Effect of Temperature, Exposure Duration, and Moisture Content on Color and Viscosity of Rice[1]

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ABSTRACT

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Rice yellowing is a problem for the rice industry. The objective of this research was to determine the effect of various temperatures and exposure durations at certain moisture content levels on yellowing in rice. Preliminary experiments were performed on stored *Oryza sativa* L. 'Cypress' rice. These experiments showed that exposure temperature and duration had a great effect on yellowing, but that the effect of moisture content was not significant ($P > 0.15$). With this information, similar experiments were performed on freshly harvested 'Cypress' and 'Bengal' rice. Color degradation, as measured by hue angle and chroma, was observed when at temperatures >50°C for exposure durations >12 hr. Temperatures >55°C with exposure durations >12 hr also resulted in dramatically lowered peak viscosity, but not all samples that showed yellowing had lowered viscosity. For the conditions of these experiments, temperature and exposure duration were the most important factors in color and viscosity change.

Postharvest yellowing of rice, or stack-burn, is a significant problem for the rice industry. Other crops such as barley, wheat, rye, speltz, cornmeal, cotton, and hay are affected by a similar phenomenon (Gilman and Barron 1930). Rice is typically harvested at 16–24% moisture content (MC) and dried to 12–14% MC for safe storage (Schroeder 1963). [Unless otherwise noted, all MC levels are % wet basis.] Delayed or improper drying can cause heat burns or heat discoloration, yielding yellow rice kernels (Sahay and Gangopadhyay 1985). Aibara et al (1984) also cited that improper handling of fresh rice, either after harvest or during storage, could cause increased respiration and therefore increased loss of quality.

While yellowing generally occurs in the paddy form, the endosperm is what is affected and, thus, yellowing is not apparent until the rice is milled. Yellowing is a form of deterioration that affects quality, appearance, flavor, and yield (Singaravadivel and Raj 1983; Phillips et al 1988; Misra and Vir 1991). The 1995 United States (USDA) Standards for Rice include number of heat damaged kernels in the criteria for establishing the grade of rice.

Yellowing does not necessarily refer to yellow-colored kernels. Colors range from yellow to orange to reddish. Factors responsible for yellowing include fungi or mold (Schroder 1963), grain water activity, and surrounding air temperature, oxygen, and carbon dioxide content (Bason et al 1990). Some of these factors may work in conjunction to cause yellowing. However, none of the existing theories on the causes of yellowing are conclusive.

This research was conducted to determine the effects of temperature, exposure duration, and MC on yellowing of rough rice. This was accomplished in three sets of experiments. Preliminary experiments were performed using stored rice to determine the range of temperatures, exposure durations, and MC levels that created yellowing. Subsequent experiments using stored rice built on this information and narrowed the treatment range. The final experiments were performed on freshly harvested rice and widened the testing range in case there were differences between stored rice and freshly harvested rice. The data were analyzed to determine which conditions most influenced the yellowing of rice, as indicated by hue angle and chroma, as well as other attributes including lipid content, head rice yield, and peak and final viscosity. Experiments were performed in the Rice Processing Program Laboratories at the University of Arkansas, Fayetteville, AR.

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MATERIALS AND METHODS

Preliminary Experiments

'Cypress' rough rice harvested from the Rice Research and Extension Center in Stuttgart, AR, on October 17, 1997, and stored at 15% MC for five months at 4°C was used for preliminary experiments. The design was generated using the Experimental Design Platform of JMP (v. 3.2, SAS Institute, Cary, NC). In the response surface menu of available designs for three factors (MC, temperature, and exposure duration), the rotatable central composite design was selected with 20 sample treatment combinations. Working from provided values (D. M. Trigo-Stockli and J. R. Pedersen, *unpublished*), five different MC levels (9.9, 17, 22, 29, and 30%), five temperatures (–16, 6, 37, 70, and 94°C) and five exposure durations (0, 2, 49, 96, and 128 hr) were generated as possible treatments. From 125 possible combinations, 20 were selected by the central composite design for actual testing with two repetitions for each treatment.

