MILLING PROPERTIES OF COMMINGLED RICE-CULTIVAR LOTS

N. N. Basutkar, T. J. Siebenmorgen, A. Mauromoustakos

ABSTRACT. *Commingling of rice lots, often of different cultivars, commonly occurs during harvest, storage, and drying operations. Because differences have been observed in the milling properties of rice cultivars, particularly between hybrid and pureline cultivars, there is a need to study the effect of commingling on the milling properties of rice lots, including degree of milling, milling yields, color, and chalkiness. 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. Milled rice yield (MRY), head rice yield (HRY), surface lipid content (SLC), and head rice color and chalkiness were measured for individual-lot samples as well as for the above-mentioned commingled samples. Kernel dimensions, total lipid content (TLC), chalkiness, and bulk density of brown rice samples of the individual-cultivar lots were also measured. The MRYs, HRYs, and head rice chalkiness of commingled samples trended according to the weighted average of the individual-lot MRYs, HRYs, and head rice chalkiness, respectively. No significant differences were observed in head rice whiteness and yellowness of the commingled samples milled to the same degree of milling (0.4% SLC). In addition, evidence suggested that commingling of cultivar lots with poor HRYs can deleteriously affect HRYs of commingled samples to some extent, and speculative evidence suggested that the individual-lot brown rice TLC, length, width, and bulk density affect the milling dynamics of commingled samples. These findings are intended to help decide if individual-cultivar lots should be commingled, given the brown rice and milling properties of these cultivar lots.*

Keywords. *Brown rice, Chalk, Commingling, Head rice yield, Milling.*

U.S. rice production has almost quadrupled from 1960/61 to 2012/13 (USDA, 2014), due in part to the development of hybrid rice. Acreage of hybrid cultivars has increased in large part due to greater agronomic yields, stronger disease resistance, and more efficient use of soil nutrients, as compared to pureline cultivars (IRRI, 1988). However, differences have been observed in the milling properties of hybrid and pureline cultivars (Lanning and Siebenmorgen, 2011; Siebenmorgen et al., 2006).

Milling is primarily the removal of the germ and bran layers, which contain most of the lipids present in a rice kernel. The remaining endosperm consists predominantly of starch. Thus, milling decreases the lipid content and increases the relative starch content of white rice (Azhakanandam et al., 2000; Park et al., 2001). Consequently, degree of milling (DOM), i.e., the extent of bran removal during milling, affects milling yield (Cooper and Siebenmorgen, 2007) and functional characteristics, including texture of the cooked rice (Saleh and Meullenet, 2007) and pasting properties (Perdon et al., 2001). As rice bran is present on the surface of a rice kernel and contains 15% to 20% lipids (Juliano, 1985), surface lipid content (SLC) is directly related to the extent to which rice is milled and is an indicator of the DOM of rice (Hogan and Deobald, 1961; Miller et al., 1979; Pomeranz et al., 1975). In addition, as yellow and red pigments in rice are mainly concentrated in the bran, yellowness of kernels decreases, whereas whiteness increases, with an increase in DOM (Lamberts et al., 2007).

Various rice kernel characteristics such as kernel topography (Bhashyam and Srinivas, 1984; Pomeranz and Webb, 1985), physical dimensions (Chen and Siebenmorgen, 1997; Chen et al., 1999; Pomeranz and Webb, 1985; Webb, 1980), and moisture content (Andrews et al., 1992; Reid et al., 1998) have been shown to affect rice milling performance. Variation in these characteristics among rice cultivars leads to increased complexity in managing milling and processing operations. For example, Bhashyam and Srinivas (1984) and Pomeranz and Webb (1985) showed that kernels with deeper surface grooves require longer milling durations or greater milling pressure to reach a specified DOM.

In studies of long-grain (Chen and Siebenmorgen, 1997) and medium-grain (Chen et al., 1999) cultivars, it was observed that when rice was lightly milled, the SLC of thicker kernels was significantly lower than that of thinner kernels. This suggested that thicker kernels are milled at a faster bran removal rate than the thinner kernels during the initial stages of milling. When the extent of milling was increased beyond a certain bulk DOM, this difference in kernel SLCs progressively decreased, and ultimately no significant difference was observed between the SLCs of thicker and thinner kernels.

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Degree of milling affects both milled rice yield (MRY), which is the mass percentage of rough rice remaining as milled rice (intact and broken kernels obtained from milling), and head rice yield (HRY), which is the mass percentage of rough rice remaining as head rice, i.e., milled kernels that are at least three-quarters of their original length (USDA, 2009). Head rice is more valuable than broken rice, and thus maximizing HRY is of economic importance. As DOM is increased, more of the bran is removed, with consequent reduction in MRY and HRY. Therefore, commingling cultivars differing in the aforementioned properties that affect DOM may result in over-milling of some rice, thereby reducing milling yields.

Chalkiness is a major rice kernel defect, as it reduces kernel strength and therefore HRY (Ambardekar et al., 2011). Moreover, chalky portions of kernels appear opaque, whereas non-chalky portions appear translucent, thereby often deleteriously affecting the marketability of rice. Chalkiness usually occurs when high nighttime air temperatures (NTATs) are experienced during critical stages of kernel development. Cultivars vary in NTAT susceptibility (Ambardekar et al., 2011; Cooper et al., 2008; Counce et al., 2000) and thus can differ in chalkiness.

Commingling of rice cultivars commonly occurs during harvest, drying, and storage operations. Because kernels of different physical dimensions, topographies, and chalkiness may be mixed during commingling, there could be a resultant impact on milling properties, particularly when cultivars with dissimilar properties are commingled. As the aforementioned studies report only the impacts of single-cultivar characteristics on DOM, milling yields, color, and chalkiness, this research was conducted to address the consequences of commingling on the aforementioned properties.

MATERIALS AND METHODS

SAMPLE PROCUREMENT AND PREPARATION

The study was conducted using four long-grain cultivars, including two hybrids (CL XL729 and CL XL745) and two purelines (CL 151 and Wells), grown in both 2011 and 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 procured from Harrisburg, Arkansas, and Wells was procured from Forest City, Arkansas. The 2011 lots were selected to have high HRYs, while the 2012 lots were selected to have low HRYs; this was done to determine if commingling had a similar effect on rice of different levels of milling yield. All lots were cleaned using a dockage tester (model XT4, Carter-Day Co., Minneapolis, Minn.) and conditioned to 12% ±0.5% (wet basis) moisture content. A convection oven (1370FM, Sheldon Mfg. Inc., Cornelius, Ore.) was used to measure the moisture content of rough rice by drying duplicate samples at 130°C for 24 h (Jindal and Siebenmorgen, 1987). After conditioning, the lots were refrigerated in plastic bins at 4°C ±2°C.

Before sample preparation, the bulk lots were removed from refrigerated storage and equilibrated in the same bins

Table 1. Experimental design for commingling samples from the four cultivar lots within each year.

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

to room temperature for at least 24 h. Samples from the cultivar lots were commingled in various ratios, as presented in table 1. The CL XL745/CL 151 (hybrid/pureline, H/P) commingle set also included 10:90 and 90:10 ratios to observe a more comprehensive gradation of ratios when milling hybrid and pureline cultivars than the range used for either the hybrid/hybrid (H/H) or pureline/pureline (P/P) commingles. To prepare for milling, 150 g rough rice samples were prepared for each commingling ratio. As such, the masses of the individual cultivars in the commingled samples were 15/135 g, 38/112 g, 75/75 g, 112/38 g, and 135/15 g, respective to the 10:90, 25:75, 50:50, 75:25, and 90:10 commingling ratios. To reduce bias, the individual lots of rough rice were first divided into a close approximation of the required quantities using a grain divider (Boerner Divider, Seedburo Equipment Co., Chicago, Ill.), weighed accurately to the above-mentioned values, and then mixed in respective proportions. Each commingled sample was mixed for 2 min using 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 1), four 150 g samples were prepared, allowing for samples from each commingle to be milled for either 10, 20, 30, or 40 s durations. This procedure enabled quantifying the duration required to reach the desired DOM levels. Thus, 120 samples, representing two harvest years, 11 commingling ratios and four individual-cultivar lots, and four milling durations, were prepared for each replication of the experiment. The experiment was replicated four times, thus requiring 480 samples to be milled.

