Effects of Postharvest Parameters on Functional Changes During Rough Rice Storage

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ABSTRACT

The expansion of value-added uses for rice has created a demand for quantitative models of functional changes during postharvest handling. Consequently, this study evaluated the effects of postharvest parameters on the functional properties of long-grain (cvs. Cypress and Kaybonnet) and medium-grain (cv. Bengal) rice. The experimental treatments included rough rice drying conditions (low vs. high temperature drying), storage moisture content (10, 12, and 14%), storage temperature (4, 21, and 38°C), and storage duration (up to 36 weeks). Milling, cooking, and amylograph pasting properties were analyzed. Polynomial models (up to third-order) were developed to describe the effects of postharvest factors on the functional properties. Drying treatments, storage moisture content, and storage duration affected ($P < 0.05$) all of the functional properties. Storage temperature influenced ($P < 0.01$) cooking and pasting properties, but not milling properties. Overall, there were significant interactions among the postharvest parameters. Additionally, these factors were related to the functional properties by higher-order relationships.

Rice and rice products are increasingly used in value-added consumer products (Meyers 1994). Consequently, rice processors have been forced to tighten the specifications for rice products as food ingredients. These tighter specifications require that greater attention be given to rice functional properties such as cooking and pasting properties and microbial counts in the products.

Previous literature has focused on individual postharvest factors (drying, storage, or milling conditions) and how they influence functional properties. Water absorption during cooking of milled rice increases with rough rice storage (Villareal et al 1976; Indudhara Swamy et al 1978; Tsugita et al 1983; Chrastil 1990, 1992) and volume expansion also increases with storage (Indudhara Swamy et al 1978) or remains unchanged (Bolling et al 1978). Additionally, amylograph peak viscosity of rice flour increases with rough rice storage (Yasumatsu et al 1964; Villareal et al 1976; Indudhara Swamy et al 1978; Perez and Juliano 1981; Matsue et al 1991; Dhaliwal et al 1991; Hamaker et al 1993), with the most significant changes occurring during the first three months (Perez and Juliano 1981; Hamaker et al 1993). Peak viscosity also increases at higher storage temperatures (Yasumatsu et al 1964; Villareal et al 1976; Hamaker et al 1993).

Although these specific changes are known, previous literature has neglected to evaluate or model the complex relationships between the postharvest treatments of rough rice and the end-use functional properties. Perdon et al (1997) and Daniels et al (1998) provided initial attempts at this type of modeling. However, neither experimental design was sufficiently broad to test the interactions among all of the postharvest parameters. Therefore, the specific objective of this project was to evaluate and descriptively model the interactive effects of rough rice drying treatment, storage moisture content, storage temperature, and storage duration on the milling, cooking, and amylograph pasting properties of rice.

MATERIALS AND METHODS

Experimental Design

Long-grain rice cvs. Cypress and Kaybonnet and medium-grain rice cv. Bengal were harvested in the fall of 1996 at the University of Arkansas (UA) Rice Research and Extension Center in Stuttgart, AR (Cypress and Bengal), or at the UA Northeast Research and Extension Center in Keiser, AR (Kaybonnet). The Cypress, Kaybonnet, and Bengal rice was harvested at 17.4, 18.3, and 18.0% wb moisture content (MC), respectively. Within one day of harvest, the rice was transported to the UA rice-processing laboratory in Fayetteville, AR, immediately cleaned in a Carter-Day Dockage Tester (Seedboro Equipment Co., Chicago) and placed in polyethylene buckets. Due to logistical limitations, the buckets were then placed in cold storage (–10°C) for one month before drying. Previous work (Daniels 1998) showed that minimal functional changes occur during short-term storage at this temperature.

A full-factorial experimental design included 54 different postharvest treatments (18 treatments per cultivar), excluding storage duration. The design consisted of two drying conditions (low temperature [33.3°C and 38.2% rh] vs. high temperature [60.0°C and 16.9% rh]); three storage moisture contents (10, 12, and 14%); three storage temperatures (4, 21, and 38°C); and eight storage durations (0, 3, 6, 9, 12, 16, 24, and 36 weeks).

