

Physicochemical Properties of Rice Dried in a Single Pass Using High Temperatures

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ABSTRACT

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This study evaluated the physicochemical properties of high-temperature, single-pass dried rough rice. Pureline cultivars Wells (long grain) and Jupiter (medium grain) and hybrid cultivar CL XL729 (long grain), at initial moisture contents of 17.9–18.1% were dried in a single pass to approximately 12.5% moisture content with drying air temperatures of 60, 70, and 80°C and relative humidities of 13–83%. Immediately after

drying, the samples were tempered for 1 h at the drying air temperatures in sealed plastic bags. Color, degree of milling, pasting viscosity, and thermal properties of the milled rice were evaluated. Results showed that color, degree of milling, and thermal properties were not affected by drying treatments. However, peak and final viscosities increased with increasing drying air temperatures in all three cultivars.

The rice industry continuously strives to develop faster drying methods to handle the increasing crop influx resulting from high-yielding cultivars and rapid harvesting and transportation systems (Truitt and Siebenmorgen 2006). Drying rough rice in a single pass at high temperatures (>60°C) by incorporating glass transition principles in which kernel material states are controlled during drying, coupled with proper tempering for at least 1 h immediately after drying, has the potential to increase dryer throughput with minimal reduction to milling quality (Cnossen and Siebenmorgen 2002; Ondier et al 2012). In addition, drying with high air temperatures has the potential of minimizing the deleterious activity of enzymes such as amylases, proteases, and lipases, which are sensitive to heating (Halick and Kelly 1959; Tani et al 1964; Iwasaki et al 1965; Iwasaki and Tani 1967; Dhaliwal et al 1991).

Drying rough rice with high temperatures can, however, influence milled rice quality, affecting parameters such as color (Soponronnarit et al 1999; Dillahunty et al 2001; Prachayawarakorn et al 2005), cooking properties (Iwasaki and Tani 1967; Wiset et al 2001; Tirawanichakul et al 2004), and sensory quality (Champagne et al 1998; Inprasit and Noomhorm 2001). For example, Dillahunty et al (2001) reported increasing milled rice discoloration with increasing rough rice drying temperatures (>50°C) and durations; Wiset et al (2001) observed greater water absorption in rough rice samples dried at temperatures of 85–90°C compared with samples dried at ambient temperatures; Iwasaki and Tani (1967) showed that heating rough rice to high temperatures (>60°C) for 1 h resulted in considerable changes in cooked rice texture and off-flavor development, subsequently recommending temperatures below 50°C as the safe limit of heating during artificial drying; and Champagne et al (1998) reported greater values of cooked-rice cohesiveness for samples dried at 60°C than for samples dried at 18°C and presumed the increase to result from fissures developed from the harsh drying conditions, which increased water absorption during cooking.

Although results are conflicting, studies have also shown that drying conditions influence milled rice flour physicochemical properties, such as pasting viscosity and thermal properties, which are strongly correlated with end-use product quality (Dhaliwal et al 1991; Pearce et al 2001; Tran et al 2001; Patindol et al 2003; Dang and Copeland 2004; Wang et al 2004). For example,

Dhaliwal et al (1991) showed that rough rice samples stored without drying had greater gelatinization temperatures and peak viscosities than samples stored after drying; Patindol et al (2003) observed greater pasting viscosity in medium-grain samples dried at 40 and 60°C compared with samples dried at 20°C.

Although single-pass drying at high temperatures has the potential of maximizing dryer capacity by increasing rough rice drying rates and dryer throughput, the effects of high drying-air temperatures on end-use product functionality need to be more thoroughly investigated. The objective of this study was to determine the effect of the single-pass, high-temperature drying technique described by Ondier et al (2012) on milled rice appearance and functionality. Color, degree of milling, pasting viscosity profiles, and thermal properties were evaluated.

