Effects of Drain and Harvest Dates on Rice Sensory and Physicochemical Properties

Elaine T. Champagne,1,2 Karen L. Bett-Garber,1 James Thompson,3 Randall Mutters,4 Casey C. Grimm,1 and Anna M. McClung5

ABSTRACT

Timing of field draining and harvesting of rice with meteorological conditions can allow growers to foster conditions for high head rice yield (HRY). The effects of timing of draining and harvesting on rice sensory and physicochemical properties are not well understood. The objective of this study was to determine the effects of varying drain and harvest dates on the sensory and physicochemical properties of M-202 grown in California under controlled field conditions. Drain date had a significant ($P < 0.05$), but very small, effect on protein content. Harvesting at the earliest date (9/30) resulted in rice with higher setback and lower breakdown than at the last date (10/16) and, subsequently, the early harvested rice, when cooked, was harder, more cohesive, and absorbed less saliva in the mouth. However, the differences in texture measured by the panelists were very small and would possibly not be noticed by untrained palates. The lowest levels of the lipid oxidation products 1-pentanol, hexanal, and nonanal occurred in rice with the lowest harvest moisture content (HMC): rice harvested on 10/13 and 10/16. Differences in levels of lipid oxidation products and branched chain hydrocarbons did not lead to significant ($P > 0.05$) differences in flavor. In summary, M-202 demonstrated stable composition, physicochemical properties, flavor, and texture across drain and harvest dates.

Drain and harvest dates are important factors to be considered for an optimum rice harvest. Draining date is selected based on maturation characteristics of the cultivar, expected weather, soil type, field characteristics for draining surface water, and the effects of plant evapotranspiration on drying the soil surface (Wang and Luh 1991). Draining fields early may cause moisture stress in grains before they are physiologically mature. This could affect metabolic processes and, in turn, volatile flavor compounds and starch and protein composition and structure. Early draining may also lead to lower harvest moisture contents (HMC) associated with lower head rice yield (HRY).

Harvest generally commences in most countries when the average moisture content of the grains on the panicles is in the 20–27% range. In California, rice is harvested at <24% and usually in the 18–21% range. HRY are usually reported to be higher for rice with higher moisture contents (Kester et al 1963). However, high energy expenditures are required to dry rice with high HMC, and microbial growth can be problematic at high HMC if drying is delayed (Champagne et al 2004a). Thus, harvesting later when moisture content has dropped is desirable if HRY is not sacrificed.

In California, HRY may be reduced by dry north winds that can decrease yield and HRY (Park et al 2005). The samples were then lightly milled with a Yamamoto impeller husker (model FC2K) and then milled using a McGill no. 3 mill to uniform whiteness. Broken kernels were separated from whole grain milled rice using a rice grader (Satake model RG-06A). Head rice yield (HRY) was determined using USDA-FGIS procedures (Mutters et al 2004).

Rice Samples

A plot at the Rice Research Station in Biggs, CA, was divided into three sections that could each be drained separately. The entire plot was planted in 2003 with M-202 medium grain rice and each subplot was subjected to identical cultural practices. The subplots were drained early (September 12), normal (September 18), and late (September 26), and harvested at four dates (September 30, October 6, 13, and 16) beginning when the rice in the early drain section reached 24% moisture content. These dates corresponded to 32, 38, 45, and 48 days after flowering (DAF), respectively, where DAF date is at 50% heading. Each subplot was hand-harvested in six to eight locations and threshed with a small-plot thresher. Harvest moisture content (HMC) was determined on 200 grains of each sample taken at each harvest location using a single grain moisture meter (Kett).

The rough rice was dried with room temperature air to 13% moisture. Dried samples were dehulled with a Yamamoto impeller husker (model FC2K) and then milled using a McGill no. 3 mill to uniform whiteness. Broken kernels were separated from whole grain milled rice using a rice grader (Satake model RG-06A). Head rice yield (HRY) was determined using USDA-FGIS procedures (Mutters et al 2004).

