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Milling and Functional Properties of Co-mingled Rice Cultivars

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ABSTRACT

Differences have been observed in the milling and functional properties of different rice cultivars, particularly between hybrid and pureline cultivars. Co-mingling of rice cultivars commonly occurs during harvest, storage and drying operations. Thus, there is a need to study the effect of co-mingling on the milling and functional properties of rice cultivars. 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 CL XL745/CL 151 (H/P), CL XL745/CL XL729 (H/H) and Wells/CL 151 (P/P) co-mingles, mixed in various proportions. Milled rice yield (MRY), head rice yield (HRY), surface lipid content (SLC), head rice color, head rice chalkiness and gelatinization and pasting properties of head rice flour were measured for individual lot samples, as well as the above mentioned co-mingled samples. Kernel dimensions, total lipid content (TLC), chalkiness and bulk density of brown rice samples of the individual cultivar lots were also studied to determine the effect of brown rice properties of individual cultivar lots on the milling and functional properties of co-mingled samples. The MRYs, HRYs, head rice chalkiness and pasting properties of the co-mingled samples increased or decreased with the increasing percentage of a given cultivar in the co-mingled samples. The differences in head rice whiteness and yellowness of the co-mingled samples milled to the same DOM were negligible, indicating that co-mingling did not affect the color of rice after milling to the same DOM. An investigation of gelatinization curves showed that the co-mingled samples retained characteristics of the gelatinization properties of the individual cultivars used in those co-mingles. For example, the onset gelatinization temperature (T_o) of a co-mingled sample was equivalent to the T_o of that cultivar in the co-mingle with the lower T_o. These findings will help

to make key decisions regarding the use of co-mingles depending on the brown rice, milling and functional properties of the individual cultivar lots used for co-mingling.

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OVERALL INTRODUCTION

Given that rice is the most important staple food for a majority of the world's population (USDA, 2008), it is important to grow sufficient amounts of rice to satisfy the needs of that majority. Cultivation of hybrid rice is a part of the solution that will help to meet those demands.

An intact rice kernel consists of endosperm and germ covered by first, the bran and then the hull. The kernel in this stage is called rough rice. Removal of the hull from rough rice results in brown rice. When brown rice is milled, primarily bran and germ are removed and white rice is obtained. In the removal of bran and germ, there can be inadvertent loss of endosperm that makes up white rice, particularly during extended milling, and consequently, economic losses are incurred.

Starch is the major component of rice and undergoes order-disorder transitions during gelatinization (Sivak and Preiss, 1998). Thus, gelatinization properties govern the amount of heat input required to cook rice. Starch granules form a paste after becoming gelatinized and the cooking behavior of rice is reflected by its pasting properties. Consequently, gelatinization and pasting properties of rice determine the end-use applications of rice and are therefore important for food processors from a cooking point of view to optimize and maintain process conditions and product characteristics.

Rice has cultivar-specific milling and functional properties because of differences in kernel dimensions (Chen et al., 1999; Chen and Siebenmorgen, 1997), topographies (Bhashyam and Srinivas, 1984; Pomeranz and Webb, 1985), moisture content (Andrews et al., 1992), chalkiness (Ambardekar et al., 2011; Cheng et al., 2005; Patindol and Wang, 2003) and chemical composition (Lai et al., 2001; Vandeputte et al., 2003). Moreover, functional properties of rice are also affected by the degree to which it is milled (Champagne et al., 1990; Marshall, 1992;

Perdon et al., 2001; Saleh and Meullenet, 2007). Therefore, when rice cultivars are co-mingled during operations such as harvesting, drying and storage, there could be a resultant impact on milling and functional properties. This may deleteriously affect processing operations such as milling, cooking, and parboiling. Although considerable research has been conducted on studying the milling and functional properties of individual rice cultivar lots, effects of co-mingling on these properties have not been studied. Therefore, there is a need to study the effects of co-mingling on the milling and functional properties of rice cultivars.

MILLING PROPERTIES OF CO-MINGLED RICE CULTIVARS

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INTRODUCTION

A rice kernel with the husk intact is known as rough rice, which when dehulled, gives brown rice. When brown rice is milled, initially the germ and bran layers are removed, followed by outer layers of the endosperm. Degree of milling (DOM) is the extent of removal of germ and bran during milling. As DOM increases, more of these are removed and mass of the milled kernels decreases. DOM is important as it affects milling yield (Cooper and Siebenmorgen, 2007) and functional characteristics, including, texture of cooked rice (Saleh and Meullenet, 2007) and pasting properties (Perdon et al., 2001).

Rice bran is present on the surface of a rice kernel and contains 15-20% lipids (Juliano, 1985). Therefore, surface lipid content (SLC) is directly related to the extent to which rice is milled and is an indicator of DOM of rice (Hogan and Deobald, 1961; Miller et al., 1979; Pomeranz et al., 1975). Lamberts et al. (2007) showed that yellow and red pigments in rice are mainly concentrated in the bran and thus, yellowness of kernels decreases whereas whiteness increases with an increase in DOM. Therefore, head rice yellowness and head rice whiteness can also be used as indicators of DOM.

Rice is the most important staple food for a majority of the world's human population. World rice production has almost quadrupled from 1960/61 to 2008/09 harvest years (USDA, 2013), partly due to the cultivation of hybrid rice. Acreage of hybrid cultivars has increased in large part due to greater agronomic yields, strong disease resistance and more efficient use of soil nutrients, as compared to pureline cultivars. However, differences have been observed in the milling properties of hybrid and pureline cultivars (Lanning and Siebenmorgen, 2007;

Siebenmorgen et al., 2006). Lanning and Siebenmorgen (2011) showed that hybrid rice cultivars reach a target SLC faster than pureline cultivars. This suggests that hybrid cultivars require shorter milling durations than pureline cultivars to reach a particular DOM, possibly due to differences in the bran layer thickness or the bran/embryo chemical composition.

Various rice kernel characteristics such as kernel topography (Bhashyam & Srinivas, 1984; Pomeranz & Webb, 1985), physical dimensions (Chen et al., 1999; Chen and Siebenmorgen, 1997) and moisture content (Andrews et al., 1992) have been shown to affect the milling performance of rice. Therefore, different cultivars often have different DOM levels when milled for a given duration (Siebenmorgen et al., 2006).

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. As bran is likely to be more readily removed from the ridges but left remaining in the grooves, more milling is required to remove bran from the grooves, which invariably results in the removal of endosperm from the ridges. This results in the loss of useful endosperm as well as possible, increased breakage. Therefore, milling losses are less for shallow-grooved cultivars relative to deep-grooved ones (Bhashyam and Srinivas, 1984).

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, this difference in kernel SLCs progressively decreased and ultimately, there was no significant difference between the SLCs of thicker and thinner kernels, when milled beyond a certain bulk DOM.

Head rice yield (HRY) is expressed as 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, 2005). Head rice is more valuable than broken rice and thus, maximizing HRY is of economic importance in the rice industry. HRY and DOM are significantly affected by the moisture content of rice kernels (Banaszek et al., 1989; Webb and Calderwood, 1977). For the same milling duration, a decrease in kernel moisture content causes the HRY to increase and DOM to decrease (Banaszek et al., 1989; Webb and Calderwood, 1977).

Chalkiness is a major defect in rice kernels. It usually occurs when high nighttime air temperatures (NTATs) are experienced during certain critical stages of kernel development. Also, some cultivars are more susceptible to high NTATs than others (Ambardekar et al., 2011; Cooper et al., 2008; Counce et al., 2000). One undesirable effect of chalkiness is that kernel strength is reduced. Thus, chalky kernels tend to break during milling, reducing the HRY (Ambardekar et al., 2011).

Co-mingling of rice cultivars commonly occurs during harvest, drying and storage operations. Because kernels of different physical dimensions, topographies, moisture content and chalkiness may be mixed during co-mingling, there could be a resultant impact on milling properties, particularly when dissimilar cultivars are co-mingled. Therefore, evaluating the effects of co-mingling on milled rice characteristics could provide justification for identity preservation of cultivar lots and aid in management decisions regarding cultivar co-mingling at the field or post-harvest levels. While the aforementioned studies report the impacts of single-cultivar characteristics on HRY, chalk and DOM, no research was found showing the consequences of co-mingling on these properties.

MATERIALS AND METHODS

Sample procurement and preparation

The study was conducted using four long-grain cultivars, CL XL729 and CL XL745 (hybrids) and CL 151 and Wells (purelines), grown in two separate years, 2011 and 2012. Among the 2011 lots, the CL (Clearfield™) cultivars (CL XL729, CL XL745 and CL 151) were procured from Jonesboro, AR and Wells from Stuttgart, AR. Among the 2012 lots, the CL cultivars were procured from Harrisburg, AR and Wells from Forest City, AR. The 2011 lots were selected to have high HRY while the 2012 lots were selected to have low HRY; this was done to determine if co-mingling 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, MN) and conditioned to 12±0.5% (wet basis) moisture content. A convection oven (1370FM, Sheldon Mfg. Inc., Cornelius, OR) 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. The co-mingled samples prepared are presented in table 1.1. Co-mingling ratios of 25:75, 50:50 and 75:25 were selected to reflect a broad range of co-mingling. The CL XL745/CL 151 co-mingle also included the 90:10 and 10:90 ratios to investigate effects of the common practice of planting CL 151 on the levees of CL XL745 fields. Four replicate samples of rough rice for each individual cultivar/co-mingling ratio, all weighing 150 g, were prepared for multiple milling durations. Therefore, the masses of the individual cultivars in the co-mingled 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 co-mingling 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, IL), weighed and then mixed in respective proportions. Each co-mingled sample of rough rice was thoroughly homogenized for 2 min using a rotary rice-grader (TRG, Satake, Tokyo, Japan).

Table 1.1. Co-mingles prepared for the study

Co-mingle	Cultivar-Lot Type	Co-mingling Ratios
CL XL745/CL 151	hybrid/pureline	10:90, 25:75, 50:50, 75:25, 90:10
CL XL745/CL XL729	hybrid/hybrid	25:75, 50:50, 75:25
Wells/CL 151	pureline/pureline	25:75, 50:50, 75:25

Milling yields

Each sample of 150-g 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 was then milled for 10, 20, 30 or 40 s using a laboratory mill (McGill No. 2, RAPSCO, Brookshire, TX), having a 1.5-kg mass placed on the lever arm, 15 cm from the centerline of the milling compartment. Milled rice, which comprises intact and broken kernels, was weighed to calculate milled rice yield (MRY), which was expressed as the mass percentage of 150 g of rough rice remaining as milled rice. Head rice was then separated from the brokens using a sizing device (Model 61, Grain Machinery Manufacturing Corp., Miami, FL). Head rice yield (HRY) was expressed as the mass percentage of 150 g of rough rice remaining as head rice. Cultivars vary in bran removal rates and thus have different DOM levels when milled for the same duration (Siebenmorgen et al., 2006). As HRY is linearly and directly related to SLC (Cooper and Siebenmorgen, 2007; Reid et al., 1998; Lanning and Siebenmorgen, 2011), milling the samples for various durations was essential to obtain HRY vs. SLC relationships (sometimes referred to as millability curves). From the curves, HRYs corresponding to a target SLC value were determined; this procedure accounted for differences in bran removal rates.

Surface lipid content and total lipid content

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, MN), following the method 30-20.01 (AACC Intl., 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 four individual cultivar lots. For TLC measurement, samples of brown rice were ground using a cyclone mill (3010-30, UDY, Fort Collins, CO) equipped with a 100-mesh (0.5-mm) sieve. Approximately 5 g of head rice or ground, brown rice was weighed into cellulose thimbles (33mm, i.d.×80 mm, external length) (Foss North America, Eden Prairie, MN). After pre-drying the samples and thimbles for an hour in an oven maintained at 100±2°C, the thimbles with head rice or ground, brown rice inside were placed in the lipid extractor. Aluminum cups were then weighed and placed under the thimbles in the lipid extractor. Lipids were extracted by boiling the thimbles in 70 ml of petroleum ether (boiling point 35-60°C; VWR, Suwanee, GA) and then rinsing with the petroleum ether condensate for 30 min. When most of the solvent had evaporated from the extraction cups after approximately 3 min, the cups were placed in an oven (100±2°C) to evaporate the residual solvent and later placed in a desiccator for 30 min to cool to room temperature. Finally, the cups containing the extracted lipids were weighed. The mass of the extracted lipids was obtained by subtracting the original mass of the cups from the mass of the cups containing the extracted lipids. The ratio of mass of the extracted lipids to the original mass of head rice or ground, brown rice, multiplied by 100, gave SLC and TLC percentages, respectively.

Head rice color

Whiteness ($L*$) and yellowness ($b*$) of all head rice samples were measured using a colorimeter (ColorFlex Colorimeter, Hunter Associates Laboratory, Reston, VA). The instrument's sample container, a small plastic petri dish (6-cm diameter), was filled with approximately 30 g of the sample, 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 degrees. 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 lot and co-mingled 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-sheet tray (152 mm×100 mm×20 mm), such that no two kernels were in contact with each other. A blue background was selected for scanning to have a contrast in color between the rice kernels and the background. The imaging system was configured to quantify rice-kernel surface area against this contrasting background. Using a completely chalky kernel as the reference color for chalk, the imaging system was also configured to color-classify kernel chalkiness. The system measured the number of pixels corresponding to the kernel projected area and the number of pixels corresponding to areas color-classified as chalk. The ratio of the number of pixels representing the chalky areas of the kernels to the number of pixels representing the total area of the kernels, multiplied by 100, gave percent chalk. This procedure was repeated on another set of 100 kernels from the same sample and an average of the two readings was recorded as percent chalk for that sample. The same procedure was used to measure brown rice chalkiness of the individual cultivar lot samples.

Bulk density

Bulk density of brown rice was measured for the four individual cultivars using a bulk density test weight apparatus (Filling Hopper and Stand, Seedburo Equipment Co., Chicago, IL), according to the procedure of Fan et al. (1998). The pint cup provided was weighed and placed under the funnel (hopper) of the apparatus on a collection pan. Brown rice was loaded into the hopper, and then the hopper valve was opened to allow the rice to flow into the cup until it overflowed. The sample was leveled to the top of the cup by oscillating a wooden stick provided in a zigzag motion. The cup filled with the sample was weighed. Subtracting the mass of the empty cup from the mass of the cup containing the sample gave the mass of the sample. The procedure was repeated twice. The three masses were then averaged and divided by the volume of the pint cup to obtain the bulk density in g/cm^3.

Data analysis

Brown rice properties of individual cultivar lots were compared among cultivars and across harvest years. In order to account for the variation in the DOM of different cultivars, milling durations, MRYs, HRYs and color values were adjusted for all individual cultivar lot and co-mingled samples. Regression analyses of SLC vs. milling duration were conducted on four replicate samples milled for 10, 20, 30 or 40 s. These equations were used to determine the milling durations required by samples to reach a DOM level of 0.4% SLC. Likewise, regression analyses of MRYs, HRYs and color values vs. SLCs were conducted and using these equations, their values were adjusted to 0.4% SLC. Head rice chalkiness was compared for individual cultivar lot and co-mingled samples. An average of SLCs for each milling duration (10, 20, 30 or 40 s) for each co-mingle from each year was taken and the milling duration that produced a DOM closest to 0.4% SLC was selected as the basis of comparison for that co-mingle. Regression analyses, analysis of variance (α=0.05) and comparison of means using Tukey's Honestly Significant Difference (HSD) test were performed using a statistical software (JMP Pro 10, SAS Institute, Cary, NC).

RESULTS AND DISCUSSION

Properties of bulk lots

Brown rice properties of bulk density, kernel dimensions, chalkiness and TLC of the four individual cultivar lots are presented in table 1.2. Between the cultivar lots used in the P/P (Wells/CL 151) co-mingle, 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 (CL XL745/CL 151) co-mingle, brown rice bulk density of CL XL745 was greater than that of CL 151 in both harvest years. Between the cultivar lots used in the H/H (CL XL745/CL XL729) co-mingle, there was no difference in the brown rice bulk density of CL XL745 and CL XL729 in both years.

Across harvest years, between the cultivar lots used in the P/P co-mingle, brown rice kernels of Wells were longer and narrower than those of CL 151. Between the cultivar lots used in the H/P co-mingle, 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 the brown rice kernels of CL XL745. Between the cultivar lots used in the H/H co-mingle, brown rice kernels of CL XL745 were longer and of equivalent width to those of CL XL729 in 2011. However, in 2012, brown rice kernels of CL XL745 were both longer and wider than the brown

Table 1.2. Brown rice properties of individual cultivar lots.

Year	Cultivar	Brown rice property					
		Bulk density (kg/m^3)	Length (cm)	Width (cm)	Thickness (cm)	Chalkiness (%)	TLC (%)
2011	Wells	750 de[1]	7.12 b	2.09 f	1.80 ab	3.6 d	2.45 d
	CL 151	757 bc	6.80 e	2.23 b	1.79 ab	3.2 d	2.60 bc
	CL XL745	767 a	7.28 a	2.20 c	1.81 a	3.7 d	2.28 e
	CL XL729	761 ab	6.99 c	2.21 c	1.81 a	3.4 d	2.34 e
2012	Wells	747 e	7.31 a	2.12 e	1.77 a	5.6 c	2.36 de
	CL 151	731 f	6.78 e	2.23 b	1.79 ab	5.3 c	2.95 a
	CL XL745	750 de	7.25 a	2.25 a	1.80 ab	8.0 b	2.64 bc
	CL XL729	753 cd	6.93 d	2.18 d	1.81 a	12.0 a	2.71 b

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

rice kernels of CL XL729. No significant differences were observed in the thicknesses of the four individual cultivar lots across harvest years.

There were no statistical differences in the brown rice chalkiness of the four individual cultivar lots from 2011 whereas, 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 1.2). Overall, the 2012 cultivar lots had greater brown rice chalkiness than lots comprising the same cultivars from the 2011 harvest.

Between the cultivar lots used in the P/P co-mingle, TLC of CL 151 was greater than that of Wells in both harvest years. Similarly, between the cultivar lots used in the H/P co-mingle, TLC of CL 151 was greater than that of CL XL745 in both harvest years. There was no difference in the TLCs of the cultivar lots used in the H/H co-mingle, i.e., CL XL745 and CL XL729, in both harvest years. These differences in bulk densities, kernel dimensions, chalkiness and TLCs of brown rice led to milling differences in the individual cultivar lot and co-mingled samples that are subsequently explained.

