Functional Properties of Commingled Rice-Cultivar Lots

Nikhil N. Basutkar, Terry J. Siebenmorgen,[†] Ya-Jane Wang, and James A. Patindol

Cereal Chem. 92(1):114–119

ABSTRACT

Commingling of rice cultivars commonly occurs during harvest, drying, and storage operations. Because different cultivars often have different functional properties, there is a need to study the impact of commingling on these properties. Two long-grain hybrid (H) cultivars, CL XL745 and CL XL729, and two long-grain pureline (P) cultivars, CL 151 and Wells, were used to prepare H/P, H/H, and P/P commingles in various proportions. Gelatinization and pasting properties of all individual lots and commingled samples were measured. When two cultivar lots with different onset gelatinization temperatures (T_os) were commingled, the T_o of the commingled sample was similar to the T_o of that cultivar in the commingle with the lower T_o. T_ps, T_cs, and ΔHs of commingled samples generally increased or decreased according to the mass percentages of the cultivars in the samples. Peak, breakdown, and final viscosities of commingled samples also varied according to the mass percentages of the cultivars in the commingled samples. These findings are intended to help make decisions regarding cultivar commingling and to optimize process conditions and product characteristics, given the gelatinization and pasting properties of individual-cultivar lots.

Rice is the most important staple food for a majority of the world's population. In addition to being consumed as cooked intact kernels, rice is used in the production of foods such as tortillas, breakfast cereals, puddings, and bread because of its unique functional properties and gluten-free composition. However, rice cultivars can differ in functional properties (Juliano 1998). These differences can have an impact on final product characteristics and process costs when manufacturing on an industrial scale.

Gelatinization and pasting properties of rice have a significant impact on end-use applications. Gelatinization is a process in which starch undergoes order-disorder transitions with the application of heat in excess water (Sivak and Preiss 1998). Determining the temperature and energy required for gelatinization is therefore of particular importance to food processors, who need to optimize cooking conditions and reduce process costs (Bao and Bergman 2004). After becoming gelatinized, starch granules form a paste comprising a viscous material of starch granules and leached starch molecules. Pasting properties are important indicators of cooking behavior of starch and final product quality (Manaois 2009).

Patindol and Wang (2002) observed differences in the proportion of amylose and amylopectin and in the amylopectin chain-length distribution in long-grain rice cultivars. These differences lead to differences in the gelatinization and pasting properties, as well as hardness and stickiness of rice kernels and flour (Lai et al. 2001; Cameron and Wang 2005). Onset, peak, and conclusion gelatinization temperatures (T_o, T_p, and T_c, respectively) increase with an increase in relative crystallinity of rice starches, which is an indicator of how organized the amylopectin and amylose molecular structures in the starch granules are. Moreover, a greater percentage of short amylopectin chains, with a degree of polymerization (DP) 6–9, decreases gelatinization temperatures of rice starches, whereas longer amylopectin chains, with DP 12–20, increase gelatinization temperatures (Vandeputte et al. 2003b). Similarly, increasing amylose content of starch has been shown to decrease peak and breakdown viscosities and to increase final and setback viscosities (Vandeputte et al. 2003a).

One factor that affects starch structure and relative crystallinity is chalkiness, which is a major defect in rice kernels. Chalkiness occurs when high nighttime air temperatures (NTATs) are experienced during critical stages of kernel development (Ambardekar et al. 2011). Lanning et al. (2012) observed that amylose and protein contents decreased linearly, whereas total lipid content increased linearly, with an increase in NTATs during kernel formation. Consequently, chalkiness has been associated with lower amylose (higher amylopectin) content, and shorter amylopectin average chain length (Patindol and Wang 2003).

Gelatinization temperatures and peak viscosities increase linearly with increasing NTATs, whereas setback viscosities decrease with increasing NTATs (Lanning et al. 2012). Consequently, there are similar impacts of chalkiness on gelatinization properties. Cheng et al. (2005) observed that chalkiness increased T_o, T_p, T_c, and gelatinization enthalpy (ΔH). However, Patindol and Wang (2003) observed that T_o, T_p, and T_c were similar for chalky and translucent kernels, but ΔH was greater for chalky kernels. The differences in impacts on T_o, T_p, and T_c could be because Patindol and Wang (2003) classified kernels that were half or more opaque as chalky per USDA definition, whereas Cheng et al. (2005) separated each milled kernel into chalky and translucent parts. Patindol and Wang (2003) also observed that chalky kernels had higher peak and breakdown viscosities but lower pasting temperatures and final and setback viscosities, compared with translucent kernels. Cultivars vary in NTAT susceptibility (Counce et al. 2000; Cooper et al. 2008; Ambardekar et al. 2011) and, thus, often differ in level of chalkiness, with a resultant impact on functional properties.

Another factor that affects gelatinization and pasting properties of rice kernels is the degree of milling (DOM), which is the extent of bran removal by milling. A majority of rice-kernel lipids (Juliano 1985) and a significant portion of the proteins (Lu and Luh 1991; Marshall and Wadsworth 1994) are present in the bran and germ. Therefore, milling decreases the lipid and protein contents and increases the relative starch content of milled rice. Siebenmorgen et al. (2006) observed that different cultivars reach different DOMs when milled for the same duration. Moreover, Lanning and Siebenmorgen (2011) observed that hybrid cultivars reach a target DOM faster than pureline cultivars. Therefore, it can be said that DOM affects functional properties of rice. For instance, Saleh and Meullenet (2007) found that as DOM increased, water uptake and firmness of rice decreased and stickiness increased. Champagne et al. (1990) and Marshall (1992) found that T_o, T_p, and T_c of rice kernels decreased, whereas ΔH increased, on increasing the DOM to a particular point. Greater gelatinization temperatures at lesser DOM levels may have resulted because of delayed water absorption caused by the presence of surface lipids (Maningat and Juliano 1980; Ohashi et. al 1980). Perdon et al. (2001) found that peak viscosity of rice flour increased as the DOM increased.