Drying of the rough rice occurred in a laboratory-scale drying system, which included a commercial temperature and rh air control unit (model AA, Parameter Generation and Control, Black Mountain, NC). Air was circulated through layers of rice 2.5 cm thick. Before drying, each cultivar was randomly divided into six equal lots with a Boerner divider (Seedboro Co., Chicago). Half of the lots were subjected to low-temperature drying (33.3°C and 38.2% rh) for 75 min. The remaining half were subjected to high-temperature drying (60.0°C and 16.9% rh) for 20 min. These conditions represented equilibrium moisture contents of 10.1 and 5.8%, respectively (ASAE 1995), and both reduced the rough rice moisture content by ≈2 percentage points. After the drying treatments, the rice was immediately spread on screen trays (2.5 cm deep) within an equilibration chamber (21°C) until the target storage MC was reached for each lot (less than one week).

The individual storage lots were randomly subdivided into smaller samples for subsequent sampling during storage and were placed into zipper-sealed vegetable (breathable) plastic bags. These bags were placed into airtight polyethylene buckets, which were stored at 4, 21, or 38°C. The sample bag procedure was designed to expedite sample removal while maintaining the same air condition for all samples in a given bucket.

Samples were pulled from each bucket every three weeks for a four-month period and then at longer intervals for the duration of the study. Each sample was then subjected to milling, cooking, and amylograph pasting analyses.

Functional Analyses

Head rice yield (HRY) was determined in duplicate for each sample. Initially, 150 g of rough rice was dehulled in a McGill

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sample sheller and the resulting brown rice was milled in a McGill #2 mill (Seedboro) for 26–76 sec. The milling length was adjusted to provide a target degree of milling (DOM) of 90 ± 3 on a milling meter (model MM-1B, Satake, Hiroshima, Japan). To separate head rice from broken kernels, the milled rice was sorted on a rice-sizing shaker table (4.76 mm [12/64 in.] and 3.97 mm [10/64 in.] round holes for the long- and medium-grain cultivars, respectively) (Seedboro). HRY was calculated by dividing the head rice weight by 150 g and is reported as means of duplicate analyses.

Water absorption and volume expansion after cooking in excess water (Bhattacharya and Sowbhagya 1971) were determined in duplicate. Head rice (20 g) was measured into a wire basket (7 cm tall and 2.5 cm in diameter), and the height of the uncooked rice was measured. The basket was placed into a 250-mL beaker filled with 200 mL of water at room temperature, and the beaker was immediately placed in boiling water. After 20 min, the rice and basket were removed and allowed to drain for 10 min. Measurements were then taken of both cooked rice weight (±0.001 g) and height (±0.1 cm). Water absorption was computed as the ratio of water weight absorbed to initial (raw) rice weight, and volume expansion was computed as the ratio of cooked rice height to raw rice height in the sample basket. Both properties are reported as means of duplicate analyses.

For purposes of amylography, 60 g of head rice (from the HRY analysis) was ground in a mill (Udy Cyclotec, model 1093, Tecator, Hoganas, Sweden) with a 0.5-mm screen. The resulting flour was mixed with water to produce a slurry with 8% dry matter, after the MC of the flour was determined (Juliano et al 1985). Subsequently, the slurry was subjected to a defined temperature treatment (viscograph-E, C. W. Brabender Instruments, Hackensack, NJ) according to a modified (faster) version of Approved Method 61-01 (AACC 2000) for milled rice. The slurry was initially heated from 30 to 95°C at a rate of 3°C/min, maintained at 95°C for 10 min, then cooled to 50°C at –3°C/min. Peak and final viscosities were extracted from the resulting amylographs.

Statistical Analyses and Models

To determine the postharvest factors and interactions that significantly affected HRY, water absorption, volume expansion, peak viscosity, and final viscosity of the rice, an analysis of variance (ANOVA) was performed (release 6.10, SAS Institute, Cary, NC). The data analyzed were the means of replicate analyses for all functional properties except for peak and final viscosity, for which logistics allowed only one measurement of these properties to be taken per sample. The storage temperature and storage MC were included in the ANOVA as the target values of 4, 21, and 38°C, and 10, 12, and 14%, respectively. The ANOVA was limited to three-term interactions. Significant factors and interactions ($P < 0.05$) were subsequently included in complete polynomial models for each functional property, with each variable limited to the third order. Finally, these models were analyzed through a general linear model (GLM) procedure in SAS. The significant terms in the model were determined by the Type I sum