To obtain the desired MC levels, a calculated amount of water was added to the rough rice. Rice with the adjusted MC was equilibrated at 4°C for two days with periodic mixing. To achieve the target 9.9% MC sample, rice was dried for two days in a controlled temperature and relative humidity chamber set at 43°C and 38.2% rh. After MC adjustment, rice was divided with a Boerner divider (Seedburo Equipment Co., Chicago, IL) into 400-g samples for treatment. Actual MC levels reached were determined by drying duplicate samples for 24 hr in an air-oven set at 130°C (Jindal and Siebenmorgen 1987). Temperatures and MC levels achieved in the experiment varied slightly from the design.

Duplicate 400-g samples for each MC and exposure temperature and exposure duration treatment combination were placed into aluminum trays (24 × 28 cm) covered with heavy-duty aluminum foil, then placed in ovens for treatment, after which, the rice was immediately poured onto screens and placed in an equilibration chamber (21°C, 53% rh) to dry to ≈12.5% MC. After drying, 150-g samples of rough rice, in duplicate, were dehulled (rice machine, type THU, Satake Engineering Co., Tokyo, Japan) and the resulting brown rice was milled with a laboratory mill (McGill 2, RAPSCO, Brookshire, Texas). Head rice (kernels ≥75% of the original kernel length) was separated from brokens using a sizing device (Seedburo). Head rice yield (HRY) was calculated as HRY = (head rice/150 g) × 100.

A Rapid Visco Analyser (RVA) (model 4, Newport Scientific, Warriewood, NSW, Australia) was used to determine the peak and final viscosity of the rice flour. A 20-g sample of head rice was ground into flour with a cyclone mill with a 0.5-mm sieve (model 2511, Udy Corp., Fort Collins, CO). Viscosity was determined by mixing

3 ± 0.01 g of flour at ≈12% MC with 25 ± 0.05 mL of deionized water. The MC of the rice flour was determined according to the methods described by Juliano et al (1985). The RVA was set up according to manufacturer instructions on a 12.5 min runtime; the temperature program was 1.5 min at 50°C, heating to 95°C at 12°C/min, 2.5 min at 95°C, and cooling to 50°C at 12°C/min. Two subsamples of each treatment combination were measured in the RVA. The peak and final viscosity in RVA units (1 RVU = 10 cP) were recorded and analyzed.

A color meter (Colorgard System 05, BYK Gardner, Silver Springs, MD) was used to measure the color of a 50-g sample of head rice in duplicate using the $L^*a^*b^*$ scale. These values were then converted to hue angle ($\tan^{-1} b/a$) and chroma $(a^2 + b^2)^{½}$ as described by McLellan et al (1995).

Second Experiment

The same stored Cypress rice used in the preliminary experiments was also used in this experiment, which was conducted to focus more specifically on the yellowing treatment condition range. Test conditions for this experiment included three temperatures (39, 52, and 66°C) and three exposure durations (12, 36, and 72 hr). Moisture content was held constant because it was an insignificant factor ($P > 0.15$) in affecting color change, and its interactions were also insignificant in the analysis of discoloration in the preliminary experiments. For each treatment combination, duplicate 400-g rough rice samples at ≈12.5% MC were placed into aluminum trays, covered with heavy-duty aluminum foil, and placed into the ovens. In the preliminary experiments, some of the rice samples yielded very low HRY, indicating that many kernels broke with milling. This may have been caused by uncovering the pans immediately on removal from the oven, which could have caused fissuring of the rice, resulting in excessive breakage. Because of this, the procedure in the second experiment was to leave the rice covered in the aluminum containers and cool for ≈12 hr at 21°C after exposure in the oven. The rice was then poured onto screens and dried in an equilibration chamber (21°C, 53% rh) until the rice reached ≈12.5% MC. Following drying, the milling, viscosity, and color tests described above were performed.