MILLING YIELDS

Each 150 g individual-lot and commingled sample of rough rice was first dehulled in a laboratory sheller (THU 35B, Satake, Hiroshima, Japan) having a 0.048 cm (0.019 in.) clearance between the rollers. The resulting brown rice samples were milled using a laboratory mill (McGill No. 2, RAPSCO, Brookshire, Tex.), having a 1.5 kg mass placed on the lever arm, 15 cm from the centerline of the milling compartment. Milled rice yield (MRY) was calculated as the mass percentage of the original 150 g of rough rice remaining as milled rice, comprising intact and broken kernels. Head rice was then separated from the brokens using a sizing device (model 61, Grain Machinery Manufacturing Corp., Miami, Fla.). Head rice yield (HRY) was expressed as the mass percentage of the 150 g of rough rice remaining as head rice. Samples were milled for the aforementioned milling durations to account for the impacts of DOM on various properties.

SURFACE LIPID AND TOTAL LIPID CONTENTS

Surface lipid content (SLC) of head rice and total lipid content (TLC) of ground, brown rice were measured using a lipid extraction system (Soxtec Avanti 2055, Foss North America, Eden Prairie, Minn.), following AACC Method 30-20.01 (AACC, 2000), with modifications as described by Matsler and Siebenmorgen (2005). While SLC was measured for all head rice samples, TLC was measured only for brown rice from the individual-cultivar lots. For TLC measurement, samples of brown rice were ground using a cyclone mill (3010-30, UDY, Fort Collins, Colo.) equipped with a 100 mesh (0.5 mm) sieve.

HEAD RICE COLOR

Whiteness (L^*) and yellowness (b^*) of all head rice samples were measured using a colorimeter (ColorFlex, Hunter Associates Laboratory, Reston, Va.). The instrument sample container, a small plastic dish, was filled with approximately 30 g of head rice, placed into the sample port, covered with the black cover provided, and the first measurement recorded. A second measurement was recorded by rotating the sample container by 120° to 180°. The instrument was programmed to average the two readings.

HEAD RICE AND BROWN RICE CHALKINESS

As 0.4% SLC is the degree to which rice is often milled in the rice industry, head rice chalkiness was measured for all individual-cultivar lots and commingled samples that had been milled for durations that produced a DOM closest to 0.4% SLC, while brown rice chalkiness was measured only for brown rice samples of the individual-cultivar lots. Chalkiness was measured using an image analysis system (WinSeedle Pro 2005a, Regent Instruments, Inc., Sainte-Foy, Quebec, Canada) according to the procedure of Ambardekar et al. (2011). Approximately 100 head rice kernels from a sample were placed on a transparent acrylic tray (152 mm × 100 mm × 20 mm) such that no two kernels were in contact with each other. The system measured the number of pixels corresponding to areas color-classified as chalk and the number of pixels corresponding to the entire kernel projected area. The ratio of these pixel numbers, multiplied by 100, gave the percent chalk. The same procedure was used to measure brown rice chalkiness of the individual-cultivar lot samples.

BULK DENSITY AND KERNEL DIMENSIONS

Bulk density of brown rice from each of the individual-cultivar lots was measured using a bulk density test weight apparatus (Filling Hopper and Stand, Seedburo Equipment Co., Chicago, Ill.) according to the procedure of Fan et al. (1998). Length, width, and thickness of brown rice kernels of the individual-cultivar lots were measured using an image analyzer (RIA 1A, Satake, Hiroshima, Japan).

DATA ANALYSES

Regression analyses, analysis of variance ($\alpha = 0.05$), and comparison of means using Tukey's honestly significant difference (HSD) test were performed using statistical software (JMP Pro 10, SAS Institute, Inc., Cary, N.C.).

RESULTS AND DISCUSSION

BROWN RICE PROPERTIES OF INDIVIDUAL-CULTIVAR LOTS

Brown rice bulk density, kernel dimensions, chalkiness, and TLC of the individual-cultivar lots in 2011 and 2012 are presented in table 2. Between the cultivar lots used in the H/P (CL XL745/CL 151) commingles, brown rice bulk density of CL XL745 was greater than that of CL 151 in both harvest years. In the H/H (CL XL745/CL XL729) commingles, there was no difference in the brown rice bulk density of CL XL745 and CL XL729 in both years. In the P/P (Wells/CL 151) commingles, brown rice bulk density of Wells was less than that of CL 151 in 2011. In 2012, the trend was reversed.

Between the cultivar lots used in the H/P commingles, brown rice kernels of CL 151 were shorter and wider than those of CL XL745 in 2011. However, in 2012, brown rice kernels of CL 151 were shorter and narrower than kernels of CL XL745. In the H/H commingles, brown rice kernels of CL XL745 were longer and of equivalent width to those of CL XL729 in 2011, but were both longer and wider than kernels of CL XL729 in 2012. In the P/P commingles, brown rice kernels of Wells were longer and narrower than those of CL 151 across harvest years. No significant differences were observed in the brown rice kernel thicknesses of the individual-cultivar lots used in any of the P/P, H/P, or H/H commingles in either harvest year.

No statistical differences were observed in brown rice chalkiness across the individual-cultivar lots in 2011, with a mean value of 3.5%. However, brown rice chalkiness of the 2012 lots differed significantly, ranging from 5.3% for CL 151 and 5.6% for Wells to 12.0% for CL XL729 (table 2). Between the cultivar lots used in the H/P commingles, the

Table 2. Brown rice properties of individual-cultivar lots.[a]

Year	Cultivar	Brown Rice Property					
		Bulk Density (kg m^{-3})	Length (cm)	Width (cm)	Thickness (cm)	Chalkiness (%)	TLC (%)
2011	Wells	750 de	7.12 c	2.09 g	1.81 a	3.6 d	2.45 d
	CL 151	757 bc	6.79 f	2.23 bc	1.79 ab	3.2 d	2.60 c
	CL XL745	767 a	7.28 ab	2.20 d	1.81 a	3.7 d	2.28 e
	CL XL729	761 ab	7.00 d	2.21 cd	1.81 a	3.4 d	2.34 e
2012	Wells	747 e	7.31 a	2.12 f	1.78 b	5.6 c	2.36 de
	CL 151	731 f	6.77 f	2.23 b	1.79 ab	5.3 c	2.95 a
	CL XL745	750 de	7.25 b	2.25 a	1.80 ab	8.0 b	2.64 bc
	CL XL729	753 cd	6.93 e	2.18 e	1.81 a	12.0 a	2.71 b

[a] Statistical differences in means of bulk density, kernel dimensions, chalkiness, and total lipid content (TLC), across cultivars and harvest years, are indicated by different letters, according to Tukey's honestly significant difference test, at a 0.05 level of significance.

TLC of CL 151 was greater than that of CL XL745 in both harvest years, as was the case for the lots used in the P/P commingles, in that the TLC of CL 151 was greater than that of Wells in both harvest years. No differences were observed in the TLCs of the CL XL745 and CL XL729 lots used in the H/H commingles in both harvest years. These differences in the bulk densities, kernel dimensions, chalkiness, and TLCs of brown rice are speculated to have caused differences in milling behavior of the individual-cultivar lots and commingled samples, which are subsequently addressed.