The samples were then lightly milled with a single pass through a Yamamoto mill (model VP31T) to remove residual bran. Milled samples were shipped to the USDA-ARS, Southern Regional Research Center, New Orleans, LA. When received, samples were immediately preweighed into portions for identification of volatile compounds by gas chromatography/mass spectrometry (GC/MS) (Agilent 5973, Walnut Creek, CA, USA) and sensory panel evaluation and stored in glass jars at 4°C. Samples were also shipped to the USDA-ARS Rice Research Unit, Beaumont, TX, for protein, amylose, and RVA analyses.

Chemical Analyses

Apparent amylose content was determined on the samples in duplicate using the simplified assay method developed by Juliano (1971). Protein contents ($N \times 5.95$) were determined in duplicate by the combustion method on a nitrogen determinator (FP-428, Leco, St. Joseph, MI, USA).

MATERIALS AND METHODS

Chemical Analyses

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DOI: 10.1094/CC-82-0369

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Rapid Viscosity Analyses
Paste viscosity properties of rice samples were determined using an RVA (Newport Scientific model 3D) and Approved Method 61-02 (AACC International 2000). The definitions for measured properties are pasting temperature (temperature of initial viscosity increase); peak (maximum viscosity recorded during heating and holding cycles which usually occurs soon after the heating cycle reaches 95°C); hot paste viscosity (minimum viscosity after peak); cool paste viscosity (viscosity at test finish); breakdown (difference [-] between peak and trough, indicating breakdown in viscosity of paste during the 95°C holding period); and setback (difference [-] between final and peak viscosity).

Analysis of Rice Volatile Compounds
by SPME–Gas Chromatography/Mass Spectrometry
Each white rice sample (5 g) was placed in a 12-mL vial and sealed with a crimp top fitted with a Teflon-lined septum and held at ambient temperature until analyzed in triplicate. For analysis, each sample was heated to 65°C for 15 min. Then volatile compounds were adsorbed onto a 1-cm carboxen/PDMS/DVB fiber for 15 min while the sample was still held at 65°C. The SPME fiber was desorbed at 270°C into the GC injection port in splitless mode. The oven was held at 50°C for 1 min, then the temperature was increased at a rate of 5°C/min to 100°C, with a second ramp of 15°C/min to 300°C. Separation was achieved using a 30-m capillary column with a 1-µm 5% diphenyl, 95% polydimethylsiloxane film (DB-5, Supelco). The mass spectrometer was operated in scan mode at m/z 40–400 using electron ionization.

Total volatile profiles were compared between different samples for relative volatile production using pattern recognition techniques. Of primary interest was oxidation products (e.g., 1-pentanol, hexanal, nonanal) and microbial metabolites (e.g., 3-methyl-butanol, 2,3-butandiol, isovaleric acid). Integration was performed on a target ion for each compound, and two qualifying ions were selected for each compound. The relative intensities of compounds differing widely in amounts among samples were correlated with the independent variables and physicochemical data.

Sample Preparation for Sensory Analyses
Portions of white rice (600 g) were rinsed by covering the rice three times with cold water followed by straining to remove excess water. After rinsing, the samples were transferred to preweighed rice cooker insert bowls and water was added to give a rice-to-water weight ratio of 1:1.4. The rice was soaked for 30 min and then cooked in a five-cup rice cooker-steamer (Panasonic SR-W10G HP) to completion, followed by a 10-min holding period. Samples were taken from the cookers as described by Champagne et al. (1999). Cooking was staggered so that samples were analyzed at 20-min intervals.

Sensory Evaluation Protocol
Ten panelists trained (>100 hr) in the principles and concepts of descriptive sensory analysis (Meilgaard et al. 1991) participated in the study. These experienced panelists have served on this panel for five to 12 years. The rice flavor lexicon, based on the work of Goodwin et al. (1996), included 12 unique flavor attributes that were determined by smelling and evaluation in the mouth (Fig. 1). The intensities were scored based on a universal scale for all foods (Meilgaard et al. 1991); the maximum rating for rice flavor attributes is generally ≈5. The lexicon for rice texture used by the panel was based on that developed by Lyon et al. (1999) and Goodwin et al. (1996) and is described in Fig. 2. The sensory texture profile used by the panelists included 14 sensory attributes that described rice texture at different phases of sensory evaluation, beginning with the feel of the rice when it was first placed in the mouth and ending with mouthfeel characteristics after the rice was swallowed. The six to eight subsamples taken from the subplots at each drain-harvest date were combined to provide 12 samples for the sensory analyses. Each sample was presented to the panelists twice, in separate sessions, following a randomized

