Effects of Long-Grain Rough Rice Storage History on End-Use Quality

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ABSTRACT

Rough rice (cv. Cypress) from the 1995 season was harvested, dried, and stored in laboratory-scale studies. Treatments included pre-drying conditions, drying conditions, storage temperatures, and storage durations. Temporary wet storage prior to drying affected cooking properties ($p<0.005$) and peak viscosity ($p<0.005$). Drying treatments affected head rice yield ($p<0.05$), cooking properties ($p<0.001$), and peak viscosity ($p<0.05$). Storage temperature was related ($p<0.05$) to cooking properties and peak viscosity via a second-order relationship. Head rice yield and cooking properties were also affected ($p<0.05$) by storage duration.

Key Words: rice, grain storage, grain drying, starch functionality

INTRODUCTION

RESEARCH HAS SHOWN THAT ROUGH RICE storage history can affect head rice yield and cooking quality of rice (Villareal et al., 1976; Chrastil, 1990; Hamaker et al., 1993; Tamaki et al., 1993). Changes during storage include increases in grain hardness (Dhaliwal et al., 1990; Sajwan et al., 1989; Tsugita et al., 1983), water absorption and volume expansion (Villareal et al., 1976; Tsugita et al., 1983), and peak viscosity (Villareal et al., 1976; Tsugita et al., 1983; Hamaker et al., 1993). These changes occur most rapidly in the first months of storage at 15°C (Perez and Juliano, 1982).

Although there have been numerous studies describing changes during rice storage, none has mathematically modeled the physicochemical changes as functions of storage history. Additionally, previous studies typically limited their focus to the effects of one or two storage parameters on rice quality, even though various other postharvest handling parameters, such as duration of wet holding and drying method (Calderwood and Webb, 1969), could affect rice quality.

Consequently, our study was part of an overall research program aimed at modeling mathematically physicochemical changes in rice as functions of rough rice postharvest history. Our hypothesis was that such changes are complex biochemical phenomena, which have not been modeled, even as statistical relationships in experimental studies. Therefore, our specific objective was to quantitatively describe the effects of wet holding, drying treatment, and storage history (i.e., temperature and duration) on end-use quality characteristics of long-grain rice (cv Cypress), including head rice yield, cooking properties, and starch functionality.

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MATERIALS & METHODS

Experimental design

Long-grain rice (cv Cypress) was harvested at the University of Arkansas Rice Research and Extension Center in Stuttgart, Arkansas, in September 1995, at an average moisture content (mc) of 20.5% wet basis. The rice (72 kg) was cleaned within 12h of harvest in a Carter-Day Dockage Tester (Seedburo, Chicago, IL) and mixed thoroughly, before random division into two lots. One lot was dried immediately, and the second was dried after a period of temporary storage at the harvest mc (wet holding). The experimental design was a full-factorial design, consisting of the following treatments, with all samples being stored at 12.5% mc:

- Pre-drying conditions: immediately-dried vs. 86 h wet-held
- Drying conditions: low-temperature vs high-temperature
- Storage temperature: 4, 21, and 38°C
- Storage duration: 0, 3, 7, 12, and 18 wk

The wet-holding treatment was designed to simulate an extreme delay between harvest and drying of rough rice, as might occur in transportation during the peak of the drying season. The rice was held for 86h, at the harvest mc, in large insulated containers. The temperatures at the center and edge of each container were monitored with thermocouples, and were never more than 3°C greater than ambient room temperature (~23°C). At the completion of wet holding, the rice was subjected to the same drying and storage treatments as was the immediately dried rice.

Both the immediate and delayed dried lots were randomly divided again for two separate drying treatments. Half of each lot was subjected to low-temperature drying conditions [33°C, 67.8% relative humidity (RH)] for 45 min and half was subjected to high-temperature drying conditions (54.3°C, 21.9% rh) for 45 min. These conditions represented equilibrium moisture contents of 12.7% and 6.7%, respectively (ASAE, 1995). The rice was dried by circulating air through 2.5 cm thick layers in a laboratory-scale drying system. Air conditions were controlled by a commercial temperature and relative humidity controlled air unit (Model AA, Parameter Generation and Control, Inc, Black Mountain, NC). After this treatment, the low-temperature dried samples and the high-temperature dried samples were ~17.8 and 16.5% mc, respectively.

Immediately after the drying treatment, the rice was placed on screen trays in an equilibrium chamber. The chamber was set at 33.0°C and 68.0% RH. The rice was removed ~2 wk later when the mc reached 12.5%. The purpose of this slow equilibration was to bring all samples to the same mc, without notably affecting functionality via additional fast drying.