Commingling of rice cultivars commonly occurs during harvest, drying, and storage operations. Because different cultivars

[†] Corresponding author. Phone: +1.479.575.2841. E-mail: tsiebenm@uark.edu

Department of Food Science, University of Arkansas, 2650 N. Young Ave., Fayetteville, AR 72704, U.S.A.

http://dx.doi.org/10.1094/CCHEM-04-14-0068-R

often have different starch structure and milling properties (Siebenmorgen et al. 2006), commingling could result in a significant impact on functional properties, particularly when dissimilar cultivars are commingled. Although the aforementioned studies report the impacts of single-cultivar or single-lot characteristics on gelatinization and pasting properties, no research was found showing the consequences of commingling on these functional properties.

MATERIALS AND METHODS

Sample Procurement and Preparation. The study was conducted with four long-grain cultivars, CL XL729 and CL XL745 (hybrids) and CL 151 and Wells (purelines), with each of the four lots grown in both 2011 and 2012. These cultivars were representative of the cultivars currently being grown in Arkansas, and much of the U.S. Mid-South, and represented a significant portion of the acreage for each class (hybrid and pureline) at the initiation of the project (Hardke and Wilson 2012). Among the 2011 lots, CL XL729, CL XL745, and CL 151 were procured from Jonesboro, Arkansas, and Wells was procured from Stuttgart, Arkansas. Among the 2012 lots, CL XL729, CL XL745, and CL 151 were from Harrisburg, Arkansas, and Wells was from Forest City, Arkansas. The 2011 lots were selected to have high head rice yields (HRYs), and the 2012 lots were selected to have lower; this was done to determine if commingling had a similar effect on rice of different levels of milling yield. All lots were cleaned with a dockage tester (XT4, Carter-Day, Minneapolis, MN, U.S.A.) and conditioned to 12 ± 0.5% (wet basis) moisture content. A convection oven (1370FM, Sheldon Manufacturing, Cornelius, OR, U.S.A.) was used to measure the moisture content of rough rice by drying duplicate samples at 130°C for 24 h (Jindal and Siebenmorgen 1987). The bulk lots were then refrigerated in plastic bins at 4 ± 2°C.

Before sample preparation, the bulk lots were removed from refrigerated storage and equilibrated in the same bins to room temperature for at least 24 h. Samples from the cultivar lots were commingled in various ratios, as presented in Table I. The CL XL745/CL 151 commingle set also included 10:90 and 90:10 mass ratios to observe a more comprehensive gradation of ratios when milling hybrid and pureline cultivars than the range used for either the H/H or P/P commingles. To prepare for milling, 150 g rough rice samples were prepared for each commingling ratio. Thus, the masses of the individual cultivars in the commingled samples were 15/135, 38/112, 75/75, 112/38, and 135/15 g, respective to the 10:90, 25:75, 50:50, 75:25, and 90:10 commingling ratios. To reduce sampling error, the individual lots of rough rice were first divided into a close approximation of the required quantities with a grain divider (Boerner divider, Seedburo Equipment, Chicago, IL, U.S.A.), weighed accurately to the abovementioned values, and then mixed in respective proportions for 2 min with a rotary rice grader (TRG, Satake, Tokyo, Japan).

For each of the 11 commingling ratios and the four individual-cultivar lots (0:100 and 100:0 ratios in the commingle sets) comprising the experimental design of the study (Table I), four 150 g samples were prepared, allowing for samples from each commingle to be milled for either 10, 20, 30, or 40 s durations. Thus, 120 samples, representing 11 commingling ratios and four individual-cultivar lots, four milling durations, and two harvest years, were prepared for each replication of the experiment. The experiment was replicated four times, thus requiring 480 samples to be milled.

Each 150 g rough rice sample was first dehulled in a laboratory sheller (THU 35B, Satake) having a 0.048 cm (0.019 in) clearance between the rollers. The resulting brown rice was then milled for 10, 20, 30, or 40 s with a laboratory mill (McGill number 2, RAPSCO, Brookshire, TX, U.S.A.) having a 1.5 kg mass placed on the lever arm, 15 cm from the centerline of the milling compartment. Cultivars vary in bran-removal rates and thus have different DOM levels when milled for the same duration (Siebenmorgen et al. 2006). Milling the samples for various durations was essential to obtain rice of comparable DOM that was subsequently used for measuring gelatinization and pasting properties. Head rice, that is, milled kernels that are at least three-quarters of their original length (USDA 2009), was then separated from brokens with a sizing device (model 61, Grain Machinery Manufacturing, Miami, FL, U.S.A.).

Surface Lipid Content (SLC). SLC of head rice was measured with a lipid extraction system (Soxtec Avanti 2055, Foss North America, Eden Prairie, MN, U.S.A.), following AACC International Approved Method 30-20.01, with modifications as described by Matsler and Siebenmorgen (2005). An average of SLCs across replications, for each milling duration, for each commingle, from each year, was taken. Because 0.4% SLC is a degree to which rice is often milled in the rice industry, individual-cultivar lots and commingled samples that had been milled for durations that produced a DOM closest to 0.4% SLC were used for measuring gelatinization and pasting properties.