SLC vs. milling duration, MRY vs. SLC, and HRY vs. SLC curves for the individual cultivar lots for both harvest years are presented in fig. 1.1. Figs. 1.1a and 1.1b show that SLC decreased exponentially with an increase in milling duration and figs. 1.1c-1.1f show that MRY and HRY decreased linearly with decreases in SLC. Regression analyses of SLC vs. milling duration, MRY vs. SLC and HRY vs. SLC were conducted (tables 1.4-1.6) and values (milling duration, MRY and HRY) were predicted based on these regression equations, to achieve a target DOM level of 0.4% SLC. These predicted values of the individual cultivar lots are presented in table 1.3.

CL 151 was used in the H/P and P/P co-mingles and CL XL745 was used in the H/P and H/H co-mingles each year. Therefore, CL 151 and CL XL745 were the cultivars that were used in two co-mingles in each year. Daniels et al. (1998) have shown that storage up to three months after harvest has a significant impact on milling properties. Since there was no considerable time difference in studying the milling properties of the H/P and P/P co-mingles in both years, it would have been redundant to study the milling properties of CL 151 twice in each year. Therefore, the milling properties of CL 151 were studied only once in each year and were used to represent the 0:100 ratio in the H/P and the P/P co-mingles. Similarly, as there was no considerable time difference in studying the milling properties of the H/P and H/H co-mingles in 2012, milling properties of CL XL745 were studied only once in that year and they were used to represent the 100:0 ratio in the H/P and H/H co-mingles that year. However, as there was a considerable time difference of four months in studying the H/P and H/H co-mingles in 2011, the milling properties of CL XL745 were studied twice, first as part of the H/P co-mingle and

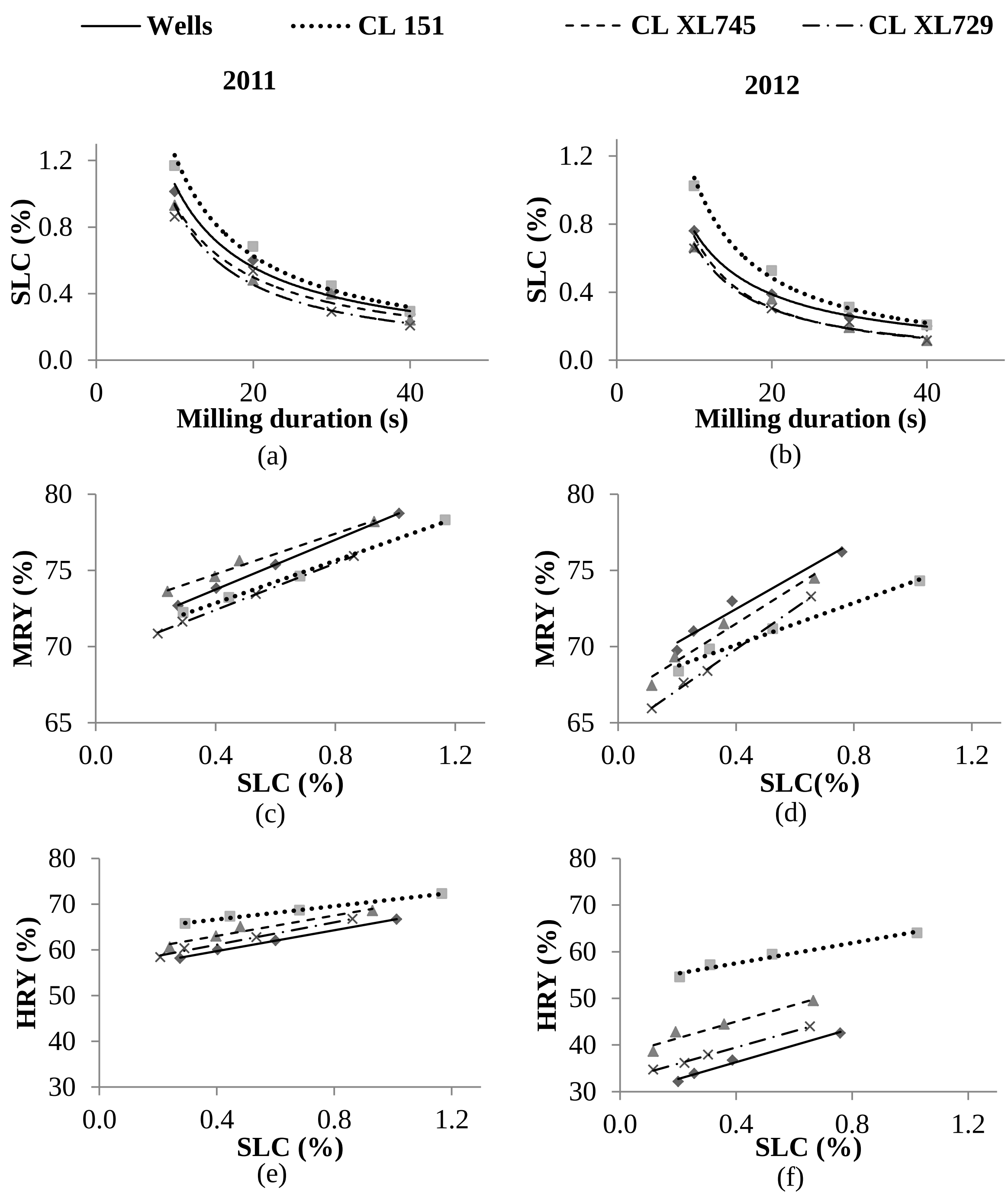

Fig. 1.1. Surface lipid content (SLC) vs. milling duration (a, b), milled rice yield (MRY) vs. SLC (c, d) and head rice yield (HRY) vs. SLC (e, f) plots of the indicated cultivar lots milled for 10, 20, 30 and 40 s using a laboratory mill. Each data point represents an average of four replicates for each milling duration.

Table 1.3. Milling durations and milling yields of individual cultivar lots adjusted[1] to a degree of milling (DOM) level of 0.4% surface lipid content (SLC).

Year	Cultivar	Milling durations and yields predicted at a DOM of 0.4% SLC		
		Milling duration (s)	MRY (%)	HRY (%)
2011	Wells	30	73.8	59.7
	CL 151	32	72.9	66.7
	CL XL745/w CL 151/CL XL729	25/30[2]	74.7/74.1	63.2/61.9
	CL XL729	25	72.3	61.2
2012	Wells	20	72.4	36.3
	CL 151	25	70.1	57.5
	CL XL745	18	71.5	45.0
	CL XL729	17	69.8	39.5

[1] Milling durations, milled rice yields (MRYs) and head rice yields (HRYs) were adjusted using regression analyses of SLC vs. milling duration, MRY vs. SLC and HRY vs. SLC, respectively (See tables 1.4-1.6 for regression analysis constants).

[2] Daniels et al. (1998) have shown that storage up to three months after harvest has a significant impact on milling properties. There was a considerable gap in studying the CL XL745/CL 151 and CL XL745/CL XL729 co-mingles in 2011. Therefore, the milling properties of CL XL745 were studied twice, first as part of the CL XL745/CL 151 co-mingle (first value in each cell in that row) and secondly as part of the CL XL745/CL XL729 co-mingle (second value in each cell in that row).

secondly as part of the H/H co-mingle in that year. Therefore, there are two values for milling duration, MRY and HRY of CL XL745 from 2011 in table 1.3. The first value in each cell in the 2011 CL XL745 row is the value of the given property of CL XL745 that was studied as part of the 2011 H/P co-mingle and was therefore used to represent the 100:0 ratio in that co-mingle. The second value in each cell in the 2011 CL XL745 row is the value of the given property of CL XL745 that was studied as part of the 2011 H/H co-mingle and was therefore used to represent the 100:0 ratio in that co-mingle. In fig. 1.1a, c and e, two curves were not used to represent the two times that CL XL745 was studied in 2011, since those curves were only used to illustrate the trends in SLC, MRY and HRY. In those curves, the first lot of CL XL745, the one that was studied as part of the 2011 H/P co-mingle, has been presented.

Between the cultivar lots used in the P/P co-mingle, CL 151 required a greater milling duration (32 s in 2011 and 25 s in 2012) than Wells (30 s in 2011 and 20 s in 2012) to reach a DOM of 0.4% SLC. Between the cultivar lots used in the H/P co-mingle, CL 151 required a greater milling duration (32 s in 2011 and 25 s in 2012) than CL XL745 (25 s in 2011 and 18 s in 2012) to reach a DOM of 0.4% SLC. Between the cultivar lots used in the H/H co-mingle, CL XL745 required a greater milling duration (30 s) than CL XL729 (25 s) to reach a DOM of 0.4% SLC in 2011. However, in 2012, there was hardly any difference (1 s) in the milling durations required by the two hybrid cultivar lots (18 s for CL XL745 and 17 s for CL XL729) to attain 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 P/P and H/P co-mingles from both years and the H/H co-mingle from 2011 are milled, it could be that the CL 151 kernels in the P/P and H/P co-mingles and the CL XL745 kernels in the H/H co-mingle will be under-milled whereas the CL XL745 kernels in the H/P co-mingle, Wells kernels in the P/P co-mingle and CL XL729 kernels in the H/H co-mingle will be over-milled. However, unlike the other co-mingles, the H/H co-mingle from 2012 might mill more homogeneously since CL XL745 and CL XL729 from 2012 had overlapping SLC vs. milling duration curves (fig. 1.1b) and thus required similar milling durations to attain 0.4% SLC. However, the dynamics of milling individual cultivar lots separately may be different than when different lots are co-mingled and milled simultaneously.

Between the cultivar lots used in the P/P co-mingle, Wells had greater MRY but lesser HRY compared to CL 151 in both harvest years. Similarly, between the cultivar lots used in the H/P co-mingle, CL XL745 had greater MRY but lesser HRY compared to CL 151 in both harvest years. On the other hand, between the cultivar lots used in the H/H co-mingle, CL XL729 had lesser MRY and lesser HRY than CL XL745 in both harvest years. 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 2012 lots, whose HRYs ranged from 36.3% for Wells to 57.5% for CL 151. These differences between HRYs of the same cultivar lot across both harvest years can be attributed in part to the greater chalkiness of the 2012 lots compared to those of the 2011 lots, demonstrating the fact that chalky kernels are weak and tend to break during milling, reducing the HRY (Ambardekar et al., 2011).

Milling durations required by the co-mingled samples to reach 0.4% surface lipid content

Parameter estimates obtained on conducting regression analyses of SLC as a function of milling duration for all co-mingled samples in both harvest years are presented in table 1.4. Milling durations required to attain a target DOM of 0.4% SLC are presented as bar charts in fig. 1.2. As previously mentioned, in the H/P co-mingle in both harvest years (fig. 1.2a), the 0:100 ratio, consisting of only CL 151, required a greater milling duration (32 s in 2011 and 25 s in 2012) than the 100:0 ratio, consisting of only CL XL745 (25 s in 2011 and 18 s in 2012). In 2011, the milling durations initially increased from the 0:100 ratio to the 10:90 ratio, and then decreased. The 10:90 ratio required the greatest milling duration, followed by the 25:75 ratio, to achieve the target DOM of 0.4% SLC. Similar trend was followed by the milling durations required by the H/P co-mingle samples in 2012. Brown rice kernels of CL 151 were shorter and wider than those of CL XL745 in 2011, but in 2012, the CL 151 brown rice kernels were shorter and narrower than those of CL XL745. In addition, TLC of CL 151 was greater than that of CL XL745 in both harvest years. Therefore, it can be reasoned that kernel length and TLC influence the milling dynamics of the H/P co-mingle whereas width does not play an important role. Consequently, the greater milling durations for the 10:90 and the 25:75 ratios suggest that when two cultivars, one with shorter and greater-TLC kernels than the other are co-mingled, in a proportion where the shorter and greater-TLC kernels are in excess, milling duration to reach a DOM of 0.4% SLC is greater than that required when milling the individual cultivars separately. When co-mingled, the shorter CL 151 kernels possibly hide between the longer CL XL745 kernels and therefore, the CL XL745 kernels mill faster than the CL 151 kernels.

In the H/H co-mingle from 2011, the 100:0 ratio, consisting of only CL XL745, required a greater milling duration (30 s) than the 0:100 ratio, consisting of only CL XL729 (25 s), to attain a DOM of 0.4% SLC (fig. 1.2b). Milling durations required by the 0:100, 50:50, 75:25 and the 100:0 ratios increased with an increase in percentage of CL XL745 in that co-mingle. However, the 25:75 ratio, like the 10:90 and the 25:75 ratios from the H/P co-mingle, required a greater milling duration than what it would have required, had it followed the aforementioned trend of the milling durations increasing with an increase in percentage of CL XL745 in the co-mingled samples. CL XL729 brown rice kernels were shorter than those of CL XL745 with no difference in their TLCs. Therefore, it can be assumed that TLCs did not play an important role in this case. Therefore, the 2011 H/H co-mingle suggests that when two cultivars, one with shorter brown rice kernels than the other, are co-mingled in a proportion where the shorter kernels are in excess, milling duration required to reach 0.4% SLC is greater than that required when the individual cultivar lots are milled separately. This might happen because the shorter CL XL729 kernels possibly hide between the longer CL XL745 kernels, similar to trends of the H/P co-mingles from both years.

In the 2012 H/H co-mingle, milling durations required to attain a DOM level of 0.4% SLC differed by only 1 s between the two individual cultivars (18 s for CL XL745 and 17 s for CLXL729). Unlike the trends of the 2011 H/H co-mingle, milling durations required by the

Table 1.4. Relationships[1] between surface lipid content (SLC) and milling duration.

Year	Co-mingle	Co-mingling Ratio	Asymptote ($\times10^{-1}$)	Scale	Growth Rate ($\times10^{-2}$)
2011	H/P (CL XL745/ CL 151)	0:100	1.401	1.916	-6.25
		10:90	0.466	1.682	-4.18
		25:75	3.131	2.351	-9.71
		50:50	0.855	1.975	-6.33
		75:25	0.106	2.042	-5.52
		90:10	2.563	1.938	-9.56
		100:0	2.225	1.711	-8.90
	H/H (CL XL745/ CL XL729)	0:100	0.303	1.430	-5.39
		25:75	1.118	1.580	-6.14
		50:50	-0.287	1.580	-4.85
		75:25	-1.245	1.590	-3.96
		100:0	-1.230	1.580	-3.65
	P/P (Wells/ CL 151)	0:100	1.401	1.916	-6.25
		25:75	1.163	1.822	-5.70
		50:50	0.165	1.621	-4.70
		75:25	1.576	1.740	-6.77
		100:0	1.535	1.624	-6.39
2012	H/P (CL XL745/ CL 151)	0:100	1.283	1.995	-8.03
		10:90	1.129	1.856	-6.48
		25:75	1.666	2.222	-8.88
		50:50	1.317	1.990	-9.05
		75:25	1.531	1.823	-9.11
		90:10	0.470	1.163	-6.13
		100:0	0.286	1.245	-6.66
	H/H (CL XL745/ CL XL729)	0:100	0.953	1.358	-8.92
		25:75	0.266	1.253	-7.35
		50:50	1.122	1.260	-9.81

	75:25	1.249	1.406	-10.62
	100:0	0.286	1.245	-6.66
P/P	0:100	1.283	1.995	-8.03
(Wells/	25:75	1.930	1.972	-10.16
CL 151)	50:50	1.671	2.208	-11.44
	75:25	1.504	1.576	-9.94
	100:0	1.765	1.612	-10.12

[1] Regression analyses of SLC as a function of milling duration were conducted on four replicate samples at 10, 20, 30 and 40-s milling durations using the prediction model SLC = a + b × e(c × Milling duration), where a = Asymptote, b = Scale and c = Growth rate.

25:75, 50:50 and 75:25 ratios were slightly less than those required by the individual cultivar lots to reach the target DOM of 0.4% SLC (fig. 1.2b). In 2012, CL XL745 brown rice kernels were both longer and wider than those of CL XL729 with no difference in their TLCs. This might have caused the 2012 CL XL745 and CL XL729 cultivar lots to have similar milling characteristics (overlapping SLC vs. milling duration curves in fig. 1.1b). However, the slightly lesser milling durations required by the 25:75, 50:50 and 75:25 ratios in the 2012 H/H co-mingle suggest that when these two cultivars are co-mingled, the shorter and narrower CL XL729 kernels mill in tandem with the longer and wider CL XL745 kernels. This can be reasoned to affect the milling of co-mingled samples of these two cultivars and help them mill slightly faster or at a similar rate to that when the individual cultivar lots are milled separately.