After pre-drying, drying, and equilibration treatments, a total of 12 lots of rice (2 pre-drying conditions, 2 drying conditions, and 3 storage temperatures) were placed in sealed plastic buckets. These lots were held at -10°C for 4 mo prior to starting the storage part of the study. Subsequently, 4 buckets representing the different pre-drying and drying conditions were placed in each of 3 controlled-temperature chambers (4, 21, and 38°C).

One random sample was taken from each bucket at 0, 3, 7, 12, and 18 wk. All samples were held in sealed plastic bags and allowed to equilibrate to room temperature for 6 to 8 h prior to subsequent analyses. The mc of each sample was evaluated in duplicate via an air-oven method at 130°C for 24h (Jindal and Siebenmorgen, 1987), to assure that the rough rice storage mc remained in the range of 12.5±0.2%.

Functional analyses

Head rice yield (HRY) was determined in triplicate as follows. Rough rice (150g) was dehulled in a McGill sample sheller, and the resulting brown rice was milled in a McGill #2 mill (Seedboro Equipment Co., Chicago, IL). Milling time was 30 to 34s for the first 2 mo and up to 47s for the remainder of the study, yielding a degree of milling of 90±3 on a Satake model MM-1B milling meter (Satake, Hiroshima, Japan). The resulting milled rice was sized on a shaker table (4.76 mm round holes; Seedburo Equipment Co., Chicago, IL) to separate head rice from broken kernels. HRY was calculated by dividing the head rice weight by the initial rough rice weight (150g).

Water absorption and volume expansion were determined in duplicate by cooking in excess water (Bhattacharya and Sowbhagya, 1971). Modifications to the method included placing 20g of raw head rice in a wire basket (7 cm ht × 3.5 cm dia). The wire basket was placed in a 250 mL beaker with 200 mL of water; the beaker was then placed in boiling water. After 20 min, the rice and basket were removed and allowed to drain for 10 min before measuring the cooked rice weight (±0.001g) and height (±0.1 cm). The water absorption was computed as the ratio of water absorbed to initial rice weight. The volume expansion was calculated as the ratio of cooked rice height to raw rice height.

For amylography, head rice (60g) was ground in a UDY Cyclotec mill (Model 1093, Tecator, Inc., Hoganas, Sweden) with a 0.5 mm screen. The flour was mixed with water to produce a slurry with 8% dry matter, after determining the mc of the flour (Juliano et al., 1985). Subsequently, the slurry was subjected to a defined temperature treatment in a Brabender viscograph-E, according to a modified version of Method 61-01 (AACC, 1996) for milled rice. The slurry was initially heated from 30 to 95°C at 3°C/min.; maintained at 95°C for 10 min and then cooled to 50°C, at 3°C/min. The peak and final viscosity were extracted from the resulting amylograph.

Statistical analysis

An analysis of variance was performed via SAS Institute, Inc. (1993) to first determine the factors and interactions thataffected ($p<0.05$) HRY, water absorption, volume expansion, peak viscosity, and final viscosity of the rice. The significant factors were subsequently included in polynomial models and analyzed through a general linear model procedure.

RESULTS & DISCUSSION

Data trends

In general, HRY increased with storage duration for all storage temperatures and all pre-drying and drying conditions (Fig 1). The average standard error among replicates was 6.4 HRY %. The greatest increases in HRY occurred in the first 3 mo of the study; after that, the HRY asymptotically approached a limit for each of the conditions. This confirmed results from Perez and Juliano (1981), Barber (1972), and Villareal et al. (1976), that the most significant changes during rice storage occur in the first 3 mo. Based on the ANOVA (Table 1) and a means comparison, HRY of the low-temperature dried rice was greater ($p<0.05$) than the HRY of the high-temperature dried rice, but there was no significant difference between the HRY of the immediately-dried rice and the delayed-dried rice. The lower HRY for the high-temperature dried rice is consistent with previous literature (Abe et al., 1992; Kunze, 1984).

The low-temperature dried rice had a greater ($p<0.001$) water absorption (Fig. 2) and volume expansion (Fig. 3) than did the high-temperature dried rice; this trend was true for all storage temperatures. Also, the sample with the greatest volume expansion ratio was the immediately, low-temperature dried rice stored at 21°C. The average standard errors for water absorption and volume expansion were 0.48 and 0.23, respectively.