Gelatinization Properties. Gelatinization properties of samples were measured with a differential scanning calorimeter (DSC) (Diamond, Perkin-Elmer, Shelton, CT, U.S.A.) equipped with an Intercooler-II system. Indium was used to calibrate the DSC. Samples of head rice (20 g) were ground with a cyclone mill (3010-30, UDY, Fort Collins, CO, U.S.A.) equipped with a 100-mesh (0.5 mm) sieve. A convection oven (1370FM, Sheldon Manufacturing) was used to measure the moisture content of rice flour by drying duplicate samples at 130°C for 1 h, following AACCI Approved Method 44-15.02. Approximately 4 mg (dry basis) of rice flour was then weighed into an aluminum DSC pan and moistened with 8 μL of deionized water using a microsyringe. The pan was then hermetically sealed. To allow the flour in the pans to be completely hydrated, the sealed pans were allowed to stand for at least 1 h before conducting thermal analysis. Using an empty pan as a reference, the aluminum pans containing the samples were heated from 25 to 120°C at a rate of 10°C/min. Data output was in the form of a thermogram; T_o, T_p, T_c, and ΔH were determined by DSC system software (Pyris Data Analysis, Perkin-Elmer).

Pasting Properties. Pasting properties of rice flour were measured with a Rapid Visco Analyser (RVA) (model 4, Newport Scientific, Warriewood, NSW, Australia), following AACCI Approved Method 61-02.01. Exact amounts of flour and deionized water to be used to make the paste were obtained with RVA software (Thermocline for Windows, version 2.0, Newport Scientific) and mixed in an aluminum canister (Perten Instruments, Springfield, IL, U.S.A.). The canister and paddle provided were then inserted into the RVA and the tower lowered to start the pasting cycle. The cycle comprised holding the paste at 50°C for 1.5 min,

TABLE I
Experimental Design for Commingling Samples from Four Cultivar Lots Harvested in 2011 and Again in 2012

Commingle	Cultivar Lot Type	Commingling Ratios
CL XL745/CL 151	Hybrid/pureline	0:100, 10:90, 25:75, 50:50, 75:25, 90:10, 100:0
CL XL745/CL XL729	Hybrid/hybrid	0:100, 25:75, 50:50, 75:25, 100:0
Wells/CL 151	Pureline/pureline	0:100, 25:75, 50:50, 75:25, 100:0

heating to 95°C at 12.2°C/min, holding at 95°C for 2 min, cooling to 50°C at 12.2°C/min, and finally holding at 50°C for 1.5 min. Peak and breakdown viscosities are indicators of cooking behavior of starch, whereas final viscosity is an indicator of final product characteristics. Therefore, the pasting properties studied included peak, breakdown, and final viscosities, where breakdown viscosity is the difference between peak viscosity and trough viscosity (minimum viscosity of the paste after peak viscosity is reached).

Data Analyses. Analysis of variance (α = 0.05) and comparison of means with Tukey's honestly significant difference test were performed with statistical software (JMP Pro 10, SAS Institute, Cary, NC, U.S.A.).

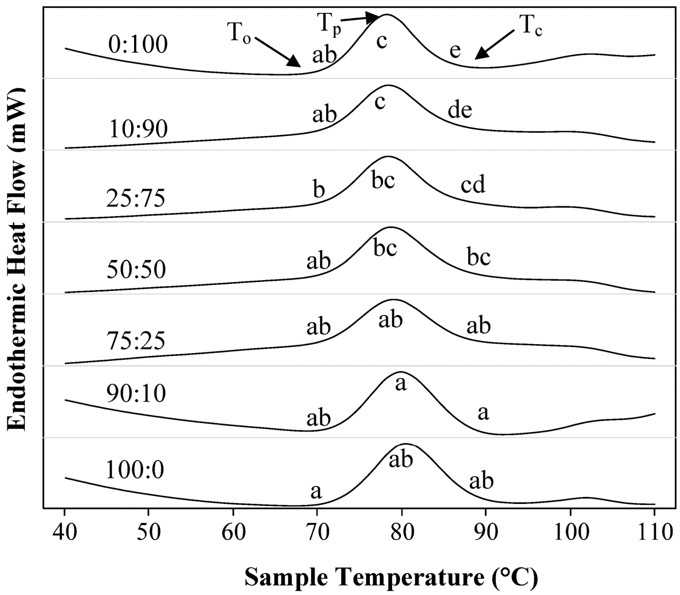

Fig. 1. Gelatinization curves showing onset (T_o), peak (T_p), and conclusion (T_c) gelatinization temperatures of the 2011 CL XL745/CL 151 commingled samples. The ratios represent the relative masses of CL XL745:CL 151 in the commingled samples. Each gelatinization curve is the curve for a single replicate whose gelatinization temperatures most closely represent the mean of each gelatinization temperature of the four replicates. Statistical differences are indicated by different letters and apply to means (four replicates) of T_o, T_p, and T_c, according to Tukey's honestly significant difference test, at a 0.05 level of significance. Statistical comparisons apply separately to T_o, T_p, and T_c.