Final Experiment

Cypress and Bengal rice harvested from Stuttgart, AR, and Keiser, AR, in Fall 1998 was used for this experiment. Immediately on arrival at the University of Arkansas Rice Processing Laboratory, the rice was cleaned with a dockage tester (model XT4, Carter Day Co., Minneapolis, MN). The rice was then rebagged and placed in storage at 4°C for approximately two months.

Two replicate 400-g samples of rice from a high harvest lot MC (≈21%) and a lower harvest lot (≈18%) MC from each cultivar and harvest location combination were placed in aluminum containers and covered with heavy-duty aluminum foil. The rice was then exposed to seven different temperatures (35, 40, 45, 50, 55, 60, and 70°C) for three durations (12, 36, or 72 hr). After exposure,

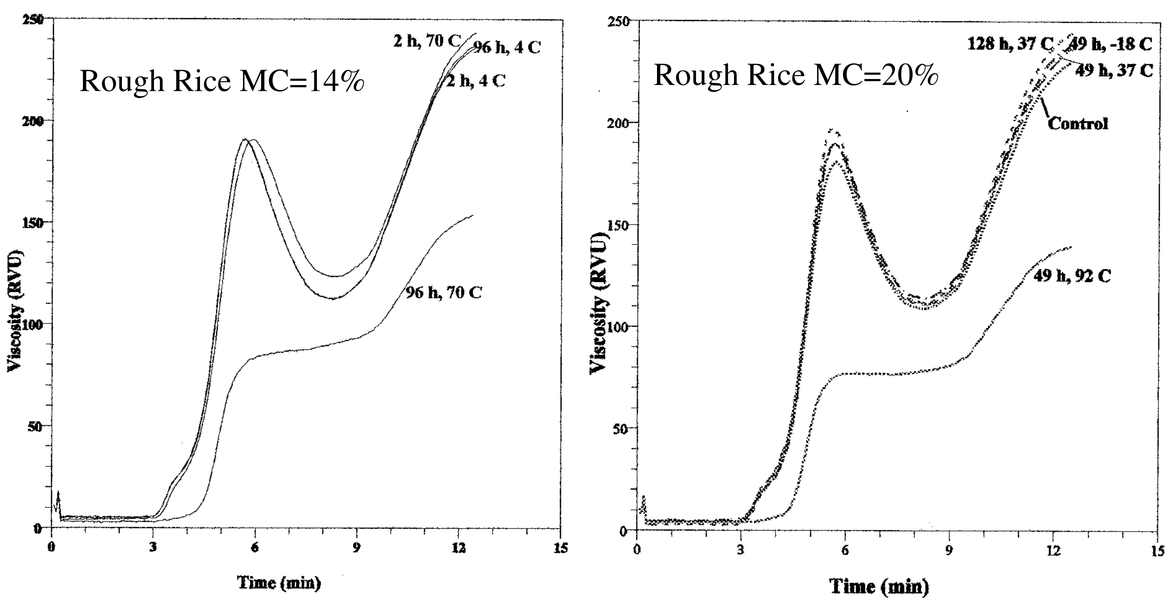

Fig. 1. Preliminary experiment results for viscosity of Cypress rice exposed to indicated temperatures and durations.