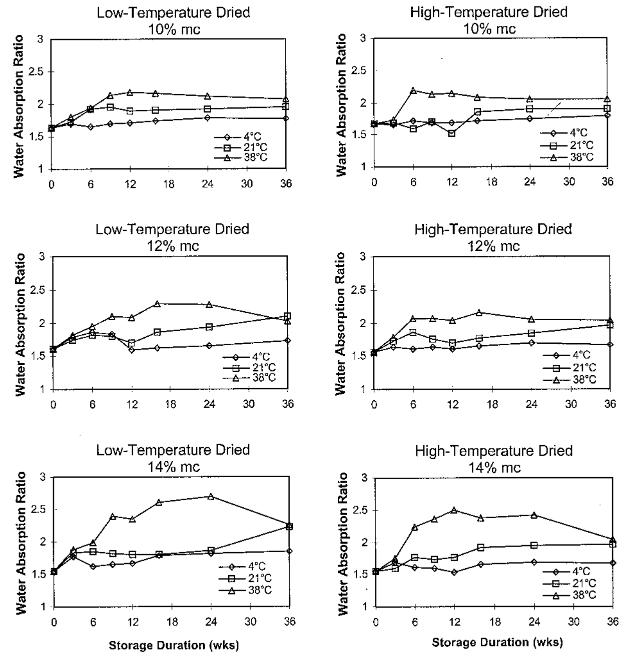

Fig. 2. Water absorption ratios as a function of rough rice storage duration and temperature for low- and high-temperature-dried rice (cv. Kaybonnet) stored at 10, 12, and 14% moisture content.

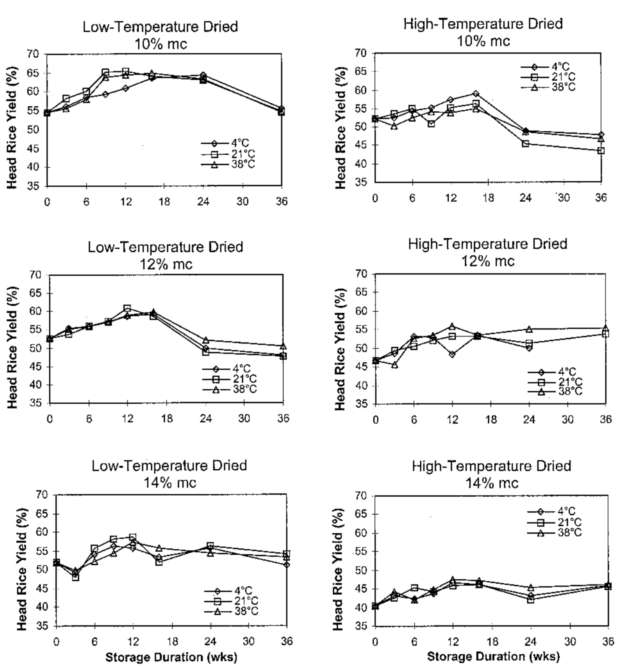

Fig. 1. Head rice yield as a function of rough rice storage duration and temperature for low- and high-temperature-dried rice (cv. Kaybonnet) stored at 10, 12, and 14% moisture content.

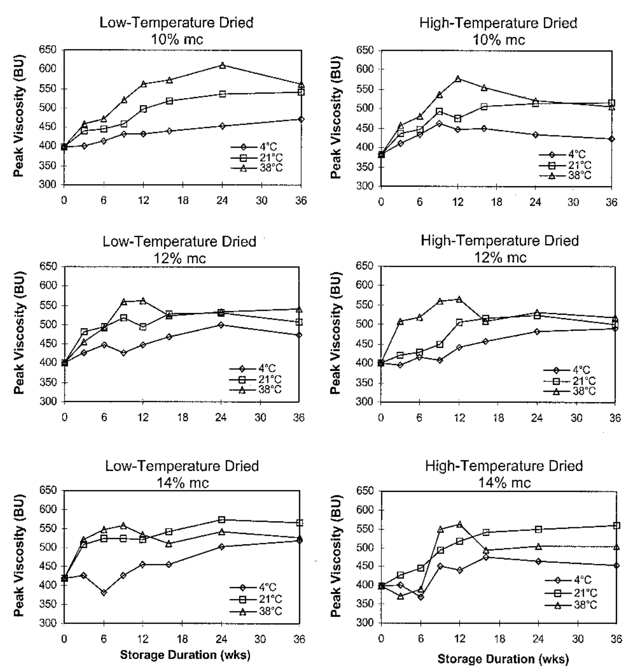

Fig. 3. Peak viscosity as a function of rough rice storage duration and temperature for low- and high-temperature-dried rice (cv. Kaybonnet) stored at 10, 12, and 14% moisture content.