TABLE II
Onset (T_o), Peak (T_p), and Conclusion (T_c) Gelatinization Temperatures and Gelatinization Enthalpies (ΔH) of the CL XL745/CL 151 (Hybrid/Pureline) Commingled Samples in 2011 and 2012[z]

	Gelatinization Temperatures (°C)				
Year, Ratio	T_o	T_p	T_c	$T_c - T_o$	ΔH (kJ/g)
2011					
0:100	72.7ab	78.1c	83.5e	10.8c	9.3a
10:90	72.0ab	78.4c	84.8de	12.8b	9.4a
25:75	71.9b	78.6bc	85.1cd	13.2b	10.1a
50:50	72.2ab	78.7bc	86.4bc	14.2ab	9.3a
75:25	72.1ab	79.3ab	87.4ab	15.3a	10.5a
90:10	73.0ab	79.8a	88.7a	15.7a	9.5a
100:0	73.1a	79.5ab	87.2ab	14.1ab	9.7a
2012					
0:100	75.6B	80.7C	87.2D	11.5D	11.0A
10:90	75.8B	81.0BC	87.5CD	11.6CD	10.1A
25:75	75.7B	80.6C	87.7BCD	12.1BCD	10.7A
50:50	75.7B	80.8BC	88.6ABC	12.9AB	11.2A
75:25	75.9B	81.4ABC	89.4A	13.5A	11.2A
90:10	76.2AB	81.6AB	89.0AB	12.7ABC	10.1A
100:0	76.8A	82.0A	89.4A	12.6ABCD	10.9A

[z] Measured for samples that had been milled for durations that produced a degree of milling level closest to 0.4% surface lipid content. Statistical differences in means (four replicates) of T_o, T_p, T_c, $T_c - T_o$, and ΔH, in a given year, are indicated by different letters (lowercase in 2011 and uppercase in 2012), according to Tukey's honestly significant difference test, at a 0.05 level of significance.

RESULTS AND DISCUSSION

The 2011 commingled samples required a greater duration to attain 0.4% SLC, that is, the samples milled more slowly than the 2012 commingled samples, with the 30 s milling duration producing a DOM closest to 0.4% SLC for the 2011 samples and the 20 s milling duration producing a DOM closest to 0.4% SLC for the 2012 samples. The reasons for this difference in the milling behavior across years could be because the milling dynamics within a milling chamber for samples with kernels that break apart easily (the 2012 samples had greater chalkiness and fissured kernels, yielding lower HRYs than in 2011) is quite different than that for samples comprising sound kernels (Huck et al. 2012). Additionally, the old rotor in the laboratory mill was replaced with a new one before the 2012 samples were milled, which would correspond to a more aggressive milling action imparted to the 2012 samples. Therefore, the 2011 samples milled for 30 s and the 2012 samples milled for 20 s were used to study gelatinization and pasting properties.

Gelatinization Properties. Gelatinization curves of the 2011 H/P commingled samples are presented in Figure 1 to graphically illustrate the changes in gelatinization curves for different commingling ratios in that commingle. Additionally, T_o, T_p, T_c, $T_c - T_o$,

TABLE III
Onset (T_o), Peak (T_p), and Conclusion (T_c) Gelatinization Temperatures and Gelatinization Enthalpies (ΔH) of the CL XL745/CL XL729 (Hybrid/Hybrid) and Wells/CL 151 (Pureline/Pureline) Commingled Samples in 2011 and 2012[z]

Commingle,	Gelatinization Temperatures (°C)				
Year, Ratio	T_o	T_p	T_c	$T_c - T_o$	ΔH (kJ/g)
CL XL745/CL XL729					
2011					
0:100	72.5ab	78.5b	86.8b	14.4ab	10.2a
25:75	72.0b	78.6b	87.4ab	15.4a	10.4a
50:50	72.5ab	79.5a	87.8a	15.3ab	10.0a
75:25	72.0b	79.3ab	87.2ab	15.2ab	9.6a
100:0	73.1a	79.5a	87.2ab	14.1b	9.7a
2012					
0:100	77.6A	82.6A	90.0A	12.4A	11.4A
25:75	76.8B	81.8A	89.7A	12.9A	12.0A
50:50	76.8B	82.3A	89.9A	13.1A	11.9A
75:25	77.1AB	82.1A	90.2A	13.0A	11.3A
100:0	76.8B	82.0A	89.4A	12.6A	10.9A
Wells/CL 151					
2011					
0:100	72.7c	78.1b	83.5c	10.8a	9.3a
25:75	72.7c	78.5b	84.5bc	11.8a	9.0a
50:50	73.2c	78.8b	84.9abc	11.6a	8.5a
75:25	74.8b	80.1a	86.5ab	11.7a	9.8a
100:0	76.3a	80.8a	86.8a	10.5a	9.1a
2012					
0:100	75.6A	80.7A	87.2A	11.5B	11.0A
25:75	75.5AB	81.1A	88.0A	12.5AB	11.5A
50:50	75.3AB	80.6A	87.1A	11.8AB	10.5AB
75:25	75.1AB	80.6A	87.7A	12.6AB	10.5AB
100:0	74.8B	80.5A	87.7A	12.9A	9.6B

[z] Measured for samples that had been milled for durations that produced a degree of milling level closest to 0.4% surface lipid content. Statistical differences in means (four replicates) of T_o, T_p, T_c, $T_c - T_o$, and ΔH, in a given year, are indicated by different letters (lowercase in 2011 and uppercase in 2012), according to Tukey's honestly significant difference test, at a 0.05 level of significance.

and ΔH of the H/P commingled samples are presented in Table II, as are those of the H/H and P/P commingled samples in Table III. In general, the gelatinization temperatures and enthalpies were greater for the 2012 samples than the 2011 samples in each commingle set. The 2012 samples had greater brown rice and head rice chalkiness compared with the 2011 samples (data not shown). The greater brown rice chalkiness (and associated lesser overall kernel strength) was one of the reasons that the 2012 samples had lower HRYs than the 2011 samples. The greater gelatinization temperatures and enthalpies in the 2012 samples corroborate the observation by Cheng et al. (2005) in that increases in chalkiness led to increases in gelatinization temperatures and enthalpies.