MATERIALS AND METHODS

Sample Collection and Preparation

Long- and medium-grain pureline cultivars (Wells and Jupiter, respectively) and a hybrid long-grain cultivar (CL XL729) were harvested from Stuttgart, Arkansas, in the fall of 2010 at moisture contents (MCs) ranging from 17.8 to 18.1% (moisture content is expressed on a wet basis unless specified otherwise). All samples were cleaned (MC Kicker grain tester, Mid-Continent Industries, Newton, KS, U.S.A.) and stored in sealed plastic tubs (0.22 m³) at 4°C for two months. Prior to each drying trial, samples were withdrawn from storage, sealed in plastic bags, and allowed to equilibrate to room temperature (24°C) overnight. The MCs of the rough rice samples were then measured by drying duplicate 15 g samples for 24 h in a convection oven (1370 FM, Sheldon Manufacturing, Cornelius, OR, U.S.A.) maintained at 130°C (Jindal and Siebenmorgen 1987).

Drying Conditions

The fluidized-bed system described by Ondier and Siebenmorgen (2010) was used for the drying experiments. Rough rice samples (500 g) were dried in a single pass at 60, 70, and 80°C and 13, 23, 33, 43, 53, 63, 73, and 83% rh from initial MC to approximately 12.5% MC. Immediately after drying, samples were tempered in sealed plastic bags, at the drying air temperature, for 1 h to allow moisture equilibration within the rice kernels, thereby minimizing fissuring upon exposure to cooling air (Cnossen and Siebenmorgen 2002; Schluterman and Siebenmorgen 2007). Samples were then spread in thin layers and exposed to ambient conditions (23 ± 1°C and 36 ± 2% rh) for 10 min. Each drying trial was replicated. An in-depth description of the drying experiment can be found in Ondier et al (2012). Control samples from each cultivar lot were spread on screens in thin layers and gently dried to 12.5% MC in an environment in which temperature and rela-

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tive humidity were maintained at $26 \pm 1^\circ\text{C}$ and $54 \pm 2\%$, respectively, by using a conditioning system (AA-558, Parameter Generation & Control, Black Mountain, NC, U.S.A.). After drying, all rough rice samples were stored at 4°C for approximately four months before quality analyses. Postdrying studies have shown that quality deterioration is usually not visible immediately after drying, thereby justifying the practice of delaying quality analysis for more than 48 h after drying (Sharma and Kunze 1982; Nguyen and Kunze 1984; Siebenmorgen et al 2005).

Milling Analyses

Duplicate 150 g subsamples of rough rice, obtained from each sample dried to the desired 12.5% MC, were dehulled with a laboratory huller (Satake rice machine, Satake Engineering Co., Tokyo, Japan), milled for 30 s with a laboratory mill (McGill No. 2, Rapscore, Brookshire, TX, U.S.A.), and aspirated for 30 s with a seed blower (South Dakota Seed Blower, Seedboro, Chicago, IL, U.S.A.) to remove loose bran particles from the surface of rice kernels. Head rice was then separated from broken kernels with a double-tray sizing machine (Grainman, Grain Machinery Manufacturing, Miami, FL, U.S.A.). Head rice was considered as milled-rice kernels that remained at least three-fourths of the original kernel length (USDA 2005).

Color

The whiteness and yellowness of duplicate 15 g head rice subsamples from each milled sample were measured with a Commission Internationale de l'Eclairage system L^* and b^* color scale with a colorimeter (ColorFlex, Hunter Associates Laboratory, Reston, VA, U.S.A.). The instrument was calibrated before testing with black and white plates supplied by the manufacturer. Samples were placed in a clear plastic cup and covered with a black plastic cup prior to color measurement to avoid interference from ambient light. After taking the first color reading, the sample cup was rotated approximately 180° , and a second reading of the same sample was taken. Both readings were averaged to obtain one whiteness (L^*) and yellowness (b^*) measurement. The color measurements were reflective indices of the sample surface, that is, the greater the L^* value, the whiter the milled rice, and the greater the b^* value, the more yellow the milled rice.