### Phases/Attributes

<table>
<thead>
<tr>
<th>Phase/Attribute</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Initial</strong></td>
<td>Place 6–7 grains of rice in mouth behind front teeth. Press tongue over surface and evaluate.</td>
</tr>
<tr>
<td>Starchy Coating</td>
<td>Amount of paste-like thickness perceived on the product before mixing with saliva (three passes).</td>
</tr>
<tr>
<td><strong>Stickiness</strong></td>
<td>Maximum ease of passing tongue over the rice surface when saliva starts to mix with sample.</td>
</tr>
<tr>
<td>Roughness</td>
<td>Amount of irregularities in the surface of the product.</td>
</tr>
<tr>
<td><strong>Stickiness to Lips</strong></td>
<td>Degree to which kernels adhere to lips.</td>
</tr>
<tr>
<td><strong>Stickiness Between Grains</strong></td>
<td>Degree to which the kernels adhere to each other.</td>
</tr>
<tr>
<td><strong>Springiness</strong></td>
<td>Degree to which the grains return to original shape after partial compression.</td>
</tr>
<tr>
<td><strong>Cohesiveness</strong></td>
<td>Degree to which the grains deform rather than crumble, crack, or break when biting with molars.</td>
</tr>
<tr>
<td><strong>Hardness</strong></td>
<td>Force required to bite through the sample with the molars.</td>
</tr>
<tr>
<td><strong>Evaluating during chew</strong></td>
<td>Maximum degree to which the sample holds together in a mass while chewing.</td>
</tr>
<tr>
<td><strong>Chewiness</strong></td>
<td>Amount of work to chew the sample.</td>
</tr>
<tr>
<td>Uniformity of Bite</td>
<td>Evenness of force throughout bites to chew.</td>
</tr>
<tr>
<td><strong>Moisture Absorption</strong></td>
<td>Amount of saliva absorbed by sample during chewing.</td>
</tr>
<tr>
<td><strong>Evaluating after swallow</strong></td>
<td>Maximum degree to which the sample holds together in a mass while chewing.</td>
</tr>
<tr>
<td><strong>Residual Loose Particles</strong></td>
<td>Amount of loose particles in mouth.</td>
</tr>
<tr>
<td><strong>Toothpack</strong></td>
<td>Amount of product adhering in/on the teeth.</td>
</tr>
</tbody>
</table>

**Fig. 1.** Descriptive sensory analysis attributes and definitions used to evaluate cooked rice flavor and mouthfeel (water-like/metallic and astringent).

**Fig. 2.** Sensory descriptive texture attributes and their definitions used to evaluate cooked rice texture.
design. During a session, the panelists were presented a standard (warm-up sample of commercial medium-grain rice) and three samples.

Statistical Analyses
Sensory data were analyzed using a split-plot with four harvest dates as the main unit and three field drain dates as the subunit. Harvest date samples were randomly chosen for a given session with two replicates for each harvest date, for a total of eight sessions. Within each session, the three drain dates were randomly presented. The panelists within a session were considered a subsample. Proc mixed (SAS Institute, Cary, NC) was used for analysis of variance (ANOVA). Least square (LS) means (Tukey’s adjustment method) was used to compare treatment means. All other data sets were analyzed with a two-way factorial design and Tukey’s HSD mean comparison using the Analyst option (SAS). Significance is reported at P < 0.05 for all data.

RESULTS
Harvest Moisture Content (HMC)
Table I shows mean rough rice moisture at harvest for each drain and harvest date. Before 10/9, the weather was calm and the rice was exposed to dew for 10–15 hr per day. During this period, average paddy moisture dropped. From 10/9 through 10/14, there were two periods of north wind, and significant dew was present for only one night. Mean moisture content dropped >6% during these few days. Calm conditions and dew resumed after 10/14 and moisture increased.

