

IMPACTS OF THICKNESS GRADING ON MILLING YIELDS OF LONG-GRAIN RICE

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ABSTRACT. *As kernel dimensional-variability can adversely affect milling yield and quality of rice, limited thickness-grading to remove thin kernels was evaluated. Along with unfractionated (UNF) rice, rough rice was mechanically sieved, resulting in two thickness fractions, Thick (> 2 mm) and Thin (< 2 mm), of four currently-produced, long-grain cultivars. Milled-rice yield (MRY), head-rice yield (HRY), lipid and protein content, bulk density, and milled-rice chalkiness were determined for each cultivar/fraction. Thickness grading returned between 67% and 90% Thick kernels. MRYS of Thick kernels were greater than Thin, and trended greater than UNF. Moreover, HRYs of Thick kernels were greater than both Thin and UNF. For Thin, greater total lipid and crude protein content, and lower bulk density, suggest incompletely-filled kernels. Thick kernels had less chalkiness than Thin, and trended to less chalkiness compared to UNF. Thickness-grading improved milling-yield parameters of Thick, and showed promise for reducing chalkiness. Although thickness-grading to remove the Thin kernels would create an extra process operation and flow, benefits to milling yield, and to improved visual perception through reduced chalkiness and greater kernel uniformity, could justify this procedure.*

Keywords. *Head rice yield, Milled rice yield, Rough rice, Thickness grading.*

Milling yield, either milled rice yield (MRY) or head rice yield (HRY), largely determines the economic value of rough rice (*Oryza sativa*). Both indices can be affected by multiple factors, including genetics and production, environmental, and processing conditions (McKenzie, 1994). MRY represents the mass fraction of unprocessed, rough rice that remains as milled rice, which includes both head rice and broken kernels. HRY represents the mass fraction of rough rice that remains as head rice, synonymous with “whole kernels” (USDA-FGIS, 2009) and defined as the well-milled rice kernels three-fourths or more of the original kernel length. Well-milled rice refers to the degree of milling, the extent of bran removal from brown rice during the milling operation. A greater degree of milling is invariably accompanied by increased mass loss (decreased MRY) (Wadsworth, 1994), and decreased HRY (Sun and Siebenmorgen, 1993; Lanning and Siebenmorgen, 2011). Achieving maximum HRY is important, as head rice is more valuable than broken kernels. Thus, the goal of the milling operation is to mill rice to a desired degree of

milling, while avoiding over-milling, and maximizing MRY and HRY.

Rice bran contains between 15% and 20% oil, accounting for the majority of lipids in the rice kernel (Juliano, 1985). Because of this lipid distribution, degree of milling can be quantified based on the surface lipid content (SLC) of milled rice (Hogan and Deobald, 1961; Pomeranz et al., 1975; Miller et al., 1979). Measuring SLC of milled rice is important, as the degree of milling greatly impacts functional properties (Perdon et al., 2001; Saleh et al., 2008), and sensory properties such as rancidity of under-milled rice (Wadsworth, 1994). Residual lipids of under-milled rice have a tendency to become rancid during storage, occurring in as little as 60 days in a hot, humid environment (Wadsworth, 1994). This is not usually an issue in developing countries, as the milled rice is not typically stored for extended periods before consumption; however, rancidity can be a problem elsewhere (Wadsworth, 1994).

When long-grain rice was milled in bulk and subsequently fractionated as milled rice, Chen et al. (1998) reported that at low degree of milling levels, the thinnest kernel fraction (<1.49 mm) had greater SLC than the other kernel fractions. This difference across thickness fractions of the bulk rice could lead to under-milling of the thin kernels. Given the impacts of elevated SLC values on storage of milled rice, millers tend to over-mill the thick kernels in a bulk lot in order to simultaneously mill the thin kernels to the desired degree of milling. Over-milling of the bulk rice increases milling duration and cost, and reduces MRY and HRY.

As increased milling decreases both MRY and HRY, it is generally undesirable to remove any more bran than

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absolutely necessary for each lot of rice. Therefore, it is important to monitor lot-to-lot milling variability (Lanning and Siebenmorgen, 2011; Siebenmorgen et al., 2006b), and carefully control degree of milling during processing (Wadsworth, 1994). Moreover, size-exclusion techniques, such as thickness grading, could reduce milling variability inherent within lots as described by Chen et al. (1998). Size grading has been shown to be beneficial to milling operations for other cereal grains by improving dehulling efficiency and grain uniformity of oat (*Avena sativa*) (Doehlert et al., 2002; Doehlert et al., 2004), and milling yield and flour properties of grain sorghum (*Sorghum bicolor*) (Lee et al., 2002).