Degree of Milling

Surface lipid content of head rice was measured as an indication of the degree of milling. Surface lipids were extracted with a Soxtec extractor (Avanti 2055, Foss North America, Eden Prairie, MN, U.S.A.) according to the method of Matsler and Siebenmorgen (2005). Duplicate head rice samples (4–5 g) from each milled sample were predried at 100°C for 1 h, boiled in petroleum ether for 20 min, and rinsed with petroleum ether condensate for 30 min. Extraction cups containing the extracted lipids were dried at 100°C for 30 min to remove residual petroleum ether and weighed. Surface lipid content was determined as the mass ratio of lipids extracted from the surface of kernels to the original head rice sample mass.

Pasting Viscosity Profiles

To determine pasting viscosity profiles, duplicate 20 g head rice subsamples from each milled sample were ground into flour with a cyclone mill with a 0.5 mm sieve (model 2511, Udy Corp., Fort Collins, CO, U.S.A.). The MC of the flour was determined by drying duplicate 5 g samples in a convection oven at 130°C for 1 h (Jindal and Siebenmorgen 1987). Flour samples were prepared for viscosity analysis by mixing 3.00 ± 0.01 g of flour (at approximately 12% MC) with 25.00 ± 0.05 mL of deionized water. Water corrections were made to account for the samples being above or below 12% MC. Peak and final viscosities of the rice flour were determined with a Rapid Visco Analyzer (RVA, model 4, Newport Scientific, Warriewood, NSW, Australia). The RVA was set up on a 12.5 min runtime (1.5 min at 50°C , heating to 95°C at $12^\circ\text{C}/\text{min}$, 2.5 min at 95°C , cooling to 50°C at $12^\circ\text{C}/\text{min}$, and held for 1 min at 50°C), following AACC International Approved Method 61-02.01. Peak and final viscosities were recorded in centipoise (1 RVA unit = 12 cP).

Thermal Properties

Differential scanning calorimetry (DSC) was used to measure the thermal properties of rice flour produced from the cyclone mill (model 2511, Udy Corp.). Duplicate flour samples (4.0 ± 0.1 mg) prepared from each milled sample dried at 60, 70, and 80°C and 13, 53, and 83% rh were weighed into aluminum pans and hydrated with 8 μL of deionized water with a microsyringe. The pans were hermetically sealed and allowed to equilibrate for 12 h. DSC was conducted with a calorimeter (Pyris 1, Perkin Elmer, Norwalk, CT, U.S.A.) at a scanning rate of $10^\circ\text{C}/\text{min}$ from 25 to 120°C with an empty pan as the reference. The onset (T_o), peak (T_p), and conclusion (T_c) gelatinization temperatures and gelatinization enthalpy of the rice flour were obtained from each DSC thermogram, as generated by the calorimeter system software (version 9.1, Pyris series, Perkin Elmer).

Statistical Analysis

The experimental variables included rice cultivar (pureline and hybrid), kernel type (medium grain and long grain), and drying conditions (temperature and relative humidity). The main effects and interactions of all variables on milled rice physicochemical properties were determined with analysis of variance (JMP 9.0.1., SAS Institute, Cary, NC, U.S.A.). Means were compared with the Tukey significance test at $\alpha = 0.05$.

RESULTS AND DISCUSSION

Color

Whiteness (expressed as L^* values) and yellowness (expressed as b^* values) of Wells, Jupiter, and CL XL729 rice samples dried in a single pass at 60, 70, and 80°C and 13–83% rh and then tempered at the drying air temperature for 1 h immediately after drying are shown in Table I. No significant differences ($P > 0.05$) were observed between the whiteness and yellowness of experimental samples dried at increasing relative humidity; hence, the

TABLE I
Whiteness (Expressed as L^* Values) and Yellowness (Expressed as b^* Values) of Wells, Jupiter, and CL XL729 Rice Samples Dried in a Single Pass at 60, 70, and 80°C to 12.5% Moisture Content^z