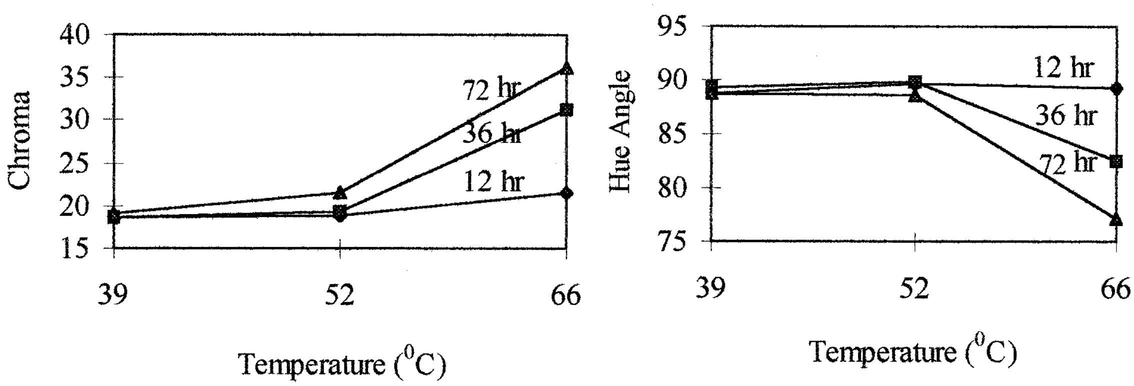

Fig. 2. Second experiment results for chroma and hue angle values of Cypress rice exposed to indicated temperatures for 12, 36, or 72 hr. Higher chroma values indicate discoloration. Each data point represents mean of four color measurements (two subsamples from two treatment replicates).

the rice was left covered in the aluminum containers and cooled for ≈12 hr at 21°C. The rice was then poured onto screens and dried in an equilibration chamber (21°C, 53% rh) until the rice reached ≈12.5% MC.

Perdon et al (1997) found that pasting properties of rice change rapidly during the first six weeks after harvest, then level out. To ensure the changes we observed were due to treatment and not storage, the rice was sealed in plastic bags and stored at 4°C for six weeks after drying. After storage, the color, viscosity, and HRY were measured on duplicate subsamples as described above. In addition, the surface lipid content of the head rice was measured. For this measurement a Soxtec lipid extractor (HT1043, Tecator, Sweden) with petroleum ether as the solvent (bp 35–60°C) was used according to the method described by Chen et al (1997).

RESULTS AND DISCUSSION

Preliminary Experiment

Data from this experiment were analyzed using JMP software. A second-order response surface was fit to the temperature, exposure duration, and MC data to describe color and viscosity changes. Temperature and exposure duration were not significant individually but the interaction was significant ($P = 0.0097$). MC was not significant in any interaction. The temperature × exposure duration interaction also significantly affected peak and final viscosity ($P = 0.005$ and 0.017, respectively). The peak viscosity greatly decreased at the 70°C, 96 hr and at 92°C, 49 hr treatment combinations relative to lower temperature and shorter duration exposures (Fig. 1). Although Fig. 1 shows only the viscosity for the 14% and 20% MC samples, temperature and exposure duration combinations at other MC levels responded similarly.

These data showed that the exposure duration by temperature interaction affected both color and viscosity. Because MC did not affect color or viscosity, it was dropped as a treatment variable for the second experiment.

Second Experiment

A second-order response surface that included both temperature and exposure duration showed that the interaction between these factors was again significant for both hue angle and chroma ($P = 0.0013$ and 0.0072, respectively). Changes in chroma and hue angle resulting from the Cypress rough rice exposure to three treatment temperatures for the three exposure durations are shown in Fig. 2.

Again, peak and final viscosity were significantly affected by the temperature × exposure duration interaction ($P = 0.0048$ and 0.0062, respectively). Exposure durations >12 hr combined with high temperatures greatly decreased viscosity. While there was not much change at 52°C with increasing duration (data not shown), there was a dramatic change in viscosity at 66°C (Fig. 3). HRY, however, was influenced only by exposure duration ($P = 0.0052$). HRY increased slightly the longer the rice was exposed to heat.

This experiment again showed that the interaction of temperature and exposure duration had a great effect on color and viscosity of rice. This confirmed the results of the preliminary experiments. The final experiments were performed to determine whether these results were consistent in freshly harvested rice.

Final Experiment

Although the treatments tested in the final experiment included one at 70°C, analysis included only temperatures ≤60°C because of excessive crumbling during milling of the rice treated at 70°C.