Luh and Mickus (1991) reported the importance of size grading of paddy rice to enhance milling operations and to reduce kernel breakage during milling of parboiled rice. Thickness grading has also been proposed as a means of improving kernel uniformity by removing thin, rough-rice kernels, and designating the thin kernels for parboiling (Matthews et al., 1982). Jindal and Siebenmorgen (1994) showed that thicker kernels of rice produced dramatically greater HRY when compared to thinner kernels. Sun and Siebenmorgen (1993) reported greater HRY for the thickest kernels when compared to bulk, unfractionated rice of three long-grain cultivars. In the case of the cultivar Newbonnet, weighted average HRY from separately-milled thick and thin fractions exceeded that of bulk rice (Sun and Siebenmorgen, 1993). Matthews and Spadaro (1976) also indicated that breakage of milled rice was greatest in the thinnest fraction, two- to six-times that of other fractions, regardless of cultivar. Rohrer et al. (2004) reported that, when fractionated as rough rice prior to milling, thin kernels milled to a lower SLC and HRY compared to thicker kernels at the same milling duration. Thus, if milled as a separate processing stream, thin kernels would require shorter milling durations, likely resulting in decreased breakage and increased milling yield.

In addition to potential MRY and HRY increases resulting from size grading of rice, others have reported divergent physicochemical and phytochemical properties associated with different size fractions. For example, protein content is generally greater for thinner rice kernels (Matthews et al., 1981; Chen et al., 1998). Hamaker (1994) reported that protein is not uniformly distributed in the rice kernel, with greater protein content present in the bran and outer periphery of the endosperm. The bran contains the protein-rich aleurone layer (Lu and Luh, 1991; Marshall and Wadsworth, 1994), which forms prior to development of the endosperm (Lu and Luh, 1991).

Following formation of the bran/aleurone layer, the kernel accumulates starch in the endosperm and first attains full length, then full width, and lastly full thickness (Lu and Luh, 1991). With this pattern of development, the thinnest kernels of a harvested rice lot are likely incompletely filled. Moreover, as the bran layer forms before the endosperm is filled, thin kernels have been shown to have proportionally greater bran. Matthews and Spadaro (1976) showed that bran milled from the thickest (2.0 to 2.4 mm) fraction was 11% of brown rice mass on average, while bran milled from the thinnest (1.6 to 1.8 mm) fraction was greater, an

average of 17.8% of brown rice mass. Given the composition of rice bran, it follows that thin kernels have greater protein (Chen et al., 1998) and lipid (Matthews et al., 1981) contents compared to thick, fully-developed kernels.

While thin kernels have more bran, lipids, and protein, the bran of thicker kernels contains greater phytochemical concentrations (Rohrer and Siebenmorgen, 2004). Chen and Bergman (2005) report similar trends, but make a distinction between mature and immature thin kernels, with mature thin kernels having similar phytochemical content to mature thick kernels, while immature thin kernels had lower bran phytochemicals than mature thick kernels. Given increasing interest in protein-rich and phytochemical byproducts, it may also be of benefit to segregate thin kernels from rough rice in order to maintain separate streams of bran following milling of either thick or thin kernels.

Matthews et al. (1981) and Siebenmorgen et al. (2006a) have reported greater starch content of the endosperm of thicker rice kernels, and thicker kernels have a greater amylose-to-amylopectin ratio (Matthews et al., 1981). Wadsworth et al. (1979) also indicated that peak and setback viscosity increased with increasing thickness of a long-grain rice cultivar. Chalkiness, with its linkage to starch accumulation in the rice endosperm (Ashida et al., 2009; Kim et al., 2000; Lisle et al., 2000; Patindol and Wang, 2003), may also be strongly associated with thin, incompletely-filled kernels. Chalkiness of milled rice kernels is an important factor for U.S. rice exports, and the domestic market downgrades chalky rice (USDA-FGIS, 2009). Moreover, elevated chalkiness of milled rice suggests even greater pre-milled chalkiness, which contributes to greater kernel breakage during milling operations and reduced HRY (Webb, 1985).