MILLING BEHAVIOR OF INDIVIDUAL-CULTIVAR LOTS

Surface lipid content vs. milling duration, MRY vs. SLC, and HRY vs. SLC curves for the individual-cultivar lots from both harvest years are presented in figure 1. Figures 1a and 1b show that SLC decreased exponentially with an increase in milling duration, and figures 1c to 1f show that MRY and HRY decreased linearly as milling progressed (decreases in SLC). Regression analyses of SLC vs. milling duration, MRY vs. SLC, and HRY vs. SLC data were conducted for each year/cultivar dataset. From each
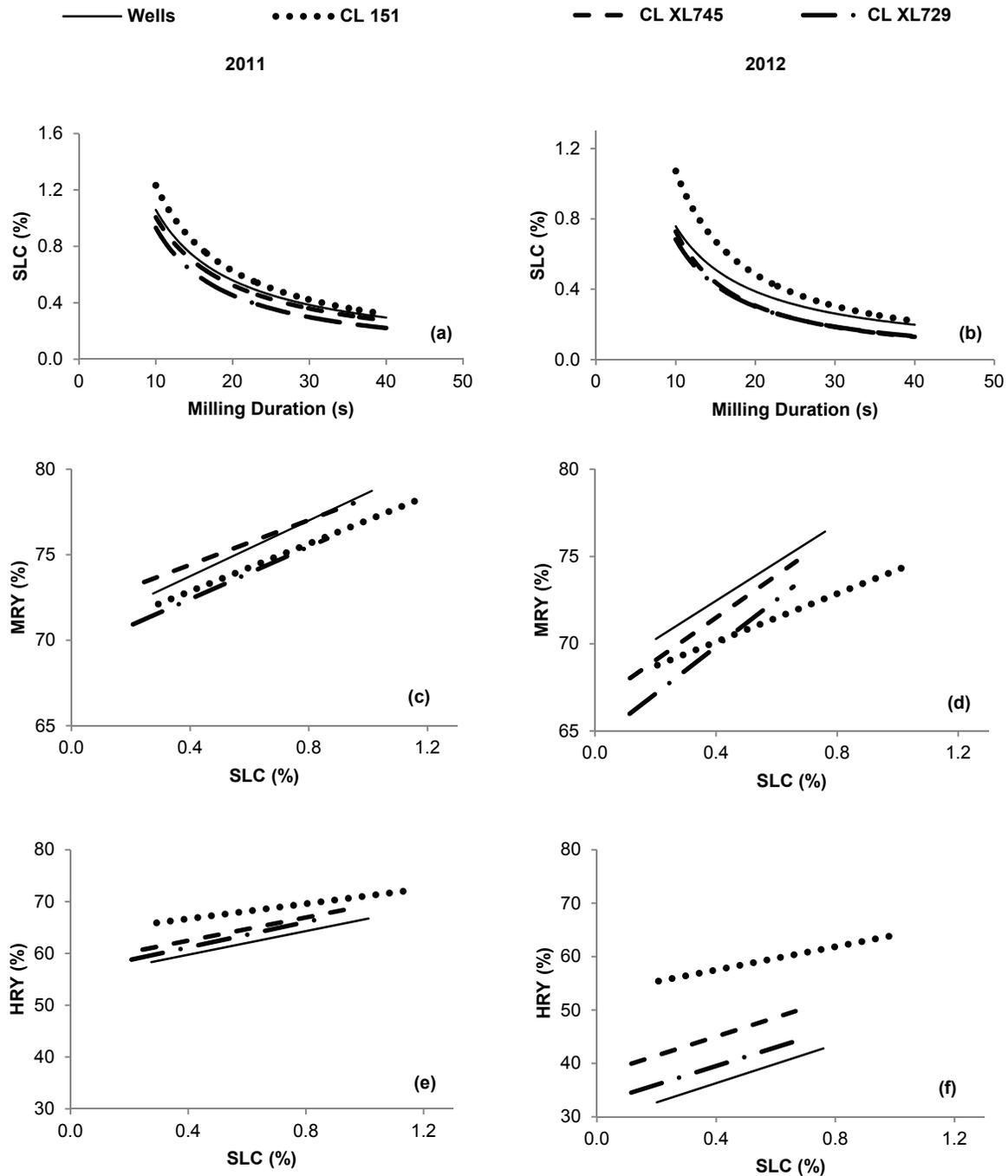

Figure 1. (a and b) Surface lipid content (SLC) vs. milling duration, (c and d) milled rice yield (MRY) vs. SLC, and (e and f) head rice yield (HRY) vs. SLC for the indicated individual-cultivar lots produced in either 2011 or 2012 and milled for 10, 20, 30, and 40 s (four replicates) using a laboratory mill.

appropriate regression, values of milling duration, MRY, or HRY were predicted at a target DOM of 0.4% SLC. These predicted values for the individual-cultivar lots are presented in table 3.

Between the cultivar lots used in the H/P commingles, CL 151 required a greater milling duration (32.0 s in 2011 and 24.8 s in 2012) than CL XL745 (28.3 s in 2011 and 18.1 s in 2012) to reach a DOM of 0.4% SLC. For the H/H commingle lots, CL XL745 required a greater milling duration (28.3 s) than CL XL729 (25.1 s) to reach a DOM of 0.4% SLC in 2011. However, in 2012, no significant differences were observed in the milling durations required by the two hybrid cultivar lots to attain a DOM of 0.4% SLC (standard errors not shown). In the P/P commingles, CL 151 required a greater milling duration (32.0 s in 2011 and 24.8 s in 2012) than Wells (29.5 s in 2011 and 19.5 s in 2012) to reach a DOM of 0.4% SLC. These differences in the milling durations required by the individual-cultivar lots to attain 0.4% SLC suggest that when the H/P and P/P commingles from both years and the H/H commingle from 2011 are milled, the CL 151 kernels in the H/P and P/P commingles and the CL XL745 kernels in the H/H commingle could be under-milled, whereas the CL XL745 kernels in the H/P commingle, the Wells kernels in the P/P commingle, and the CL XL729 kernels in the H/H commingle could be over-milled. However, the dynamics of milling individual-cultivar lots separately may be different from when different lots are commingled and milled simultaneously.

Between the lots used in the H/P commingles, CL XL745 had a greater MRY but lesser HRY than CL 151 in both harvest years. On the other hand, in the H/H commingles, CL XL729 had lesser MRY and lesser HRY than CL XL745 in both harvest years. In the P/P commingles, Wells had a greater MRY but lesser HRY than CL 151 in both harvest years. The HRYs of the 2011 lots ranged from 59.7% for Wells to 66.7% for CL 151 and were found to be far superior to the HRYs of the 2012 lots, which ranged from 36.3% for Wells to 57.5% for CL 151. These differences in HRYs across harvest years can be attributed in part to the greater brown rice chalkiness of the 2012 lots compared to that of the 2011 lots (table 2), demonstrating that chalky kernels tend to break during milling, reducing HRY (Ambardekar et al., 2011). Lesser HRYs in 2012 than in 2011 could also have been due to lesser harvest moisture

contents in 2012, with consequent kernel fissuring and reduced HRYs due to rapid moisture adsorption.

MILLING DURATIONS REQUIRED BY THE COMMINGLED SAMPLES TO ATTAIN 0.4% SURFACE LIPID CONTENT

Milling durations required to attain a target DOM of 0.4% SLC were estimated using regression analyses of SLC vs. milling duration data for each commingled sample set and are presented in figure 2. In the H/P commingle from 2011, the milling durations initially increased from the 0:100 ratio to the 10:90 ratio, decreased to the 50:50 ratio, and leveled off thereafter. Similarly, milling durations required by the 2012 H/P commingle increased from the 0:100 ratio to the 10:90 ratio, decreased to the 90:10 ratio, and then remained constant. CL 151 brown rice kernels were shorter and had greater TLC and lesser brown rice bulk density than those of CL XL745 in both years. When commingled, properties of the CL 151 kernels, particularly the greater TLC (with presumably an associated greater bran layer thickness), are postulated to cause the CL 151 kernels to mill more slowly than the CL XL745 kernels. Therefore, these factors can be reasoned to have caused, or at least contributed to, the increase in milling duration required by the 10:90 ratio commingle to reach the 0.4% SLC level.

