Effects of Rough Rice Storage Conditions on the Amylograph and Cooking Properties of Medium-Grain Rice cv. Bengal[1]

A. A. PERDON,[2] B. P. MARKS,[2,3] T. J. SIEBENMORGEN,[2] and N. B. REID[2]

ABSTRACT

Rough rice (cv. Bengal) was stored at four moisture contents (8.8, 10.7, 12.9, and 13.6% MC) and three temperatures (3, 20, and 37°C) for up to six months. The amylograph overall paste viscosity of the milled rice increased during storage. This increase was most apparent in all samples stored at 37°C. For rice stored at 20 and 37°C at all MC levels, a 30–50% increase in peak viscosity (PV) was observed during the first three months of storage. PV subsequently leveled off for rice stored at 12.9 and 13.6% MC but declined for samples stored at 8.8 and 10.7% MC. The final viscosities also increased during storage. The water-absorption ratio of the samples during cooking in excess water increased by an average of 15% over six months of storage. The amylograph and cooking properties were significantly affected ($P < 0.05$) by rough rice storage duration, temperature, MC, and their respective interactions.

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Previous research has shown that the physicochemical properties of rice change during storage. This phenomenon is known as aging. As rice ages, head rice yield (HRY) increases (Villareal et al 1976), water absorption during cooking increases, and cooked rice texture becomes fluffier and harder (Villareal et al 1976; Indudhara Swamy et al 1978; Chrastil 1990, 1992). Additionally, Perez and Juliano (1981) showed that at 15°C these changes were most significant during the first three to four months of storage.

One of the most sensitive indexes of the aging process in rice is the change in pasting properties, as measured by an amylograph. The overall viscosity of rice paste increases dramatically during storage (Villareal et al 1976, Indudhara Swamy et al 1978, Hamaker et al 1993). These changes depend on storage temperature and duration. Viscosity increases at higher storage temperatures during the first three months and tends to level off afterward. However, an extended 48-month storage study showed that viscosity began to decrease after 24 months (Indudhara Swamy et al 1978). The effect of rice moisture content (MC) during storage has not been studied as extensively as storage temperature and duration. The MC may be one of the factors that explains the differences observed in paste viscosity after prolonged storage.

Attempts to explain these functionality changes have focused on the properties of rice components, such as starch, protein, and lipids, and the interactions among them during storage (Chrastil 1994). As with functionality, changes in starch and protein components were most apparent at temperatures >35°C (Chrastil 1994).

Using the published data, modeling physicochemical changes as functions of time and temperature should be possible. In addition, the effect of rice MC during storage should be included. A descriptive model would be a useful tool in the food-processing industry, where consistent behavior of raw material is required.

This study was part of an overall research program aimed at quantitatively modeling changes in the physicochemical properties of rice as functions of storage history. The specific objective was to evaluate the effects of rough rice MC, storage temperature, and storage duration on the amylograph, and the cooking properties of rice cv. Bengal (Linscombe et al 1993), which currently accounts for the majority of the medium-grain rice production in Arkansas.

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[2]Research assistant, assistant professor, professor, and graduate assistant, respectively, Biological and Agricultural Engineering Department, University of Arkansas, Fayetteville, AR 72701.

[3]Corresponding author: E-mail: bpml@engr.uark.edu

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MATERIALS AND METHODS

Sample Preparation

Rough rice (cv. Bengal) was harvested from the University of Arkansas Rice Research and Extension Center, Stuttgart, AR, during September 1995. Immediately after harvest, the rough rice samples were cleaned in a dockage tester (Carter-Day Co., Minneapolis, MN) and immediately air-dried at room temperature (≈20°C) over a 14-day period. Samples were taken after different drying durations to yield rough rice with 8.8, 10.7, 12.9, and 13.6% MC (wb). The MC of the rice was measured by drying duplicate samples for 24 hr in an air oven at 130°C (Jindal and Siebenmorgen 1987). Each of the four lots of rice at the different MC levels was split into three 10-kg portions using a Boerner divider (model 34, Seedburo Equipment Co., Chicago, IL) and placed in sealed plastic buckets. The buckets were held at –10°C for four months before storage at different treatment temperatures. It was assumed that this temporary, low-temperature storage of the dry rice resulted in no significant changes in functional properties.