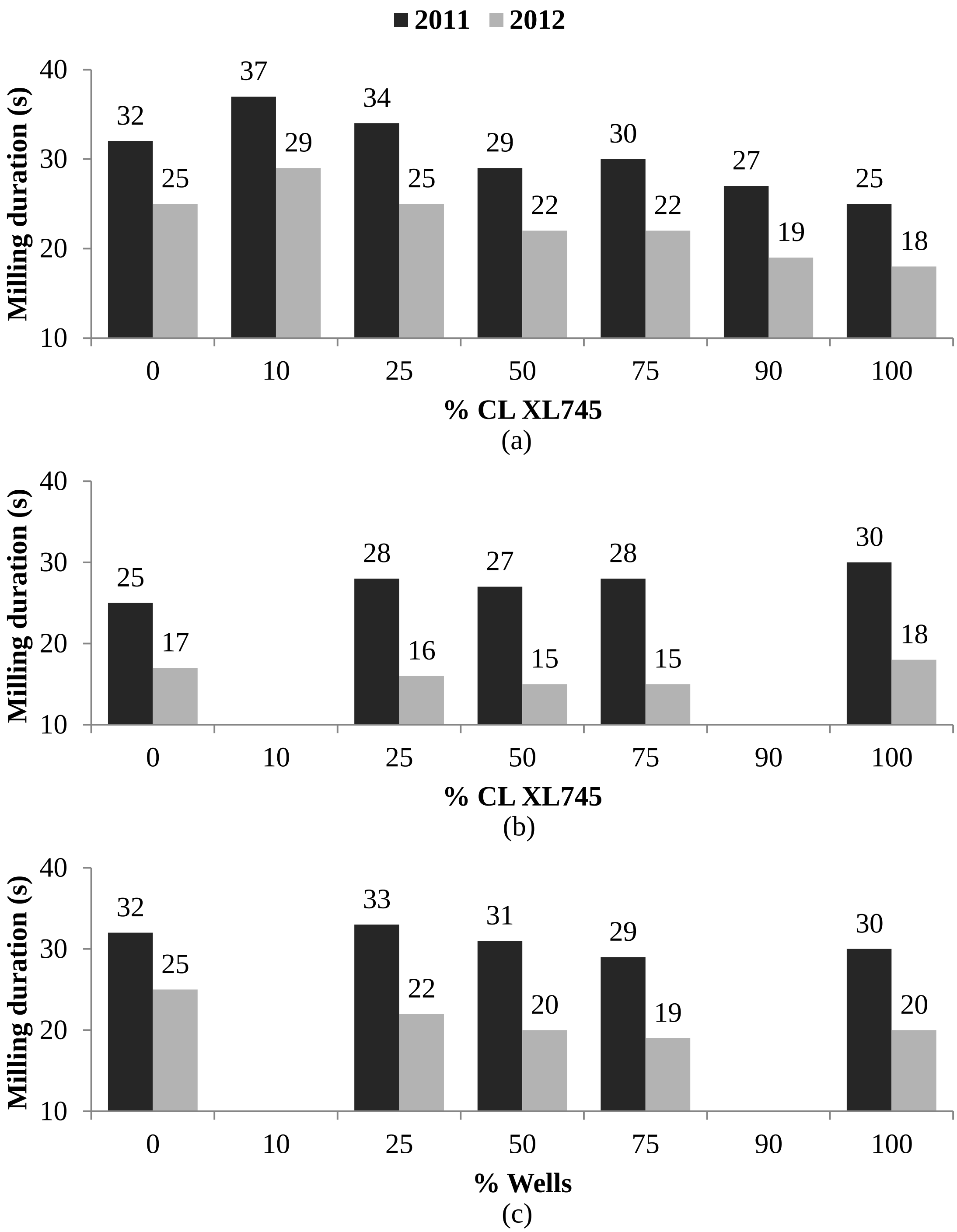

Fig. 1.2. Milling durations for the CL XL745/CL 151 (a), CL XL745/CL XL729 (b) and Wells/CL 151 (c) co-mingles in 2011 and 2012, estimated using regression analysis constants in table 1.4, at a degree of milling level of 0.4% surface lipid content.

In the 2011 P/P co-mingle, the 0:100 ratio, consisting of only CL 151, required a slightly greater milling duration (32 s) than the 100:0 ratio, consisting of only Wells (30 s), to reach a target DOM of 0.4% SLC (fig. 1.2c). The predicted milling durations increased from the 0:100 ratio to the 25:75 ratio and then decreased to the 50:50 ratio and then remained more or less constant. In 2011, CL 151 brown rice kernels were shorter and wider and had a greater TLC than those of Wells (table 1.2). Since the H/P co-mingle showed that width may not play an important role in influencing the milling of co-mingled samples containing different-TLC cultivars, greater milling duration required by the 25:75 ratio from the 2011 P/P co-mingle, like the 10:90 and 25:75 ratios from the H/P co-mingle from both years, again points out that when two cultivar lots, one with shorter and greater-TLC kernels than the other are co-mingled, in a proportion where the shorter and greater-TLC kernels are in excess, the milling duration required to reach a DOM of 0.4% SLC is greater than that required when the individual cultivar lots are milled separately. This might happen because the shorter CL 151 kernels probably hide between the longer Wells kernels, causing the Wells kernels to mill faster than the CL 151 kernels.

In the 2012 P/P co-mingle, the predicted milling durations required to attain 0.4% SLC decreased to the 50:50 ratio and then remained more or less constant (fig. 1.2c). Unlike the 2011 P/P co-mingle, the 25:75 ratio did not require a greater milling duration than the 0:100 and the 50:50 ratios. Similar to trends in 2011, CL 151 brown rice kernels were shorter and wider and had a greater TLC than those of Wells in 2012 (table 1.2). Therefore, the absence of a greater milling duration for the 25:75 ratio in the 2012 P/P co-mingle, as compared to trends of the 2011 P/P co-mingle, suggests that there are factors other than co-mingling proportion, kernel dimensions and TLC that influence the milling characteristics of co-mingled samples. Bulk density of CL 151 was greater than that of Wells in 2011 but in 2012, the trend was reversed.

However, in the H/P and H/H co-mingles from both years, the trends in bulk densities of the individual cultivar lots used in these co-mingles remained constant. Therefore, bulk density might be one of the factors that impacts the milling of co-mingled samples.

The H/P and P/P co-mingles suggest that when there are differences in TLCs and lengths of the cultivars being co-mingled, milling duration required by the co-mingle that contains a greater proportion of the cultivar with shorter and greater-TLC kernels to reach a DOM of 0.4% SLC is greater than that when the individual cultivar lots are milled separately. However, there was no difference in the TLCs of CL XL745 and CL XL729 brown rice kernels in both years and the 25:75 ratio still required a greater milling duration that the other ratios in this co-mingle in 2011. In the 2012 H/H co-mingle, milling durations required by the co-mingled samples were slightly less or close to those required by the individual cultivar lots when milled separately. This difference in trends of milling durations required by the H/H co-mingles in 2011 and 2012 was probably due the differing kernel dimensions of the two individual cultivars over the two years. In 2011, CL XL745 kernels were longer and of equivalent width to those of CL XL729 while in 2012, CL XL745 kernels were longer and wider than those of CL XL729. Therefore, it can be said that when the two cultivars being co-mingled have equivalent TLCs, widths of the brown rice kernels of the cultivars being co-mingled impact the milling of co-mingles of these cultivars. Trends in widths of the cultivars used in the H/P co-mingle were reversed over the two years, suggesting that when TLCs of the cultivars being co-mingled are different, width does not impact the milling of co-mingles. Lastly, the P/P co-mingle from 2012 suggested that there are factors other than co-mingling proportion, kernel dimensions and TLCs that influence the milling dynamics of co-mingled samples. Bulk density might be one of these factors as trends in bulk densities of Wells and CL 151 reversed over the two years, but they remained same for cultivars used in the other two co-mingles.

Milled rice yields of co-mingled samples

Based on the linear regression analyses of MRY vs. SLC, the resulting equations and R^2 values are presented in table 1.5. MRYs adjusted to a DOM level of 0.4% SLC are presented in fig. 1.3. There were consistent trends in all co-mingles across both harvest years. As presented in fig. 1.3, MRYs increased or decreased with the increasing percentage of a particular cultivar in a co-mingle. For instance, in the H/P co-mingle from the 2011 harvest, MRYs of the co-mingled samples increased from 72.9% to 74.7% as the percentage of CL XL745 in the samples increased from 0 to 100% (fig. 1.3a). This can also be interpreted as a decrease in MRYs of the co-mingled samples from 74.9% to 72.9% with an increase in the percentage of CL 151 in the samples. Similarly, MRY of the 2011 H/H co-mingle increased from 72.3% to 74.1% as the percentage of CL XL745 in that co-mingle increased from 0 to 100% (fig. 1.3b). Likewise, MRY of the P/P co-mingle from 2011 increased as the percentage of Wells in the co-mingle increased, except for the 25:75 co-mingling ratio that had a slightly less MRY than the 0:100 ratio (fig. 1.3c).

Similar trends were observed for the 2012 lots, with their MRYs being less than those of the 2011 lots (fig. 1.3), because chalkiness of the 2012 lots was greater than that of the 2011 lots. Chalky parts of the kernels are speculated to have disintegrated during milling, thereby leading to lesser MRYs for the 2012 lots as compared to the 2011 lots. The 25:75 ratio from the 2012 P/P co-mingle, unlike the 25:75 ratio from the 2011 P/P co-mingle, also followed the trend of the MRYs increasing with an increase in percentage of Wells in the co-mingle. Therefore, MRY of the 25:75 ratio from the 2011 P/P co-mingle not following the aforementioned trend may be attributed at least in part to experimental error.

Table 1.5. Relationships[1] between milled rice yield (MRY) and surface lipid content (SLC).

Co-mingle	Co-mingling Ratio	2011 Equation	2011 R^2	2012 Equation	2012 R^2
H/P	0:100	70.1 + 6.9×SLC	.99	67.4+6.9×SLC	.97
(CL XL745/	10:90	70.6 + 7.0×SLC	.98	67.5 + 6.9×SLC	.96
CL 151)	25:75	71.4 + 5.4×SLC	.99	67.4 + 7.2×SLC	.96
	50:50	70.9 + 7.2×SLC	.95	67.5 + 7.6×SLC	.97
	75:25	71.4 + 6.6×SLC	.97	67.5 + 8.6×SLC	.96
	90:10	71.8 + 6.6×SLC	.95	67.3 + 10.0×SLC	.96
	100:0	72.2 + 6.4×SLC	.90	66.6 + 12.1×SLC	.94
H/H	0:100	69.2 + 7.7×SLC	.93	64.5 + 13.3×SLC	.98
(CL XL745/	25:75	70.4 + 6.3×SLC	.98	66.1 + 11.3×SLC	.97
CL XL729)	50:50	71.0 + 6.5×SLC	.87	65.8 + 13.5×SLC	.95
	75:25	71.2 + 6.2×SLC	.96	66.4 + 12.1×SLC	.96
	100:0	71.6 + 6.3×SLC	.98	66.6 + 12.1×SLC	.94
P/P	0:100	70.1 + 6.9×SLC	.99	67.3 + 6.9×SLC	.97
(Wells/	25:75	69.6 + 7.8×SLC	.97	67.3 + 8.0×SLC	.97
CL 151)	50:50	69.6 + 8.5×SLC	.98	68.0 + 7.9×SLC	.95
	75:25	69.9 + 8.1×SLC	.99	67.4 + 11.0×SLC	.96
	100:0	70.5 + 8.1×SLC	.98	68.0 + 11.0×SLC	.94

[1] Linear regression analyses of MRY as a function of SLC were conducted on four replicate samples milled for 10, 20, 30 and 40-s durations.

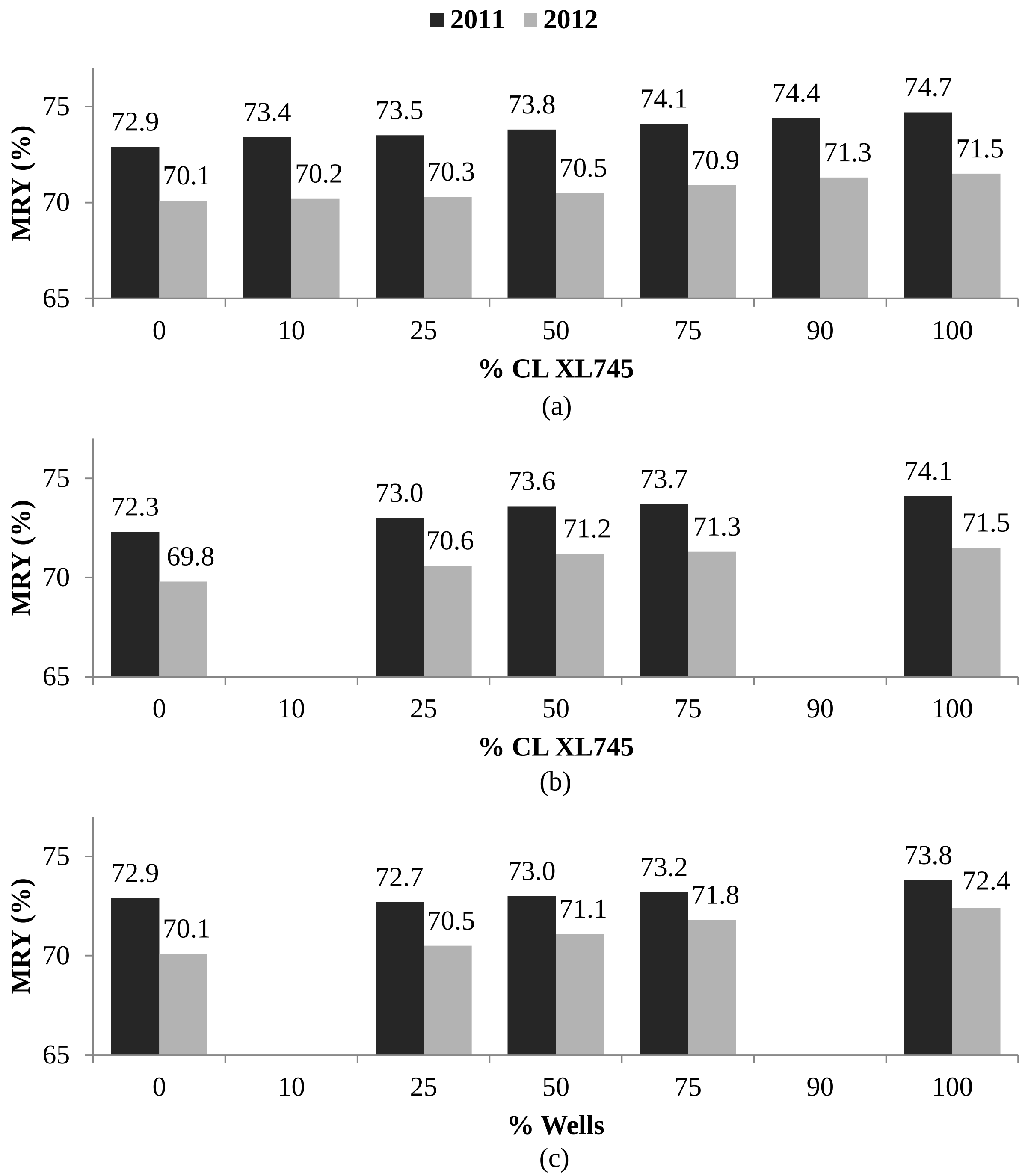

Fig. 1.3. Milled rice yields (MRYs) of the CL XL745/CL 151 (a), CL XL745/CL XL729 (b) and Wells/CL 151 (c) co-mingles in 2011 and 2012, estimated using the regression equations presented in table 1.5, at a degree of milling level of 0.4% surface lipid content.

To compare MRYs of the co-mingled samples to their weighted average MRYs determined using the MRYs of the individual cultivar lots, the differences between MRYs and weighted average MRYs of the co-mingled samples are presented in fig. 1.4. Differences between the two were less than ±0.5 percentage points for all co-mingles across both harvest years. Therefore, it can be said that when two cultivars are co-mingled in any proportion and milled to a target DOM of 0.4% SLC, the resulting MRY of the co-mingled samples will be very close to the weighted average of the MRYs of the individual cultivar lots milled separately.

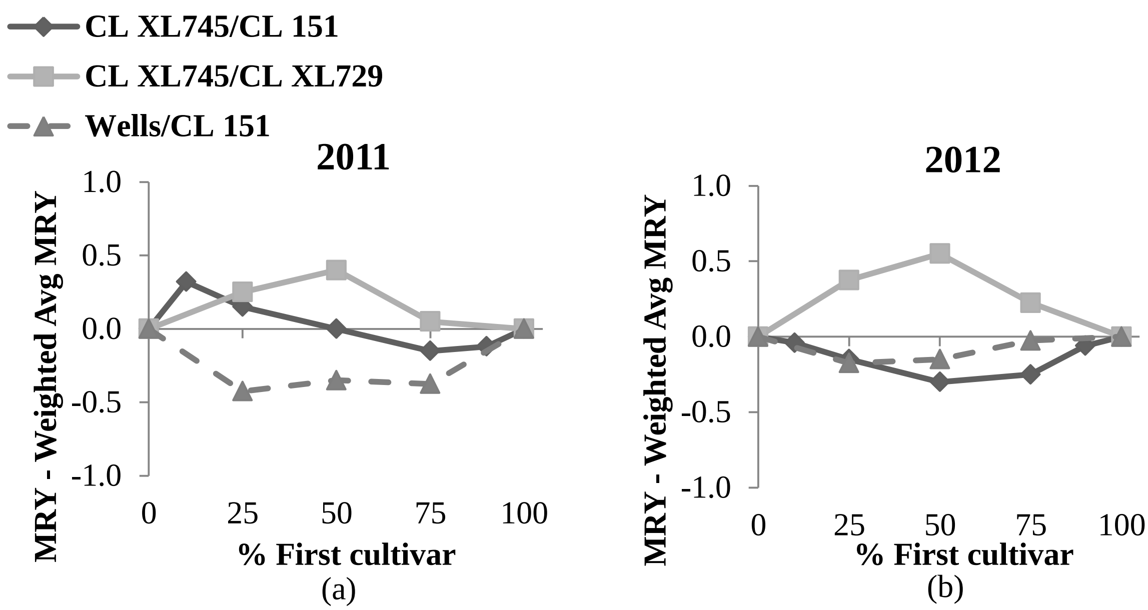

Fig. 1.4. Differences between milled rice yields (MRYs) (fig. 1.3) and weighted average MRYs for each co-mingle in 2011 (a) and 2012 (b). % First cultivar is the percentage of the first cultivar in the co-mingle, i.e., CL XL745 in the CL XL745/CL 151 and CL XL745/CL XL729 co-mingles and Wells in the Wells/CL 151 co-mingle. Weighted average MRY for each co-mingled sample was calculated using MRYs of the individual cultivar lots in that co-mingle, as presented in table 1.3. For e.g., the weighted average MRY of the 10:90 ratio in the 2011 CL XL745/CL 151 co-mingle
= (10× MRY of CL XL745+ 90× MRY of CL 151)/100 = (10×74.7+90×72.9)/100 = 73.1%

Head rice yields of co-mingled samples

Based on the linear regression analyses of HRY vs. SLC, the resulting equations and R^2 values are presented in table 1.6. HRYs of the co-mingled samples adjusted to a DOM level of 0.4% SLC are presented in fig. 1.5. Like MRYs, there were consistent trends in HRYs of all co-mingles across both harvest years. As presented in fig. 1.5, HRYs increased or decreased with an increasing percentage of a particular cultivar in a co-mingle. For instance, in the H/P co-mingle from the 2011 harvest, HRYs decreased from 66.7% to 63.2% as the percentage of CL XL745 in the co-mingle increased from 0 to 100% (fig. 1.5a). Similarly, HRY of the H/H co-mingle from 2011 increased from 61.2% to 61.9% with an increase in percentage of CL XL745 in the co-mingle (fig. 1.5b). Likewise, HRY of the P/P co-mingle from 2011 decreased from 66.7% to 59.7% with an increase in percentage of Wells in the co-mingle (fig. 1.5c). Similar trends were observed for the 2012 lots, with their HRYs being less than those of the 2011 lots (fig. 1.5), because brown rice chalkiness of the 2012 lots was greater than that of the 2011 lots, resulting in a greater tendency for kernels to break during milling because of reduced kernel strength.