Although size grading of rough rice at the commercial scale would introduce an additional processing step, there are many potential advantages, including greater MRY and HRY, reduced milling duration and cost, reduced chalkiness, and improved kernel-uniformity of milled rice. As such, the goal of this research was to examine limited thickness grading in a manner potentially compatible with commercial-scale milling operations, as a means of reducing variability and increasing MRY and HRY.

MATERIALS AND METHODS

BULK RICE PROCUREMENT AND CONDITIONING

Four long-grain rice cultivars, two purelines (CL 151 and Wells) and two hybrids (CL XL729 and CL XL745), were evaluated. Three of the cultivar lots (CL 151, CL XL729, and CL XL745) were combine-harvested in 2011 from large-scale strip-trials near Jonesboro, Arkansas. The Wells lot was also combine-harvested and was obtained from the University of Arkansas Rice Research and Extension Center, Stuttgart, Arkansas. Lots were cleaned with a dockage tester (Model XT4, Carter-Day, Minneapolis, Minn.), and conditioned to approximately 12.5% (wet basis) moisture content. Rough rice moisture

contents were measured by drying duplicate samples at 130°C for 24 h in a convection oven (1370FM, Sheldon Mfg. Inc., Cornelius, Ore.) (Jindal and Siebenmorgen, 1987). Lots were then stored at 4±1°C prior to use. One day prior to thickness grading, bulk samples were removed from refrigerated storage and equilibrated to room temperature (22±1°C).

THICKNESS GRADING

In addition to bulk, unfractionated (UNF) rice, a portion of each bulk rice lot was thickness graded using the previously-referenced dockage tester equipped with a No. 24 screen (2- × 12-mm slot) in the top-most, vertically-oscillating position. A No. 22 screen (1.5- × 12-mm slot) was used in the underlying, laterally-oscillating position and was the final screen, allowing passage of only fines and the few un-filled kernels remaining after initial cleaning. Bulk rice was screened only once, and split into only two thickness fractions, Thick (>2 mm) and Thin (<2 mm) rough rice. A modification of the procedure reported by Matthews and Spadaro (1976), this thickness-grading procedure was designed to more closely reflect what could potentially occur at a milling facility with high rough-rice throughput. Prior to sample preparation and milling, bulk density of rough rice for each cultivar/fraction was determined as described by Fan et al. (1998).

For determination of total lipid content (TLC) and crude protein content (CP), 50-g samples of UNF, Thick, and Thin kernels were reserved. Sufficient 150-g samples of UNF and Thick rice were then prepared to facilitate multiple milling durations of 10, 20, 30, and 40 s, allowing determination of degree of milling impacts on MRY and HRY of UNF and Thick rice. Because of the limited quantity of bulk, rough rice available, and the relative proportion of Thin to Thick kernels, 150-g samples of Thin kernels were only prepared for the 30-s milling duration. Four replicate samples of each cultivar/fraction/milling-duration were prepared and maintained at room temperature for up to one week prior to milling.

MILLING YIELDS

For each 150-g milling sample, the rice was first dehulled using a laboratory sheller (THU 35B, Satake, Hiroshima, Japan) with a clearance of 0.048 cm between the rollers. The resultant brown rice samples were milled for 10, 20, 30, or 40 s using a laboratory mill (McGill No. 2, RAPSCO, Brookshire, Tex.). The mill was equipped with a 1.5-kg weight on the lever arm, situated 15 cm from the milling chamber centerline. MRY was determined, and head rice was separated from brokens using a sizing device (Model 61, Grain Machinery Manuf. Corp., Miami, Fla.) in order to determine HRY.

TOTAL LIPID CONTENT, SURFACE LIPID CONTENT, AND CRUDE PROTEIN CONTENT

Brown rice TLC, and surface lipid content (SLC) of head rice samples were measured. Both TLC and SLC were determined using a lipid extraction system (Avanti 2055, Foss North America, Eden Prairie, Minn.) according to

AACC method 30-20 (AACC Intl., 2000), with modifications to the petroleum ether washing duration, as described by Matsler and Siebenmorgen (2005). TLC and SLC were expressed as the mass percentage of extracted lipid to the original brown or head rice, respectively.

