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Impact of Harvest Lodging on Rough Rice Milling Yield and Market Price

Michael E. Salassi, Michael A. Deliberto, Steven D. Linscombe, Charles E. Wilson, Jr., Timothy W. Walker, Garry N. McCauley, and David C. Blouin

ABSTRACT

Lodging of a rice (*Oryza sativa* L.) plant just before harvest can significantly impact the quality of the harvested crop yield as well as the market returns received for sale of the crop. The purpose of this study was to quantify the level and significance of lodging on the milling yield and market price of rough rice. A 2-yr study was conducted in the major rice-growing regions of Arkansas, Louisiana, Mississippi, and Texas to evaluate the impact of early and late lodging before harvest. The study included two rice planting dates and a range of rice varieties predominately grown in the regions. Results suggest that lodging does have a significant impact on milling yield, although impacts of planting date and time of lodging were not significant. Lodging was found to have a greater impact on whole grain (head rice) milling yield than total grain milling yield. Head rice yield reductions of 30.19 to 55.30 g kg^{-1} were observed. Although market price effects will vary with the general level of average rough rice market prices in a given year, results for the 2011 and 2012 crop years showed market price reductions of \$0.0075 to \$0.0119 per kg, due to crop lodging impacts on milling yield alone.

Rice is produced in six states across the United States. The bulk of U.S. medium grain rice and virtually all of U.S. short grain rice is produced in California. In 2012, California rice production accounted for 20.8% of total U.S. harvested rice acreage and 22.6% of total U.S. rice production (USDA, 2013a). The remainder of the country's rice production is located in five states in the southeast: Arkansas, Louisiana, Mississippi, Missouri. and Texas. This southeast rice production is primarily comprised of long grain rice varieties, with some medium grain rice varieties produced each year as well. Arkansas and Louisiana are the largest rice-producing states in the southeast. In 2012, Arkansas harvested 520,000 ha of rice, representing 48.0% of total U.S. harvested area and 48.1% of total U.S. rice production (USDA, 2013a). Louisiana, with 160,000 harvested hectares in 2012, accounted for 14.8% of U.S. harvested area and 12.8% of U.S. total production. Mississippi, Missouri, and Texas each accounted for <7.0% of U.S. rice harvested area and total rice production.

Rice is also a relatively high valued crop. Average crop market values per area across all U.S. rice production have averaged more than $2,400 per hectare over the last two production years (USDA, 2013b). The market value of a rice crop in any given year is determined by two factors: (i) rough rice yield per hectare and (ii) market price for rough rice received by producers at the time of crop sale. Rice yield per harvested hectare is influenced by a variety of factors including rice variety planted, rice production practices, incidence and degree of pests, weather during the growing season and harvest field conditions, as well as several other factors (Saichuk et al., 2012). The market price for rough rice received by rice producers is influenced by general rice market supply and demand conditions, which establish the general market price level for a given year. In addition, the quality of the rough rice harvested has the effect of adjusting the actual rough rice market price received above or below the general price level, depending on the specific quality parameters of alternative lots of rough rice sold.

Several factors can influence the quality of milled rice which ultimately impacts the rough rice market price received by the producer. Some of these factors include milling yield (the percentage of whole and broken grains of milled rice per unit of rough rice), heat-damaged kernels, red rice, chalkiness, and color (USDA, 2009). Milling quality, in addition to total grain yield, has always been an important area of research in both rice variety development work as well as research into impacts of alternative rice production practices and input use on rice yield. Expected rice milling yield and yield component stability has been important crop variety characteristics evaluated in the release of new commercial rice cultivars (Blanche et al., 2011; Sha et al., 2006; Moldenhauer et al., 2007; Linscombe et al., 2000, 2006). Studies evaluating factors which impact rice milling yield have included cultivar and planting date (Blanche and Linscombe, 2009; Blanche et al., 2009; Sha and Linscombe, 2007; Sha et al., 2007), seeding and fertilization rate (Bond et al., 2008; Harrell and Blanche, 2010; Ottis and Talbert, 2005; Walker et al., 2006), high air temperatures (Liu et al., 2013), soil moisture management during the grain-filling

M.E. Salassi and M.A. Deliberto, Dep. of Agricultural Economics and Agribusiness, LSU Agricultural Center, Baton Rouge, LA; S.D. Linscombe, Rice Research Station, LSU Agricultural Center, Crowley, LA; C.E. Wilson, Rice Research and Extension Center, Univ. of Arkansas, Stuttgart, AR; T.W. Walker, Delta Research and Extension Center, Miss. St. Univ., Stoneville, MS; G.N. McCauley, David Wintermann Rice Research Center at Eagle Lake, Texas A&M AgriLife Research, Eagle Lake, TX; D.C. Blouin, Dep. of Experimental Statistics, Louisiana State Univ., Baton Rouge, LA. Received 9 May 2013. *Corresponding author (msalassi@agcenter.lsu.edu).