To compare HRYs of the co-mingled samples to their weighted average HRYs determined using the HRYs of the individual cultivar lots, the differences between HRYs and weighted average HRYs are presented in fig. 1.6. In 2011, when HRYs of all the individual cultivar lots were good (around 60% and greater), differences between HRYs and weighted average HRYs of the co-mingled samples were less than ±1 percentage point. Therefore, it can be said that when two cultivars with good HRYs are co-mingled in any proportion and milled to a target DOM of 0.4% SLC, the resulting HRY of co-mingled samples will be close to the weighted average of HRYs of the individual cultivar lots milled separately. In 2012, when HRYs of all the individual cultivar lots, except CL 151, were low (less than 50%), differences between HRYs and weighted average HRYs of the co-mingled samples were between 0 and -3.5 percentage points. Therefore, it can be said that if a co-mingle 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 co-mingle will be less than the weighted average of HRYs of the individual cultivar lots milled separately. In all

Table 1.6. Relationships [1] between head rice yield (HRY) and surface lipid content (SLC).

Co-mingle	Co-mingling Ratio	2011 Equation	2011 R^2	2012 Equation	2012 R^2
H/P	0:100	63.8 + 7.2×SLC	.96	53.1+10.9×SLC	.95
(CL XL745/	10:90	63.4 + 8.0×SLC	.97	50.3 + 12.3×SLC	.94
CL 151)	25:75	63.3 + 7.3×SLC	.95	49.0 + 11.6×SLC	.94
	50:50	62.1 + 8.7×SLC	.93	44.4 + 13.4×SLC	.96
	75:25	60.7 + 7.9×SLC	.97	40.7 + 14.6×SLC	.97
	90:10	60.1 + 9.1×SLC	.97	40.4 + 13.9×SLC	.94
	100:0	58.9 + 10.7×SLC	.91	37.9 + 17.7×SLC	.91
H/H	0:100	56.4 + 12.0×SLC	.90	32.5 + 17.4×SLC	.97
(CL XL745/	25:75	57.1+ 11.0×SLC	.97	32.9 + 19.1×SLC	.98
CL XL729)	50:50	57.3 + 11.3×SLC	.86	31.6 + 25.3×SLC	.96
	75:25	57.3 + 11.4×SLC	.97	33.1 + 22.8×SLC	.96
	100:0	57.6+ 10.7×SLC	.95	37.9 + 17.7×SLC	.91
P/P	0:100	63.8 + 7.2×SLC	.96	53.1 + 10.9×SLC	.95
(Wells/	25:75	62.6 + 7.9×SLC	.97	42.7 + 15.9×SLC	.96
CL 151)	50:50	59.9 + 9.9×SLC	.98	40.3 + 13.6×SLC	.93
	75:25	58.8 + 9.0×SLC	.96	34.6 + 15.0×SLC	.90
	100:0	55.2 + 11.3×SLC	.95	29.1 + 17.9×SLC	.96

[1] Linear regression analyses of HRY as a function of SLC were conducted on four replicate samples milled for 10, 20, 30 and 40-s durations.

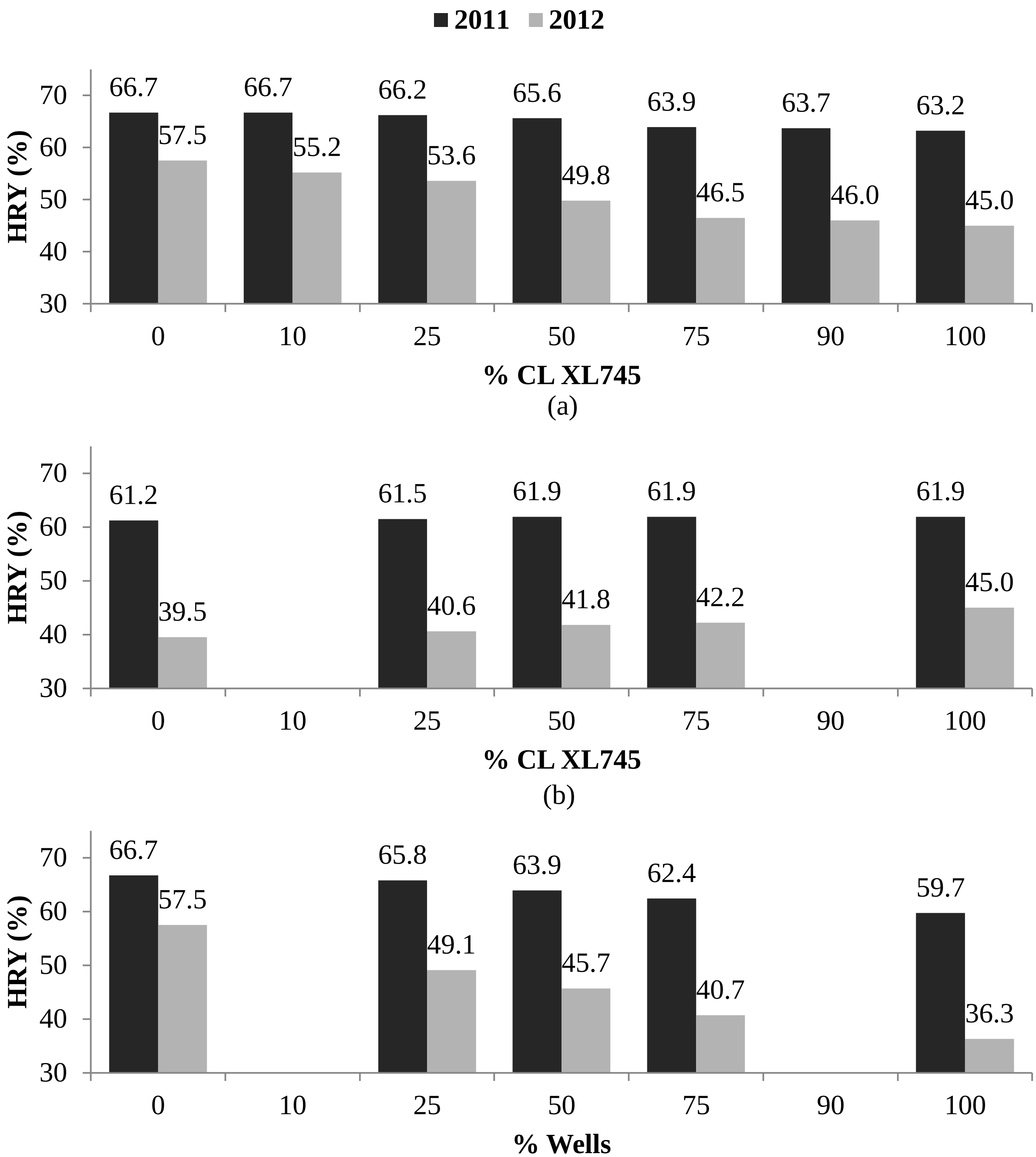

Fig. 1.5. Head rice yields (HRYs) of the CL XL745/CL 151 (a), CL XL745/CL XL729 (b) and Wells/CL 151 (c) co-mingles in 2011 and 2012, estimated using the regression equations presented in table 1.6, at a degree of milling level of 0.4% surface lipid content.

the co-mingles, there was one cultivar with longer kernels than the other (table 1.2). Therefore, as previously mentioned, there is a possibility that the shorter kernels hide between the longer kernels during milling. If this happens when the kernel strength of the longer kernels is less (shown by reduced HRY for the 2012 lots), the longer kernels will be milled more, undergoing more stress during milling and therefore more breakage, as they have more tendency to break. Therefore, it can be reasoned that differences between HRYs and weighted average HRYs are greater for lots that have at least one cultivar with weaker kernels and experience over-milling of the weaker-kernel cultivar, leading to increased breakage due to lesser kernel strength of that cultivar.

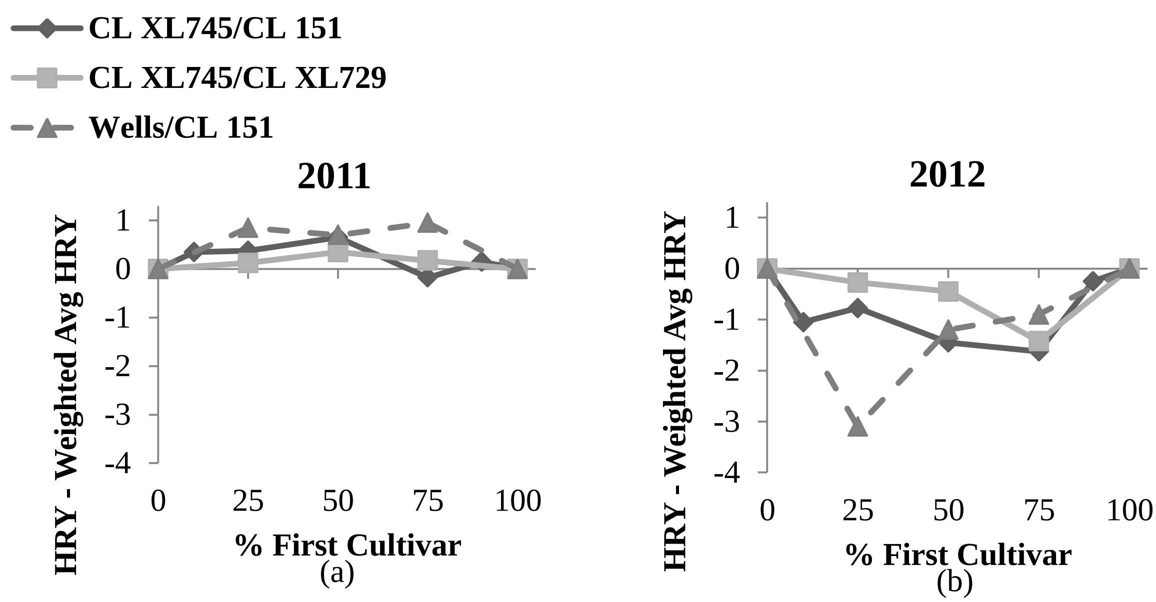

Fig. 1.6. Differences between head rice yields (HRYs) (fig. 1.5) and weighted average HRYs for each co-mingle in 2011 (a) and 2012 (b). % First cultivar is the percentage of the first cultivar in the co-mingle, i.e., CL XL745 in the CL XL745/CL 151 and CL XL745/CL XL729 co-mingles and Wells in the Wells/CL 151 co-mingle. Weighted average HRY for each co-mingled sample was calculated using HRYs of the individual cultivar lots in that co-mingle, as presented in table 1.3. For e.g., the weighted average HRY of the 10:90 ratio in the 2011 CL XL745/CL 151 co-mingle

= (10× HRY of CL XL745 + 90× HRY of CL 151)/100 = (10×63.2+90×66.7)/100 = 66.4%

Head rice color of co-mingled samples

Based on the linear regression analyses of $L*$ vs. SLC and $b*$ vs. SLC, $L*$ and $b*$ values of samples in each co-mingle, adjusted to a DOM level of 0.4% SLC, are presented as bar charts in fig. 1.7. There were negligible differences in both, the $L*$ and the $b*$ values, of samples in each co-mingle. This shows that when the DOM of samples was adjusted to 0.4% SLC, the appearance of the samples, that is an important quality parameter, would not be different. Obtaining comparable values of $L*$ and $b*$ at a single DOM level of 0.4% SLC verified that color values can be used as indicators of DOM of individual cultivar lot as well as co-mingled samples.

Head rice chalkiness of co-mingled samples

Head rice chalkiness was measured on samples milled for durations that produced a DOM level closest to 0.4% SLC. This duration was 30 s for all the 2011 co-mingles and 20 s for all the 2012 co-mingles. Head rice chalkiness of co-mingled samples are presented in fig. 1.8. Like trends of brown rice chalkiness, the 2012 cultivar lots had greater head rice chalkiness than lots comprising the same cultivars from the 2011 harvest. Head rice chalkiness increased or decreased with an increase in the percentage of a given cultivar in a co-mingle. In the H/P co-mingle from 2011, head rice chalkiness of CL XL745 was less than that of CL 151. Consequently, chalkiness of the co-mingled samples of these two cultivars decreased as the percentage of CL XL745 in those samples increased. In the H/P co-mingle from 2012, there was no difference in the head rice chalkiness of CL XL745 and CL 151. Consequently, no differences were observed in the head rice chalkiness of the 2012 H/P co-mingle samples. Similarly, in the H/H co-mingle from 2011, no difference was observed in the head rice chalkiness of CL XL745 and CL XL729 and consequently, no differences were observed in the head rice chalkiness of the

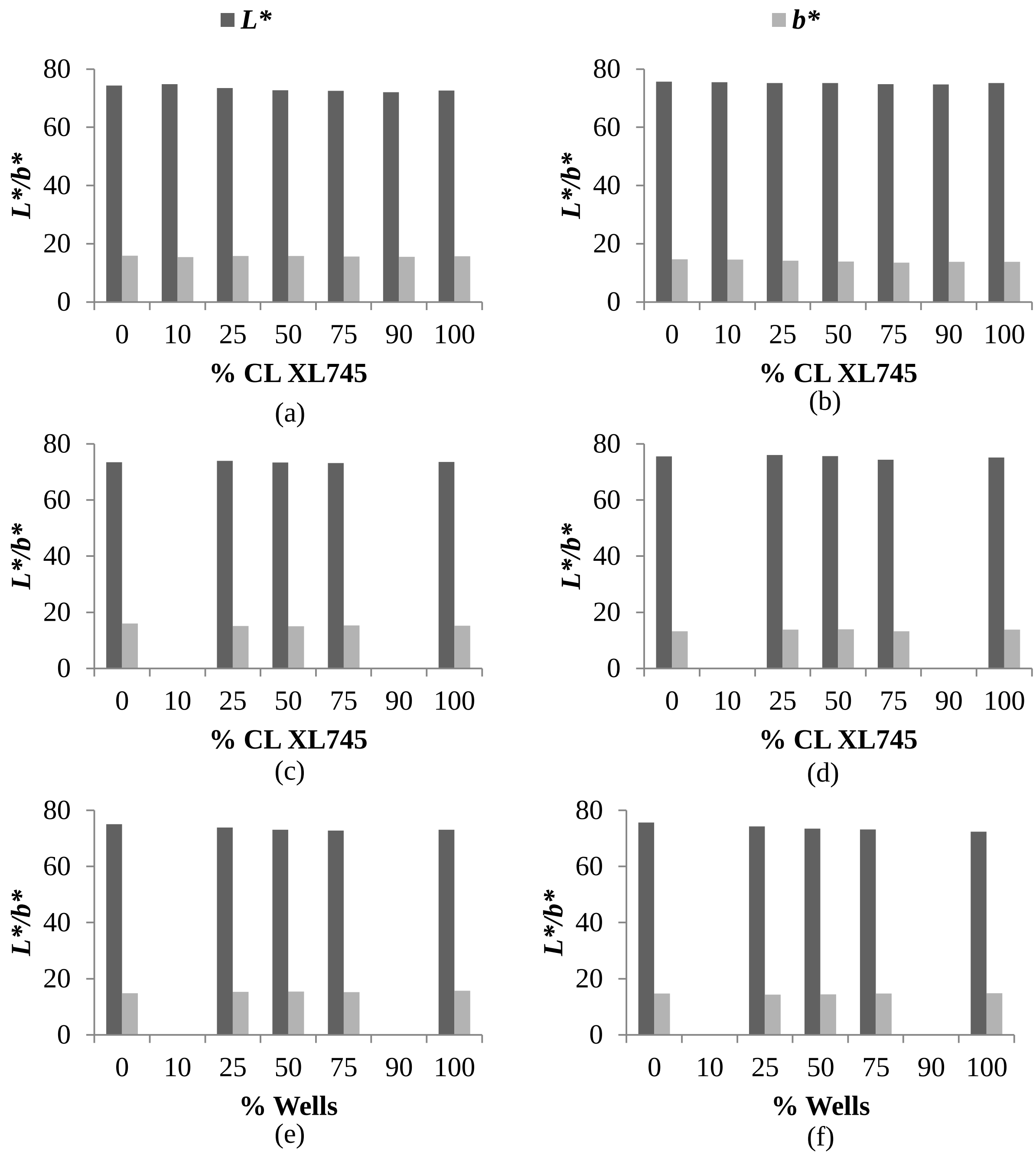

Fig. 1.7. Head rice whiteness (*L**) and yellowness (*b**) of the 2011 CL XL745/CL 151 (a), 2012 CL XL745/CL 151 (b), 2011 CL XL745/CL XL729 (c), 2012 CL XL745/CL XL729 (d), 2011 Wells/CL 151 (e) and 2012 Wells/CL 151 (f) co-mingles, adjusted to a degree of milling level of 0.4% surface lipid content, estimated using linear regression analyses of *L** vs. SLC and *b** vs. SLC, respectively.

2011 H/H co-mingle samples. In the H/H co-mingle from 2012, head rice chalkiness of CL XL745 was less than that of CL XL729. Consequently, chalkiness of the co-mingled samples in the 2012 H/H co-mingle decreased with an increase in percentage of CL XL745 in those samples. In the P/P co-mingles from 2011 and 2012, head rice chalkiness of Wells was less than that of CL 151. Consequently, head rice chalkiness of the co-mingled samples of these two cultivars decreased with an increase in percentage of Wells in the co-mingled samples in both harvest years.