In the H/H commingle from 2011, there was a slight trend in increasing milling durations away from the 0:100 ratio, with the durations remaining constant with ratios beyond the 25:75 ratio. In the 2011 P/P commingle, there was also a very slight trend in increasing milling durations away from the 0:100 ratio, but then the durations generally decreased with ratio. Therefore, the trends in milling durations of the 2011 H/H and P/P commingles of slight increases away from the 0:100 ratio are similar to the trends in milling durations required by the H/P commingles. As Wells and CL XL745 kernels are longer than those of CL 151 and CL XL729, respectively, differences in kernel-to-kernel milling rates could have contributed to this trend.

Differences were observed between trends in milling durations required by the H/H commingles from 2011 to 2012. Bran removal rates are speculated to have been different in the 2012 vs. the 2011 commingles due to overall kernel integrity differences and associated lower HRYs in 2012 vs. 2011. The milling dynamics within a milling chamber for samples with kernels that break apart easily is quite different from the milling dynamics for samples comprising sound kernels (Huck et al., 2012). Additionally, in 2011, the CL XL745 kernels were of similar width to those of CL XL729, whereas in 2012, they were wider than those of CL XL729. Trends in other brown rice properties of these two cultivars remained constant over the two years.

Similarly, differences were observed between trends in milling durations required by the P/P commingle from 2011 to 2012. In addition to the overall milling yield differences, differences may also have occurred because Wells had a greater brown rice bulk density than that of CL 151 in 2011. However, in 2012, the trend was reversed, with trends in other brown rice properties remaining constant over the two years.

Table 3. Milling durations and yields of individual-cultivar lots predicted at a degree of milling level of 0.4% surface lipid content.[a]

Year	Cultivar	Milling Duration (s)	MRY (%)	HRY (%)
2011	Wells	29.5	73.7	59.7
	CL 151	32.0	72.9	66.7
	CL XL745	28.3	74.4	62.5
	CL XL729	25.1	72.4	61.2
2012	Wells	19.5	72.4	36.3
	CL 151	24.8	70.1	57.5
	CL XL745	18.1	71.5	45.0
	CL XL729	16.7	69.8	39.5

[a] Milling duration, milled rice yield (MRY), and head rice yield (HRY) were predicted using regression analyses of surface lipid content (SLC) vs. milling duration, MRY vs. SLC, and HRY vs. SLC , respectively.
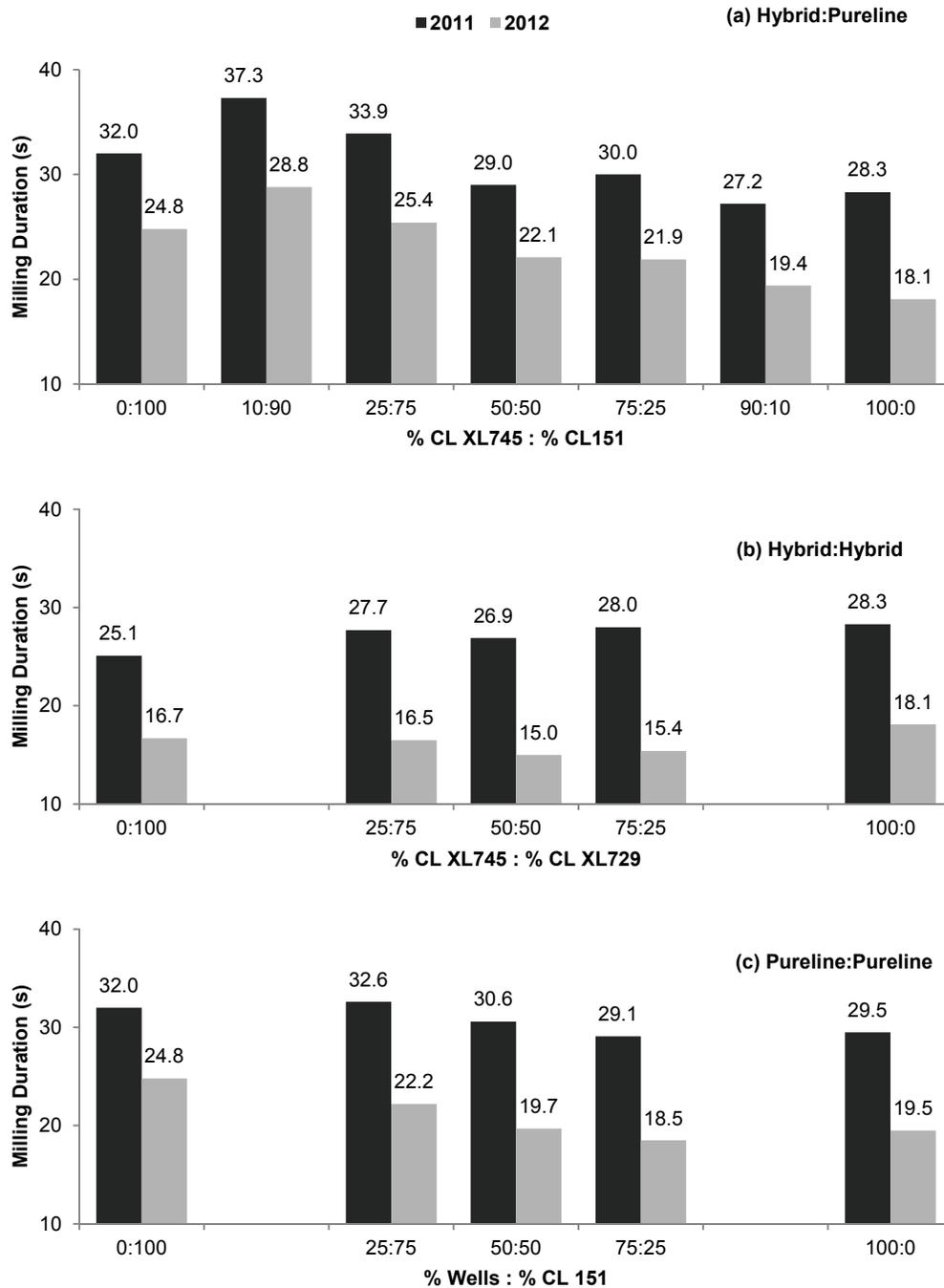
Figure 2. Milling durations required to attain a degree of milling level of 0.4% surface lipid content (SLC), estimated using regression analyses of SLC vs. milling duration data, for the (a) CL XL745/CL 151, (b) CL XL745/CL XL729, and (c) Wells/CL 151 commingles in 2011 and 2012.