of squares generated from GLM. The R^2 values for the models were obtained by including only the significant polynomial terms from the first GLM step in a second GLM analysis.

RESULTS AND DISCUSSION

The results from Kaybonnet are used to illustrate the overall trends for all three cultivars unless otherwise noted. However, the statistical analyses and polynomial models were derived using pooled data from all three cultivars. The complete data sets are reported by Daniels (1998).

Storage Trends for Functional Properties

For most lots, rough rice drying condition, storage MC, and storage temperature influenced HRY. HRY of all lots increased during the first three months of storage (Fig. 1), which is consistent with the earlier report of Daniels et al (1998). Thereafter however, HRY either declined or leveled off for the remainder of the study. The low-temperature dried rice exhibited higher HRY than did the high-temperature dried rice. The effect of storage MC was also apparent; rice stored at the lowest MC (10%) exhibited higher HRY than did the rice stored at 12 or 14% MC. The MC effect could be partially influenced by the milling procedure because the DOM target of 90 was difficult to achieve for the rice stored at 10% MC. Based on averages for all three cultivars, the DOM for the 10% MC rice was 4.3 lower than the target of 90. However, this difference might account for HRY values ≈0.5% higher than if the 90 DOM was obtained (Reid et al 1998), which would only explain a small portion of the observed HRY differences.

Rough rice drying treatment, storage MC, storage temperature, and storage duration influenced the cooking properties of the rice. Water absorption ratios of all the lots increased with storage (Fig. 2). The volume expansion ratios were similar, however, not all lots showed an increase with storage duration (Daniels 1998). All low-temperature dried lots exhibited a greater water absorption value than did the corresponding high-temperature dried lots. In all cases, both cooking ratios increased with increasing storage temperature, particularly at 38°C. Similar trends were observed by Matsue et al (1991), Hamaker et al (1993), and Perdon et al (1997).

The amylograph pasting properties (peak and final viscosities) mimicked the trends of the cooking properties: both peak and final viscosity increased with storage; low-temperature dried lots yielded greater viscosities than did the high-temperature dried lots; and the viscosities increased more dramatically when stored at higher temperatures (Fig. 3). Some slight variations to these trends were

TABLE I
Analysis of Variance for Significance of Postharvest Conditions on Functionalities of Rice

		Analysis of Variance (*P* values)				
Source	**df**	**HRY[a]**	**Water Abs.**	**Vol. Expansion**	**Peak Viscosity**	**Final Viscosity**
Temperature (T)	2	ns[b]	0.0001	0.0001	0.0001	0.0001
Duration (t)	6	0.0001	0.0001	0.0001	0.0001	0.0001
T × t	12	ns	0.0001	0.0001	0.0221	0.0008
Drying Conditions (DC)	1	0.0001	0.0001	ns	0.0076	0.0170
T × DC	2	ns	ns	ns	ns	0.0122
t × DC	6	0.0001	0.0004	0.0327	0.0315	ns
T × t × DC	12	ns	ns	ns	ns	ns
Moisture Content (MC)	2	0.0001	ns	0.0011	ns	ns
T × MC	4	ns	0.0001	0.0001	0.0131	0.0078
t × MC	12	0.0002	0.0330	0.0005	ns	ns
T × t × MC	24	ns	0.0334	0.0474	ns	ns
DC × MC	2	0.0174	0.0013	0.0001	ns	0.0383
T× DC × MC	4	ns	0.0399	0.0068	ns	ns
t × DC × MC	12	0.0058	ns	0.0313	ns	0.0432
Cultivar (V)	2	0.0001	0.0001	0.0001	0.0001	0.0001
T × V	4	ns	0.0001	0.0001	0.0001	ns
t × V	12	0.0001	0.0001	0.0001	0.0001	ns
T × t × V	24	ns	0.0003	ns	0.0152	0.0136
DC × V	2	0.0457	ns	ns	ns	ns
T × DC × V	4	0.0453	ns	0.0011	ns	ns
t × DC × V	12	0.0001	0.0001	0.0043	ns	0.0098
MC × V	2	0.0010	0.0001	0.0001	ns	0.0037
T × MC × V	8	ns	0.0028	ns	0.0270	ns
t × MC × V	24	ns	0.0001	0.0432	ns	ns
DC × MC ×V	4	0.0001	0.0001	0.0001	ns	0.0001
Mean		50.09	1.82	2.67	534	752