In the 2011 H/P commingle (Table II), there was no difference in the T_os of the pure CL 151 sample (0:100 ratio) and the pure CL XL745 sample (100:0 ratio). Consequently, there were no differences in the T_os of the commingled samples of these two cultivar lots. In the 2012 H/P commingle, T_o of CL 151 was less than that of CL XL745. However, T_os of the commingled samples were similar to the T_o of CL 151, which was the cultivar in that commingle with the lower T_o.

In the 2011 H/H commingle (Table III), there was no difference in the T_os of CL XL729 (0:100 ratio) and CL XL745 (100:0 ratio), and T_os of the commingled samples were essentially similar to each other. For the 2012 H/H commingle, T_o of CL XL745 was less than that of CL XL729, and consequently, T_os of the commingled samples were similar to the T_o of CL XL745, the cultivar in the commingle with the lower T_o. These trends were also seen in the P/P commingles from both years, except for the 75:25 ratio in 2011. These recurring trends suggest that when two cultivar lots with different T_os are commingled, the T_o of the commingled sample will be similar to the T_o of that cultivar in the commingle with the lower T_o. In other words, regardless of being heated in a pure-cultivar or commingled sample, starch granules will start gelatinizing at the same temperature. Thus, the temperature at which gelatinization is detected in a commingled sample will be that at which starch granules of the cultivar in that commingle with the lower T_o start to gelatinize. Because commingling is simply mixing of individual-cultivar lots, chemical and structural properties, such as starch composition, structure, and relative crystallinity, of kernels from the individual-cultivar lots should not be affected.

In the 2011 H/P commingle (Table II), T_p and T_c of CL 151 (0:100 ratio) were less than T_p and T_c of CL XL745 (100:0 ratio), and T_ps and T_cs of the commingled samples proportionately in-

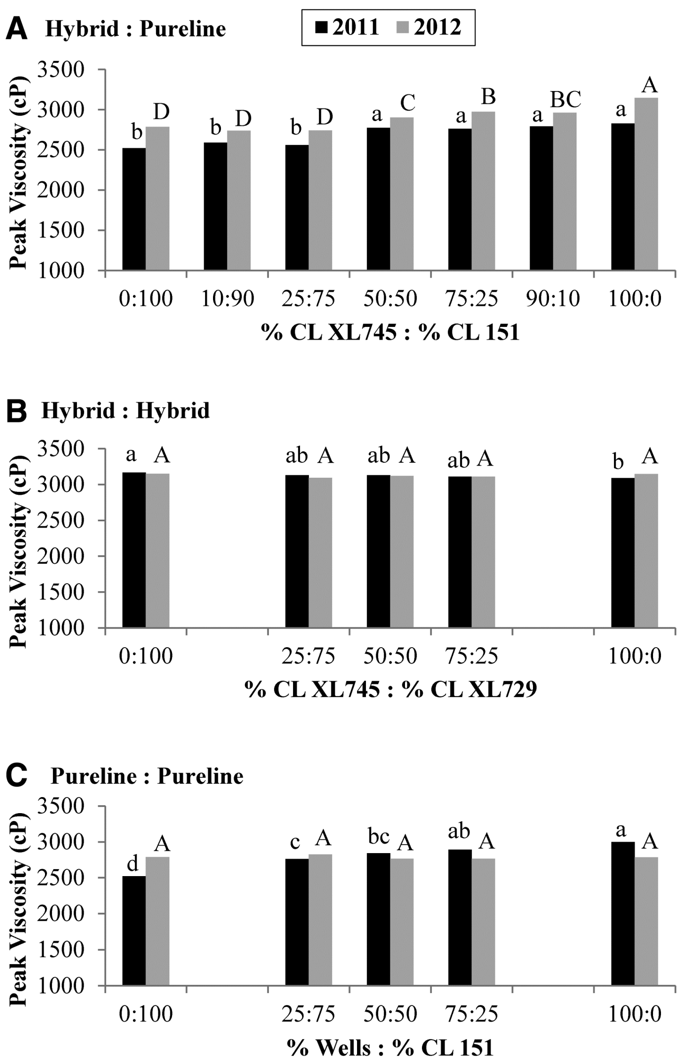

Fig. 2. Peak viscosities (means of four replicates) of the commingled samples in 2011 and 2012, measured for samples milled for durations that produced a degree of milling level closest to 0.4% surface lipid content: **A,** CL XL745/CL 151; **B,** CL XL745/CL XL729; and **C,** Wells/CL 151. Statistical differences in means of peak viscosities of samples, in a given commingle in a given year, are indicated by different letters (lowercase in 2011 and uppercase in 2012), according to Tukey's honestly significant difference test, at a 0.05 level of significance.