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period (Zhang et al.,, 2008) and irrigation water salinity (Zeng and Shannon, 2000).

Rice milling yield is estimated as the proportional quantity of whole kernels and total milled rice (whole and broken kernels combined) that are produced in the milling of rough rice to a well-milled degree (USDA, 2009). As a result, rice-milling yield is directly impacted by factors which can lead to the breakage or fissuring of rice kernels during the milling process. Traditional pre-harvest factors which have been identified to impact rice-milling yield have included time of planting, irrigation and N rates, cultivar selection, panicle structure and harvest moisture content (Siebenmorgen et al., 2013). Much of the research which has previously been conducted on optimal rice harvest moisture content has shown that head rice yield (whole grain milled rice yield) is adversely affected by harvesting rice that has a moisture content which is either too high or too low (Geng et al., 1984; Siebenmorgen et al., 1992; Jodari and Linscombe, 1996). Studies have also identified ranges for the optimal rice harvest moisture content to optimize head rice milling yield (Juliano and Perez, 1993; Siebenmorgen et al., 2007).

Harvesting rice outside these optimal ranges of grain moisture content (either above or below) causes the rice kernel to be more susceptible to fissuring during the milling process. Lodging can cause the moisture content of the grains on the impacted plant to decrease or increase beyond desirable ranges. Plant stem damage or breakage caused by lodging could cause the grain moisture content to decrease either by disruption of moisture through the stem to the grains or by the occurrence of lodging during extremely dry climatic conditions. Conversely, lodging could also cause the grain moisture content to increase if lodging should occur during wet conditions. Previous research has shown the ability of rough rice grain to absorb water (Lu et al., 1994).

Milling yield has been shown to be a significant factor in establishing the market price for a specific lot of rice. Whole grain milled rice is sold for direct food use as a stand-alone product, while broken grain rice is sold for use in more processed foods. Because of this differential product demand, whole grain rice commands a higher price in the market compared with broken grain rice. Early studies by Brorsen et al. (1984, 1988) have shown empirically that, although rough rice grades do have an influence on rough rice prices, the most important factor in determining the market price of a specific lot of rough rice is the head rice (whole grain) milling yield. Later research has shown that the importance of head rice (whole grain)-milling yield in determining rice market price remains dominant over a range of harvest moistures (Siebenmorgen et al., 2008). Because of this dominance of head rice yield in establishing market price, estimating the basis for rough rice market prices (i.e., the difference between cash and futures prices) is much more complex for rice than for other grains. Numerical quality grades for other grains establish a minimum value of quality and quantity per sales unit, whereas a numerical quality grade for rice conveys no information about a specific quantity per sales unit (Giesler et al., 1998). Distinct from other grains, the milling yield for a lot of rice must also be included to completely specify the market price (value) of specific lot of rice. The importance of milling yield in determining rice market value is also central to the price discovery of rice in international markets. Export prices of milled rice from all major rice-exporting countries are expressed in terms of grade and milling yield, with lots of rice with higher milling yield commanding higher prices in the international market (Childs and Burdett, 2000; FAO, 2013).

One factor which can significantly impact the milling yield of harvested rough rice is the incidence of crop lodging at harvest time. Lodging in cereal crops has been defined as the state of permanent displacement of the stems from their upright position (Rajkumara, 2008). Adverse weather in the days and weeks just before harvest can cause the rice plant to lodge in the field. The extent of lodging in the field as well as the duration of the lodged crop down in the field, along with field conditions and weather during this time, can have a significant impact on the resulting milling quality of the harvested rice crop, in addition to the potential reduction in the amount of yield in the field actually recovered by the harvester.