To determine which treatments significantly affected yellowing as measured by hue angle and chroma, a model that included all main effects and two factor interactions was fit first. Statistical analysis showed cultivar, location, and MC interactions were significant ($P = 0.001$) for chroma, with the temperature × exposure duration interaction having a highly significant effect ($P < 0.0001$). With this information, a final model was developed to describe chroma using linear and quadratic effects of temperature, a linear effect of duration, and the temperature × duration interaction for each cultivar and location combination. Results showed that the model fit all combinations of cultivar and location for these factors, as shown by highly significant P values ($P < 0.0001$ to 0.03). Figure 4 shows that as temperature increased to >45°C, chroma increased, indicating a more intense color. Discoloration, as measured by chroma, could be controlled if temperatures were kept <50°C for exposure durations <36 hr.

For hue angle, a model that included the main effects and two-way interactions showed the main effects of cultivar and location ($P = 0.001$) and MC ($P = 0.04$) as significant but none of the interactions between these factors were significant. Temperature and exposure duration, as well as their interaction, were highly significant ($P < 0.0001$). A reduced model fitting the main effects of cultivar and location, linear effects of MC and duration, quadratic effects of temperature, and the interaction of temperature × duration was then tested. This model showed all of these factors to be significant ($P < 0.0001$) except for MC, which was marginally significant ($P = 0.05$). Although the cultivar and location effects were statistically significant, there was not a large range, so samples over all cultivars and locations were averaged and plotted. Figure 5 shows that holding rough rice for 72 hr at >45°C caused hue angle to decrease, indicating that the rice became more reddish. Again, this discoloration could be controlled if temperatures were kept <50°C for exposure durations <36 hr.

Viscosity of Cypress rice was affected by exposure duration and temperature (Fig. 6). The separation of the 60°C and 72-hr viscosity profile shown in Fig. 6 did not appear at the 12- or 36-hr exposure durations (data not shown), nor did it appear in any of the Bengal samples. This suggested that a certain level of exposure temperature and exposure duration was necessary to affect viscosity. This also showed that the appearance of yellowing did not necessarily mean that there were changes in functional properties. Chroma and hue angle values of the rice showed yellowing at 55°C for 36- and 72-hr exposure durations, yet there was not a decrease in the viscosity of those samples (data not shown).

Surface lipid content and HRY for both Bengal and Cypress did not change with the different MC levels, temperatures, or exposure

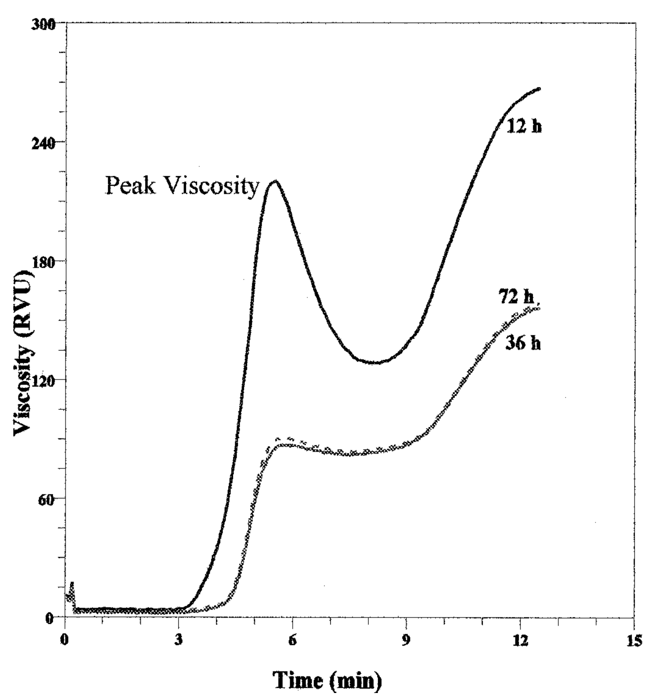

Fig. 3. Second experiment results for viscosity of Cypress rice exposed to 66°C for indicated durations.