Temperature ($^\circ\text{C}$)	Wells		Jupiter		CL XL729	
	L^*	b^*	L^*	b^*	L^*	b^*
60	$73.7 \pm 0.14a$	$14.9 \pm 0.14b$	$72.4 \pm 0.15c$	$16.1 \pm 0.12d$	$71.1 \pm 0.15e$	$15.0 \pm 0.14f$
70	$74.2 \pm 0.14a$	$15.0 \pm 0.14b$	$72.5 \pm 0.15c$	$16.5 \pm 0.12d$	$70.7 \pm 0.15e$	$15.1 \pm 0.14f$
80	$74.2 \pm 0.14a$	$15.6 \pm 0.14b$	$72.5 \pm 0.15c$	$16.9 \pm 0.12d$	$70.5 \pm 0.15e$	$15.6 \pm 0.14f$
Control	73.1a	15.8b	72.2c	16.7d	71.8e	15.4f

^z Control samples were dried at 26°C and 54% rh to 12.5% moisture content. Means are compared within columns (Tukey, $\alpha = 0.05$). Values designated by the same letter are not significantly different. Results for samples at 13, 23, 33, 43, 53, 63, 73, and 83% rh were pooled because they were not significantly different.

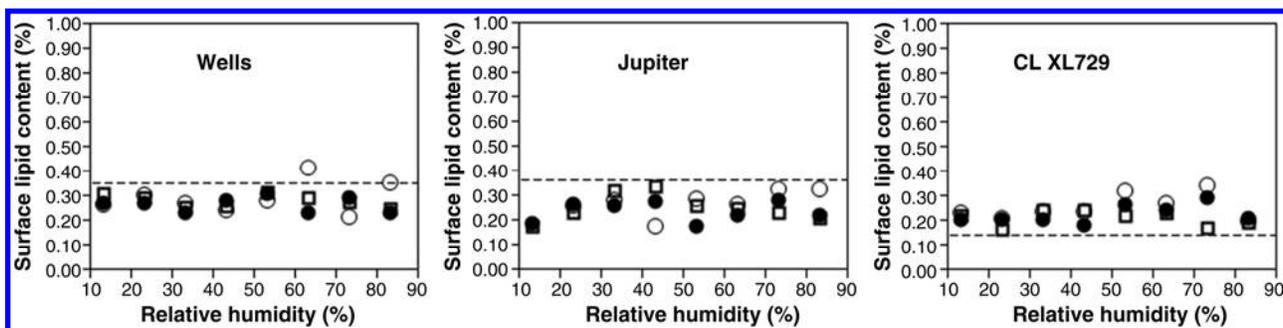


Fig. 1. Surface lipid contents of Wells, Jupiter, and CL XL729 rice samples dried in a single pass at 60 (●), 70 (□), and 80°C (○) and 13, 23, 33, 43, 53, 63, 73, and 83% rh to 12.5% moisture content. Control samples (----) were dried at 26°C and 54% rh to 12.5% moisture content.

