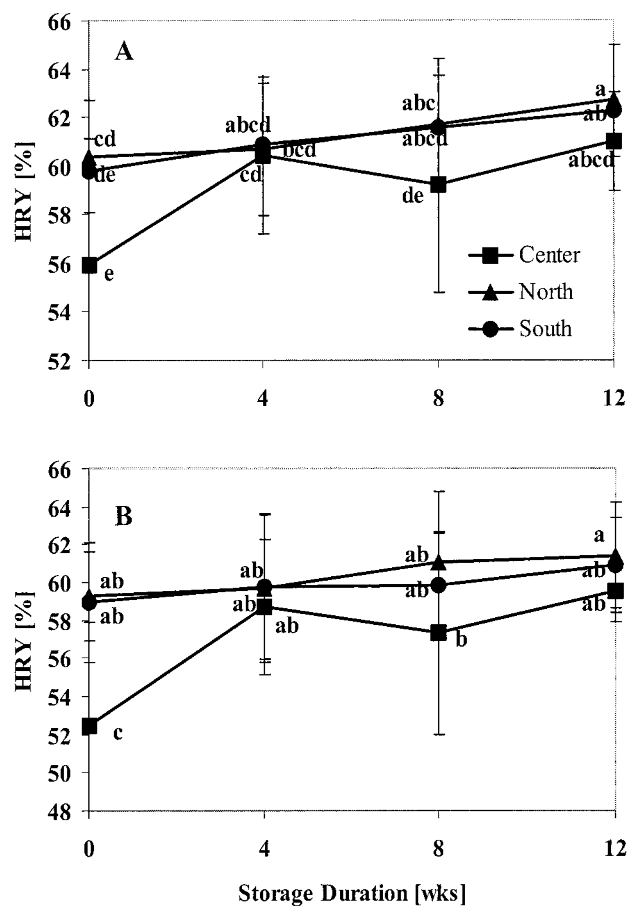

Fig. 4. Head rice yield (HRY) values as a function of storage duration and bin sample location for manual aeration (**A**) and controlled aeration (**B**). Error bars show ± standard deviation. Values with the same letter in each graph are not significantly different at $P < 0.05$.

completely dry when the study commenced (Fig. 3A). Therefore, it had high MC readings initially, leading to a statistically significant reduction in MC over time. Once dry, the MC was relatively stable, with a slight decrease from 12.8 to 12.5%. The rice in the center of the manually aerated bins had higher MC than that in the N or S bin locations at the sampling times of 8 and 12 weeks. Most likely, this was due to the effect of the stirring devices in these bins. Typically, a stirrer will cause the fines and small grains to aggregate in the center of the bin. When the bin is aerated, the center of the bin will be more resistant to air flow, thus the center section of the bin will receive a lower exposure to aeration. These results may be explained by the phenomenon of the rice in the center of the bins not receiving the same air flow rates as that at the edges, thus the slight drying action of aeration was not seen in the center

Overall, the rice in the controller-aerated bins had a slight reduction in average MC from 12.7 to 12.3% over the 12-week period (Fig. 3B). Although statistically significant, the change does not appear physically meaningful. In addition to storage duration, the sampling position also influenced the MC of rice that was treated with controlled aeration (Fig. 3B). The MC of rice at the center bin location was significantly lower than rice sampled from either N or S locations over the first four weeks, but the differences were reduced as storage duration progressed. This suggests that the consistent aeration during storage helped to alleviate differences in MC as a function of sampling position during storage. Howell et al (2000) showed that spatial location within a bin produced significant changes in MC. In that case, the C location was highest followed by N and S. In that study, the rice was not aerated frequently. Aeration as a whole contributed significantly to the varied MC of rice within a bin. Without it, rice properties are affected by both grain depth and spatial location, but with aeration, rice quality is more uniform.

Head rice yield was significantly influenced by storage duration, aeration treatment, and spatial location within the bins. Overall, HRY increased slightly as storage duration increased (Fig. 4). In both aeration treatments, the average HRY increased about two percentage points over the duration of the study. Similar trends were reported by Daniels et al (1998). However, the results presented here show a much smaller magnitude of increase in HRY. In almost every case of the laboratory storage experiments, HRY increased approximately ten percentage points in 12 weeks of storage for the same cultivar used in the present study (Daniels et al 1998). The smaller magnitude found in the present work is more characteristic of those found in practice. Perhaps the environment encountered during on-farm storage, with its highly variable nature, does not allow for such large increases. Lastly, HRY at the C location in the bin had significantly lower values initially in both the manual and controlled aeration treatments.

Although the numerical values displayed for the functional properties of rice were not identical with respect to the different aeration treatments, the trends, as a function of storage duration, were similar. Comparison of WAR, peak viscosity, MC, and HRY in Figs. 1–4, respectively, demonstrated several trends, despite the aeration treatments. WAR increased initially and then went through a period of reduction; MC decreased sharply during the first four weeks in the manually controlled aeration treatment and then decreased slightly over time; and HRY increased with storage duration, with the C bin location demonstrating a consistently lower HRY %.

CONCLUSIONS

Data analysis showed that the functional properties of the rice were most influenced by the storage duration of the rice. The HRY was also affected by the spatial location within a storage bin. Comparisons of the two aeration treatments demonstrated that the trends exhibited by the functional properties do not seem to be adversely affected by a controlled aeration treatment compared with a manual aeration treatment, though the magnitudes of the physicochemical properties were significantly different in some cases. The functional properties of rice stored in farm-scale bins behaved very similarly to those of rice in controlled laboratory conditions. However, the farm-stored rice did not exhibit the same magnitude of change as rice in previous laboratory-scale studies. A logical next step would begin to model the microenvironments caused by spatial and depth positions using the data available from controlled, storage studies on rough rice.

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