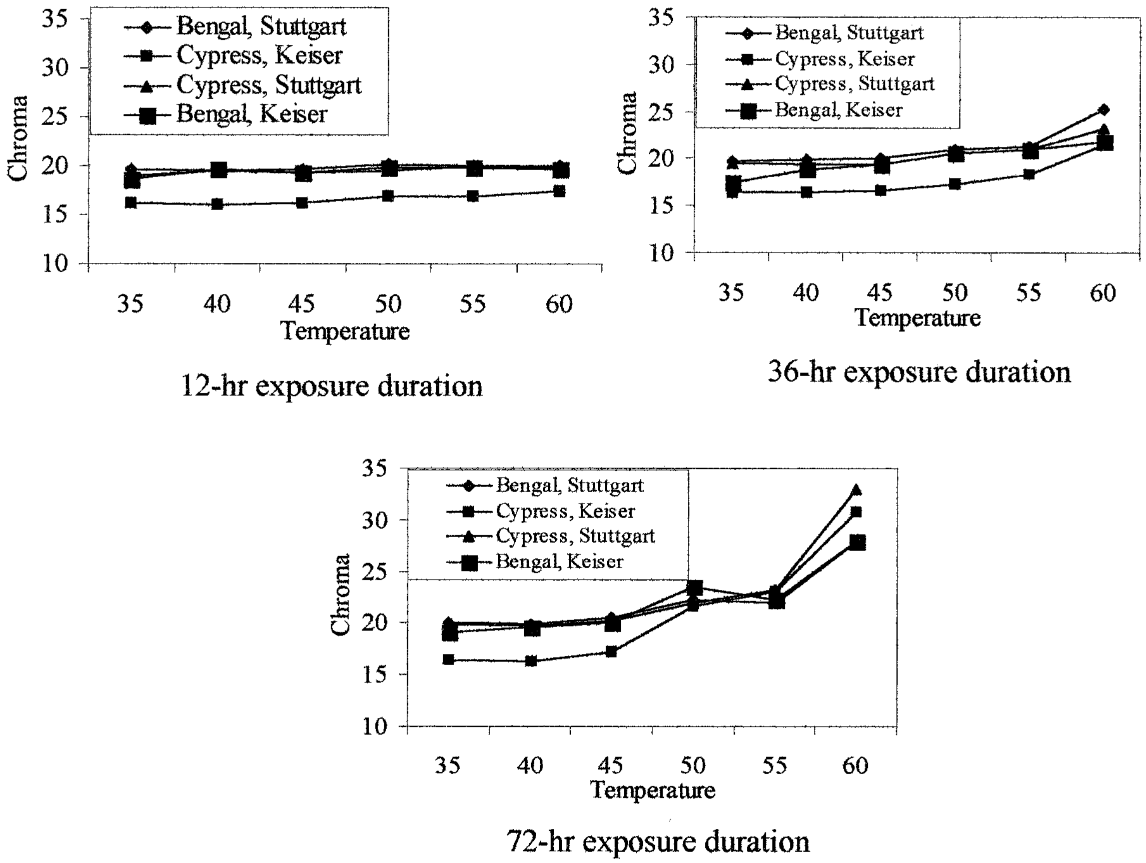

Fig. 4. Final experiment chroma values after exposing rough rice from each cultivar-location combination to temperatures and durations indicated. Each point represents combined data for Bengal and Cypress samples at high and low moisture content levels (mean value of 16 color measurements).