The pre-drying conditions also affected cooking properties. The delayed drying conditions, particularly for the low-temperature dried samples, resulted in lower water absorption ($p<0.0001$) and lower volume expansion ($p<0.0005$) when compared to samples that were immediately dried after harvest. This trend could have been caused by

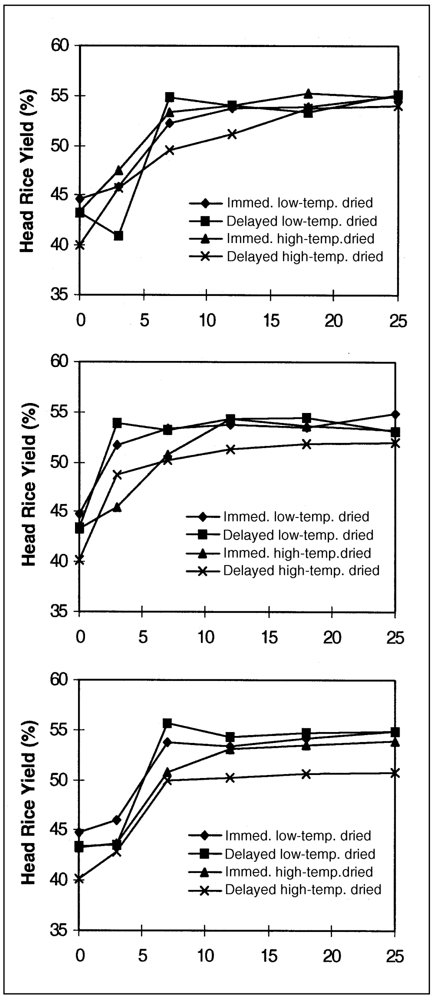

Fig. 1—Head rice yield as related to storage duration, pre-drying, and drying treatment for Cypress rice stored at 4, 21, and 38°C.

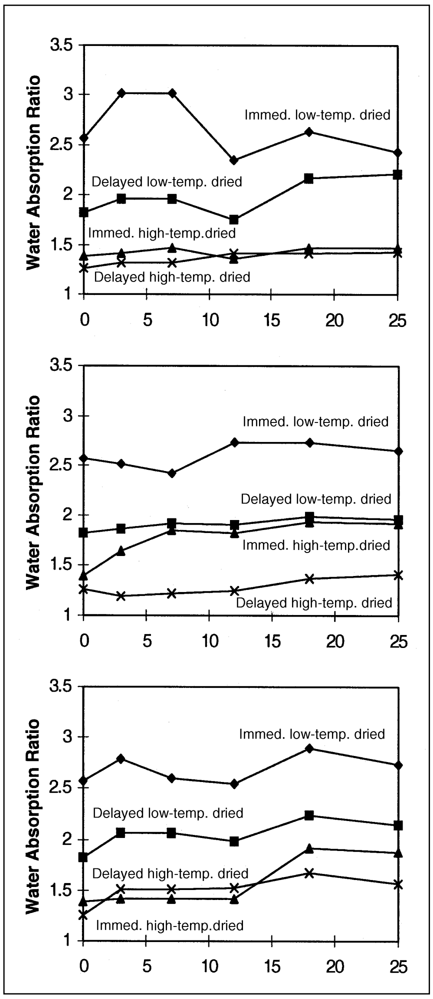

Fig 2—Water absorption ratios as related to storage duration, pre-drying, and drying treatment for Cypress rice stored at 4, 21, and 38°C.

longer opportunity for degradative biochemical processes to occur, affecting the integrity of the rice kernels and starch properties. On average, the water absorption and volume expansion for all samples increased slightly with storage duration, even though the increases were not great. Studies conducted by Chrastil (1992), Villareal et al., (1976), and Tsugita et al. (1983) also reported increases in cooking ratios during storage.

The pre-drying and drying conditions also affected peak viscosity, with the immediately dried rice having a greater ($p<0.05$) peak viscosity than did the delayed-dried rice. The viscosity of the low-temperature dried rice was also greater ($p<0.05$) than that of the high-temperature dried rice. On average, the peak viscosity did not follow a pattern over time. This did not support the results of Hamaker et al. (1993) and Perdon et al. (1997), which showed significant increases in peak viscosity during the first 3 mo of storage. However, the rice weused was a different cultivar, which might explain some of the inconsistency. Additioanl studies using cv. Cypress from the 1996 harvest season are currently underway to further verify these differences. Final viscosity showed no significant trends with postharvest treatment.

Table 1—Analysis of variance p values for the significance of postharvest conditions on the functionalities of Cypress rice

		Analysis of Variance p-values				
Source	**df**	**HRY**[a]	**Water Absorption**	**Volume Expansion**	**Peak Viscosity**	**Final Viscosity**
Temperature (T)	2	NS[b]	0.0273	0.0257	NS	NS
Duration (t)	5	0.0001	0.0055	NS	NS	NS
T * t	6	NS	0.0326	NS	NS	NS
Drying Cond. (DC)	1	0.0201	0.0001	0.0001	0.0259	NS
T * DC	2	NS	NS	0.0043	NS	NS
t * DC	3	NS	0.0279	NS	NS	NS
T * t * DC	6	NS	0.0324	NS	NS	NS
Holding Cond. (HC)	1	NS	0.0001	0.0004	0.0024	NS
T * HC	2	NS	0.0312	NS	NS	NS
t * HC	3	NS	NS	NS	NS	NS
T * t * HC	6	NS	NS	NS	NS	NS
DC * HC	1	NS	0.0005	0.0001	NS	NS
T * DC * HC	2	NS	0.0352	0.0013	NS	NS
t * DC * HC	3	NS	NS	NS	NS	NS