Lodging of a rice plant can be caused by the relationship between stem structure integrity in relation to greater grain yields in response to higher N fertilization levels (Basak et al., 1962). Alternatively, even if N levels or grain yield weights are not excessive, adverse weather in the days just before harvest can lodge a rice crop in the field. This lodging impact on the rice crop can vary greatly in terms of the degree of severity as well as the proportion of the field impacted. Lodging impacts rice grain yield by its influence on yield components. Rice grain yield is generally a function of three primary components: 1000-grain weight, number of spikelets, and percent of filled spikelets (Yoshida, 1981). The 1000-grain weight component is determined by grain length, grain width, and grain thickness (Liu et al., 2010). Research has shown that these three yield component values are predictors of total rice grain yield (Li et al., 1997; Sheehy et al., 2001). Production factors such as seeding rate and N fertilization rate has been shown to impact rice yield components (Bond et al., 2008; Walker, 2006). Lodging would influence rice grain yield by its adverse impact on yield components, particularly the 1000-grain weight and percent of filled spikelets.

Studies have investigated morphological traits associated with the lodging of rice. Islam et al. (2007) conducted a study to determine genotypic variation in lodging resistance and lodging-related morphological traits among hybrid and non-hybrid check varieties. Large genotypic differences across rice varieties were found. Among lodging-related traits, dry weight per unit length, breaking resistance and lodging index of lower internodes were found to be significantly correlated with a visual score of lodging. Kashiwagi et al. (2005) found that the sturdiness of the lower part of the rice plant, in relation to the upper part, was related to the length from the plant base to the flag leaf as well as the weight of the lower stem were factors responsible for decreasing sturdiness of lodged rice plants. Lodging at different grain-filling stages has also been found to have differential effects on rice yield and grain quality (Lang et al., 2012). Setter et al. (1997) evaluated the impacts of self-shading and canopy photosynthesis reduction due to lodging on rice yield. Results indicated that a 1% reduction in grain yield occurred for every 2% of lodging when lodging occurred during the grain-filling period. The ability of the rice plant to have sufficient stem strength to support a crop with high grain yield is critical for rice cultivars to be successful in commercial production.

Lodging resistance is a very important characteristic for commercial rice cultivars. Evaluation of rice breeding lines and cultivars in variety development programs includes lodging resistance as an evaluation factor under alternative seeding rates and N fertilization levels. Potential for lodging is currently a critical area of study in the evaluation of newer hybrid rice lines developed in the United States (Walker et al., 2008; Wu, 2009). Much of the current research in lodging resistance has focused on factors which impact lower plant stem strength (Chuanren et al., 2004). Lower plant physical stem strength has been found to be positively correlated with total amounts of K and Si in stems during the grain-filling period (Zhang et al., 2010). The potential use of plant growth retardants in increasing lodging resistance by reducing plant height and increasing stem diameter has also been investigated (Sinniah et al., 2012). Evaluation of quantitative trait loci (QTLs) has been conducted in several studies seeking to identify traits for rice stem strength (Kashiwagi and Ishimaru, 2004; Kashiwagi et al., 2008; Ishimaru et al., 2008, Kashiwagi et al., 2010).

Quality standards for rough rice have long been established by USDA for the three major rice grain types (USDA, 2009). Rice grades are based on the determination of seeds, objectionable seeds, heat-damaged kernels, red rice and damaged kernels, chalky kernels, and color. Each of the six U.S. rice grades has maximum limits for these factors. Although rice grades do influence rough rice market price, they are not the primary factor which determines the market price level of a given lot of rough rice. An early study verified that the primary factor in determining rough rice market price for a given lot of rice in a given year was the head rice yield, that is, the milling yield (Brorsen et al., 1984). As such, weekly milled rice prices quotes have been stated in terms of a price for whole grain milled rice (head rice) and a price for broken grain rice (USDA, 2011, 2012). Whole grain milled rice is sold for use as food meals, entrees, and side dishes, while broken milled rice is sold for use in more processed food products (USA Rice Federation, 2013). As a result of this differentiation in food product demand, whole milled rice commands a higher market price than broken grain milled rice (USDA, 2011, 2012). One of the major areas of economic research evaluating of the current potential for hybrid rice production in the southeastern United States is investigating the impact of the tradeoff between higher yields from hybrid varieties and the potentially lower market price resulting from lower milling quality tests for hybrids (Salassi and Deliberto, 2010; Deliberto and Salassi, 2011; Lyman and Nalley, 2013).

The general objective of this study was to estimate the impact of lodging on rough rice milling yield and market price. More specifically, the study objectives were to attempt to quantify the impacts of rice crop lodging before harvest on the rough rice milling yield and, using these observed changes in rice milling yield, to estimate the impact of crop lodging on the resulting rough rice market price received. Although the quantity of rice grain yield harvested from a rice crop under lodged conditions can also impact producer economic returns per hectare, the specific focus of this research study is to document the relationship between lodging and rice milling yield and resulting market price per unit.