Head rice SLC, indicative of degree of milling, was determined using intact, head rice kernels. TLC was determined using brown rice flour, because previous research has shown that the TLC determined using whole kernels of brown rice produces erroneously low values (Siebenmorgen et al., 2006a). For brown rice sample preparation, the roller clearance of the sheller resulted in approximately 92% of the rough rice in each sample being dehulled. Only hull-free kernels were ground in a cyclonic sample mill (3010-30, UDY, Fort Collins, Colo.) fitted with a 100-mesh (0.5-mm) sieve to produce brown rice flour for determination of TLC.

CP was also determined using brown rice flour, and was quantified by an external laboratory using standard method 990.03 (AOAC International, 2006). Briefly, total N (percentage by mass) of brown rice flour was determined by combustion via an elemental analyzer (Model NA2000, Fisons Instruments, UK). Total N was multiplied by 5.95 to yield the sample CP, also expressed as a percentage by mass.

CHALKINESS

Chalky area of milled rice (200 kernels of each cultivar/fraction/replicate) was determined by the procedure of Ambardekar et al. (2011). This method used a scanning system (WinSeedle Pro 2005a™, Regent Instruments Inc., Sainte-Foy, Quebec, Canada). Upon scanning the kernels, the software determined number of color pixels associated with both non-chalky and chalky tissue, as previously identified through a calibration procedure, and calculated the percentage of the total-kernel area that was chalky.

DATA ANALYSIS

Milled rice yield and HRY versus SLC linear modeling and goodness of fit (R^2), analysis of variance (ANOVA, $\alpha=0.05$), and means separation using Fisher's Least Significant Difference procedure ($LSD_{0.05}$) were conducted using statistical software (JMP release 9.0, SAS Institute, Cary, N.C.).

RESULTS AND DISCUSSION

THICKNESS GRADING

Thickness-grading of rough rice resulted in Thick fractions ranging from 67% to 89% of the bulk rice on a mass basis (fig. 1). CL 151, CL XL729, and CL XL745 (released after 2007, Blanche et al., 2011; RiceTec, 2012) had 85% or greater Thick kernels, while the Wells cultivar (released in 1999, Moldenhauer et al., 2007), had only 67% Thick kernels. Thus, the Wells lot, with 33% Thin kernels, had from two to three times the mass of Thin kernels observed for the other three cultivar lots (fig. 1). A second Wells lot procured from the same location as the CL 151,

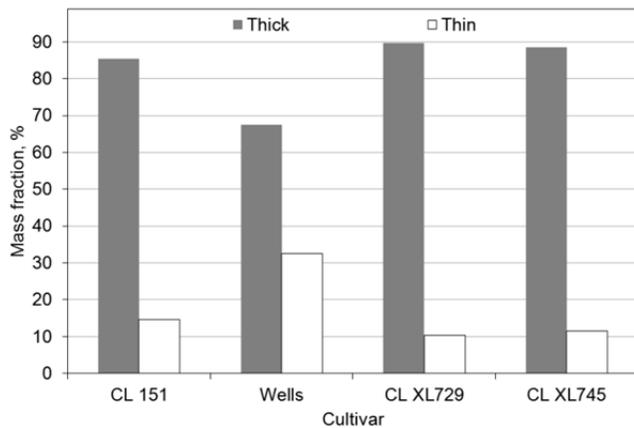


Figure 1. Mass fractions resulting from thickness grading of rough rice of four long-grain cultivars using a dockage tester (Model XT4, Carter-Day, Minneapolis, Minn.) equipped with a No. 24 screen (2 × 12 mm slot) in the top-most, vertically-oscillating position. Fractions comprise thickness >2 mm (Thick) and <2 mm (Thin).

CL XL729, and CL XL745 cultivars, but rejected for use in this experiment because of poor HRY, also had a greater proportion of Thin kernels (22%) than the other cultivars produced in the same environment.