MILLING YIELDS OF COMMINGLED SAMPLES

Milled rice yields and HRYs were predicted at a DOM of 0.4% SLC using regression analyses of MRY vs. SLC and HRY vs. SLC data for each commingled sample set and are presented in figures 3 and 4, respectively. Consistent trends were observed in all commingles across both harvest years. MRYs and HRYs either increased or decreased with the increasing percentage of a particular culti-

var in a commingle in both harvest years. For example, in the H/P commingle from 2011, MRYs of the commingled samples increased from 72.9% to 74.4% (fig. 3), and HRYs decreased from 66.7% to 62.5% (fig. 4), as the percentage of CL XL745 in the samples increased from 0% to 100%. This can also be interpreted as a decrease in MRYs of the commingled samples from 74.4% to 72.9% and an increase in HRYs from 62.5% to 66.7% with an increase in the percentage of CL 151 in the samples.
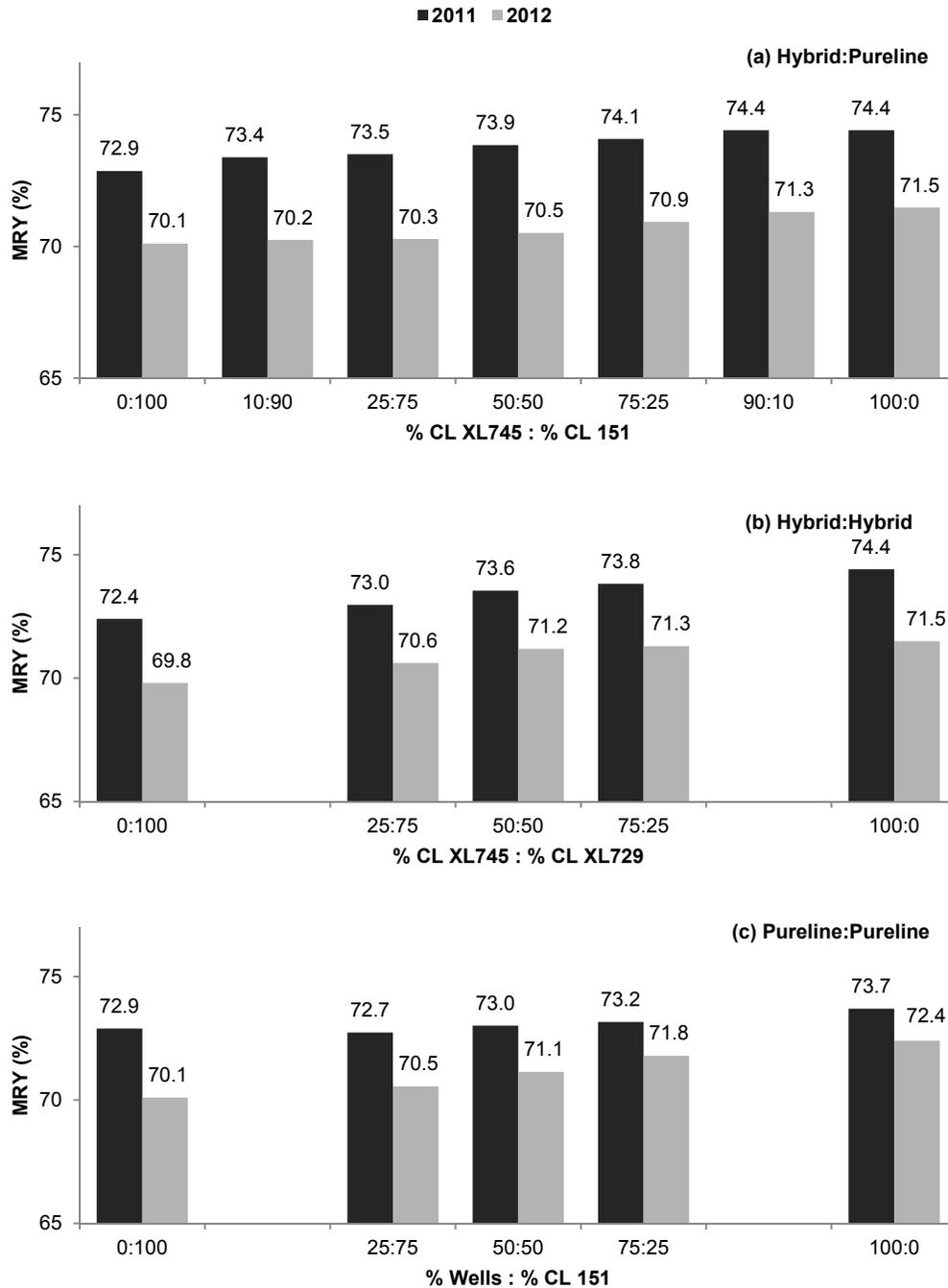
Figure 3. Milled rice yields (MRYs) predicted at a degree of milling level of 0.4% surface lipid content (SLC), estimated using regression analyses of MRY vs. SLC data, for the (a) CL XL745/CL 151, (b) CL XL745/CL XL729, and (c) Wells/CL 151 commingles in 2011 and 2012.

Based on these consistent trends in MRYs and HRYs with respect to commingling ratio, the actual commingled sample MRY and HRY values from figures 3 and 4, respectively, were compared to weighted average values calculated from the individual-cultivar lots in the mass ratio of a commingle. Differences between the MRYs of figure 3 and the weighted average MRYs of the commingled samples are presented in figure 5. These differences were less than ±0.5 percentage points for all commingles across both harvest years. Therefore, when two cultivars were commingled in any proportion and milled to a target DOM of

0.4% SLC, the resulting MRY of the commingled sample was very close to the weighted average MRY of the individual-cultivar lots milled separately. Similar to comparisons of commingled sample MRYs to the corresponding weighted average MRYs, HRYs of the commingled samples were compared to the corresponding weighted average HRYs. Differences between the HRYs of figure 4 and weighted average HRYs are presented in figure 6. In 2011, when HRYs of all the individual-cultivar lots were good (around 60% and greater), the differences between HRYs and weighted average HRYs of the commingled samples
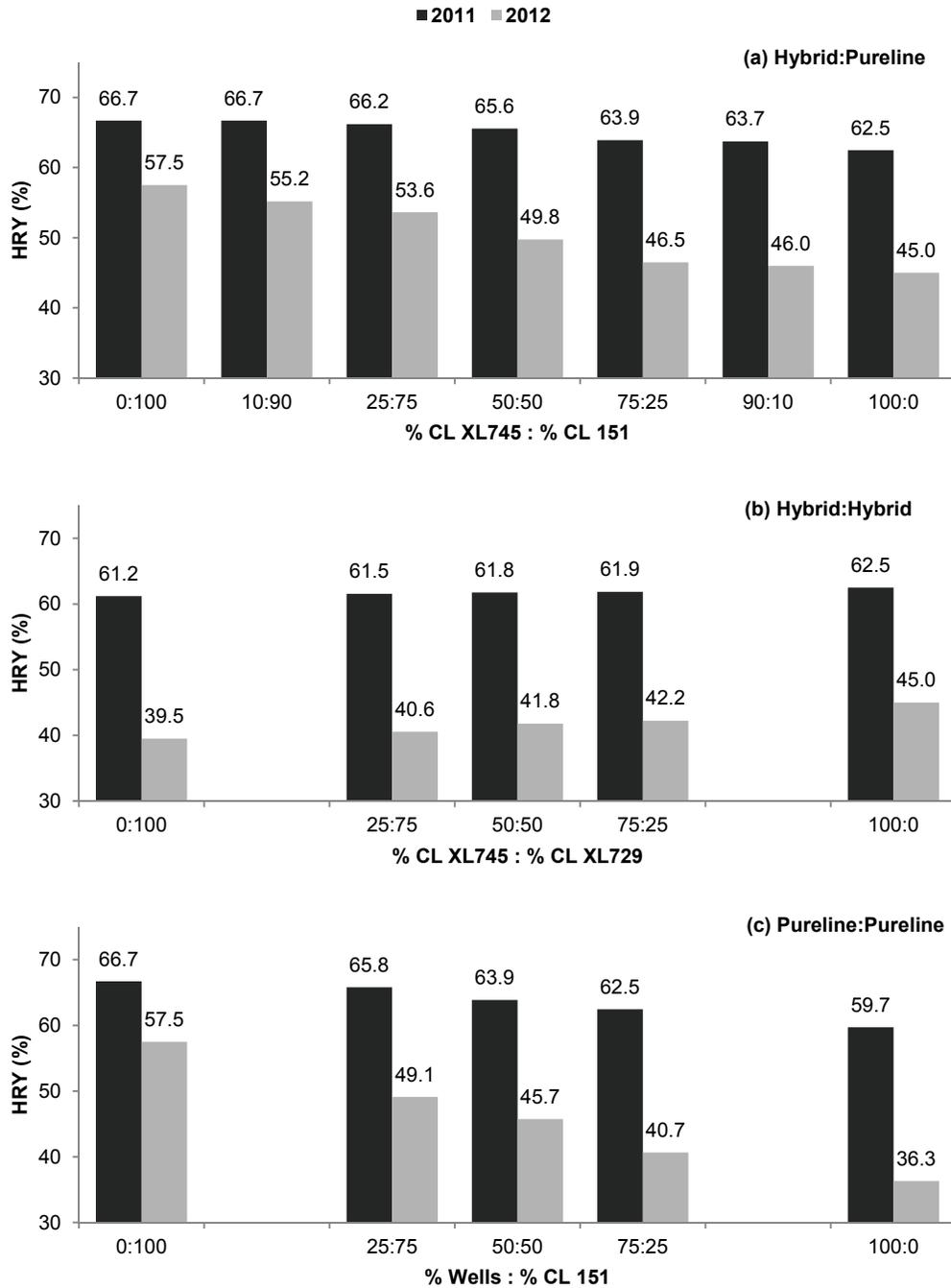
Figure 4. Head rice yields (HRYs) predicted at a degree of milling level of 0.4% surface lipid content (SLC), estimated using regression analyses of HRY vs. SLC data, for the (a) CL XL745/CL 151, (b) CL XL745/CL XL729, and (c) Wells/CL 151 commingles in 2011 and 2012.