MATERIALS AND METHODS

Field experiments were conducted during 2011 and 2012 at four locations across the southeastern U.S. rice production region. The four locations at which field experiments were conducted included: (i) the Louisiana State University Agricultural Center Rice Research Station in Crowley, LA, (ii) the University of Arkansas Rice Research Station in Stuttgart, AR, (iii) the Mississippi State University Delta Branch Research and Extension Center in Stoneville, MS, and (iv) the Texas A&M AgriLife Rice Research Station in Eagle Lake, TX. These four study locations represent the range of rice-growing environments and conditions typical for southeastern U.S. rice production.

Three lodging treatments were evaluated in this study: early lodging, late lodging, and standing (no lodging). For the early and late lodging treatments, the rice crop was manually lodged in the plots at a specified time in relation to harvest. Manual lodging of the rice plants in this study involved using a piece of plywood board to uniformly push over the crop, after which sufficient weight was momentarily applied to the plywood board to lodge the plants parallel to the ground. The timing of early lodging occurred when the rice panicles were first observed turning yellow (approximately 5–7 d before field drainage). The timing of late lodging occurred approximately 1 wk before harvest maturity. For the standing treatment to be used as a check, no lodging was conducted.

Two planting dates were evaluated in the study. The first planting date was at the earliest typical planting date for the specific production area and the second planting date was approximately 30 d later. For the two southernmost locations, Louisiana and Texas, these planting dates were approximately 15 March and 15 April of each year. For the two northernmost locations, Arkansas and Mississippi, these planting dates were approximately 1 April and 1 May of each year.

Several rice varieties were evaluated for each lodging treatment and planting date at each location. For the test locations in Arkansas, Mississippi, and Texas, the following six rice varieties were evaluated: CL 151, Cheniere, Presidio, Jupiter, Wells, and CLXL745. At the Louisiana location, the following seven varieties were evaluated: CL 151, Cheniere, Presidio, Jupiter, Wells, LAH10, and Cocodrie. The majority of these varieties are long-grain rice varieties. CL 151 is a long-grain Clearfield herbicide-resistant variety. Cheniere, Presidio, Wells, and Cocodrie are conventional long-grain rice varieties. Jupiter is a conventional medium-grain rice variety. And, CLXL745 and LAH10 are hybrid rice varieties.

Rice varieties included in the tests were planted in 4.87-m plots in a randomized block split plot design in a multiple environment trial (MET) with year and location effects as random environmental effects, planting dates as the whole plot factor, replication blocks nested within planting date, and varieties as the split plot factor randomized to plots within each replication. All rice varieties were drill seeded in test plots with permanent irrigation flood established after planting. Fixed effects for the model were planting date and variety. Random effects for the model were year, location, planting area, block, and plot. Background justification for the handling of random and fixed effects in models over multiple environments was presented in Blouin et al. (2011). Hand harvested samples were taken from each treatment when the plot reached harvest maturity. All samples were dried to approximately 12% moisture and shipped to the Rice Research Station in Crowley, LA, for milling evaluation tests. Milling yields in grams of milled head rice (whole grain) and total milled rice (whole grain plus brokens) per kilogram of rough rice were determined for each sample. Following Walker et al. (2006), the components of rice milling yield referenced in this article will be referred to as whole grain milling yield and total grain milling yield. Over the 2 yr of the study, a total of 1200 observations were obtained over all locations, planting dates, varieties, replications, and lodging treatments. Analysis of variance, least squares means, and evaluation of least squares means differences using the Tukey–Kramer method were conducted using the PROC Mixed Procedure in SAS (SAS Institute, 2011).

Rough rice market prices based on milling yield were estimated for each rice sample. In addition to the milling yield, these estimated rough rice market prices are also determined by the rough rice market prices for whole grain (head rice) and broken grain (second heads). The rough rice market prices of milled rice samples in this study were estimated using the following rice market price equation:

$$\text{RRMP} = (\text{WGMP} \times \text{WGY}) + (\text{SHMP} \times \text{SHY}) \qquad [1]$$

where RRMP = the rough rice market price for a specific rough rice sample in dollars per kilogram, WGMP = the rough rice market price for whole grain yield in dollars per kilogram, WGY = the whole grain milling yield in grams of whole grain per kilogram of rough rice expressed in percent, SHMP = the rough rice market price for second heads yield in dollars per kilogram, and SHY = the second heads milling yield in grams of second heads per kilogram of rough rice expressed in percent.