One bucket of rice at each MC was stored in temperature-controlled chambers set at 3, 20, and 37°C, for a total of 12 lots. Subsamples (≈600 g) were removed from each lot at 0, 1, 2, 3, 4, 5, and 6 months. Each subsample was allowed to equilibrate to room temperature before milling and subsequent analyses.

At each sampling time, the rough rice was hulled and milled in a laboratory milling system. A 150-g portion of rough rice was dehulled in a McGill sample sheller (Rapsco, Brookshire, TX). The resulting brown rice was milled in a McGill No. 2 mill operated with a 1.5-kg weight positioned 15 cm from the mill saddle centerline on the mill lever arm. Head rice was separated from the broken rice in a Seedburo sizer fitted with two 4.0-mm (10/64 in.) sizing plates. Because MC affects the degree of milling, milling times were established by milling samples from each lot after different drying durations and analyzing the total lipids with a Soxtec fat extractor (Tecator AB, Hoganäs, Sweden) with petroleum ether as the solvent (Soxtec 1983). Total lipids were plotted against milling times for each lot. From these plots, the milling durations that yielded rice with 0.75% total lipids were calculated and used for testing. These milling durations ranged from 35 sec for rice at 13.6% MC to 100 sec for rice at 8.8% MC. HRY was computed as the mass percentage of head rice relative to 150 g of the starting rough rice.

Amylography, using a Brabender Viscograph-E (C. W. Brabender, South Hackensack, NJ), was conducted in duplicate according to approved method 61-01 for milled rice (AACC 1995), using a heating rate of 3°C/min and a cooling rate of 3°C/min. The head rice was ground in a cyclone mill (Udy Corp., Fort Collins, CO) fitted with a 0.5-mm screen. The MC of the ground rice was measured using an air-oven method (Juliano et al 1985). Slurry (500 g) containing 8% dry matter in water was used for the amylography. The peak and final viscosity (PV and FV, respectively) data from each sample were recorded and analyzed.

For cooking properties, the water-absorption and volume-expansion ratios of the rice when cooked in excess water were measured in duplicate (Bhattacharya and Sowbhagya 1971). A wire basket (4.3 cm i.d. × 7 cm) containing 20 g of head rice was placed in a 250-mL beaker with 150 mL of deionized water at an initial temperature of 20–25°C. The beaker was placed for 20 min in a cooker filled with boiling water. After removal of the basket from the cooker, the excess water was drained for 10 min before weighing. The water-absorption ratio was computed as the increase in mass of the cooked rice divided by the initial mass of the raw rice. The volume-expansion ratio was computed as the ratio of the cooked rice height to the raw rice height.

Data Analyses

Analysis of variance was performed to determine the variables that contributed significantly (α = 0.05) to the PV, FV, and water-absorption ratio. Subsequently, models describing the amylograph and cooking properties as functions of storage duration, storage temperature, and MC of rice were constructed using the general linear model procedure (SAS Institute, Cary, NC).

RESULTS AND DISCUSSION

Changes in Functional Properties

During storage at all temperatures, HRY did not change significantly with time. The mean HRY for all samples was 67.92%, with a standard deviation of 0.82%. However, as seen in previous research, the amylograph properties of the rice changed with rough rice storage duration and temperature. For example, rice at 8.8% MC had a PV of 620 BU at the beginning of the storage study (Fig. 1). PV increased to 805 BU after one month of storage at 37°C and reached a maximum of 890 BU after three months. PV began to decrease after three months. At 8.8% MC and 20°C, PV increased from an initial 620 to 770 BU at two months and began decreasing after two months. At 3°C, less overall change in PV was observed, with an increase from 620 to 760 BU at one month of storage and then a decrease that leveled off to ≈680 BU. For the most part, similar trends were observed in the other lots at different MC levels. At this time, the decrease in PV after three months of storage cannot be explained. Consequently, future work will seek to explain the fundamental cause of this phenomenon.