were less than ±1 percentage point (fig. 6a), leading to the same conclusion stated above for MRYs. However, in 2012, when HRYs of all the individual-cultivar lots, except CL 151, were low (less than 50%), the differences between HRYs and weighted average HRYs of the commingled samples were between 0 and -3 percentage points (fig. 6b). Figure 6b indicates that if a commingle contains at least one cultivar with a low HRY and is milled to a target DOM

of 0.4% SLC, the resulting HRY of the commingle will be less than the level expected by calculating the weighted average HRY of the individual-cultivar lots milled separately. The discussion above regarding milling dynamics inside a mill for good vs. poor HRY samples is particularly relevant when measuring HRYs. Figure 6b suggests a small deleterious impact on HRYs when the individual-cultivar lots being commingled have poor HRYs.
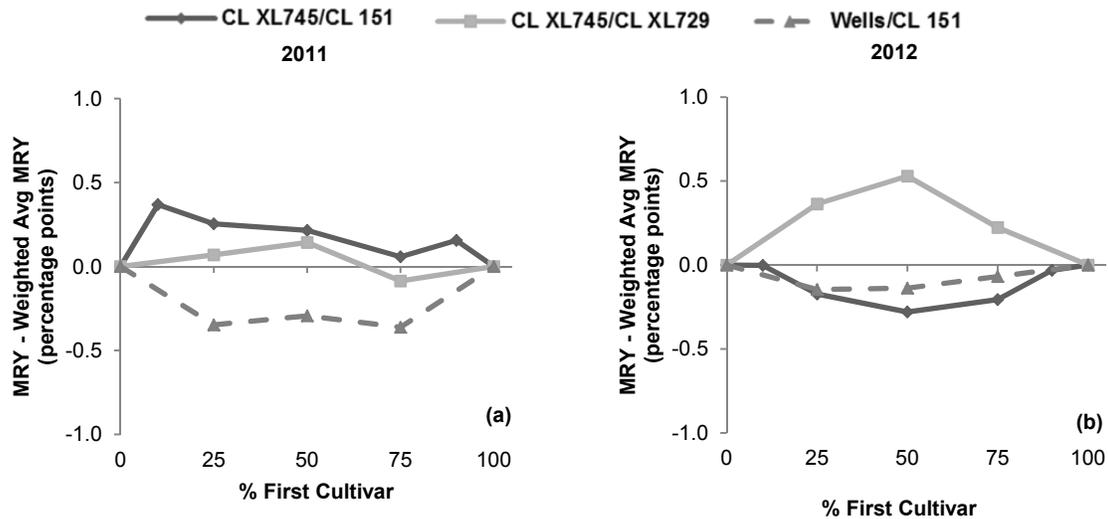
Figure 5. Differences between milled rice yields (MRYs, fig. 3) and weighted average MRYs for each commingle in (a) 2011 and (b) 2012 ("% First cultivar" is the percentage of the first cultivar in the indicated commingles). Weighted average MRY for each commingled sample was calculated using MRYs of the individual-cultivar lots in the mass ratio of that commingle.
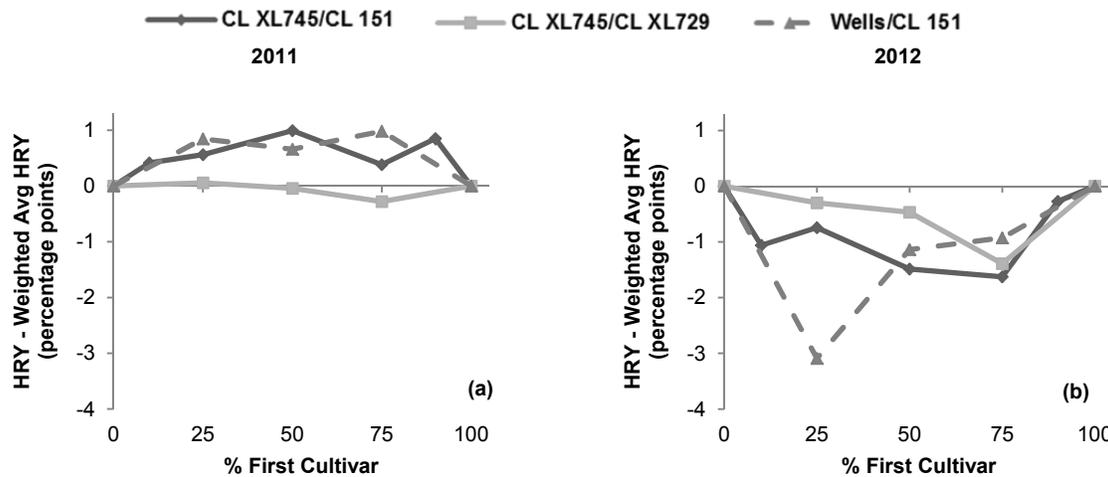

Figure 6. Differences between head rice yields (HRYs, fig. 4) and weighted average HRYs for each commingle in (a) 2011 and (b) 2012 ("% First cultivar" is the percentage of the first cultivar in the indicated commingles). Weighted average HRY for each commingled sample was calculated using HRYs of the individual-cultivar lots in the mass ratio of that commingle.

HEAD RICE COLOR OF COMMINGLED SAMPLES

Head rice whiteness ($L*$) and yellowness ($b*$) were predicted at a DOM of 0.4% SLC, using the regression analyses of $L*$ vs. SLC and $b*$ vs. SLC of each individual cultivar and commingling ratio from each year. The means and standard deviations of these predicted values for each commingle set are presented in table 4. Negligible differences were observed in both the $L*$ and the $b*$ values of commingled samples across commingling ratios. This indicates that when the DOM of commingled samples was adjusted to 0.4% SLC, head rice color of the commingled samples (an important quality parameter) did not vary significantly.

HEAD RICE CHALKINESS OF COMMINGLED SAMPLES

Head rice chalkiness was measured on samples milled for durations that produced a DOM level closest to 0.4%

Table 4. Means and standard deviations (SD) of head rice whiteness ($L*$) and yellowness ($b*$) of commingled samples from the 2011 and 2012 harvest years.