HMC of the early drained rice was significantly lower than that drained at the late date (Table I). HMC at early and normal drain dates were not significantly different from each other, nor did HMC at the normal and late drain dates differ. HMC of samples from the first two harvest dates (9/30 and 10/6) were significantly higher than those from the last two dates (10/13 and 10/16). There were no significant drain-by-harvest date interactions.

Apparent Amylose and Protein Contents
Table I shows the mean apparent amylose and protein contents for each drain and harvest date. Apparent amylose content was significantly higher at the late drain date than at earlier dates. However, the numerical differences in apparent amylose contents were very small and physiologically insignificant. Harvest date and drain-by-harvest date interactions were insignificant. Lu et al (1988) observed no significant change in protein content of three cultivars with prolonged harvest date (5- or 10-day delay corresponding to 35 and 40 DAF). Asano et al (1999, 2000) observed protein content of Koshihikari to decrease by no more than 0.7% by a 10-day delay in harvesting of mature rice. In contrast, Chae and Jun (2002) found protein contents of three milled cultivars to increase significantly (P < 0.05) from 40 to 70 DAF. Drain-by-harvest date interactions were not significant for protein.

RVA Paste Viscosity Properties
Table I shows the mean RVA paste viscosity properties for each drain and harvest date. Breakdown was significantly lower for early (96.9) drain date compared to normal (106.4) and late (104.2) drain dates. Early (165.3) drain date also resulted in significantly higher hot paste viscosity than at normal (156.5) and late (157.6) drain dates. Setback was significantly lower at normal drain date than at the other two dates. Drain date did not significantly affect peak viscosity.

Harvest date did not significantly affect peak, cool paste viscosity, and pasting temperature. Breakdown was significantly affected by harvest date, with the earliest date (95.8) being significantly lower than at later dates (10/6, 10/4.5; 10/13, 103.3; 10/16, 106.5). This is in agreement with Matsue et al (1991), who reported lower breakdown with earlier harvesting. Different harvest dates were reported by Lu et al (1988) to have little influence on pasting properties. Setback was significantly higher at the earliest harvest date (3.1) than at the last harvest date (–7.2). There were no significant drain-by-harvest date interactions.

Volatile Compounds
Either no or very low levels of common microbial metabolites 2-methyl-butanal, 3-methyl-butanal, 2-methyl-butanol, 3-methyl-butanol, 2-methyl-propanol, 2, 3-butandiol, ethyl hexadecanoate, 1-octene-3-ol, acetic acid, and isovaleric acid were found in the sample headspace. Common lipid oxidation products 1-pentanol, hexanal, 2-heptanal, and nonanal were found in all the samples. Drain date and drain-by-harvest date interactions did not significantly affect the levels of these products. Figure 3 shows the mean levels of each product for each harvest date. The levels of 1-pentanol and hexanal were significantly lower at the 10/13 harvest date than at other dates. Although not significant numerically, the lowest level of 2-heptanal also occurred on the 10/13 harvest date. The level of nonanal at the 10/13 date was significantly lower than levels at the 9/30 and 10/6 dates. The levels at 10/13 and 10/16 were not significantly different.

The lowest levels of these lipid oxidation products occurring in rice harvested on 10/13 (and 10/16 for nonanal) correspond to rice harvest date (9/30, 32 DAF) than at the 10/13 and 10/16 dates (45 and 48 DAF). The numerical differences in protein contents were very small and physiologically insignificant. Lu et al (1988) observed no significant change in protein content of three cultivars with prolonged harvest date (5- or 10-day delay corresponding to 35 and 40 DAF). Asano et al (1999, 2000) observed protein content of Koshihikari to decrease by no more than 0.7% by a 10-day delay in harvesting of mature rice. In contrast, Chae and Jun (2002) found protein contents of three milled cultivars to increase significantly (P < 0.05) from 40 to 70 DAF. Drain-by-harvest date interactions were not significant for protein.