Thickness grading of commonly-produced, long-grain rice cultivars in the mid-1970s (Matthews and Spadaro, 1976) resulted in only 2% to 54% kernels equivalent to the Thick-kernel fraction herein. Later reports by this group showed a Thick kernel range of 14% to 80% for three cultivars (Wadsworth et al., 1982). Sun and Siebenmorgen (1993) report between 20% and 70% Thick kernels for three long-grain rice cultivars. In contrast, the range of 67% to 90% Thick kernels from this current study was narrower, and approached or exceeded the maximum proportion of Thick kernels of cultivars reported previously. Thus, there appears to be a shift toward greater kernel thickness with current long-grain rice cultivars produced in the mid-South region of the United States. As a result, the simplified thickness-grading approach presented here should provide for a minimal thin-fraction processing stream.

MILLING YIELDS

Milling ‘curves’ can be used to express changes in MRY and HRY in response to increasing degree of milling (decreasing SLC). As previously mentioned, insufficient rice was available to produce enough Thin kernels to develop milling curves for the thin fraction. Thus, the impact of degree of milling was only evaluated for UNF rice and Thick kernels. The best fit of the MRY and HRY data to SLC were linear relationships and were statistically significant ($\alpha=0.05$), with R^2 values exceeding 0.90 for all cultivars (table 1). Compared to UNF rice, Thick kernels showed a trend for greater MRY y-intercept values for all cultivars, indicating greater MRY, even at greater degrees of milling (table 1).

For cultivars CL 151, Wells, and CL XL729, the MRY slope for the Thick kernels declined compared to that of UNF rice, indicating lesser decrease in MRY with increasing degree of milling (table 1). In contrast, the MRY slope increased for Thick kernels of CL XL745 as compared to UNF rice (table 1), suggesting that this cultivar may be more valuable for applications requiring lightly-milled rice. When considering the greater y-intercept values for Thick kernels of these four popular mid-South cultivars, these data indicate that thickness grading consistently improved MRY, regardless of degree of milling. Trends observed for MRY were also observed for HRY for all cultivars. HRY y-intercept values were significantly greater (no overlap of the 95% confidence intervals) for Thick kernels when compared to UNF rice of the same cultivar (table 1), indicating improved HRY regardless of degree of milling. As with MRY, the HRY slope was altered as a result of size fractioning, decreasing for Thick kernels of all cultivars except CL XL745 when compared to UNF rice (table 1).

At the 30-s milling duration, which yielded a degree of milling close to the target 0.4% SLC for all cultivars, thickness grading resulted in a trend of greater MRY of Thick kernels when compared to UNF rice, with the exception of Wells (fig. 2). MRYs of Thick kernels of both CL 151 and CL XL729 were significantly greater than that of UNF rice (fig. 2). MRYs for both Thick kernels and UNF rice were significantly greater than that of Thin kernels at the 30-s milling duration for all cultivars (fig. 2).

Table 1. Relationships between milled rice yield (MRY), or head rice yield (HRY), and surface lipid content (SLC) as affected by thickness grading (rough rice) of four long-grain cultivars.

Cultivar	Fraction	MRY = ^[a]	R ² ^[b]	HRY =	R ²
CL 151	UNF	6.9×SLC + 70.1	0.99	7.2×SLC + 63.8	0.96
	Thick	6.3×SLC + 71.4	0.94	6.3×SLC + 67.4	0.93
Wells	UNF	8.1×SLC + 70.5	0.98	11.3×SLC + 55.2	0.95
	Thick	8.0×SLC + 70.9	0.95	10.0×SLC + 59.7	0.96
CL XL729	UNF	9.0×SLC + 69.4	0.94	11.8×SLC + 56.5	0.94
	Thick	6.2×SLC + 72.4	0.96	8.1×SLC + 63.7	0.91
CL XL745	UNF	6.6×SLC + 72.1	0.96	11.1×SLC + 58.6	0.93
	Thick	7.6×SLC + 72.6	0.92	12.5×SLC + 60.9	0.94

^[a] Linear regression analyses for MRY and HRY as a function of SLC were conducted on four replicate samples at 10-, 20-, 30-, and 40-s milling durations for unfractionated (UNF) and Thick (>2 mm) kernel fractions.

^[b] R² indicates the goodness of fit of the data to the predicted equation.