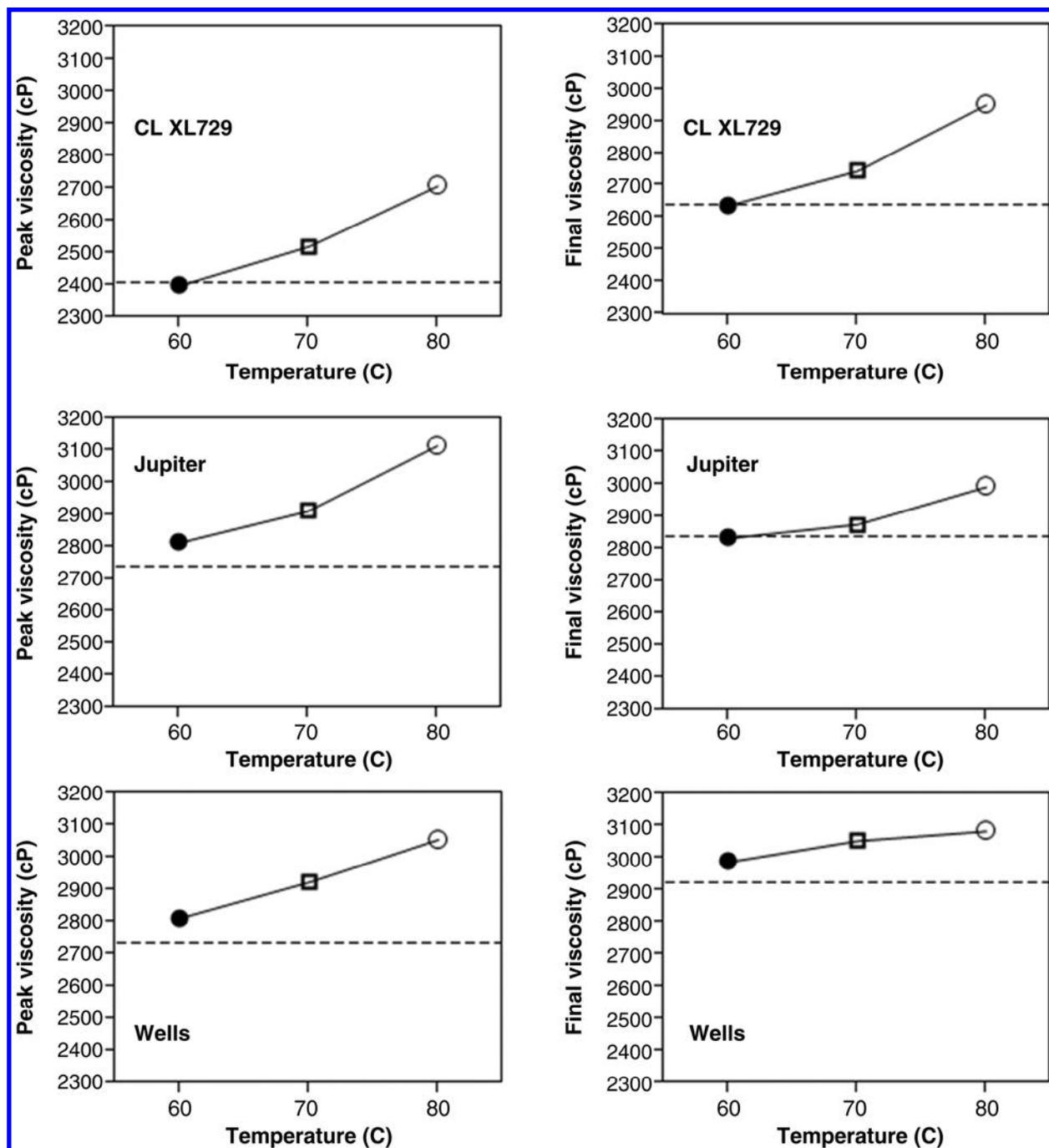


Fig. 2. Peak and final viscosities of Wells, Jupiter, and CL XL729 rice samples dried in a single pass at 60 (●), 70 (□), and 80°C (○) to the desired 12.5% moisture content. Control samples (----) were dried at 26°C and 54% rh to 12.5% moisture content. Results for samples at 13, 23, 33, 43, 53, 63, 73, and 83% rh were pooled because they were not significantly different.

average whiteness and yellowness of the eight relative humidities is presented for each drying air temperature. Results showed that the drying air conditions did not have a significant effect ($P > 0.05$) on the color, as indicated by L^* and b^* values, of the experimental samples. It is important to note that at constant temperature, samples dried at 83% rh were exposed to the drying air conditions for longer durations compared with samples dried at 13% rh; for example, the drying durations to 12.5% MC for Wells samples initially at 18.1% MC and dried at 13% rh and 60, 70, and 80°C were 24, 22, and 14 min, respectively, whereas the durations at 83% rh were 170, 120, and 105 min, respectively (Ondier et al 2012). The results, therefore, show that the rice dried at high temperatures for almost 3 h did not incur a significant decrease in whiteness or increase in yellowness, even after four months of storage at 4°C.