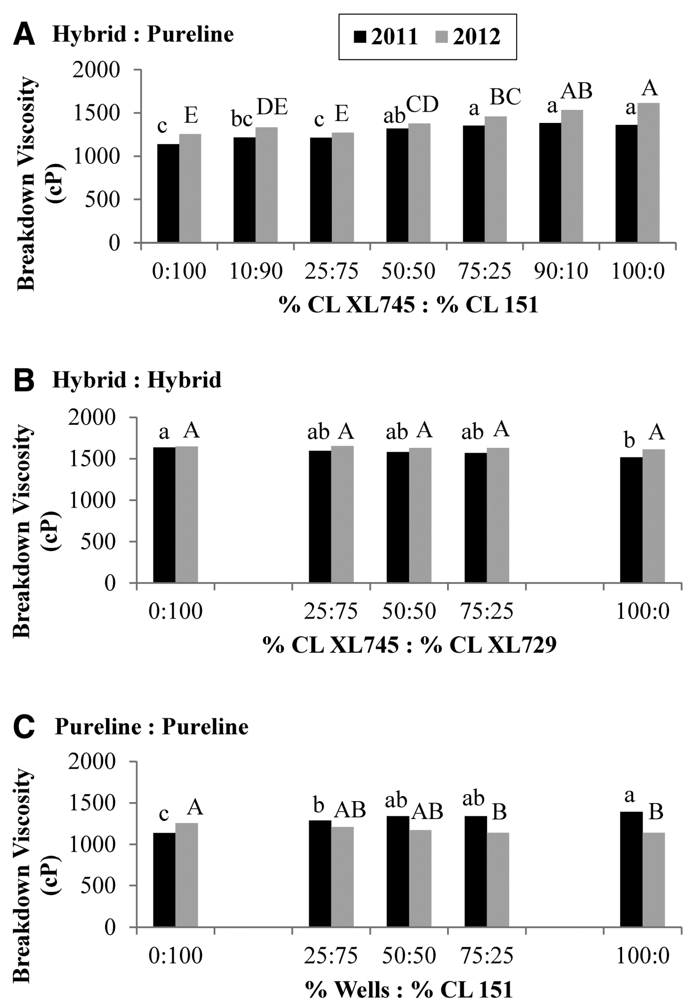

Fig. 3. Breakdown viscosities (means of four replicates) of the commingled samples in 2011 and 2012, measured for samples milled for durations that produced a degree of milling level closest to 0.4% surface lipid content: **A,** CL XL745/CL 151; **B,** CL XL745/CL XL729; and **C,** Wells/CL 151. Statistical differences in means of breakdown viscosities of samples, in a given commingle in a given year, are indicated by different letters (lowercase in 2011 and uppercase in 2012), according to Tukey's honestly significant difference test, at a 0.05 level of significance.

creased with the associated increase in the percentage of CL XL745 in the samples until the 75:25 ratio. A similar trend was observed in 2012 for T_ps and T_cs of the H/P commingled samples.

In the 2011 H/H commingle (Table III), T_p of CL XL729 was less than that of CL XL745, and T_ps of the commingled samples proportionately increased with the associated increase in the percentage of CL XL745 in the samples until approximately the 50:50 ratio and then remained constant. There was no difference in the T_cs of CL XL745 and CL XL729 in 2011, and consequently, no differences were observed in the T_cs of commingled samples of these two cultivars. T_ps and T_cs of the 2011 P/P commingled samples proportionately increased with the associated increase in the percentage of Wells in the samples. No differences were observed in the T_ps and T_cs of the 2012 H/H and P/P commingled samples; a similar trend was observed for T_cs in the 2011 H/H commingled samples. Therefore, when T_ps and T_cs of the two cultivars being commingled were different, the T_ps and T_cs of commingled samples varied according to the mass percentages of the cultivars in the samples.

Values of $T_c - T_o$ represent the range in onset and conclusion temperatures. Thus, depending on trends in T_o and T_c, trends in $T_c - T_o$ of commingled samples were different. For example, the $T_c - T_o$ values increased to a certain value and then remained constant in the 2011 and 2012 H/P commingled samples (Table II), but they remained equivalent to the $T_c - T_o$ of one of the cultivars in the commingle in the 2011 H/H and the 2012 P/P commingled samples (Table III). There were no differences in the $T_c - T_o$ values of both the pure cultivars and commingled samples in the 2012 H/H and the 2011 P/P commingle sets. Additionally, there were no differences in the ΔH values of any commingled sample sets, except in the 2012 P/P commingled samples, in which ΔHs proportionately increased with the associated increase in the percentage of CL 151 in the samples.

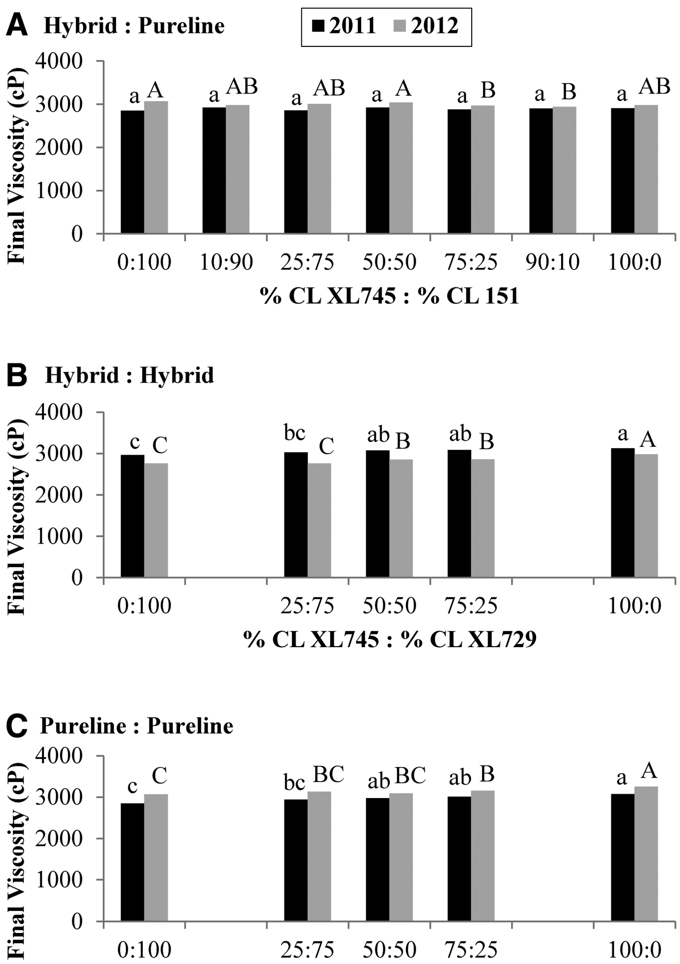

Fig. 4. Final viscosities (means of four replicates) of the commingled samples in 2011 and 2012, measured for samples milled for durations that produced a degree of milling level closest to 0.4% surface lipid content: **A,** CL XL745/CL 151; **B,** CL XL745/CL XL729; and **C,** Wells/CL 151. Statistical differences in means of final viscosities of samples, in a given commingle in a given year, are indicated by different letters (lowercase in 2011 and uppercase in 2012), according to Tukey's honestly significant difference test, at a 0.05 level of significance.