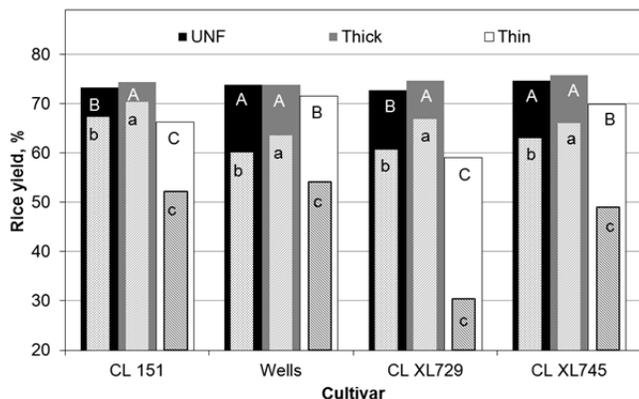


Figure 2. Rice yield [milled rice yield (MRY) or head rice yield (HRY); milling duration of 30 s] of thickness fractions, in response to thickness grading of rough rice of four long-grain cultivars. Fractions comprise Thick (>2 mm), Thin (<2 mm), and unfractionated (UNF) rice. Solid bars indicate MRY and inset, crosshatched bars indicate HRY. Letters inset within each bar facilitate the comparison of means within a cultivar; uppercase letters are associated with MRY, and lowercase letters with HRY; means with the same letter were not significantly different ($P > 0.05$).

Although significant, the difference in MRYs of Thick and Thin kernels for the Wells lot was less than that observed for the other three cultivars.

At this typical degree of milling, HRY of the Thick kernels was significantly greater than that of UNF rice for all cultivars (fig. 2). As observed for MRY, the differences between HRYs of the Wells fractions were not as great as observed for the other three cultivars. HRYs of the Thin kernels of all cultivars were significantly less than both Thick kernels and UNF rice at the 30-s milling duration (fig. 2). With the exception of Wells, this was partially the result of greater degrees of milling of the Thin kernels relative to Thick kernels and UNF rice (fig. 3), a trend also shown by Rohrer et al. (2004). However, Thin kernels of all cultivars, including Wells, had significantly lower MRY and HRY than the Thick kernels or UNF rice (fig. 2). Thus, the reduced MRY/HRY was attributed primarily to greater breakage of Thin kernels during the milling process; a

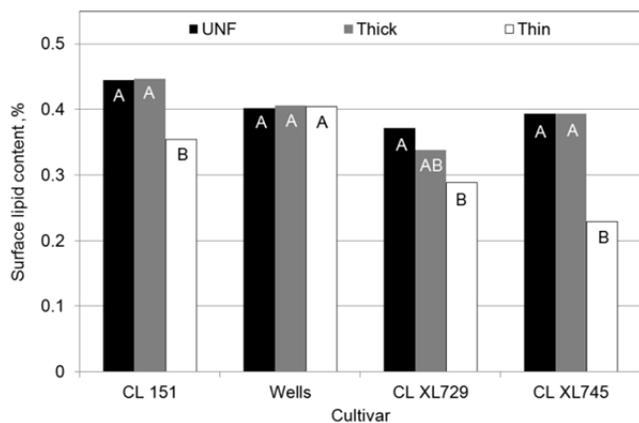


Figure 3. Surface lipid content (head-rice kernels; milling duration of 30 s) of rice fractions in response to thickness grading of rough rice of four long-grain cultivars. Fractions comprise Thick (>2 mm), Thin (<2 mm), and unfractionated (UNF) rice. Letters inset within each bar facilitate comparison within a cultivar; means with the same letter were not significantly different ($P > 0.05$).

tendency reported by both Matthews and Spadaro (1976) and Sun and Siebenmorgen (1993).

PHYSICOCHEMICAL PROPERTIES

Given that thickness grading improved both MRY and HRY, physicochemical properties of the different cultivars/fractions were evaluated to determine contributing or corroborating factors leading to differences between fractions, as well as to ascertain other potential benefits of thickness grading. As brown rice prior to milling, Thin kernels had significantly greater lipid content (TLC) than Thick kernels, regardless of cultivar lot (fig. 4). Moreover, with all lots except Wells, TLC of the Thin kernels was also significantly greater than UNF rice. This, in conjunction with degree of milling data (fig. 3), indicates that when milled as separate fractions, bran is removed from Thin kernels at a faster rate than Thick kernels. This is supported by data of Matthews and Spadaro (1976), who showed greater bran removal as kernel thickness decreased.