[a] Head rice yield.
[b] Not significant at α = 0.05.

TABLE II
Significant Polynomial Variables ($P < 0.05$) Affecting Head Rice Yield (HRY), Water Absorption, Volume Expansion, Peak Viscosity, and Final Viscosity of Rice During Storage

Property	**Highest Order Significant Variables and Variable Interactions in Model[a]**			**R^2**
HRY	t^3 × DC × V	t × DC × M	DC × MC × V	0.867
Water absorption	$T^2 \times t^2$ × MC	T × t^2 × V	T × MC × V	
	t^2 × DC × V	t^2 × MC × V	t^3 × V	0.846
Volume expansion	$T^2 \times t^3$ × MC	T^2 × DC × MC	T × DC × V	
	t^2 × DC × V	t^2 × MC × V	DC × MC × V	0.817
Peak viscosity	$T^2 \times t^2$ × V	t^2 × MC	$T^2 \times t^3$	
	DC			0.833
Final viscosity	$T^2 \times t^3$	T^2 × T × V	T^2 × DC	
	T × MC	t^3 × DC × V	DC × MC × V	0.850

[a] T = storage temperature, t = storage duration, DC = drying condition, MC = moisture content, and V = cultivar.

observed among the three cultivars (Daniels 1998). However, these deviations did not affect the general observations reported here.

Statistical Analysis and Models

The data in Figures 1–3 suggest that the functional properties of the rice were not all related to postharvest factors through simple linear relationships. ANOVA was conducted as an initial step in identifying the significant factors and interactions affecting the functional properties (Table I). The significant terms ($P < 0.05$) were included in polynomial models (Table II). The purpose of these models was to determine the degree of influence that the postharvest factors had on milling, cooking, and pasting properties. The models described the data well, with all models yielding $R^2 > 0.82$. Additionally, the highest terms of each model included interactions of two or more factors, suggesting that the rates of functional changes were significantly influenced by all of the postharvest parameters.

Rough rice drying condition, storage MC, and storage duration were significant terms in all of the models. Storage temperature, however, influenced all functional properties except HRY. This suggests that the changes in cooking and pasting properties were likely due to temperature-dependent processes such as would be controlled by enzymes within the kernels, whereas the fundamental mechanism for HRY changes is unknown.

Interaction terms in the models reveal some important relationships. For example, significant interactions between drying condition and storage temperature suggest that high-temperature drying not only decreases the initial values of the measured functional properties (Figs. 1–3) but also affects the rate at which they change during storage. Also, the interaction of storage temperature and MC significantly affected cooking and pasting properties, with the exception of peak viscosity. This was also seen in the data trends. However, the interaction of storage temperature, MC, and drying condition—a significant term found in the volume expansion model—is not easily interpreted visually from the data curves. This example illustrates why statistical analysis was needed to correctly identify model terms that represent the complex relationships between the postharvest parameters and functional changes.

CONCLUSIONS

Overall, this study showed that rough rice postharvest parameters affect the end-use functionalities of rice through complex relationships. Descriptions of these relationships suggest that the functional properties can be manipulated by managing postharvest operations. For example, if a rice processor wanted to maximize cooking ratios, both rough rice storage temperature and storage MC could be increased slightly to increase the rate of aging (i.e., the age-induced increase in these functional properties) during the first few months of storage. However, higher storage temperature and MC could obviously also lead to deleterious effects such as increased mold growth. Therefore, predictive models are important tools in developing optimal postharvest strategies that maximize desirable functional changes while still preserving the biological stability of the product. Ultimately, such tools could help the industry meet the functional needs of specific end-users.

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