Year	Commingle	$L*$		$b*$	
		Mean	SD	Mean	SD
2011	CL XL745/CL 151	73.2	0.61	15.7	0.36
	CL XL745/CL XL729	74.1	0.57	15.0	0.37
	Wells/CL 151	72.3	1.05	15.7	0.62
2012	CL XL745/CL 151	75.2	0.48	14.5	0.93
	CL XL745/CL XL729	76.2	0.54	12.8	0.52
	Wells/CL 151	74.1	0.83	14.8	0.41

SLC. This duration was 30 s for all the 2011 commingles and 20 s for all the 2012 commingles. Head rice chalkiness values of commingled samples are presented in figure 7. Similar to the trends of brown rice chalkiness (table 2), the 2012 commingled samples had greater head rice chalkiness than those from 2011. Head rice chalkiness of the commingled samples trended according to the weighted average of
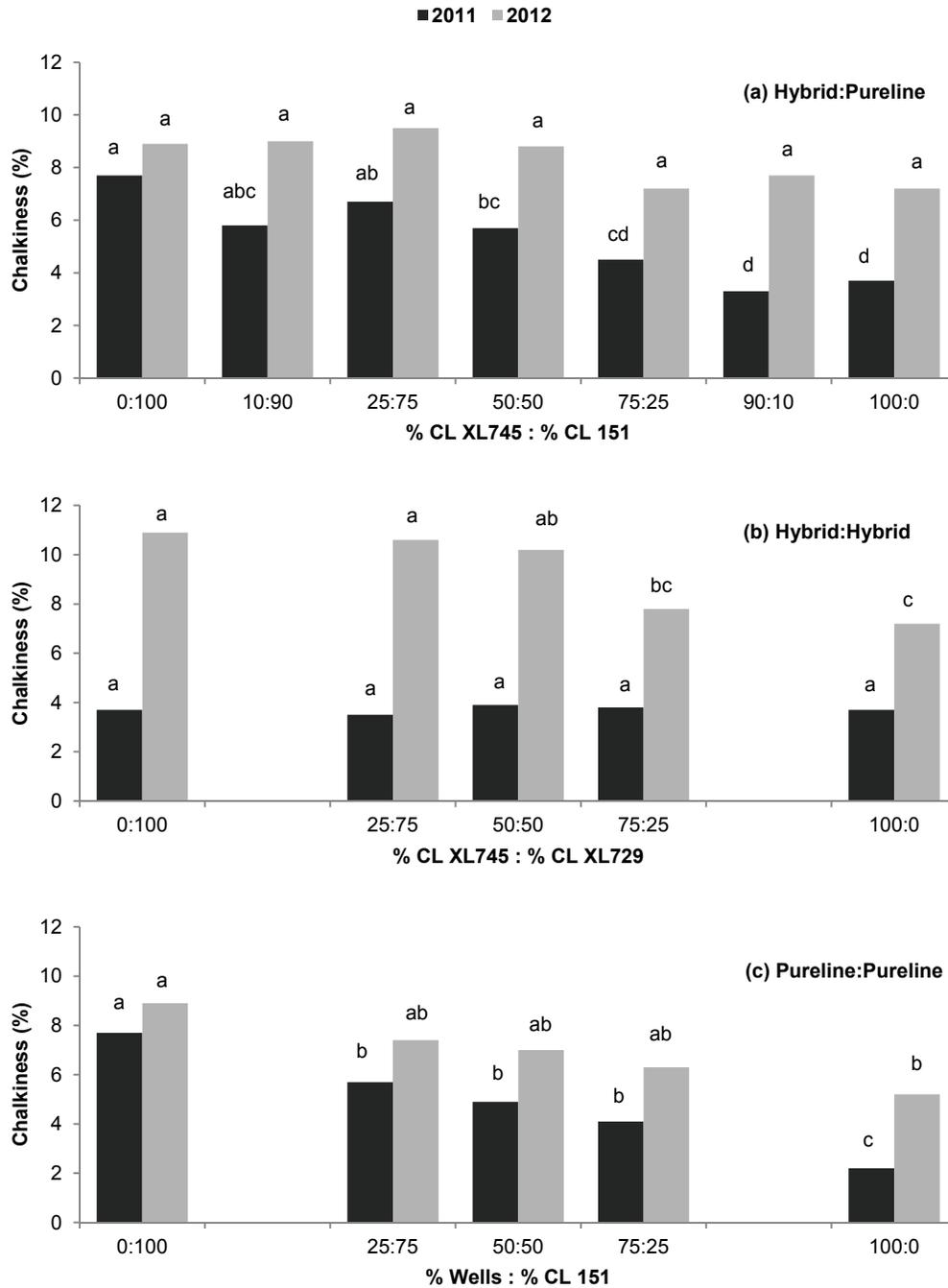
Figure 7. Head rice chalkiness (mean of four replicate samples) of the (a) CL XL745/CL 151, (b) CL XL745/CL XL729, and (c) Wells/CL 151 commingles in 2011 and 2012, measured for samples that had been milled for durations that produced a degree of milling level closest to 0.4% surface lipid content. Statistical differences in means of head rice chalkiness of samples, in a given commingle in a given year, are indicated by different letters, according to Tukey's honestly significant difference test, at a 0.05 level of significance.

the individual-lot chalkiness values. The 2011 H/P commingle is an example of this in which the head rice chalkiness of CL XL745 was less than that of CL 151; the chalkiness of the commingled samples of these two cultivars decreased as the percentage of CL XL745 increased.

Differences between the head rice chalkiness of commingled samples in figure 7 and the corresponding weighted average head rice chalkiness of the individual-

cultivar lots are presented in figure 8. Except in two cases, the differences between the two values were less than one percentage point; the trends do not indicate positive or negative differences. Figure 8 indicates that the head rice chalkiness levels of commingled samples were predicted sufficiently accurately by the weighted average calculations.
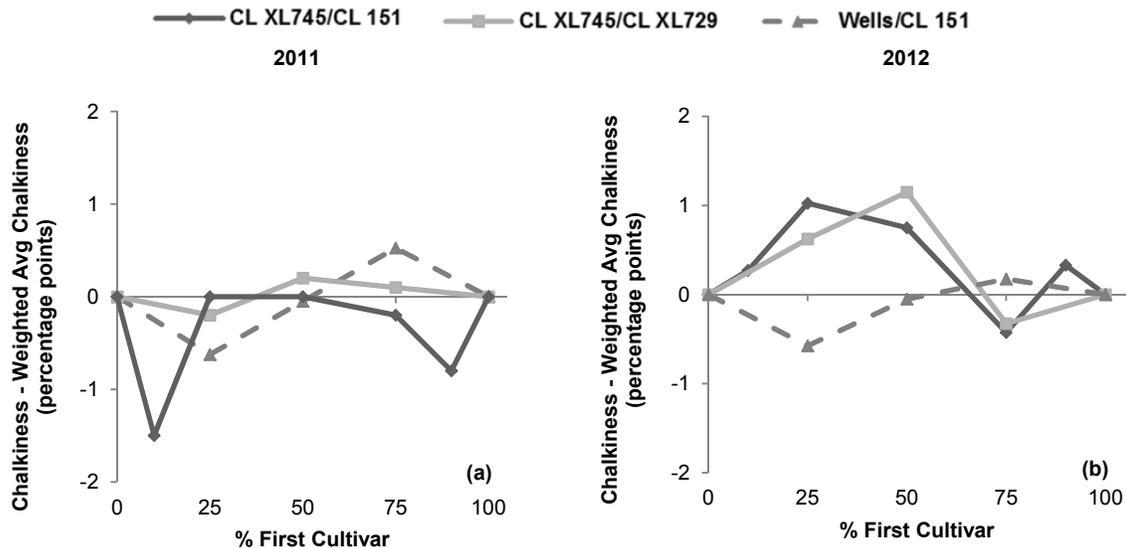
Figure 8. Differences between head rice chalkiness (fig. 7) and weighted average head rice chalkiness for each commingle in (a) 2011 and (b) 2012 ("% First cultivar" is the percentage of the first cultivar in the indicated commingles). Weighted average head rice chalkiness for each commingled sample was calculated using head rice chalkiness of the individual-cultivar lots in the mass ratio of that commingle.