As with TLC, Thin kernels were greater in CP than Thick kernels (fig. 5). Matthews et al. (1981) showed similar trends for the Starbonnet cultivar, with increasing CP and lipids, as well as decreased starch content, as kernel thickness decreased. As previously stated, a significant portion of both lipids and CP are found in the bran layer, which forms prior to starch accumulation and development of the endosperm. The combined trends for increased TLC (fig. 4) and CP (fig. 5) of Thin relative to Thick kernels generally support the premise of delayed development of Thin kernels, with a proportionally thicker bran layer resulting from lesser development of the endosperm. Further supporting this premise, bulk density of Thin kernels was significantly reduced compared to that of Thick kernels for all cultivars (fig. 6), again consistent with the premise of delayed endosperm development in the Thin kernels. Although for Wells, relatively lesser differences in TLC, CP, and bulk density of Thick and Thin kernels, suggest that a significant proportion of Thin kernels of

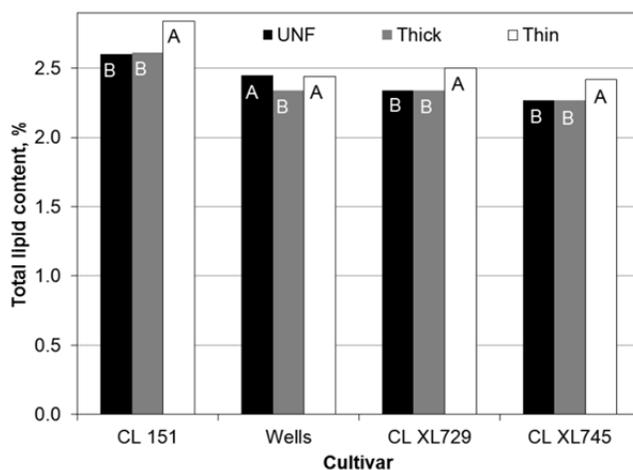


Figure 4. Total lipid content (brown rice) of rice fractions in response to thickness grading of rough rice of four long-grain cultivars. Fractions comprise Thick (>2 mm), Thin (<2 mm), and unfractionated (UNF) rice. Letters inset within each bar facilitate comparison within a cultivar; means with the same letter were not significantly different ($P > 0.05$).

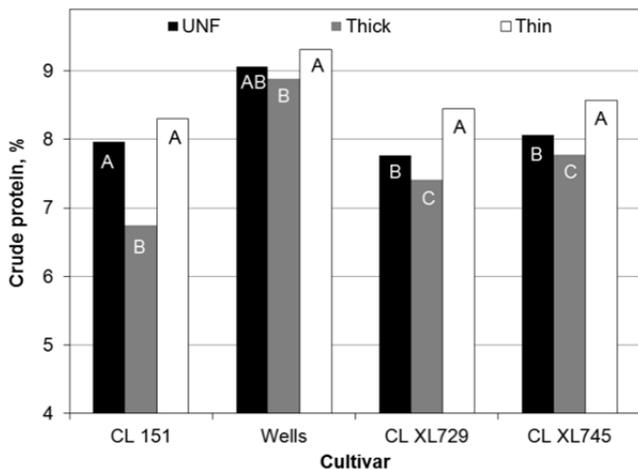


Figure 5. Crude protein (brown rice) of rice fractions in response to thickness grading of rough rice of four long-grain cultivars. Fractions comprise Thick (>2 mm), Thin (<2 mm), and unfractionated (UNF) rice. Letters inset within each bar facilitate comparison within a cultivar; means with the same letter were not significantly different ($P>0.05$).

Wells are mature, the result of inherent qualities of this cultivar.

Thickness grading also affected milled rice chalkiness, as Thin kernels had significantly greater chalkiness than Thick kernels for all cultivars (fig. 7). As with other measured parameters, the relative differences between Thick and Thin fractions were much less for Wells than the other cultivars evaluated (fig. 7). Except for Wells, chalky area of Thin kernels was also significantly greater than that of UNF rice (fig. 7). Kim et al. (2000) also indicated that greater chalkiness was associated with smaller kernels within bulk rice and that increasing chalk ultimately affected sensory quality of cooked rice. Moreover, increased chalkiness of Thin kernels likely contributed to decreased MRY/HRY of milled rice, as chalky kernels tend to be structurally weaker and break or crumble during milling (Webb, 1985).