CONCLUSION

Co-mingling proportion, kernel lengths, widths, TLCs and bulk density of brown rice are speculated to affect the milling durations required by co-mingled samples to reach a particular DOM. MRYs and HRYs of co-mingled samples increased or decreased with an increase in percentage of a given cultivar in a co-mingle. However, if the co-mingle contained at least one cultivar with a HRY less than 50% and longer kernels than the other cultivar in the co-mingle, the resulting HRY of the co-mingle was less than the weighted average of the HRYs when the individual cultivar lots were milled separately. Therefore, co-mingling such cultivars should be avoided. This will help the millers to decide whether two individual cultivar lots can be co-mingled before milling. Head rice whiteness and yellowness are important indicators of DOM and appearance of milled rice kernels. Head rice whiteness or head rice yellowness of co-mingled samples do not show any significant differences after adjusting them to 0.4% SLC. Head rice chalkiness is another important factor in determining the appearance of rice and has a impact on marketability of rice. Head rice chalkiness, like the MRY and HRY trends, increased or decreased with an increase in percentage of a given cultivar in a co-mingle. Therefore, head rice color and head rice chalkiness suggest that co-mingling rice cultivars does not affect the appearance of rice when milled to a particular DOM.

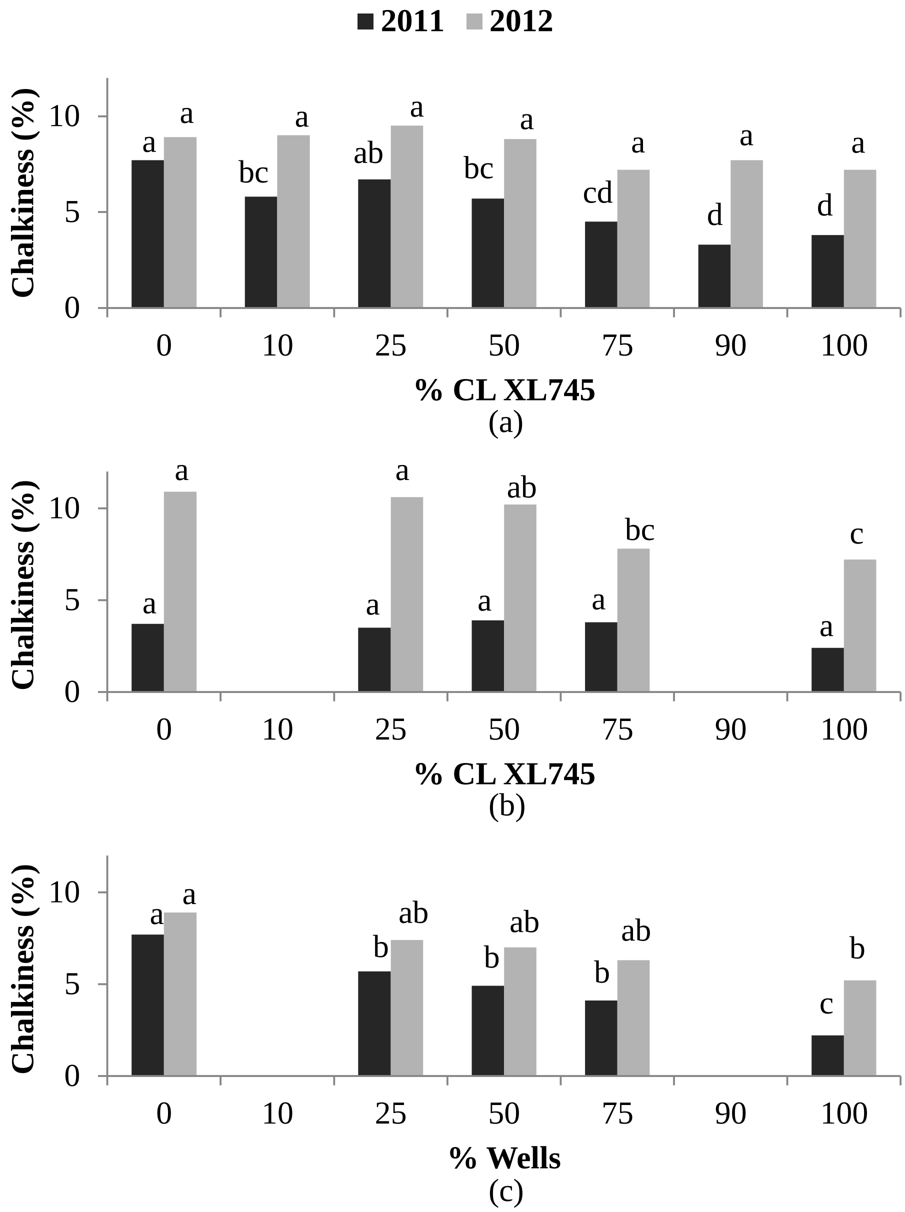

Fig. 1.8. Head rice chalkiness of the CL XL745/CL 151 (a), CL XL745/CL XL729 (b) and Wells/CL 151 (c) co-mingles in 2011 and 2012, measured for samples that had been milled for durations that produced a degree of milling level closest to 0.4% surface lipid content. Statistical differences in means of head rice chalkiness of samples, in a given co-mingle in a given year, are indicated by different letters, according to Tukey's Honestly Significant Difference test, at a 0.05 level of significance. Each data point is the mean of four replicate samples.

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APPENDIX

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January 8, 2014

To Whom it May Concern,

Nikhil Basutkar is the first author of both manuscripts submitted as part of this thesis. Nikhil conducted over 51% of the work for both manuscripts.

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FUNCTIONAL PROPERTIES OF CO-MINGLED RICE CULTIVARS

Nikhil Basutkar, Terry Siebenmorgen, Ya-Jane Wang, James Patindol

INTRODUCTION

Rice is the most important staple food for a majority of the world's human 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 due to its unique functional properties and gluten-free composition. However, rice cultivars can differ slightly in functional properties. These differences can have a considerable 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), and determining the temperature and energy required for gelatinization is therefore of particular importance to food processors who need to optimize cooking conditions, maintain product characteristics and reduce process cost (Bao and Bergman, 2004). After getting gelatinized, starch granules form a paste comprising a viscous material of disintegrated starch granules and leached amylose. Pasting properties are important indicators of final product quality as they reflect the cooking behavior of starch (Newport Scientific, 1998).

Starch is a major component of milled rice and is present in the endosperm. A majority of the 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 rice. The extent of removal of bran and germ during milling is referred to as degree of milling (DOM). DOM affects functional properties of rice. For instance, Saleh and Meullenet (2007) investigated the effects of DOM on textural properties of cooked rice, and found that as DOM increased, water uptake and firmness of rice decreased and its stickiness increased. These changes were attributed to a decrease in protein and surface lipid contents (SLCs) with an increase in DOM. Champagne et al. (1990) and Marshall (1992) found that peak, onset and conclusion gelatinization temperatures (T_p, T_o and T_c respectively) of rice kernels decreased while gelatinization enthalpy (ΔH) increased on increasing the DOM to a particular point. Greater gelatinization temperatures at lower DOM levels may have resulted due to delayed water absorption caused by the presence of surface lipids (Maningat and Juliano, 1980; Ohashi et. al, 1980). Similarly, Perdon et al. (2001) found that peak viscosity of rice flour increased as the DOM increased.

Gelatinization and pasting properties of rice are also affected by starch composition and structure (Lai et al., 2001; Vandeputte et al., 2003a; Vandeputte et al., 2003b). One of the factors that affect starch composition and structure is chalkiness, which is a major defect in rice kernels. Chalky parts of a rice kernel consist of loosely-packed, spherical starch granules with air spaces between them while translucent parts contain densely-packed, polygonal starch granules (Lisle et al., 2000). Chalkiness is also associated with lower amylose (higher amylopectin) content and shorter amylopectin average chain length (Patindol and Wang, 2003). As starch is the most important component of rice in influencing functional properties (Zhou et al., 2002), quantifying chalkiness is of importance. Cheng et al. (2005) observed that chalkiness increased T_p, T_o, T_c and ΔH. However, Patindol and Wang (2003) observed that T_p, T_o and T_c were similar for chalky and translucent kernels, but ΔH was greater for chalky kernels. The differences in impacts on T_p, T_o and T_c could be due to the fact that kernels that were half or more opaque were classified as chalky as per USDA definition by Patindol and Wang (2003) whereas Cheng et al. (2005) had separated each milled kernel into chalky and translucent parts. Patindol and Wang (2003) also observed that chalky kernels had greater peak and breakdown viscosities but lesser pasting temperatures and setback and final viscosities, as compared to translucent kernels.

While 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 co-mingling cultivars with different DOM or chalkiness on these properties. Co-mingling of rice cultivars commonly occurs during harvest, drying and storage operations. As different cultivars often have different milling properties (Siebenmorgen et al., 2006) and chalkiness (Ambardekar et al., 2011; Lanning et al., 2012), there could be a resultant impact on functional properties, particularly when dissimilar cultivars are co-mingled.

MATERIALS AND METHODS

Sample procurement and preparation

The study was conducted using four long-grain cultivars, CL XL729 and CL XL745 (hybrids) and CL 151 and Wells (purelines), all grown in two separate years, 2011 and 2012. Among the 2011 lots, the CL (Clearfield™) cultivars (CL XL729, CL XL745 and CL 151) were procured from Jonesboro, AR and Wells from Stuttgart, AR. Among the 2012 lots, the CL cultivars were procured from Harrisburg, AR and Wells from Forest City, AR. The 2011 lots were selected to have high head rice yields while the 2012 lots were selected to have low head rice yields; this was done to determine if co-mingling 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, MN) and conditioned to 12±0.5% (wet basis) moisture content. A convection oven (1370FM, Sheldon Mfg. Inc., Cornelius, OR) 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 bulk lots were co-mingled in various ratios, as presented in table 2.1. Co-mingling ratios of 25:75, 50:50 and 75:25 were selected to reflect a broad range of co-mingling. The CL XL745/CL 151 co-mingle also included 90:10 and 10:90 ratios to investigate a more expansive range of co-mingling of hybrid and pureline cultivars as there is a common practice of planting CL 151 on the levees of CL XL745 fields, which would produce an approximate 90:10 mixture. Four replicate samples of rough rice for each individual cultivar/co-mingling ratio, all weighing 150 g, were prepared for multiple milling durations. Therefore, the masses of the individual cultivars in the co-mingled 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 co-mingling 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, IL), weighed and then mixed in respective proportions. Each co-mingled sample of rough rice was thoroughly homogenized for 2 min using a rotary rice-grader (TRG, Satake, Tokyo, Japan).

Table 2.1. Co-mingles prepared for the study

Co-mingle	Cultivar-Lot Type	Co-mingling Ratios
CL XL745/CL 151	hybrid/pureline (H/P)	10:90, 25:75, 50:50, 75:25, 90:10
CL XL745/CL XL729	hybrid/hybrid (H/H)	25:75, 50:50, 75:25
Wells/CL 151	pureline/pureline (P/P)	25:75, 50:50, 75:25

Each sample of 150-g 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 was then milled for 10, 20, 30 or 40 s using a laboratory mill (McGill No. 2, RAPSCO, Brookshire, TX), having a 1.5-kg mass placed on the lever arm, 15 cm from the centerline of the milling compartment. Head rice, i.e., milled kernels that are at least three-quarters of their original length (USDA, 2005), was then separated from brokens using a sizing device (Model 61, Grain Machinery Manufacturing Corp., Miami, FL). 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 pasting and gelatinization properties.

Surface lipid content

SLC of head rice was measured using a lipid extraction system (Soxtec Avanti 2055, Foss North America, Eden Prairie, MN) following the method 30-20.01 (AACC Intl., 2000), with modifications as described by Matsler and Siebenmorgen (2005). Approximately 5 g of head rice was weighed into cellulose thimbles (33 mm, i.d.×80 mm, external length) (Foss North America, Eden Prairie, MN). After pre-drying the samples and the thimbles for an hour in an oven maintained at 100±2°C, the thimbles with head rice inside were placed in the lipid extractor. Aluminum cups were then weighed and placed under the thimbles in the lipid extractor. Lipids were extracted by boiling the thimbles in 70 ml of petroleum ether (boiling point 35-60°C; VWR, Suwanee, GA) and then rinsing with the petroleum ether condensate for 30 min. When most of the solvent had evaporated from the extraction cups after approximately 3 min, the cups were placed in an oven (100±2°C) to evaporate the residual solvent and later placed in a desiccator for 30 min to cool to room temperature. Finally, the cups containing the extracted lipids were weighed. The mass of the extracted lipids was obtained by subtracting the original mass of the cups from the mass of the cups containing the extracted lipids. The ratio of mass of the extracted lipids to the original mass of head rice, multiplied by 100, gave SLC percentage.

As 0.4% SLC is the degree to which rice is often milled in the rice industry, gelatinization and pasting properties were measured on all individual cultivar lot and co-mingled samples that had been milled for durations that produced a DOM closest to 0.4% SLC. An average of SLCs for each milling duration for each co-mingle from each year was taken and the milling duration that produced a DOM closest to 0.4% SLC was selected as the basis of comparison for that co-mingle.

Gelatinization properties

Gelatinization properties of samples were assessed using a differential scanning calorimeter (DSC) (Diamond, Perkin Elmer, Norwalk, CT) equipped with an Intercooler-II system, according to the method of Wang et al. (1992). Indium was used to calibrate the DSC. First, samples of head rice were ground using a cyclone mill (3010-30, UDY, Fort Collins, CO), equipped with a 100-mesh (0.5-mm) sieve. A convection oven (1370FM, Sheldon Mfg. Inc., Cornelius, OR) was used to measure the moisture content of rice flour by drying duplicate samples at 130°C for 1 hour, following the Approved Method 44-15.02 (AACC, 2009). Approximately 4 mg (dry basis) of rice flour was 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 reference, the aluminum pans containing the samples were thermally scanned from 25°C to 120°C at a heating rate of 10°C/min. Data output was in the form of a thermogram that was used to determine T_p, T_o, T_c and ΔH. Gelatinization range (T_c-T_p) was also calculated.

Pasting properties

Pasting properties of rice flour were assessed using a Rapid Visco Analyser (RVA) (model 4, Newport Scientific, Warriewood, NSW, Australia), following the Approved Method 61-02.01 (AACC, 2009). Exact amounts of flour and deionized water to be used to make the paste were obtained using a RVA software (Thermocline for Windows, v.2.0, Newport Scientific, Warriewood, NSW, Australia) and mixed in an aluminum canister (Perten Instruments, Springfield, IL). The canister and paddle provided were then inserted into the RVA and the tower lowered to start the cycle. The cycle consisted of first holding the paste at 50°C for 1.5 min, then heating to 95°C at 12.2°C/min, followed by holding at 95°C for 2 min, then cooling to 50°C at 12.2°C/min and finally holding at 50°C for 1.5 min. Output from an RVA included pasting temperature, peak time and peak, hot paste (trough), final, breakdown and setback viscosities. Breakdown viscosity was calculated by subtracting hot paste viscosity from peak viscosity, setback viscosity by subtracting peak viscosity from final viscosity and paste consistency (total setback) by subtracting hot paste viscosity from final viscosity.

Data analysis

Analysis of variance (α=0.05) and comparison of means using Tukey's Honestly Significant Difference (HSD) test were performed using a statistical software (JMP Pro 10, SAS Institute, Cary, NC).

RESULTS AND DISCUSSION

For all 2011 co-mingles, the 30-s milling duration produced a DOM closest to 0.4% SLC and for all 2012 co-mingles, the 20-s milling duration produced a DOM closest to 0.4% SLC. Therefore, the 2011 samples milled for 30 s and the 2012 samples milled for 20 s were used to study gelatinization and pasting properties.

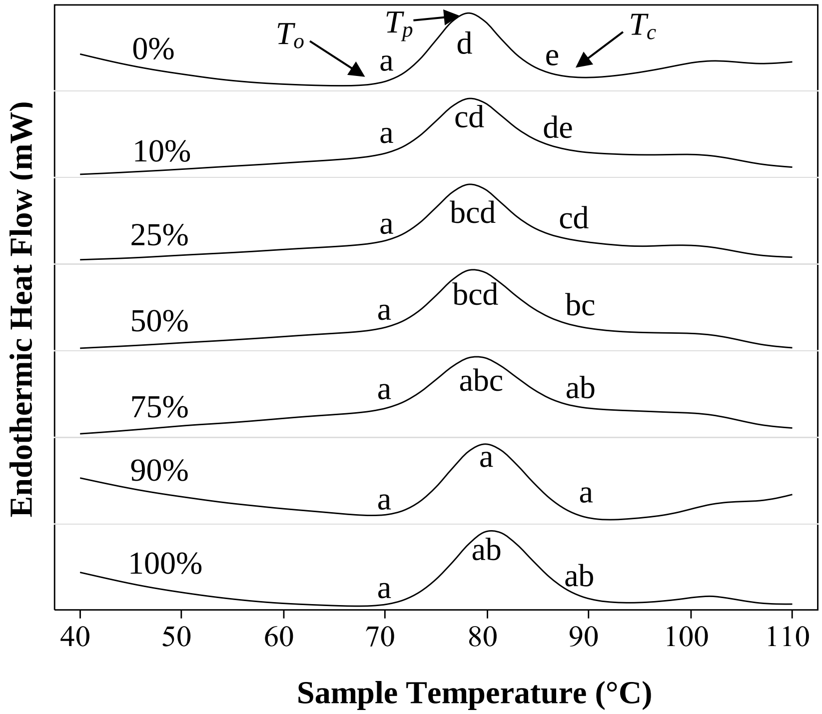
Gelatinization properties of co-mingled samples

2011 CL XL745/CL 151 co-mingle

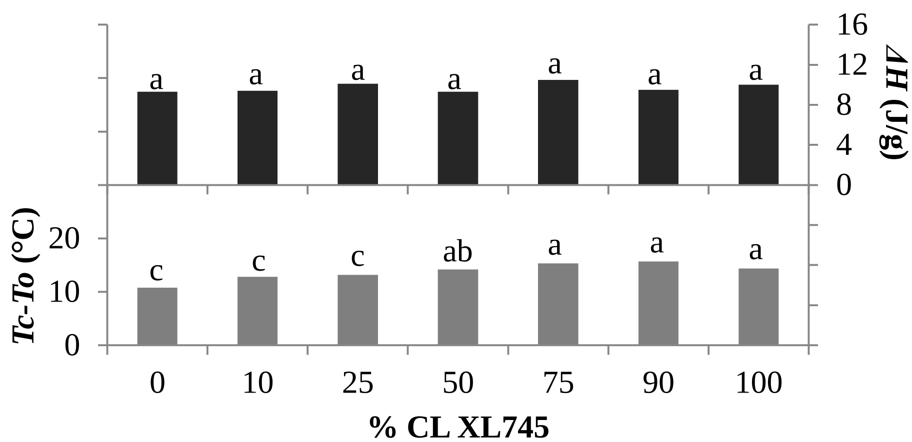
Gelatinization temperatures of the 2011 CL XL745/CL 151 (H/P) co-mingle samples are presented in fig. 2.1a and T_c-T_o and ΔH of the same samples are presented in fig. 2.1b. The 0% CL XL745 sample consisted of only CL 151 and the 100% CL XL745 sample consisted of only CL XL745. In 2011, there was no difference in the T_os of the pure CL 151 and pure CL XL745 samples, indicating that there was no difference in the temperatures at which the starch granules of CL 151 and CL XL745 started to gelatinize. Consequently, no differences were observed in the T_os of the co-mingled samples of these two cultivars. Therefore, all of these co-mingled samples started gelatinizing at the same temperature. T_p of the pure CL 151 sample was less than that of the pure CL XL745 sample, indicating that maximum gelatinization rate of the CL 151 starch granules occurred at a lesser temperature than that of the CL XL745 starch granules. Consequently, T_ps of the co-mingled samples of these two cultivars increased with an increase in percentage of CL XL745 in the co-mingled samples. Like T_p, T_c of the pure CL XL745 sample was greater than that of the pure CL 151 sample, indicating that all the CL 151 starch granules had completed gelatinization at a lower temperature than that required by all the CL XL745 starch granules. Consequently, T_cs of the co-mingled samples of these two cultivars increased with an increase in percentage of CL XL745 in the co-mingled samples. Since there were no differences in the T_os of the individual and co-mingled samples but the T_cs increased with an increase in percentage of CL XL745 in the samples, T_c-T_o of the samples also increased proportionately with an increase in percentage of CL XL745 in the samples (fig. 2.1b). In addition, as there was no difference in the ΔHs of the pure CL 151 and CL XL745 samples, no differences were observed in the ΔHs of all the co-mingled samples of these two cultivars.