Patindol et al (2003) observed similar trends in which whiteness (L^* values) of medium-grain Bengal and long-grain Cypress cultivars dried at 20, 40, and 60°C to 12.5% MC in a single pass were not significantly different ($P > 0.05$). Some studies have reported increased yellowness with exposure to temperatures ranging from 45 to 50°C (Dillahunty et al 2001; Bunyawani-chakul et al 2005; Ambardekar and Siebenmorgen 2012). Increased solubility and interaction of the chemical compounds within the rice kernel caused by exposure of high-MC rough rice to high temperatures has been proposed as a possible cause for the decreased whiteness and increased yellowness. This proposition is supported by findings from Ambardekar and Siebenmorgen (2012), who showed that rice yellowing was greater in high-MC samples exposed to temperatures of 60–80°C compared with low-MC samples exposed to the same temperatures and exposure durations. Belefant-Miller et al (2005) reported similar findings in an induced-yellowing study in which milled samples incubated at 78°C for 114 h in test tubes with 10 µL of water showed greater yellowing than samples incubated in dry test tubes for the same duration. The authors concluded that MC is an important factor in inducing yellowing in rice exposed to elevated temperatures. Ambardekar and Siebenmorgen (2012) also showed that significant yellowing was induced in high-MC (>18%) samples only after exposing, but not drying, for durations of 4 h at 60°C and 30 min at 80°C. In the current study, drying rough rice in a single pass at high temperatures quickly reduced MC within the first few minutes; it is stipulated that this rapid decrease in MC limited yellowing or browning reactions and thus maintained milled rice color.

Degree of Milling

Degree of milling values, expressed as surface lipid content (SLC), of rice samples dried at the experimental conditions and milled for 30 s, are shown in Figure 1. Results showed that increasing drying air temperatures from 60 to 80°C and relative humidities from 13 to 83% did not affect the head rice degree of milling in either the pureline or hybrid cultivars ($P > 0.05$). However, the SLC values of the treatment and control samples were significantly different, that is, the SLCs of hybrid CL XL729 sam-

ples were significantly greater ($P < 0.05$) than the SLCs of the control samples, whereas SLCs of the pureline Jupiter and Wells samples were significantly lower ($P < 0.05$) than the SLCs of the control samples. Generally, hybrids have a lower SLC and greater degree of milling (Lanning and Siebenmorgen 2011) than pureline cultivars for comparable milling durations. Lanning and Siebenmorgen (2011) showed that the bran removal rates of hybrids exceeded that of purelines and that hybrids generally had lower total lipid content than purelines, both of which allow a lower SLC to be reached in a given milling duration. The lower brown rice total lipid content is reasoned to be associated with a thinner bran layer. The high-temperature drying conditions may have increased adherence of the thin bran layer to the endosperm of the hybrid cultivar but loosened the outer layers of the relatively thicker bran layer of the pureline cultivars.

Pasting Viscosity Profiles

At any of the three drying air temperatures, drying air relative humidity did not have a significant effect ($P > 0.05$) on peak or final viscosities of rice flour from all three cultivar lots; hence, values averaged across drying air relative humidity are presented. However, peak and final viscosities of all three cultivar lots increased with increasing drying air temperatures and were significantly greater ($P < 0.05$) than the controls at 70 and 80°C (Fig. 2). Dhaliwal et al (1991) reported similar increases in peak and final viscosities with increasing drying air temperatures. Ambardekar and Siebenmorgen (2012) also reported similar increases in peak and final viscosities for samples exposed to elevated temperatures of 60, 70, and 80°C. The high peak and final viscosities resulting from drying rough rice at elevated temperatures are associated with increased cooked rice cohesiveness (Champagne et al 1998) because of increasing water binding capacity of the starch granules and subsequent disintegration of the granules during cooking (Ruby and Elsie 1960; Wang et al 2004).