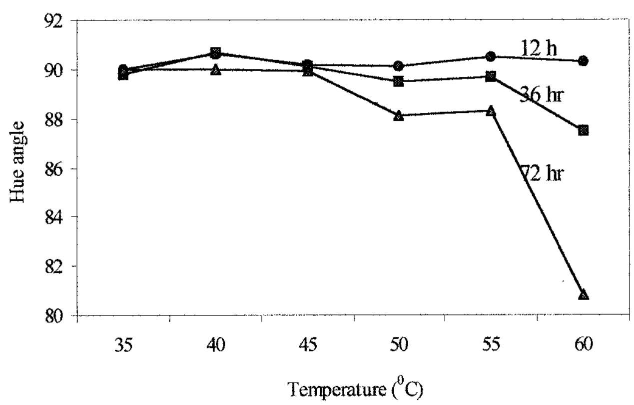

Fig. 5. Final experiment hue angle values after exposing rough rice to temperatures and durations indicated. Lower values indicate darker colored rice. Each point represents combined data of Bengal and Cypress samples (mean value of 32 color measurements).

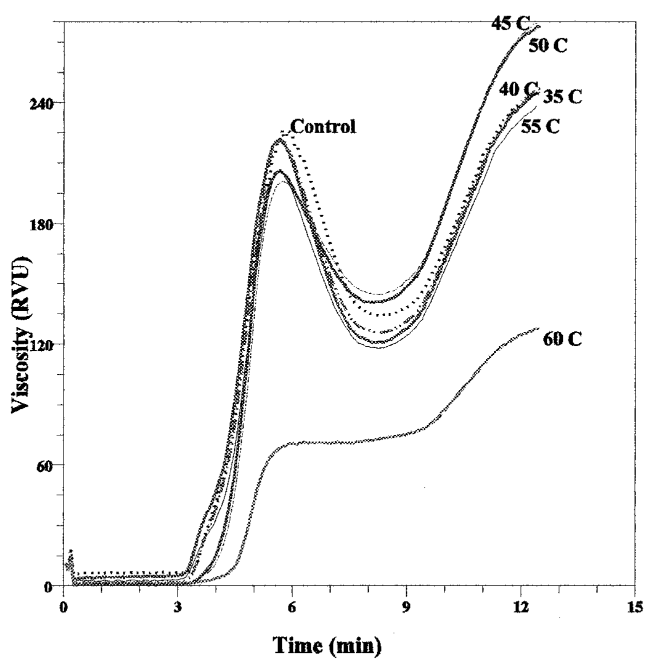

Fig. 6. Final experiment viscosity profiles for Cypress rice exposed to indicated temperatures for 72 hr.

durations. Both cultivars showed a tendency to increased HRY at higher temperatures, although there was not a dramatic change. Surface lipid content, measured to determine whether the treatments affected the degree of milling of rice, was not affected by treatment conditions.

CONCLUSIONS

These experiments showed that the combined effects of temperature and exposure duration are the most important factors influencing yellowing, as measured by hue angle and chroma of bulk samples. All experiments showed similar trends in color change due to exposing rough rice to various temperature and duration treatments. Overall, all experiments showed that by minimizing the time rice was held at >50°C to exposure durations <12 hr, yellowing was minimized. MC did not have an effect on yellowing; the MC at which samples were exposed to the various temperature treatments did not influence the response in color change developed by the samples. However, it should be noted that MC profoundly affects the respiration rate of rice and microflora associated with the rice (Dillahunty et al 2000). One of the consequences of elevated respiration rates is heat production. This heat, if not reduced in the grain mass, will increase grain temperature. This study showed that if temperature is allowed to increase to certain levels for sufficient durations, discoloration could occur. Thus, while MC was not influential as a treatment variable, it does have tremendous impact on the treatment variables that affect discoloration and viscosity changes.

Viscosity was also affected by exposure duration and temperature. Longer treatment temperature and exposure duration combinations decreased peak viscosities. This was shown in all experiments. Lowered viscosity indicates that physicochemical changes occurring during the yellowing process could affect the functional properties of the rice. Quantifiable changes in color of samples did not necessarily correspond to reductions in viscosity.

While this research showed that the temperature and exposure duration of rice affected color and viscosity, additional research is needed. In the current study, color measurements were made on bulk samples. However, observations indicated that some kernels within the bulk samples incurred much greater color change than others. Thus, research on the effects of treatment variables on individual kernels should now be studied.

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