Pasting Properties. Peak, breakdown, and final viscosities of all individual-cultivar lots and commingled samples are presented in Figures 2, 3, and 4, respectively. In the H/P commingled samples from both years (Fig. 2A), peak viscosity of the pure CL 151 sample (0:100 ratio) was less than that of the pure CL XL745 sample (100:0 ratio); peak viscosities of the commingled samples of these two cultivars proportionately increased with the associated increase in the percentage of CL XL745 in the samples in both years. In the 2011 H/H commingled samples (Fig. 2B), peak viscosity of the pure CL XL745 sample (100:0 ratio) was statistically, yet only slightly, less than that of the pure CL XL729 sample (0:100 ratio). Because of these slight differences, peak viscosities of the commingled samples of these two cultivars were equivalent and also equivalent to the peak viscosities of the individual-cultivar lots in that year. In the 2012 H/H commingled samples, there was no difference in the peak viscosities of the pure CL XL745 and CL XL729 samples, and thus no differences were observed in the peak viscosities of the commingled samples of these two cultivars. In the 2011 P/P commingled samples (Fig. 2C), peak viscosity of the pure CL 151 sample (0:100 ratio) was less than that of the pure Wells sample (100:0 ratio). As a result, peak viscosities of the commingled samples of these two cultivars proportionately increased with the associated increase in the percentage of Wells in the commingled samples. However, in the 2012 P/P commingled samples, no differences were observed in the peak viscosities of the commingled samples because there was no difference in the peak viscosities of the pure samples used for commingling, which was similar to the trend observed for peak viscosities in the 2012 H/H commingled samples. Therefore, if the peak viscosities of the individual-cultivar lots were different, then the peak viscosities of the commingled samples either increased or decreased proportionately with the associated increase in the percentage of a given cultivar in the commingle.

Breakdown (Fig. 3) and final (Fig. 4) viscosities followed trends similar to those of peak viscosity. A specific example is the H/P commingle set from both years (Fig. 3A), in that breakdown viscosity of CL 151 (0:100 ratio) was less than that of CL XL745 (100:0 ratio) and that breakdown viscosities of the commingled samples of these two cultivars proportionately increased with the associated increase in the percentage of CL XL745 in the samples. There was no difference in the final viscosities of CL 151 and CL XL745 in both years (Fig. 4A), and essentially negligible differences were observed in the final viscosities of the commingled samples of these two cultivars. These trends were also observed for both breakdown (Fig. 3B and C) and final (Fig. 4B and C) viscosities of the H/H and P/P commingle sets. These consistent trends in viscosity properties indicate that commingled samples retained the pasting properties of the individual-cultivar lots used for commingling, that is, if any of the aforementioned viscosities of the individual-cultivar lots used in a commingle were different, then the respective viscosities of the commingled samples either increased or decreased proportionately with the associated mass increase in the percentage of a given cultivar in the commingle.

CONCLUSIONS

Commingling of cultivar lots did not adversely impact pasting properties because peak, breakdown, and final viscosities of commingled samples either increased or decreased proportionately with the associated increase in the mass percentage of a given cultivar in the commingled samples. Pasting properties are dependent on the swelling power of starch granules, whereas gelatinization properties are dependent on the energy required to break the crystalline structure of starch. Commingling may have an impact on processes involving gelatinization, based on findings herein pertaining to T_o. Specifically, the temperature at which gelatinization was detected in a commingled sample, T_o, was that temperature at which starch granules of the cultivar in that commingle with the lower T_o started to gelatinize. Thus, starch granules in a commingled sample with the least T_o would determine the T_o of the commingled sample. Additionally, when T_ps, T_cs, and ΔHs of the two cultivars being commingled were different, the T_ps, T_cs, and ΔHs of commingled samples varied according to the mass percentages of the cultivars in the samples. Because commingling is simply mixing of individual-cultivar lots, the chemical and structural properties, such as starch composition, structure, relative crystallinity, and swelling power, of the individual-cultivar lots should not be affected. Therefore, starch granules of a particular cultivar retain their inherent properties after commingling, resulting in deducible gelatinization and pasting properties for commingled samples.

ACKNOWLEDGMENTS

The authors acknowledge the financial support of the corporate sponsors of the University of Arkansas Rice Processing Program, and the Rice Processing Program staff who assisted with data collection.

LITERATURE CITED

AACC International. Approved Methods of Analysis, 11th Ed. Method 30-20.01. Crude fat in grain and stock feeds. Approved April 13, 1961. Method 44-15.02. Moisture—Air-oven methods. Approved October 30, 1975. Method 61-02.01. Determination of the pasting properties of rice with the Rapid Visco Analyser. Approved October 15, 1997. Available online only. AACCI: St. Paul, MN.

Ambardekar, A. A., Siebenmorgen, T. J., Counce, P. A., Lanning, S., and Mauromoustakos, A. 2011. Impact of field-scale nighttime air temperatures during kernel development on rice milling quality. Field Crops Res. 122:179-185.