CONCLUSIONS

Milled rice yield, head rice yield, and head rice chalkiness of the commingled samples trended according to the weighted average of the individual-cultivar lot MRYs, HRYs, and head rice chalkiness values, respectively. However, a small deleterious impact was observed on the HRYs of commingled samples when cultivar lots having poor HRYs were commingled. Head rice whiteness and yellowness of commingled samples were not significantly different when the DOM of samples was adjusted to 0.4% SLC, indicating that commingling did not affect the color of commingled samples. Some speculative evidence was found showing the effect of TLC, length, width, and bulk density of brown rice kernels of the individual lots on the milling dynamics of commingled samples.

REFERENCES

AACC. (2000). Method 30-20.01. In *Approved Methods of the American Association of Cereal Chemists* (10th ed.). St. Paul, Minn.: AACC International.

Ambardekar, A. A., Siebenmorgen, T. J., Counce, P. A., Lanning, S. B., & Mauromoustakos, A. (2011). Impact of field-scale nighttime air temperatures during kernel development on rice milling quality. *Field Crops Res., 122*(3), 179-185. http://dx.doi.org/10.1016/j.fcr.2011.03.012.

Andrews, S. B., Siebenmorgen, T. J., & Mauromoustakos, A. (1992). Evaluation of the McGill No. 2 rice miller. *Cereal Chem., 69*(1), 35-43.

Azhakanandam, K., Power, J. B., & Lowe, K. C. (2000). Qualitative assessment of aromatic Indica rice *Oryza sativa* L. proteins,

lipids, and starch in grain from somatic embryo- and seed-derived plants. *J. Plant Physiol., 156*(5-6), 783-789. http://dx.doi.org/10.1016/S0176-1617(00)80248-5.

Bhashyam, M. K., & Srinivas, T. (1984). Varietal difference in the topography of rice grain and its influence on milling quality. *J. Food Sci., 49*(2), 393-401. http://dx.doi.org/10.1111/j.1365-2621.1984.tb12430.x.

Chen, H., & Siebenmorgen, T. J. (1997). Effect of rice kernel thickness on degree of milling and associated optical measurements. *Cereal Chem., 74*(6), 821-825. http://dx.doi.org/10.1094/CCHEM.1997.74.6.821

Chen, H., Siebenmorgen, T. J., & Du, L. (1999). Quality characteristics of medium-grain rice milled in a three-break commercial milling system. *Cereal Chem., 76*(4), 473-475.:http://dx.doi.org/10.1094/CCHEM.1999.76.4.473.

Cooper, N. T., & Siebenmorgen, T. J. (2007). Correcting head rice yield for surface lipid content (degree of milling) variation. *Cereal Chem., 84*(1), 88-91. http://dx.doi.org/10.1094/CCHEM-84-1-0088.

Cooper, N. T., Siebenmorgen, T. J., & Counce, P. A. (2008). Effects of nighttime temperature during kernel development on rice physicochemical properties. *Cereal Chem., 85*(3), 276-282. http://dx.doi.org/10.1094/CCHEM-85-3-0276.

Counce, P. A., Keisling, T. C., & Mitchell, A. J. (2000). A uniform, objective, and adaptive system for expressing rice development. *Crop Sci., 40*(2), 436-443. http://dx.doi.org/10.2135/cropsci2000.402436x.

Fan, J., Siebenmorgen, T. J., Gartman, T. R., & Gardisser, D. R. (1998). Bulk density of long- and medium-grain rice varieties as affected by harvest and conditioned moisture contents. *Cereal Chem., 75*(2), 254-258. http://dx.doi.org/10.2135/cropsci2000.402436x.

Hogan, J. T., & Deobald, H. J. (1961). Note on a method of determining the degree of milling of whole milled rice. *Cereal Chem., 38*(3), 291-293.

Huck, A. C., Lanning, S. B., & Siebenmorgen, T. J. (2012). Milling characteristics of high and low quality rice. *Discovery Magazine, 13*, 28-37. Fayetteville, Ark.: University of Arkansas, Dale Bumpers College of Agricultural, Food, and Life Sciences.

IRRI. (1988). Hybrid rice. In *Proc. Intl. Symp. Hybrid Rice.* Los

Baños, Philippines: International Rice Research Institute.

Jindal, V. K., & Siebenmorgen, T. J. (1987). Effects of oven drying temperature and drying time on rough rice moisture content determination. *Trans. ASAE, 30*(4), 1185-1192. http://dx.doi.org/10.13031/2013.30542.

Juliano, B. O. (1985). Rice bran. In *Rice: Chemistry and Technology* (pp. 647-688). St. Paul, Minn.: AACC International.

Lamberts, L., De Bie, E., Vandeputte, G. E., Veraverbeke, W. S., Derycke, V., De Man, W., & Delcour, J. A. (2007). Effect of milling on colour and nutritional properties of rice. *Food Chem., 100*(4), 1496-1503. http://dx.doi.org/10.1016/j.foodchem.2005.11.042.

Lanning, S. B., & Siebenmorgen, T. J. (2011). Comparison of milling characteristics of hybrid and pureline rice cultivars. *Appl. Eng. Agric., 27*(5), 787-795. http://dx.doi.org/10.13031/2013.39560.

Matsler, A. L., & Siebenmorgen, T. J. (2005). Evaluation of Soxtec system operating conditions for surface lipid extraction from rice. *Cereal Chem., 82*(3), 282-286. http://dx.doi.org/10.1094/CC-82-0282.

Miller, B. S., Lee, M. S., Pomeranz, Y., & Rousser, R. (1979). A rapid, objective method to measure the degree of milling of rice. *Cereal Chem., 56*(3), 172-180.

Park, J. K., Kim, S. S., & Kim, K. O. (2001). Effect of milling ratio on sensory properties of cooked rice and on physicochemical properties of milled and cooked rice. *Cereal Chem., 78*(2), 151-156. http://dx.doi.org/10.1094/CCHEM.2001.78.2.151.

Perdon, A. A., Siebenmorgen, T. J., Mauromoustakos, A., Griffin,

V. K., & Johnson, E. R. (2001). Degree of milling effects on rice pasting properties. *Cereal Chem, 78*(2), 205-209. http://dx.doi.org/10.1094/CCHEM.2001.78.2.205.

Pomeranz, Y., & Webb, B. D. (1985). Rice hardness and functional properties. *Cereal Foods World, 30*(11), 784-788.

Pomeranz, Y., Stermer, R. A., & Dikeman, E. (1975). NMR-oil content as an index of degree of rice milling. *Cereal Chem., 52*(2), 849-853.

Reid, J. D., Siebenmorgen, T. J., & Mauromoustakos, A. (1998). Factors affecting the slope of head rice yield vs. degree of milling. *Cereal Chem., 75*(5), 738-741. http://dx.doi.org/10.1094/CCHEM.1998.75.5.738.

Saleh, M. I., & 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*(2), 119-124. http://dx.doi.org/10.1094/CCHEM-84-2-0119.

Siebenmorgen, T. J., Matsler, A. L., & Earp, C. F. (2006). Milling characteristics of rice cultivars and hybrids. *Cereal Chem., 83*(2), 169-172. http://dx.doi.org/10.1094/CC-83-0169.

USDA. (2009). United States standards for rice, revised. Washington, D.C.: USDA Federal Grain Inspection Service.

USDA. (2014). U.S. rice acreage, yield, and production. NASS Quick Stats. Washington, D.C.: USDA National Agricultural Statistics Service. Retrieved from www.ers.usda.gov/data-products/rice-yearbook-2014.aspx.

Webb, B. D. (1980). Rice quality and grades. In B. S. Luh (Ed.), *Rice: Production and Utilization* (pp. 543-565). Westport, Conn.: AVI Publishing.