2012 CL XL745/CL 151 co-mingle

Gelatinization temperatures of the 2012 H/P co-mingle samples are presented in fig. 2.2a and T_c-T_o and ΔH of the same samples are presented in fig. 2.2b. In 2012, T_o of the pure CL XL745 sample was greater than that of the pure CL 151 sample, indicating that CL XL745 starch granules started to gelatinize at a greater temperature than that required by the CL 151 starch granules. However, there were no differences in the T_os of the co-mingled samples of these two cultivars and the T_o of the pure CL 151 sample. This indicates that the starch granules in these co-mingled samples started gelatinizing at the same temperature as starch granules in the pure CL 151 sample (cultivar in the co-mingle with the lower T_o). Like T_o, T_p of the pure CL XL745 sample was greater than that of the pure CL 151 sample. Consequently, T_ps of the co-mingled samples of these two cultivars increased with an increase in percentage of CL XL745 in the co-mingled samples. Like T_p, T_c of the pure CL XL745 sample was greater than the T_c of the pure CL 151 sample. T_cs of the co-mingled samples of these two cultivars increased till the 75:25 ratio and leveled off thereafter. As T_c and T_o of CL XL745 were greater than the T_c and T_o of CL 151, there was no difference in the T_c-T_o of these two pure cultivars (fig. 2.2b). Like T_c, T_c-T_o of the co-mingled samples also increased till the 75:25 ratio and then remained more or less constant. In addition, there were no difference in the ΔHs of the pure and co-mingled samples in this co-mingle.

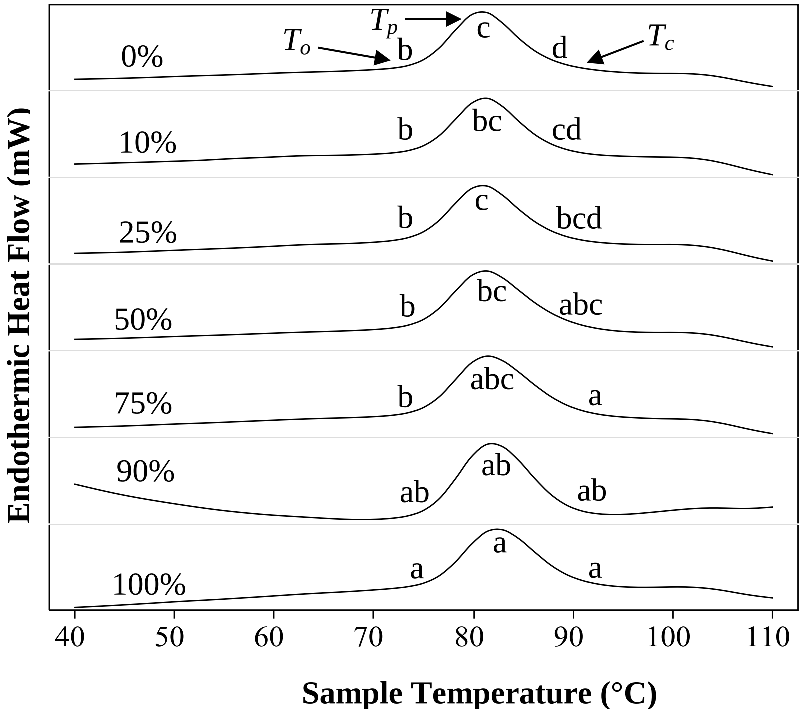


(a)

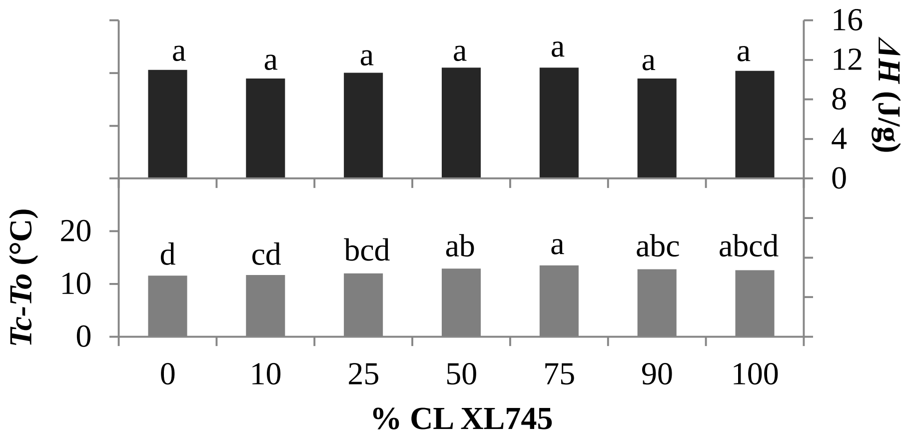


(b)

Fig. 2.1. Gelatinization curves (a) showing onset (T_o), peak (T_p) and conclusion (T_c) gelatinization temperatures and bar charts (b) showing the gelatinization range (T_c-T_o) and gelatinization enthalpy (ΔH) of the 2011 CL XL745/CL 151 co-mingle samples. The percentages in fig. 2.1a are the percentages of CL XL745 in the co-mingle. Each gelatinization curve in fig. 2.1a is the curve for a single replicate whose gelatinization temperatures most closely represent the mean of each gelatinization temperature of the four replicates. Each data point in fig. 2.1b represents the mean of four replicates. Statistical differences in T_o, T_p, T_c, T_c-T_o and ΔH means are indicated by different letters, according to Tukey's Honestly Significant Difference test, at a 0.05 level of significance. Statistical comparisons in fig. 2.1a apply separately to T_o, T_p and T_c.



(a)



(b)

Fig. 2.2. Gelatinization curves (a) showing onset (T_o), peak (T_p) and conclusion (T_c) gelatinization temperatures and bar charts (b) showing the gelatinization range (T_c-T_o) and gelatinization enthalpy (ΔH) of the 2012 CL XL745/CL 151 co-mingle samples. The percentages in fig. 2.2a are the percentages of CL XL745 in the co-mingle. Each gelatinization curve in fig. 2.2a is the curve for a single replicate whose gelatinization temperatures most closely represent the mean of each gelatinization temperature of the four replicates. Each data point in fig. 2.2b represents the mean of four replicates. Statistical differences in T_o, T_p, T_c, T_c-T_o and ΔH means are indicated by different letters, according to Tukey's Honestly Significant Difference test, at a 0.05 level of significance. Statistical comparisons in fig. 2.2a apply separately to T_o, T_p and T_c.

2011 CL XL745/CL XL729 co-mingle

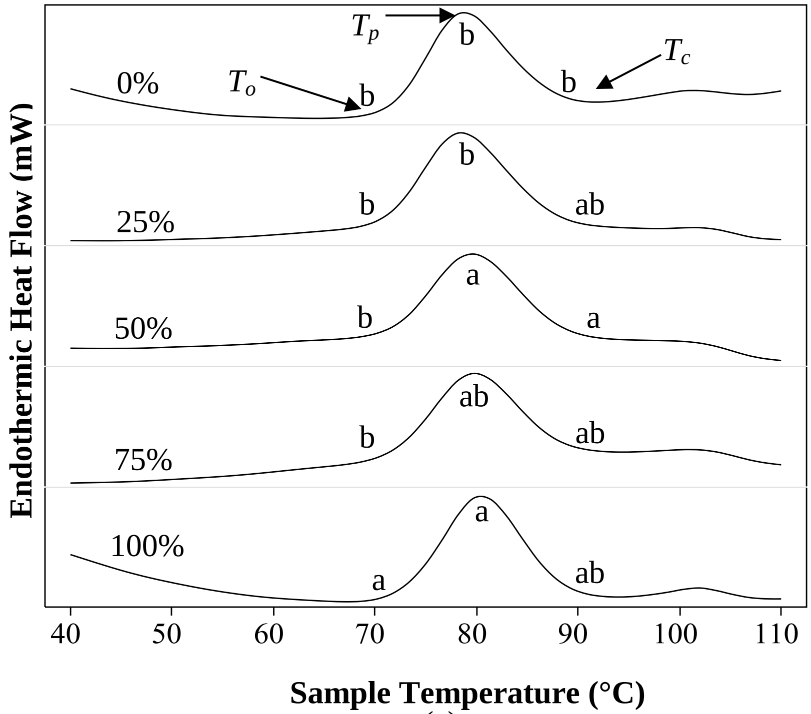
Gelatinization temperatures of the 2011 CL XL745/CL XL729 (H/H) co-mingle samples are presented in fig. 2.3a and T_c-T_o and ΔH of the same samples are presented in fig. 2.3b. In 2011, T_o of the pure CL XL745 (100% CL XL745) sample was greater than that of the pure CL XL729 (0% CL XL745) sample. Consequently, no differences were observed in the T_os of the co-mingled samples of these two cultivars and T_o of the pure CL XL729 sample. Such as trends of the 2012 H/P co-mingle, T_o of the co-mingled samples was similar to the T_o of that cultivar in the co-mingle with the lower T_o. Starch granules in a co-mingled sample consist of starch granules of the individual cultivars that have been co-mingled. As co-mingling is just mixing of individual cultivars, it should not affect chemical and structural properties such as starch composition and starch granular structure of the individual cultivars. The above observations that starch granules in a co-mingled sample start gelatinizing at the same temperature at which starch granules in the cultivar in that co-mingle with the lower T_o starts to gelatinize verifies this notion. T_p of the pure CL XL729 sample was less than T_p of the pure CL XL745 sample. Consequently, T_ps of the co-mingled samples of these two cultivars increased with an increase in percentage of CL XL745 in the samples until the 50:50 ratio and remained constant thereafter. Unlike T_o and T_p, no differences were observed in the T_cs of the pure and co-mingled samples of these two cultivars. Like T_c, no difference was observed in the T_c-T_o of the pure CL XL745 and CL XL729 samples. As starch granules in the co-mingled samples and the pure CL XL729 sample had equivalent T_cs and T_os, no differences were observed in the T_c-T_o of the co-mingled samples and the pure CL XL729 sample (fig. 2.3b). However, as the co-mingled samples had equivalent T_cs and lower T_os than that of the pure CL XL745 sample, T_c-T_o of these co-mingled samples was greater than that of the pure CL XL745 sample. As there was no difference in the ΔHs of the pure CL XL745 and CL XL729 samples, ΔHs of the co-mingled samples of these two cultivars were equivalent.

2012 CL XL745/CL XL729 co-mingle

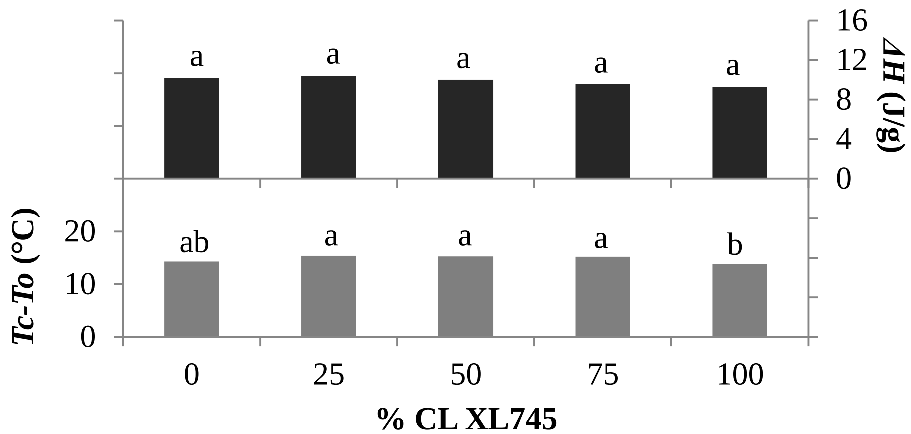
Gelatinization temperatures of the 2012 H/H co-mingle samples are presented in fig. 2.4a and T_c-T_o and ΔH of the same samples are presented in fig. 2.4b. In 2012, T_o of the pure CL XL729 sample was greater than that of the pure CL XL745 sample. Such as trends of the 2012 H/P and 2011 H/H co-mingles, T_os of the co-mingled samples of these two cultivars were equivalent to each other and to the T_o of that cultivar in the co-mingle with the lower $T_{o,}$ i.e., CL XL745. As a result, T_os of these co-mingled samples were less than the T_o of CL XL729. There was no difference in the T_ps of the pure CL XL745 and CL XL729 samples. Consequently, no differences were observed in the T_ps of the co-mingled samples of these two cultivars. Similarly, as no differences were observed each in the T_cs, T_c-T_o and ΔHs of the pure CL XL745 and CL XL729 samples, there were no differences in the T_cs, T_c-T_o and ΔHs of the co-mingled samples of these two cultivars.

2011 Wells/CL 151 co-mingle

Gelatinization temperatures of the 2011 Wells/CL 151 (P/P) co-mingle samples are presented in fig. 2.5a and T_c-T_o and ΔH of the same samples are presented in fig. 2.5b. In 2011, T_o of the pure CL 151 (0% Wells) sample was less than the T_o of the pure Wells (100% Wells) sample. T_os of the 25:75 and 50:50 ratios were equivalent to the T_o of CL 151. Similar to trends of the H/P and H/H co-mingles described earlier, T_o of these co-mingled samples was equivalent to the T_o of that cultivar in the co-mingle with the lower T_o. However, T_o of the 75:25 ratio was greater than the T_o of the 0:100, 25:75 and 50:50 ratios and less than the T_o of the 100:0 ratio. This may be due to the fact that CL 151 starch granules were three times less than the Wells

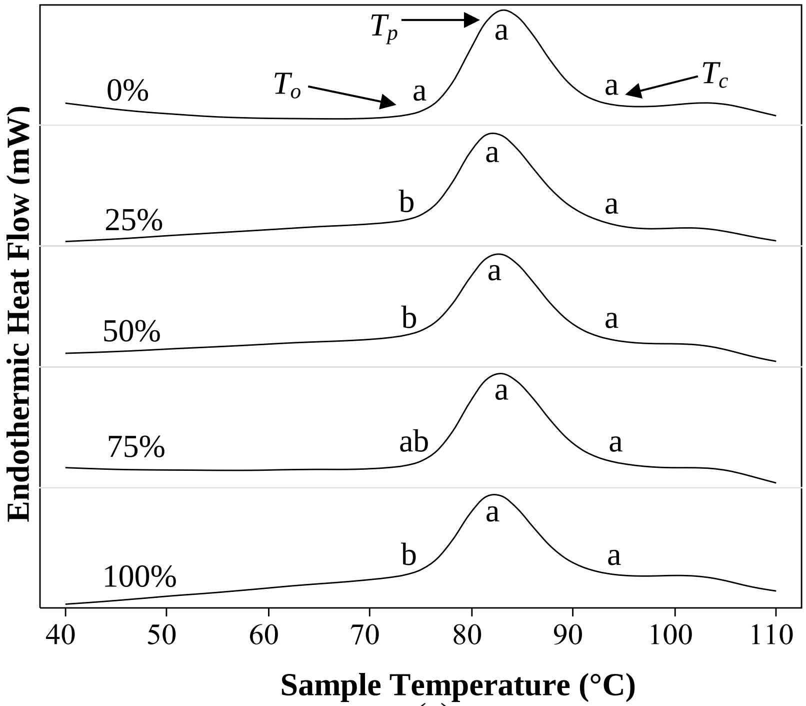


(a)



(b)

Fig. 2.3. Gelatinization curves (a) showing onset (T_o), peak (T_p) and conclusion (T_c) gelatinization temperatures and bar charts (b) showing the gelatinization range (T_c-T_o) and gelatinization enthalpy (ΔH) of the 2011 CL XL745/CL XL729 co-mingle samples. The percentages in fig. 2.3a are the percentages of CL XL745 in the co-mingle. Each gelatinization curve in fig. 2.2a is the curve for a single replicate whose gelatinization temperatures most closely represent the mean of each gelatinization temperature of the four replicates. Each data point in fig. 2.3b represents the mean of four replicates. Statistical differences in T_o, T_p, T_c, T_c-T_o and ΔH means are indicated by different letters, according to Tukey's Honestly Significant Difference test, at a 0.05 level of significance. Statistical comparisons in fig. 2.3a apply separately to T_o, T_p and T_c.