### TABLE I

<table>
<thead>
<tr>
<th>Drain date</th>
<th>Moisture</th>
<th>Apparent Amylose</th>
<th>Protein</th>
<th>Peak Viscosity</th>
<th>Hot Paste Viscosity</th>
<th>Cool Paste Viscosity</th>
<th>Setback</th>
<th>Pasting Temp (°C)</th>
<th>Breakdown</th>
</tr>
</thead>
<tbody>
<tr>
<td>Early</td>
<td>21.1a</td>
<td>18.1a</td>
<td>5.1a</td>
<td>262.1a</td>
<td>165.3a</td>
<td>264.0a</td>
<td>1.9a</td>
<td>70.2ab</td>
<td>96.9a</td>
</tr>
<tr>
<td>Normal</td>
<td>22.1ab</td>
<td>17.9b</td>
<td>5.3b</td>
<td>262.9a</td>
<td>156.5b</td>
<td>255.9b</td>
<td>-7.0b</td>
<td>70.3a</td>
<td>106.4b</td>
</tr>
<tr>
<td>Late</td>
<td>22.7b</td>
<td>18.3c</td>
<td>5.2b</td>
<td>261.8a</td>
<td>157.6b</td>
<td>261.3ab</td>
<td>-0.5a</td>
<td>69.9b</td>
<td>104.2b</td>
</tr>
<tr>
<td>Harvest date</td>
<td>9/30</td>
<td>25.9a</td>
<td>18.2a</td>
<td>259.0a</td>
<td>163.2a</td>
<td>262.1a</td>
<td>3.1a</td>
<td>70.2a</td>
<td>95.8a</td>
</tr>
<tr>
<td></td>
<td>10/6</td>
<td>24.3a</td>
<td>18.1a</td>
<td>264.6a</td>
<td>160.1ab</td>
<td>262.0a</td>
<td>-2.6ab</td>
<td>70.0a</td>
<td>104.5b</td>
</tr>
<tr>
<td></td>
<td>10/13</td>
<td>18.1b</td>
<td>18.1a</td>
<td>259.9a</td>
<td>156.6b</td>
<td>259.9a</td>
<td>-0.9ab</td>
<td>70.2a</td>
<td>103.3b</td>
</tr>
<tr>
<td></td>
<td>10/16</td>
<td>19.6b</td>
<td>18.1a</td>
<td>265.6a</td>
<td>159.2ab</td>
<td>258.4a</td>
<td>-7.2b</td>
<td>70.2a</td>
<td>106.5b</td>
</tr>
</tbody>
</table>

a Values followed by the same letter in the same column are not significantly different (P < 0.05).

b Difference (–) between final and peak viscosities.

c Difference (–) between peak and trough, indication of breakdown in viscosity of paste during 95°C holding period.

d Harvest dates correspond with 32, 38, 45, and 48 days after flowering (DAF).
Fig. 3. Effects of harvest date on levels of lipid oxidation products.

Fig. 4. Effects of harvest date on levels of branched chain hydrocarbons with 9, 11, 13, and 15 carbon chain lengths.

with the lowest HMC. Linear functions describe the relationships between levels of 1-pentanol, hexanal, and nonanal and HMC with $r^2 = 0.60, 0.82$, and 0.85, respectively.

Branched chain hydrocarbons (BCH) with molecular weights of 128, 156, 185, and 212 corresponding to 9, 11, 13, and 15 carbon chain lengths, respectively, were observed in the GC/MS chromatograms. Drain date and drain-by-harvest date interactions did not significantly affect the levels of these BCH. Figure 4 shows the mean levels of each BCH for each harvest date. The levels of BCH-9 were significantly lower at the 9/30 and 10/16 harvest dates than at the 10/6 and 10/13 dates. The level of BCH-11 was significantly lower at the earliest harvest date (9/30) than at the 10/6 date. The levels of BCH-13 and BCH-15 were significantly higher at the last harvest date (10/16) than at the earlier dates. Branched chain hydrocarbons may arise from oxidation of branched chain fatty acids and breakdown of diterpenes (Merkle and Larick 1994).