[a]HRY = head rice yield
[b]NS = not significant at α=0.05

Table 2—Significant polynomial variables ($p<0.05$) affecting functional properties of long-grain rice, cv Cypress, during storage

Property	**Highest Order Significant Variables and Variable Interactions of Model**[a]		**R^2**
HRY	t^2	DC	0.8891
Water absorption	T^2*t^2*DC	$T^2*HC*DC$	0.9645
Volume expansion	T^2*t	$T^2*HC*DC$	0.9462
Peak viscosity	T^2*HC	DC	0.6214
Final viscosity	no significant variables		NS

[a]T=storage temperature, t=storage duration, DC=drying condition, HC=pre-drying holding condition.

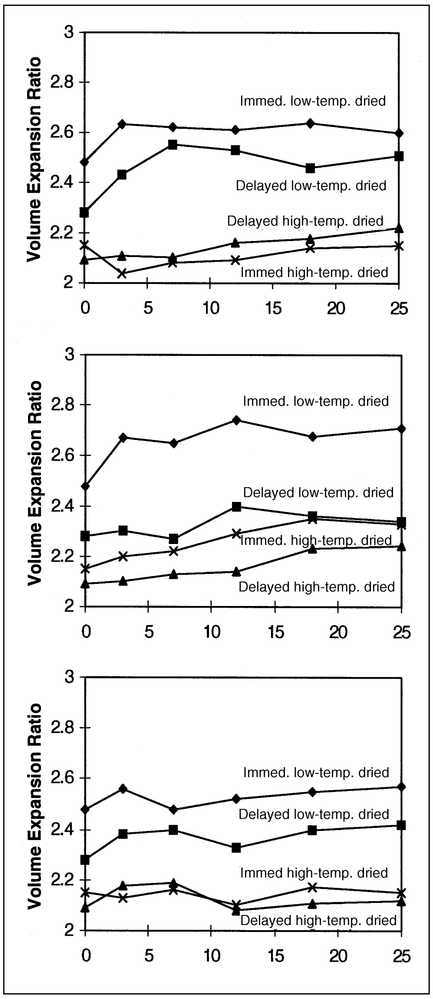

Fig. 3—Volume expansion ratios as related to storage duration, pre-drying, and drying treatment for Cypress rice stored at 4, 21, and 38°C.

Statistical analysis and models

The functional properties of the rice (Fig. 1 to 3) were evidently not all related to pre-drying, drying, and storage conditions by simple linear relationships. As a first step in identifying important factors, an analysis of variance was performed. The significance of the different experimental factors and their interactions, with respect to the different functional properties, were determined (Table 1).

The significant variables and relationships ($p<0.05$) were subsequently included in a polynomial model (Table 2). The specific model coefficients were not determined, because the primary purpose of the polynomial models was to evaluate the degrees to which the various factors and interactions influenced the functional properties. This statistical modeling is a first step toward predictive models for changes in functionalities, which will require considerable additional data across cultivar, crop year, and postharvest treatments. However, the models, specifically for HRY and cooking properties, adequately explained a major portion of the data variability, with $R^2<0.89$ for these properties. The fit for the peak viscosity model was not as good.

The effect of storage temperature (second order) was significant for water absorption, volume expansion, and peak viscosity. Storage duration was also significant, to varying degrees, for HRY and cooking properties. The pre-drying and drying conditions were also significant terms in the models for HRY, cooking properties, and peak viscosity, except that the pre-drying condition was not significant in the HRY model.

CONCLUSIONS

OVERALL, QUALITATIVE ANALYSIS OF THE data showed that the functional properties of long-grain rice were not related to postharvest factors by simple linear relationships. Statistical analysis confirmed this by showing higher-order influences of duration and temperature on several properties, as well as significant interactions among postharvest factors. This supports the hypothesis that physicochemical changes in rice are complex functions of postharvest conditions. Consequently, previous research that focused on specific experimental parameters, without testing the interactions, did not fully describe the true relationships between postharvest treatments and functional changes.

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Ms received 7/21/97; revised 2/3/98; accepted 3/19/98.

Manuscript 97083 of the Arkansas Agricultural Experiment Station. This project was supported by funding from the Arkansas Rice Research and Promotion Board.