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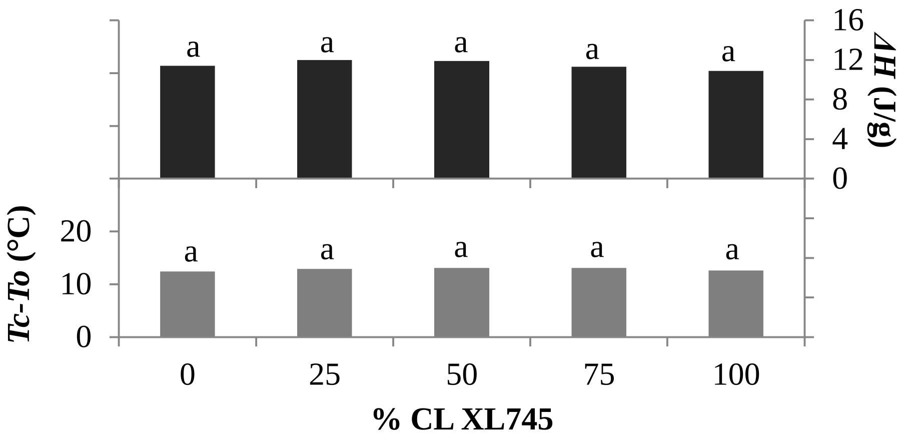


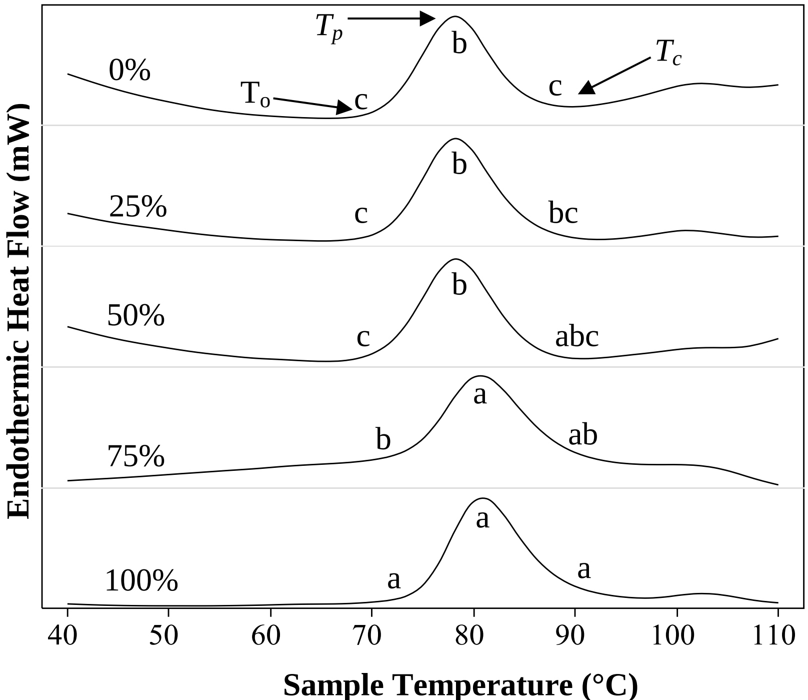
(b)

Fig. 2.4. Gelatinization curves (a) showing onset (T_o), peak (T_p) and conclusion (T_c) gelatinization temperatures and bar charts (b) showing the gelatinization range (T_c-T_o) and gelatinization enthalpy (ΔH) of the 2012 CL XL745/CL XL729 co-mingle samples. The percentages in fig. 2.4a are the percentages of CL XL745 in the co-mingle. Each gelatinization curve in fig. 2.4a is the curve for a single replicate whose gelatinization temperatures most closely represent the mean of each gelatinization temperature of the four replicates. Each data pointin fig. 2.4b represents the mean of four replicates. Statistical differences in T_o, T_p, T_c, T_c-T_o and ΔH means are indicated by different letters, according to Tukey's Honestly Significant Difference test, at a 0.05 level of significance. Statistical comparisons in fig. 2.4a apply separately to T_o, T_p and T_c

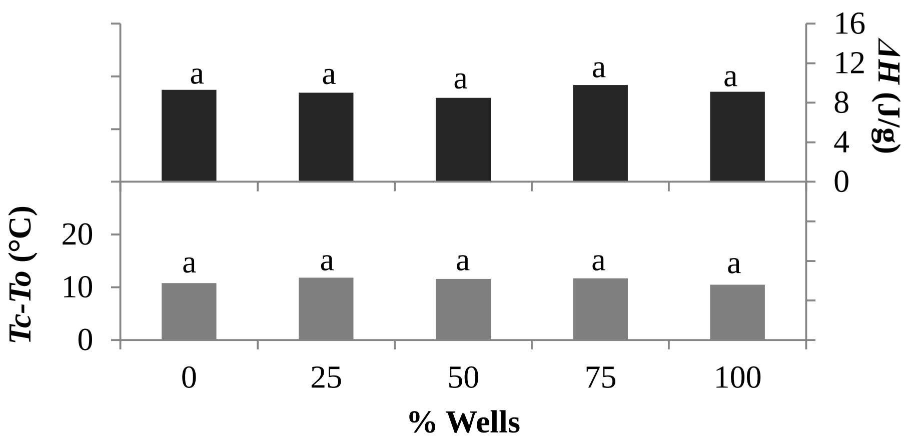
starch granules in the 75:25 ratio and may be surrounded by them. This may have caused the Wells starch granules to delay heat transfer to the CL 151 starch granules, thereby delaying the onset of gelatinization, leading to a greater T_o for the 75:25 ratio. However, since this trend of T_o of the co-mingled samples being greater than the T_o of the cultivar with the lower T_o in the co-mingle was not observed for the H/P and H/H co-mingles, it might be in part due to an experimental error. T_p and T_c of the pure CL 151 sample were both less than those of the pure Wells sample. Consequently, T_ps and T_cs of the co-mingled samples of these two cultivars increased with an increase in percentage of Wells in the samples. However, there were no differences in the T_c-T_o and ΔHs of the pure and co-mingled samples (fig. 2.5b).

2012 Wells/CL 151 co-mingle

Gelatinization temperatures of the 2012 P/P co-mingle samples are presented in fig. 2.6a and T_c-T_o and ΔH of the same samples are presented in fig. 2.6b. In 2012, T_o of the pure Wells sample was less than the T_o of the pure CL 151 sample. However, T_os of the co-mingled samples of these two cultivars were not different from the T_o of either of the pure CL 151 and Wells samples. This can be interpreted as the co-mingled samples starting to gelatinize at the same temperature as that required by the pure Wells sample, which was the cultivar in the co-mingle with the lower $T_{o.}$ Similar trends were observed in the previously described co-mingles. There was no differences in the T_ps and T_cs of the pure Wells and CL 151 samples and consequently, no differences were observed in the T_ps and T_cs of the co-mingled samples of these two cultivars. As no difference was observed in the T_cs of the pure Wells and CL 151 samples but T_o of the pure CL 151 sample was greater than that of the pure Wells sample, T_c-T_o of Wells was greater than that of CL 151 (fig. 2.6b). However, T_c-T_o of the co-mingled samples of these two cultivars were equivalent to T_c-T_o of both the pure samples. ΔH of the pure Wells sample were less than



(a)

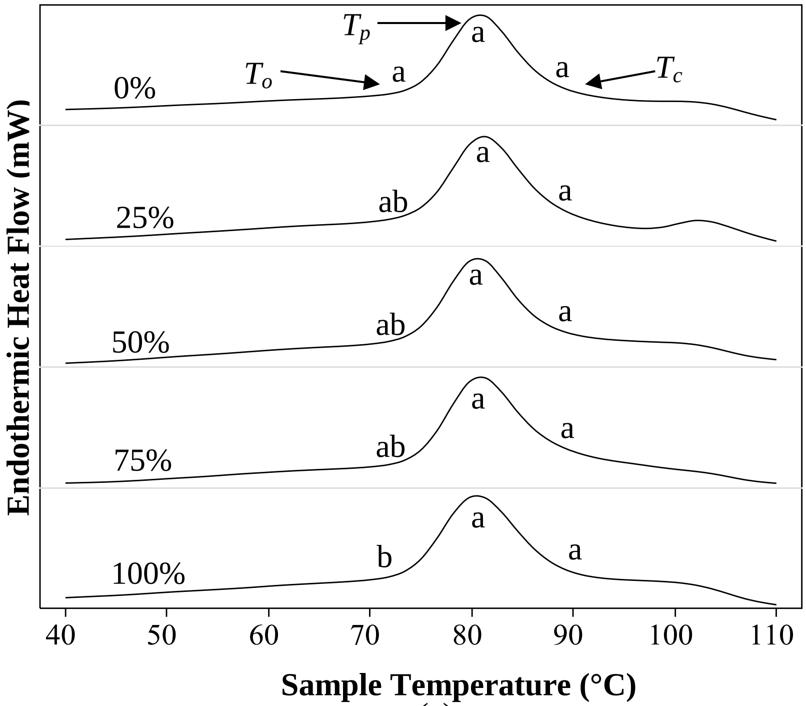


(b)

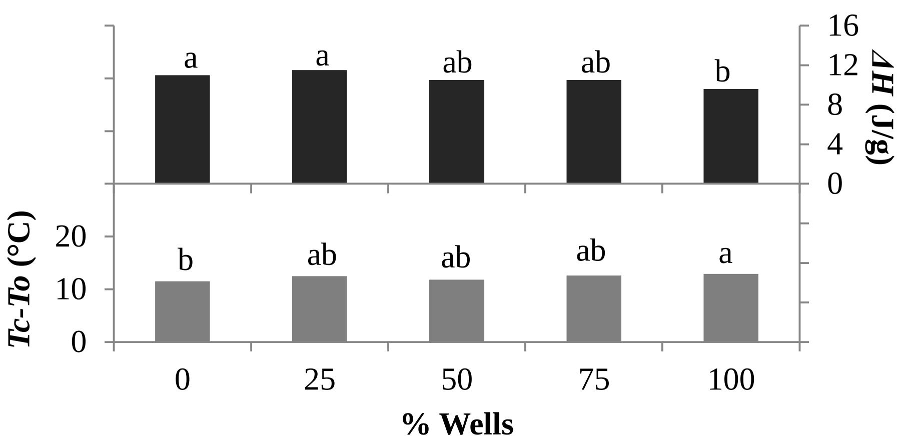
Fig. 2.5. Gelatinization curves (a) showing onset (T_o), peak (T_p) and conclusion (T_c) gelatinization temperatures and bar charts (b) showing the gelatinization range (T_c-T_o) and gelatinization enthalpy (ΔH) of the 2011 Wells/CL 151 co-mingle samples. The percentages in fig. 2.5a are the percentages of Wells in the co-mingle. Each gelatinization curve in fig. 2.5a is the curve for a single replicate whose gelatinization temperatures most closely represent the mean of each gelatinization temperature of the four replicates. Each data point in fig. 2.5b represents the mean of four replicates. Statistical differences in T_o, T_p, T_c, T_c-T_o and ΔH means are indicated by different letters, according to Tukey's Honestly Significant Difference test, at a 0.05 level of significance. Statistical comparisons in fig. 2.5a apply separately to T_o, T_p and T_c.

that of the pure CL 151 sample. Hence, ΔHs of the co-mingled samples decreased with an increase in percentage of Wells in the samples.

From the various sets of co-mingles, it can be seen that co-mingling two cultivars of equivalent T_os, T_ps, T_cs, ΔHs or T_c-T_os resulted in co-mingled samples with gelatinization properties similar to those of the pure cultivars. However, if the T_ps, T_cs and ΔHs of the two cultivars being co-mingled were different, then the T_ps, T_cs and ΔH of co-mingled samples generally increased or decreased with an increase in percentage of a given cultivar in the co-mingle. However, in a couple of cases, it was also observed that this increase leveled off beyond a certain point and gelatinization parameters remained constant with the increase in percentage of a given cultivar in the co-mingled samples beyond that point, as exhibited by T_cs of the 2012 H/P and T_ps of the 2011 H/H co-mingles. In addition, if the T_os of the two cultivars being co-minged were different, then the T_o of a co-mingled sample was equivalent to the T_o of that cultivar in the co-mingle with the lower T_o. Depending on trends in T_o and T_c, trends in T_c-T_o of a co-mingled sample may vary. They may increase with an increase in the percentage of a given cultivar in a co-mingle such as the 2011 H/P co-mingle, may increase to a certain point and then remain constant such as the 2012 H/P co-mingle, be equivalent to the T_c-T_o of one of the cultivars in the co-mingle such as the 2011 H/H co-mingle or be equivalent to T_c-T_o of both the cultivars in the co-mingle such as the 2012 H/H co-mingle and the 2011 and 2012 P/P co-mingles. This indicates that gelatinization properties of a co-mingled sample depend on the proportion and gelatinization properties of the individual cultivars being co-mingled. Therefore, it can be safely said that co-mingling may not alter the gelatinization properties of the individual cultivars in the co-mingle.



(a)



(b)

Fig. 2.6. Gelatinization curves (a) showing onset (T_o), peak (T_p) and conclusion (T_c) gelatinization temperatures and bar charts (b) showing the gelatinization range (T_c-T_o) and gelatinization enthalpy (ΔH) of the 2012 Wells/CL 151 co-mingle samples. The percentages in fig. 2.6a are the percentages of Wells in the co-mingle. Each data point in fig. 2.6b represents the mean of four replicates. Each gelatinization curve in fig. 2.6a 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 in T_o, T_p, T_c, T_c-T_o and ΔH means are indicated by different letters, according to Tukey's Honestly Significant Difference test, at a 0.05 level of significance. Statistical comparisons in fig. 2.6a apply separately to T_o, T_p and T_c.

Pasting properties of co-mingled samples

Peak viscosities of all the individual cultivar lot and co-mingled samples are presented in fig. 2.7. All co-mingles showed consistent trends in peak viscosities. If the peak viscosities of the individual cultivar lots were different, then the peak viscosities of the co-mingled samples either increased or decreased with an increase in percentage of a given cultivar in the co-mingle. If the peak viscosities of the individual cultivar lots were equivalent to each other, then the peak viscosities of the co-mingled samples were also equivalent. For instance, in the H/P co-mingles from both years, peak viscosity of the pure CL XL745 (100% CL XL745) sample was greater than that of the pure CL 151 (0% CL XL745) sample. Consequently, peak viscosities of the co-mingled samples of these two cultivars increased with an increase in percentage of CL XL745 in the samples in both years. In the 2011 H/H co-mingle, peak viscosity of the pure CL XL729 (0% CL XL745) sample was greater than that of the pure CL XL745 (100% CLXL745) sample. Peak viscosities of the co-mingled samples of these two cultivars were equivalent to each other and also equivalent to the peak viscosities of the individual cultivar lot samples in that year, indicating that they ranged between them. This can be interpreted as the peak viscosities of co-mingled samples decreasing with an increase in percentage of CL XL745 in the samples, and was probably not confirmed statistically since there was very little difference between the peak viscosities of the pure CL XL745 and CL XL729 samples. In the 2012 H/H co-mingle, as there was no difference in the peak viscosities of the pure CL XL745 and CL XL729 samples, no differences were observed in the peak viscosities of the co-mingled samples of these two cultivars. In the 2011 P/P co-mingle, peak viscosity of the pure CL 151 (0% Wells) sample was less than that of the pure Wells (100% Wells) sample. As a result, peak viscosities of the co-mingled samples of these two cultivars increased with an increase in percentage of Wells in those co-mingled samples. However, in the 2012 P/P co-mingle, such as the trend in the 2012 H/H co-mingle, no differences were observed in the peak viscosities of the co-mingled samples as there was no difference in the peak viscosities of the pure samples used in that co-mingle.

Breakdown, final and setback viscosities of the individual cultivar lot and co-mingled samples are presented in fig. 2.8, 2.9 and 2.10 respectively. These viscosities followed trends similar to those of peak viscosity. Break down viscosities of the 2011 and 2012 H/P, 2011 H/H and the 2011 and 2012 P/P co-mingles increased or decreased with an increase in percentage of a given cultivar in the co-mingles. In the 2012 H/H co-mingle, there were no differences in the breakdown viscosities of the co-mingled samples as there was no difference in the breakdown viscosities of the individual cultivar lots used for co-mingling. Similarly, final viscosities of the 2011 and 2012 H/P co-mingle samples were equivalent to each other as there were no differences in the final viscosities of the individual cultivar lots used for making those co-mingles in those years. However, in the H/H and P/P co-mingles from both years, final viscosities of the co-mingled samples increased or decreased with an increase in percentage of a given cultivar in those co-mingles. Similar to trends of the peak, breakdown and final viscosities, if there was a difference in the setback viscosities of the two individual cultivars being co-mingled, setback viscosities also increased or decreased with an increase in the percentage of a given cultivar in a co-mingle, or were equivalent if the setback viscosities of the individual cultivar lots being co-mingled were equivalent. This indicates that co-mingled samples retained the pasting properties of the individual cultivars used for co-mingling.