For FV, all samples stored at 37°C exhibited a general increase with longer storage duration (Fig. 2). The increase was most rapid during the first three months of storage. For example, with the 8.8% MC rice the FV increased from 640 BU at the beginning of the storage to 855 BU after three months and leveled off after that. No appreciable change was observed in the samples stored at 20 and 3°C.

With respect to cooking properties, all of the rice stored at 37°C showed an increase in the water-absorption ratio during the first three months of storage (Fig. 3). However, after three months the water-absorption ratio of all four lots either leveled off or declined. At 20°C, the change in water absorption for all samples was not much different from the samples stored at 3°C. There was no definite trend observed for the volume-expansion ratio of the stored rice; therefore, these data are not reported here.

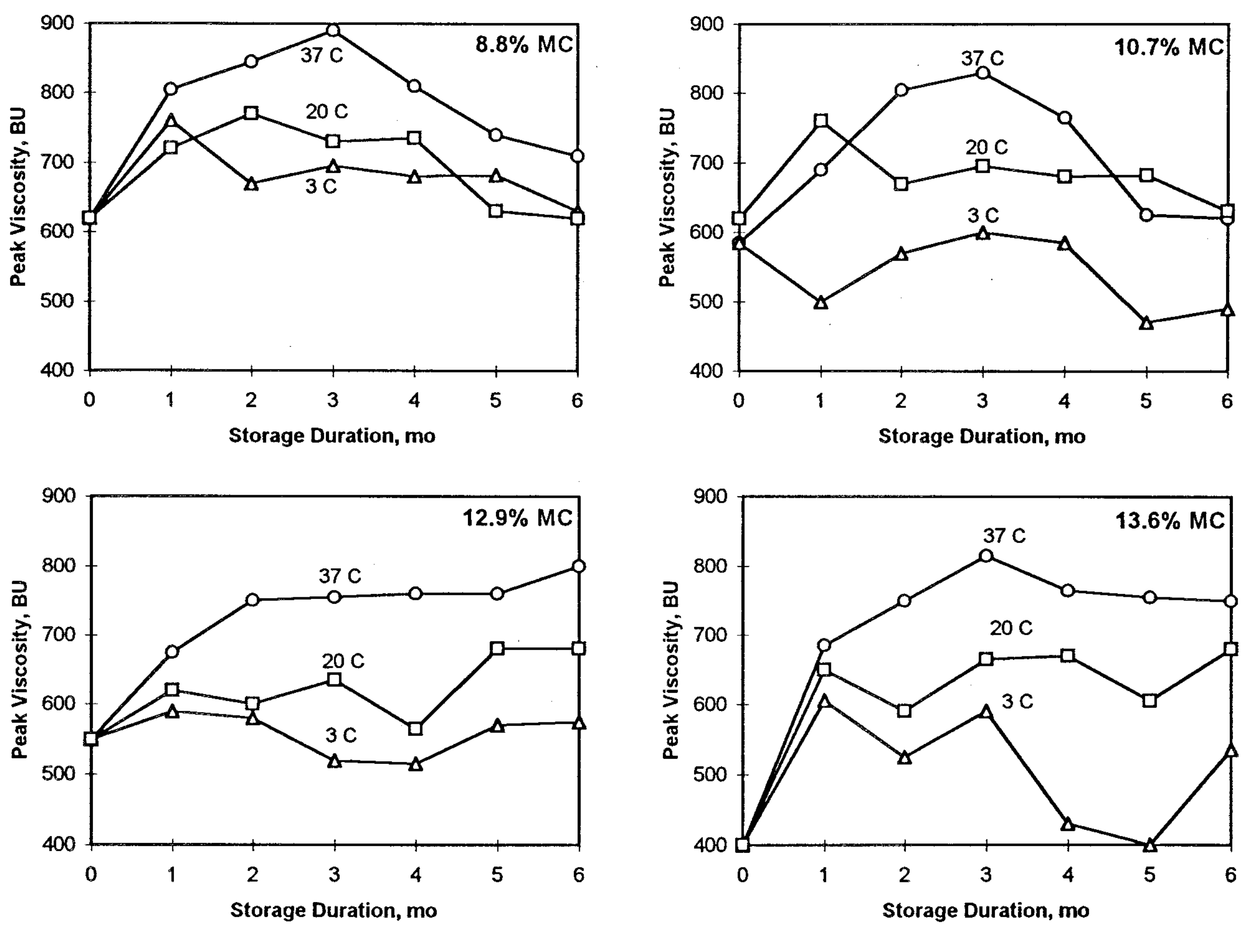

Fig. 1. Effect of storage temperature, duration, and moisture content (MC) on amylograph peak viscosity of rice cv. Bengal.

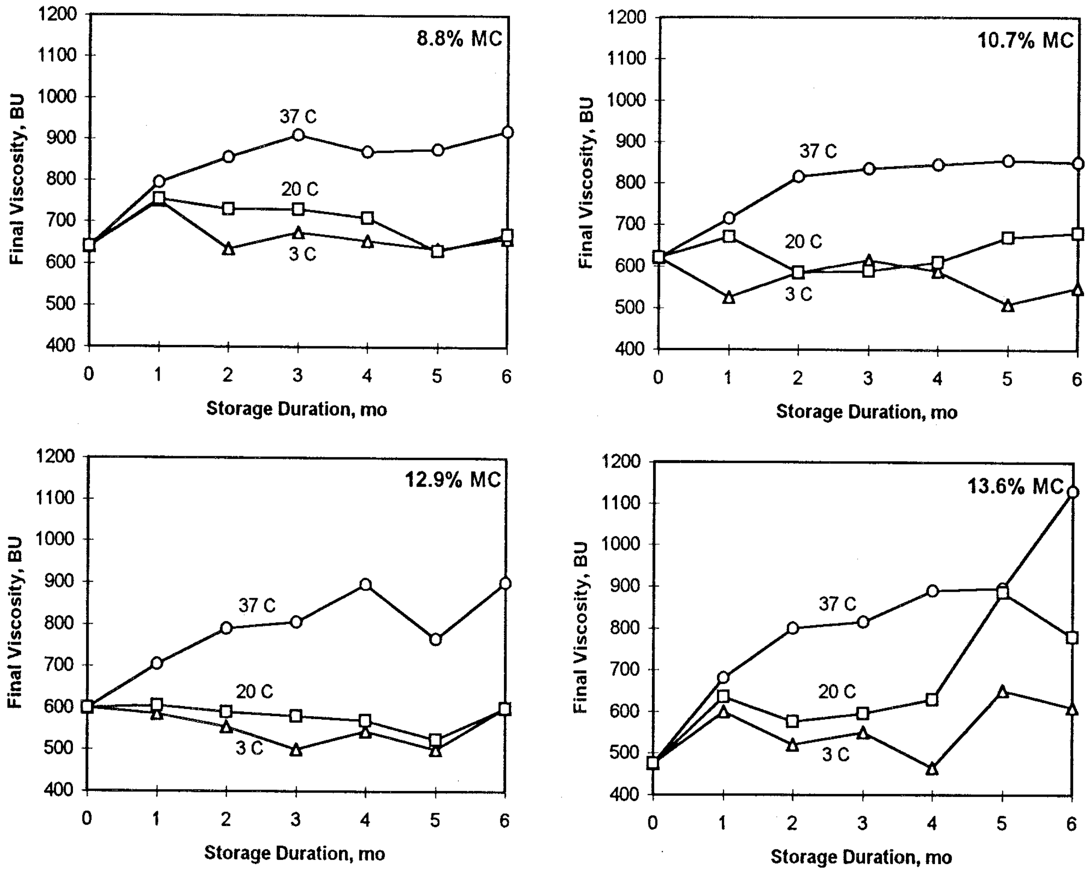

Fig. 2. Effect of storage temperature, duration, and moisture content (MC) on amylograph final viscosity of rice cv. Bengal.