**Sensory Properties**

The mean intensities of the flavor attributes for each drain and harvest date are listed in Table II. Floral and alfalfa/grassy/green bean flavor notes were not detected by the panelists. Drain and harvest dates did not significantly ($P > 0.1$) affect flavor. There were no significant ($P > 0.1$) drain-by-harvest date interactions.

Table III shows the mean intensities of the textural attributes for each drain and harvest date. These attributes were not significantly affected by drain and drain-by-harvest date interactions. Rice harvested at the earliest date (9/30) was significantly harder than that harvested late (10/16). The rice harvested at the earliest date was also significantly more cohesive and had lower moisture.
absorption properties than that harvested at the last two dates, 10/13 and 10/16. Significant differences were noted among
residual intensities with harvest date. The other textural attributes
absorption properties than that harvested at the last two dates,
and protein contents. Breakdown and setback were lowest for early
and harvest dates, respectively; however, no significant dif-
ferences in texture were measured as a result of these parameters
absorption properties than that harvested at the last two dates,
and harvest dates. The textural attributes did not change significantly in intensity with harvest date.
Hardness and cohesiveness are reported to be directly and inver-
sely correlated with setback and breakdown, respectively (Sandhya
Rani et al 1995; Champagne et al 2004b). In this study, harvest date,
and harvest dates correspond with 32, 38, 45, and 48 days after flowering (DAF).

<table>
<thead>
<tr>
<th>Harvest date</th>
<th>Early</th>
<th>Normal</th>
<th>Late</th>
</tr>
</thead>
<tbody>
<tr>
<td>9/30</td>
<td>0.6</td>
<td>0.7</td>
<td>0.5</td>
</tr>
<tr>
<td>10/6</td>
<td>0.7</td>
<td>0.7</td>
<td>0.6</td>
</tr>
<tr>
<td>10/13</td>
<td>0.8</td>
<td>0.8</td>
<td>0.7</td>
</tr>
<tr>
<td>10/16</td>
<td>0.4</td>
<td>2.6</td>
<td>0.8</td>
</tr>
</tbody>
</table>

| Harvest dates correspond with 32, 38, 45, and 48 days after flowering (DAF). | Intensities followed by the same letter in the same column are not significantly different (P > 0.1). | Initial starch coating (ISC); slickness (SLK); roughness (RGH); stickiness (STK); springiness (SPR); hardness (HRD); cohesiveness (COH); uniformity of bite (UNF); cohesiveness of mass (COH MASS); chewiness (CHW); moisture absorption (MOI ABS); residuals (RES); toothpacking (TP). | Harvest dates correspond with 32, 38, 45, and 48 days after flowering (DAF). |

CONCLUSIONS

Drain date had a significant, but very small, effect on amylose and protein contents. Breakdown and setback were lowest for early and normal drain dates, respectively; however, no significant differences in texture were measured as a result of these parameters being low. Drain date did not affect the volatile composition or flavor of the rice.

Harvest date had no effect on amylose content and a significant, but very small, effect on protein content. Harvesting at the earliest date (9/30) resulted in rice with higher setback and lower breakdown than at the last harvest date (10/16) and, subsequently, the early-harvested rice cooked harder, was more cohesive, and absorbed less saliva in the mouth. However, the differences in texture measured by the panelists were very small and would possibly not be noticed by untrained palates. The lowest levels of the lipid oxidation products 1-pentanol, hexanal, and nonanal occurred in rice with the lowest HMC (harvested on 10/13 and 10/16). Differences in levels of lipid oxidation products and branched chain hydrocarbons did not lead to significant differences in flavor.

In summary, M-202 demonstrated stable composition, physicochemical properties, flavor, and texture across drain and harvest dates. This provides growers with flexibility in selecting draining and harvest practices that will maximize HRY without sacrificing rice flavor and texture.

ACKNOWLEDGMENTS

We thank J. A. Miller (Southern Regional Research Center) and N. Gipson (Rice Quality Laboratory) for their technical assistance.

LITERATURE CITED


Linkages among breeders, producers, processors and consumers. TAMRC Consumer Product Market Research CP2-96: College Station, TX.

Vol. 82, No. 4, 2005 373