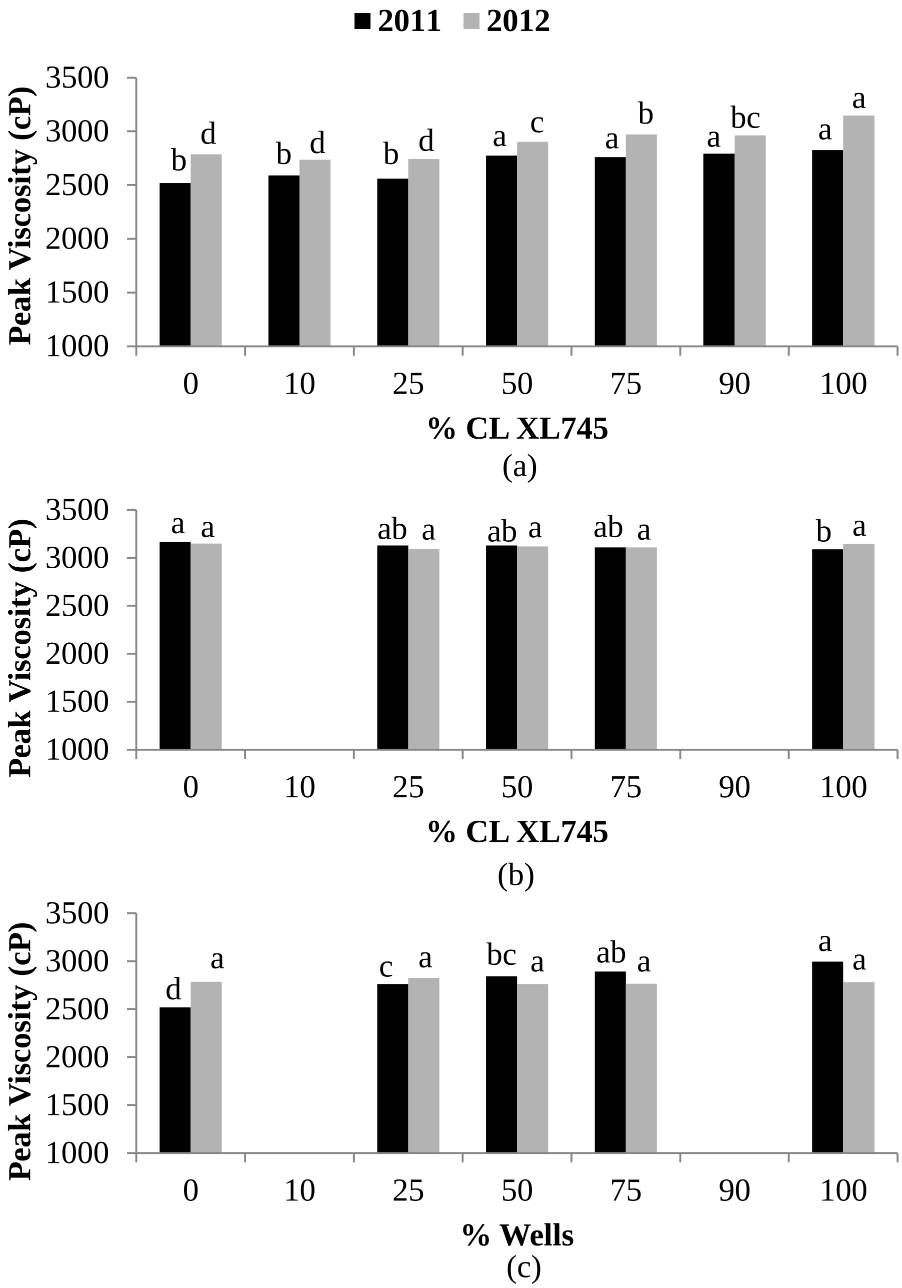


Fig. 2.7. Peak viscosities of the CL XL745/CL 151 (a), CL XL745/CL XL729 (b) and Wells/CL 151 (c) co-mingles in 2011 and 2012, measured for samples that had been milled for durations that produced a degree of milling level closest to 0.4% surface lipid content.Statistical differences in means of peak viscosities of samples, in a given co-mingle in a given year, are indicated by different letters, according to Tukey's Honestly Significant Difference test, at a 0.05 level of significance. Each data point is a mean of four replicate samples.

CONCLUSION

Since the individual cultivars retained their gelatinization properties after co-mingling, a single set of processing conditions can be used to almost uniformly cook co-mingles of cultivars with similar gelatinization properties. Therefore, co-mingling cultivars with slightly different gelatinization properties may not drastically affect final product characteristics. However, if cultivars with significantly different gelatinization properties are co-mingled, it will be very difficult to select a set of conditions to produce uniformly cooked rice or rice products. Cooking or processing at mean gelatinization temperatures and providing mean ΔH of the individual cultivars that are co-mingled will result in parts of the product being overcooked and other parts being undercooked, deleteriously affecting the product quality and may also lead to product batches being rejected if they do not meet the quality standards. In light of these findings, food processors can approve the co-mingles that can beused by them and determine and optimize their processing conditions to maintain product characteristics. Pasting properties of the individual cultivars were also retained by the co-mingled samples. Being aware of this fact will help the food processors to determine the cooking behavior of co-mingled rice cultivars and help to estimate the final product characteristics to a more accurate degree. Moreover, the impacts of co-mingling on gelatinization and pasting properties of rice can be extended to other cereals, thereby addressing co-mingling issues experienced by parts of the grain industry that use those cereals.

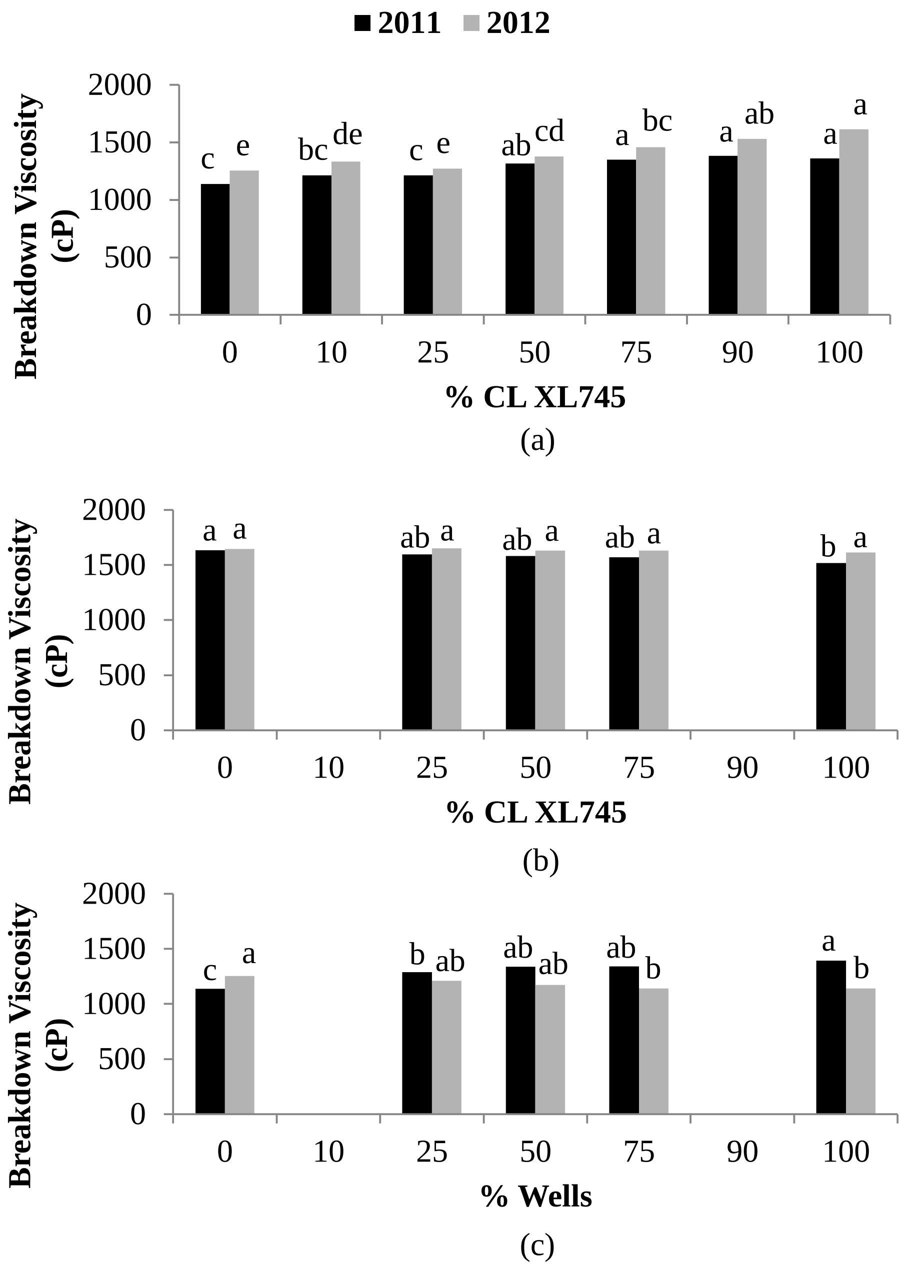


Fig. 2.8. Breakdown viscosities of the CL XL745/CL 151 (a), CL XL745/CL XL729 (b) and Wells/CL 151 (c) co-mingles in 2011 and 2012, measured for samples that had been milled for durations that produced a degree of milling level closest to 0.4% surface lipid content.Statistical differences in means of breakdown viscosities of samples, in a given co-mingle in a given year, are indicated by different letters, according to Tukey's Honestly Significant Difference test, at a 0.05 level of significance. Each data point is a mean of four replicate samples.

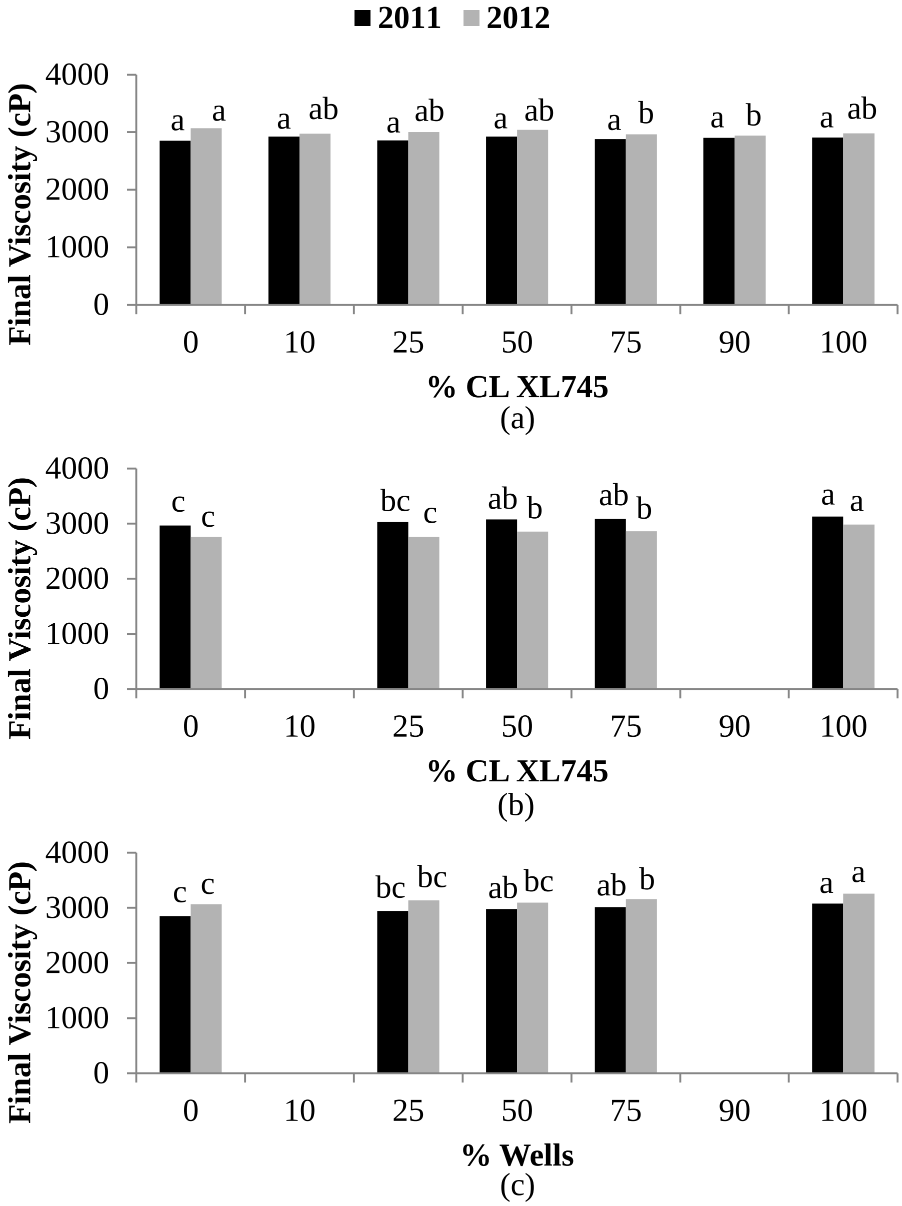


Fig. 2.9. Final viscosities of the CL XL745/CL 151 (a), CL XL745/CL XL729 (b) and Wells/CL 151 (c) co-mingles in 2011 and 2012, measured for samples that had been milled for durations that produced a degree of milling level closest to 0.4% surface lipid content.Statistical differences in means of final viscosities of samples, in a given co-mingle in a given year, are indicated by different letters, according to Tukey's Honestly Significant Difference test, at a 0.05 level of significance. Each data point is a mean of four replicate samples.

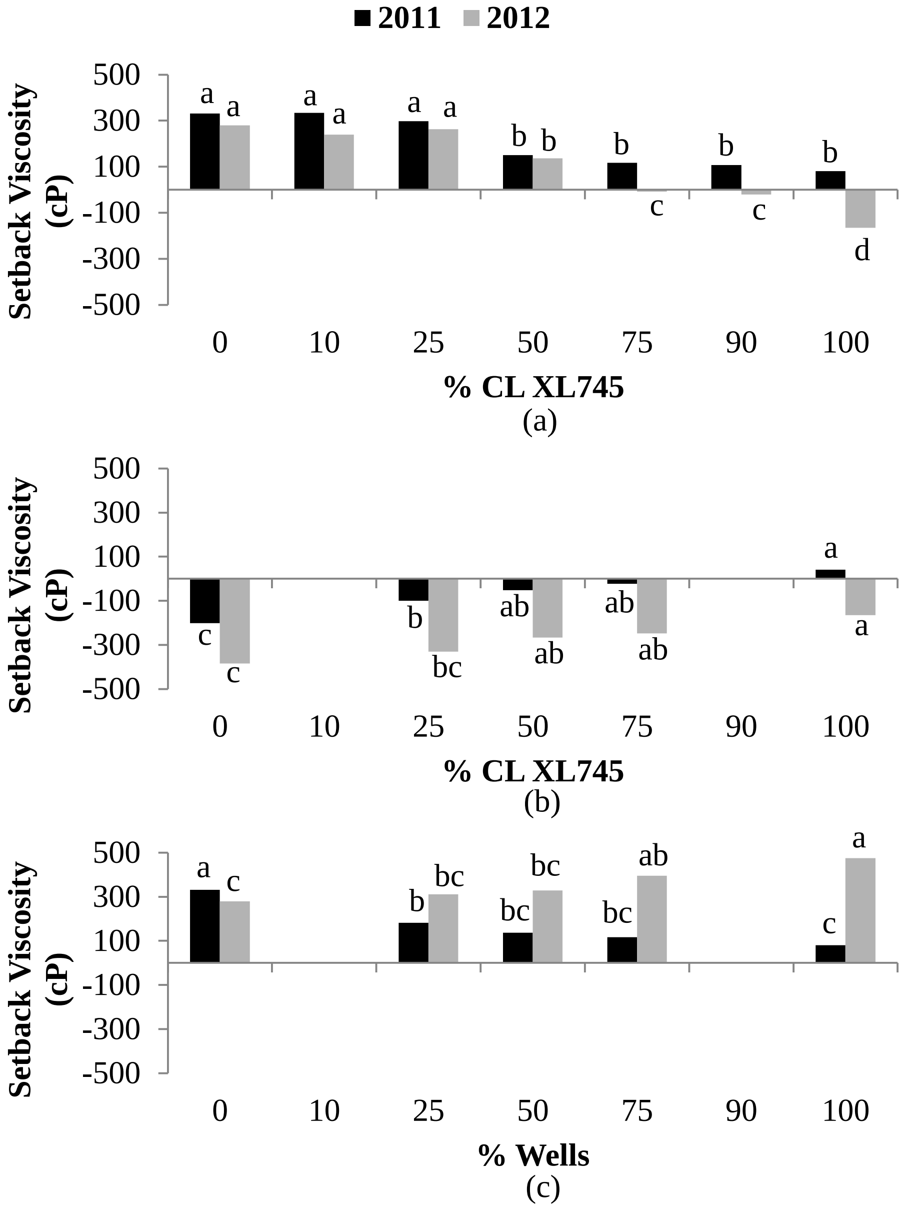


Fig. 2.10. Setback viscosities of the CL XL745/CL 151 (a), CL XL745/CL XL729 (b) and Wells/CL 151 (c) co-mingles in 2011 and 2012, measured for samples that had been milled for durations that produced a degree of milling level closest to 0.4% surface lipid content.Statistical differences in means of setback viscosities of samples, in a given co-mingle in a given year, are indicated by different letters, according to Tukey's Honestly Significant Difference test, at a 0.05 level of significance. Each data point is a mean of four replicate samples.

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APPENDIX

UNIVERSITY OF ARKANSAS
DIVISION OF AGRICULTURE

DEPARTMENT OF FOOD SCIENCE

UNIVERSITY of ARKANSAS
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of AGRICULTURAL, FOOD AND LIFE SCIENCES

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January 8, 2014

To Whom it May Concern,

Nikhil Basutkar is the first author of both manuscripts submitted as part of this thesis. Nikhil conducted over 51% of the work for both manuscripts.

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OVERALL CONCLUSIONS

The present study has implications for rice farmers, millers and processors. Effects of co-mingling rice cultivars on milling yields were strongly associated with the milling properties of the individual cultivar lots, the proportions in which the cultivars were co-mingled, and their brown rice properties. The milling yields increased or decreased with an increase in the proportion of a given cultivar in a co-mingle. These findings should help in making management decisions regarding cultivar co-mingling at the field or post-harvest levels.

Co-mingled samples were found to retain the gelatinization and pasting properties of the individual cultivar lots. For example, T_o of a co-mingle was similar to the T_o of that cultivar in the co-mingle with a lower T_o. This is very useful from a food processor's viewpoint because processing conditions can be optimized and product characteristics can be determined while using co-mingled rice cultivars, based on their knowledge of the functional properties of the individual cultivar lots in those co-mingles.

However, there still remains the possibility of a large co-mingled lot being non-homogeneous in its co-mingling and having different co-mingling ratios of the cultivars at different areas in that co-mingle. Such a scenario will make it difficult to determine the milling duration required by the entire co-mingle to reach a particular DOM, as it won't have one particular co-mingling ratio and therefore, some of the kernels will be under-milled, some over-milled and some milled to the desired degree. In addition, the presence of different co-mingling ratios in a large lot will cause variability in processing conditions and product characteristics because of the differences in gelatinization and pasting properties in different sections within the co-mingle.