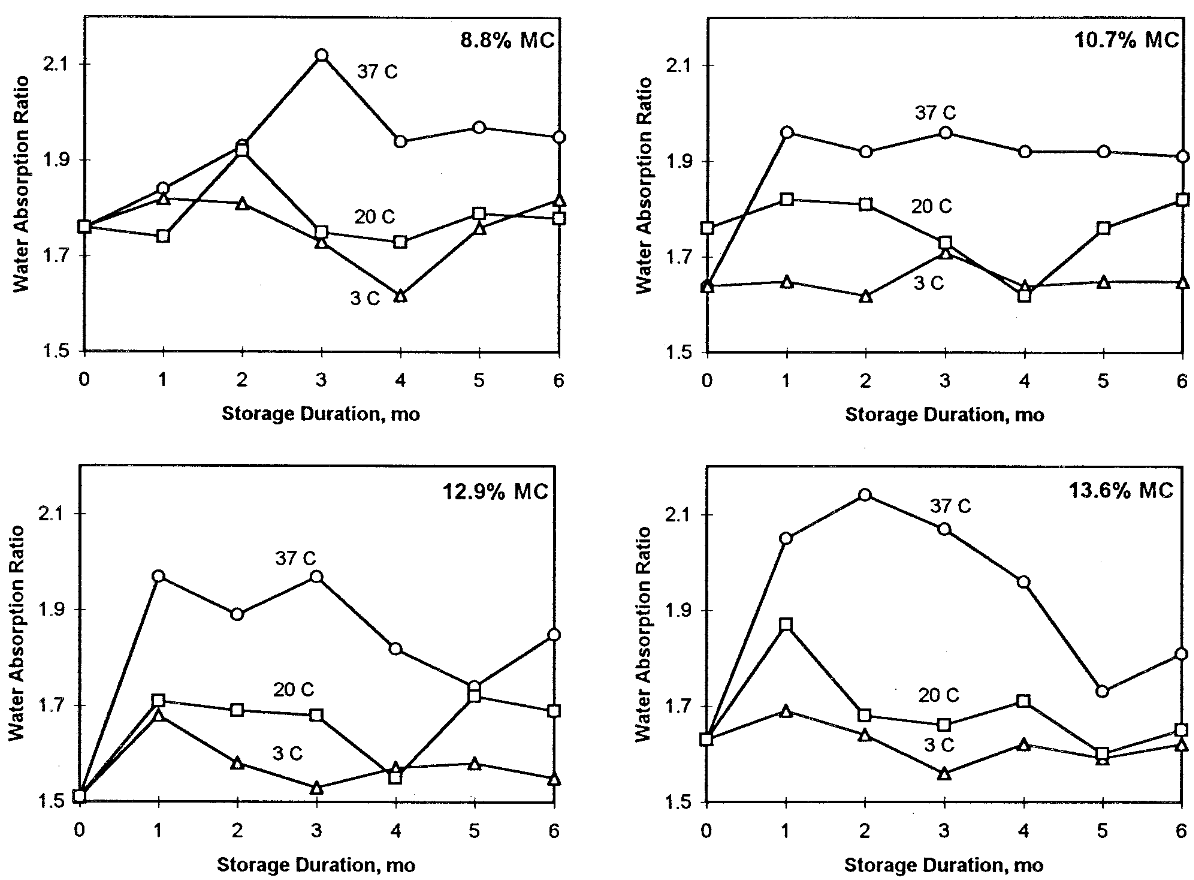

Fig. 3. Effect of storage temperature, duration, and moisture content (MC) on water-absorption ratio during cooking of rice cv. Bengal.