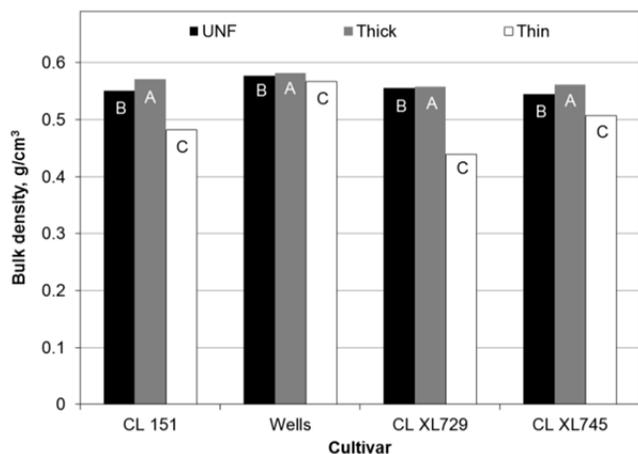


Figure 6. Bulk density (rough rice) of rice fractions in response to thickness grading of rough rice of four long-grain cultivars. Fractions comprise Thick (>2 mm), Thin (<2 mm), and unfractionated (UNF) rice. Letters inset within each bar facilitate comparison within a cultivar; means with the same letter were not significantly different ($P>0.05$).

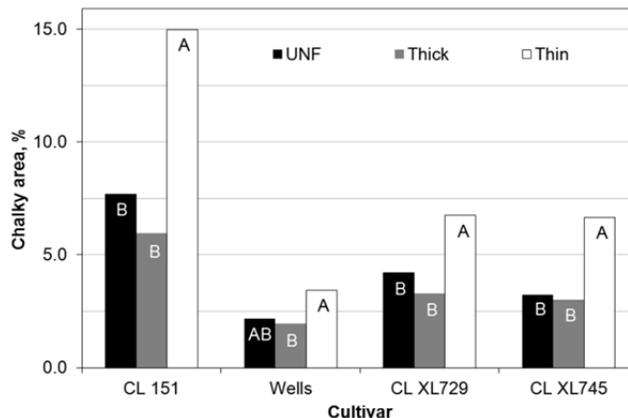


Figure 7. Chalkiness (head-rice kernels; milling duration of 30 s) of rice fractions in response to thickness grading of rough rice of four long-grain cultivars. Chalkiness represents the chalky area as a percentage of total-kernel area. Fractions comprise Thick (>2 mm), Thin (<2 mm), and unfractionated (UNF) rice. Letters inset within each bar facilitate comparison within a cultivar; means with the same letter were not significantly different ($P>0.05$).

CONCLUSIONS

The procedure presented here for single-pass, thickness grading generally resulted in greater MRY, and always resulted in significantly greater HRY, of Thick kernels when compared to UNF rice. Even for Wells, where MRY of the Thick kernels was not greater than UNF rice, HRY was still significantly increased by removing Thin kernels. It is also apparent that uniformly-thicker kernels are now a more important selection criterion for modern rice cultivars. Moreover, these four cultivars currently popular in the mid-South United States have a sufficiently large fraction of Thick kernels to minimize the secondary processing stream of Thin kernels.

It is apparent that Thin and Thick kernel fractions, as produced by a single screening with a No. 24 screen (2- × 12-mm slot), possessed different milling properties, regardless of cultivar. Excepting the Wells cultivar, the physicochemical metrics of cultivars evaluated here strongly suggest that the Thin kernels are immature in comparison to Thick kernels. The Wells cultivar exhibited more consistent characteristics across fractions. This suggests a large proportion of mature kernels within the Thin fraction of Wells, a premise supported by the findings of Chen and Bergman (2005).

Thickness grading to remove the Thin kernels would create an extra process operation and flow. However, benefits to milling yield, and to improved visual perception through reduced chalkiness and greater kernel uniformity, could justify this procedure. It has been proposed that Thin kernels be separated and diverted directly to parboiling operations (Matthews et al., 1982). However, kernel uniformity is also important to parboiling operations (Luh and Mickus, 1991); such that the Thin kernel flow would likely have to remain segregated. Were the Thin kernels diverted to flour production, the greater crude protein of these Thin kernels would lead to a protein-rich flour. Moreover, according to Ashida et al. (2009), the generally

greater chalkiness associated with Thin kernels would also enhance flour properties.

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