The observed changes in peak and final viscosities may be attributed to modification of the starch granule resulting from chemical and structural changes occurring within the rice kernels during or after exposure to high drying air temperatures. Generally, starch, not protein or other constituents, has the greatest influence on the pasting viscosity profile of rice flour (Patindol et al 2003). However, protein, which is the second most abundant component in rice flour, plays a significant role in pasting properties, because starch granules are encased in the protein matrix, causing the disulfide bonds to restrict granule swelling during gelatinization (Ruby and Elsie 1960; Hamaker and Griffin 1993; Baxter et al 2010). Given that the denaturation temperatures of rice proteins (albumin, globulin, and glutelin) range between 70 and 80°C (Ju et al 2001), it is possible that the drying air temperatures used in the current study (70 and 80°C) disrupted the disulfide bonds, thus allowing the starch granule to swell to a larger size (Hamaker and Griffin 1993), resulting in greater viscosities. In addition, the amylose and amylopectin chains of the starch granule may have interacted with the unfolded structures of the denatured protein (Dang and Copeland 2004), forming complexes that could have

TABLE II
Onset (T_o), Peak (T_p), and Conclusion (T_c) Gelatinization Temperatures (T_m) and Gelatinization Enthalpy (E) (J/kg) of Rice Flour from Wells, Jupiter, and CL XL729 Rice Samples Dried in a Single Pass at 60, 70, and 80°C to the Desired 12.5% Moisture Content²

T_m (°C)	Wells				Jupiter				CL XL729			
	T_o	T_p	T_c	E	T_o	T_p	T_c	E	T_o	T_p	T_c	E
60	75.8 ± 0.21a	81.9 ± 0.67b	85.8 ± 0.69c	9.1 ± 0.21d	64.1 ± 0.28e	70.0 ± 0.40f	76.7 ± 0.42g	6.2 ± 0.28h	74.3 ± 0.26i	79.3 ± 0.22j	86.7 ± 0.58k	8.6 ± 0.38m
70	75.7 ± 0.19a	80.4 ± 0.61b	86.1 ± 0.63c	9.4 ± 0.19d	64.9 ± 0.28e	70.9 ± 0.40f	77.4 ± 0.42g	6.8 ± 0.28h	74.2 ± 0.26i	79.6 ± 0.22j	86.8 ± 0.58k	8.2 ± 0.38m
80	76.8 ± 0.19a	80.7 ± 0.61b	86.4 ± 0.63c	8.9 ± 0.19d	64.0 ± 0.28e	69.2 ± 0.40f	76.0 ± 0.42g	7.0 ± 0.28h	74.3 ± 0.26i	79.4 ± 0.22j	86.0 ± 0.58k	9.0 ± 0.38m
Control	76.8a	81.8b	87.1c	7.0d	63.3e	69.3f	76.1g	7.0h	74.8i	80.0j	89.4k	7.8m

² Control samples were dried at 26°C and 54% rh to 12.5% moisture content. Means are compared within columns (Tukey, $\alpha = 0.05$). Values designated by the same letter are not significantly different. Results for samples at 13, 53, and 83% rh were pooled because they were not significantly different.

increased the pasting viscosity profile of the high-temperature-dried samples.

Thermal Properties

The drying air temperatures and relative humidities had no apparent effect on the thermal properties (onset and peak gelatinization temperatures and gelatinization enthalpy) of the Wells, Jupiter, and CL XL729 samples (Table II). No significant differences ($P > 0.05$) were observed between the treatment and control samples. Patindol et al (2003) reported similar findings, showing that rough rice drying conditions had no apparent effect on thermal properties of rice flour. Ambardekar and Siebenmorgen (2012) reported similar results for rough rice samples exposed to elevated temperatures of 60, 70, and 80°C for extended durations.

CONCLUSIONS

Single-pass drying of rough rice with high temperatures did not have an apparent effect on color, degree of milling, and thermal properties of Wells (pureline, long-grain), Jupiter (pureline, medium-grain), and CL XL729 (hybrid, long-grain) rice cultivars. However, the peak and final viscosities of rice flour from all three cultivar lots increased with increasing drying air temperatures.

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