TABLE I
Summary of the *P* Values from the Analysis of Variance for the Effect of Storage Conditions on the Functionalities of Rice cv. Bengal

		P value		
	df	Peak Viscosity	Final Viscosity	Water-Absorption Ratio
Temperature (*T*)	2	0.0001	0.0001	0.0001
Moisture content (*MC*)	3	0.0001	0.0001	0.0001
Storage duration (*t*)	6	0.0001	0.0001	0.0001
$T \times MC$	6	0.0198	0.1245	0.4004
$T \times t$	12	0.0003	0.0001	0.0008
$MC \times t$	18	0.0001	0.0001	0.2185

TABLE II
Highest Order Polynomial Terms of Significance ($P < 0.05$) Affecting the Amylograph Peak and Final Viscosities (PV and FV, respectively) and Water-Absorption Ratio of Rice Cv. Bengal During Storage[a]

Functional Property	Highest Order Polynomial Terms[b]	R^2
PV	$f(T^2, T \times MC, T \times t^2, MC \times t^3, MC^3 \times t^2)$	0.88
FV	$f(T \times t^2, T^2 \times t, MC^2 \times t^3, MC^3 \times t)$	0.89
Water-absorption	$f(MC^3, T \times t^3, T^2 \times t^2)$	0.81

[a] All lower order terms of the significant interactions and contributing individual factors were included in the polynomial model.
[b] *T* = storage temperature (degrees Celsius), *MC* = moisture content of the rough rice (percent wet basis), *t* = storage duration (months).

Statistical Models

Qualitative assessment of the data reported in Figs. 1–3 indicated that the functional properties were not linearly related to storage duration or temperature. To describe the relationships, analyses of variance of the different factors and their interactions in affecting the different functionalities were conducted (Table I). These results confirmed the qualitative assessment regarding the significant effect of storage duration and temperature on rice properties during storage and also revealed the significant contribution of the rice MC. The interactions of these factors also were significant. Consequently, a polynomial model was constructed to describe each of the functional properties. The general equation used was:

$$Y = f(T^i, MC^j, t^k, T^i \times MC^j, T^i \times t^k, MC^j \times t^k)$$

where Y = functional property modeled (PV, FV, or water absorption); T = storage temperature (degrees Celsius); MC = moisture content of rough rice (percent wet basis); t = storage duration (months); $i = 1, 2$; $j = 1, 2, 3$; and $k = 1, 2, 3$.

The highest order polynomial terms of significance ($P < 0.05$) and the resulting R^2 are summarized in Table II. The significant effects of the interactions and the higher order terms for storage temperature, duration, and MC on the rice functionalities suggest that the mechanism for rice aging is very complex. However, each of the statistical models included terms with T^2, MC^3, and t^3, indicating a consistently significant effect of these three storage parameters. The consistent effect of MC on the changes in the functional properties is particularly noteworthy. Previous research focused mainly on the effects of storage temperature and duration (both external or environmental factors) on rice aging. The results presented here suggest that water, an integral component of the rice kernel, also plays an important role in the aging process.

CONCLUSIONS

Changes in milled rice (cv. Bengal) functionality during storage are affected not only by storage duration and temperature but also by the rough rice storage MC. The effect of storage temperature and duration on the amylograph and cooking properties were consistent with previous research; paste viscosities and water absorption during cooking increased with storage duration and temperature. Furthermore, statistical analyses showed a significant contribution of storage MC to changes in functional properties of cv. Bengal during storage. Interactions among the different variables tested also were significant. The resulting polynomial models suggest that rice aging is a complex process. Predictive models for aging would be useful in managing rice storage conditions that will produce rice with specific and consistent functional properties. Consequently, further investigations into the fundamental mechanism for these changes are needed. Additionally, the influence of cultivar and postharvest processing conditions need to be addressed.

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