Bao, J., and Bergman, C. J. 2004. The functionality of rice starch. Pages 258-294 in: Starch in Food Structure, Function and Applications. Woodhead Publishing/CRC Press: Boca Raton, FL.

Cameron, D. K., and Wang, Y.-J. 2005. A better understanding of factors that affect the hardness and stickiness of long-grain rice. Cereal Chem. 82:113-119.

Champagne, E. T., Marshall, W. E., and Goynes, W. R. 1990. Effects of degree of milling and lipid removal on starch gelatinization in the brown rice kernel. Cereal Chem. 67:570-574.

Cheng, F. M., Zhong, L. J., Wang, F., and Zhang, G. P. 2005. Differences in cooking and eating properties between chalky and translucent parts in rice grains. Food Chem. 90:39-46.

Cooper, N. T. W., Siebenmorgen, T. J., and Counce, P. A. 2008. Effects of nighttime temperature during kernel development on rice physicochemical properties. Cereal Chem. 85:276-282.

Counce, P. A., Keisling, T. C., and Mitchell, A. J. 2000. A uniform, objective, and adaptive system for expressing rice development. Crop Sci. 40:436-443.

Hardke, J. T., and Wilson, C. E., Jr. 2012. Trends in Arkansas rice production. B.R. Wells Rice Research Studies 38-47.

Huck, A. C., Lanning, S. B., and Siebenmorgen, T. J. 2012. Milling characteristics of high and low quality rice. Discovery 13:28-37.

Jindal, V. K., and Siebenmorgen, T. J. 1987. Effects of oven drying temperature and drying time on rough rice moisture content determination. Trans. ASAE 30:1185-1192.

Juliano, B. O. 1985. Rice bran. Pages 647-688 in: Rice: Chemistry and Technology, 2nd Ed. B. O. Juliano, ed. American Association of Cereal Chemists: St. Paul, MN.

Juliano, B. O. 1998. Varietal impact on rice quality. Cereal Foods World 43:207-222.

Lai, V. M. F., Shen, M.-C., Yeh, A.-I., Juliano, B. O., and Lii, C. 2001. Molecular and gelatinization properties of rice starches from IR24 and Sinandomeng cultivars. Cereal Chem. 78:596-602.

Lanning, S. B., and Siebenmorgen, T. J. 2011. Comparison of milling characteristics of hybrid and pureline rice cultivars. Appl. Eng. Agric. 27:787-795.

Lanning, S. B., Siebenmorgen, T. J., Ambardekar, A. A., Counce, P. A., and Bryant, R. J. 2012. Effects of nighttime air temperature during kernel development of field-grown rice on physicochemical and functional properties. Cereal Chem. 89:168-175.

Lu, S., and Luh, B. S. 1991. Properties of rice caryopsis. Pages 389-419 in: Rice Production. B. S. Luh, ed. Van Nostrand Reinhold: New York, NY.

Manaois, R. V. 2009. Modification of rice starch properties by addition of amino acids at various pH levels. Master's thesis. Louisiana State University: Baton Rouge, LA.

Maningat, C. C., and Juliano, B. O. 1980. Starch lipids and their effect on rice starch properties. Starch 32:76-82.

Marshall, W. E. 1992. Effect of degree of milling of brown rice and particle size of milled rice on starch gelatinization. Cereal Chem. 69:632-636.

Marshall, W. E., and Wadsworth, J. I. 1994. Rice Science and Technology. Marcel Dekker: New York, NY.

Matsler, A. L., and Siebenmorgen, T. J. 2005. Evaluation of operating conditions for surface lipid extraction from rice using a Soxtec system. Cereal Chem. 82:282-286.

Ohashi, K., Goshima, G., Kusada, H., and Tsuge, H. 1980. Effect of embraced lipid on the gelatinization of rice starch. Starch 32:54-58.

Patindol, J., and Wang, Y.-J. 2002. Fine structures of starches from long-grain rice cultivars with different functionality. Cereal Chem. 79:465-469.

Patindol, J., and Wang, Y. J. 2003. Fine structures and physicochemical properties of starches from chalky and translucent rice kernels. J. Agric. Food Chem. 51:2777-2784.

Perdon, A. A., Siebenmorgen, T. J., Mauromoustakos, A., Griffin, V. K., and Johnson, E. R. 2001. Degree of milling effects on rice pasting properties. Cereal Chem. 78:205-209.

Saleh, M. I., and Meullenet, J.-F. 2007. Effect of moisture content at harvest and degree of milling (based on surface lipid content) on the texture properties of cooked long-grain rice. Cereal Chem. 84:119-124.

Siebenmorgen, T. J., Matsler, A. L., and Earp, C. F. 2006. Milling characteristics of rice cultivars and hybrids. Cereal Chem. 83:169-172.

Sivak, M. N., and Preiss, J. 1998. Industrial applications of starch. Adv. Food Nutr. Res. 41:163-170.

USDA. 2009. United States Standards for Rice. Federal Grain Inspection Service: Washington, DC. Available at www.gipsa.usda.gov/fgis/standards/ricestandards.pdf

Vandeputte, G. E., Derycke, V., Geeroms, J., and Delcour, J. A. 2003a. Rice starches. II. Structural aspects provide insight into swelling and pasting properties. J. Cereal Sci. 38:53-59.

Vandeputte, G. E., Vermeylen, R., Geeroms, J., and Delcour, J. A. 2003b. Rice starches. I. Structural aspects provide insight into crystallinity characteristics and gelatinisation behaviour of granular starch. J. Cereal Sci. 38:43-52.

[Received April 9, 2014. Accepted August 11, 2014.]