Redefining the seconds heads rough rice market price as a percentage of the whole grain rough rice market price and solving Eq. [1] for the whole grain rough rice market price yields the following specifications for rough rice market prices:

$$\text{MYPR} = \text{SHMP}/\text{WGMP} \qquad [2]$$

$$\text{WGMP} = \text{ARRMP}/(\text{WGY} + (\text{SHY} \times \text{MPR})) \qquad [3]$$

$$\text{SHMP} = \text{WGMP} \times \text{MPR} \qquad [4]$$

where MYPR = the milling yield rough rice price ratio of second heads to whole grain milled rice and ARRMP = the average market price over all rice of a specific grain type.

The milling yield rough rice price ratio was estimated by determining the ratio between wholesale milled price for whole grain and second heads (brokens) as reported in the *National Weekly Rice Summary* by AMS/USDA for the rice harvest months in 2011 and 2012 (USDA, 2011, 2012). The long grain and medium grain milling yield price ratios were estimated to be 58.2 and 47.8%, respectively, for 2011 and 71.1 and 64.7%, respectively, for 2012. Whole grain and second head rough rice market prices were estimated by calibrating Eq. [1] using the average rough rice market price by grain type for an average percent milling yield of 550/700 g per kilogram for whole grain and total grain. Base average rough rice market prices by grain type for each year were taken from prices reported by USDA. Those average rough rice prices, used to calibrate Eq. [1] were $0.29542 and $0.37699 per kilogram, respectively, for long grain and medium grain rice in 2011 and $0.32188 and $0.35054 per kilogram, respectively, for long grain and medium grain rice in 2012.

Estimated rough rice market prices for whole grain (WGMP) and seconds heads (SHMP) were estimated to be $0.46363 and $0.26985 per kilogram, respectively, for long grain rice in 2011, $0.60627 and $0.29013 per kilogram, respectively, for medium grain rice in 2011, $0.49031 and $0.34833 per kilogram, respectively, for long grain rice in 2012 and $0.54190 and $0.35031 per hundredweight, respectively, for medium grain rice in 2012. These rough rice grain type market values along with the milling yields from the rice samples were used in Eq. [1] to estimate the impact of milling yield from the lodging treatment on the rough rice market price of each rice sample in the study.

Analysis of variance tests were conducted on the whole grain and total grain milling yields of harvest samples across all locations, planting dates, varieties, and lodging treatments. In this study, planting date, rice variety and lodging treatment were the fixed effects, while year and location were the random effects. A significance level of $p = 0.05$ was used to evaluate the ANOVA results for both whole grain (head rice) milling yield and total grain milling yield.

RESULTS AND DISCUSSION

Results from the ANOVA tests did find differences in rice milling yield related to the lodging treatments. Differences were found with respect to lodging treatment in the mean whole grain rice yields (Table 1). Whole grain milling yield is the percent of rough rice milled out as whole grain milled rice and it was hypothesized that lodging would have an impact on head rice yield. Differences were also found in the whole grain rice mean yields in the planting date × lodging treatment and the variety × lodging treatment evaluations. The random effects of year and location were evaluated using the SAS PROC Mixed procedure and results indicated that both random effects were negligible.

Differences were also found for total rice milling yield with respect to lodging treatment (Table 2). Total rice milling yield represents that portion of rough rice milled out as whole grain (head rice) and broken grain (second heads). Total whole grain milling yield differences were found to be significant for the three lodging treatments as well as for the variety × lodging evaluation. No statistical differences were found for the planting date × lodging treatment.

Estimates of least squares mean rice milling yields across planting dates and lodging treatments evaluated in this study are presented in Table 3. Least squares means differences for milling yield by planting date and lodging treatment are shown in Table 4. Mean milling yields for the two planting date treatments were similar in both whole grain yield and total grain yield. Milling yield for the early planting date over all samples averaged 518.72 g kg^{-1} of head rice and 695.62 g kg^{-1} of total grain per hundredweight of rough rice milled. Milling yields for the late planted trials averaged 527.75 g kg^{-1} of whole grain and

Table 1. Analysis of variance for whole grain (head rice) milling yields from studies performed at four locations in 2 yr.†

Source	Numerator df	Denominator df	*F* value	*P* > *F*
Pltdate‡	1	15	0.16	0.6939
Variety	7	372	31.52	<0.0001
Pltdate × Variety	7	372	3.55	0.0010
Treatment	2	761	54.32	<0.0001
Pltdate × Treatment	2	761	4.74	0.0090
Variety × Treatment	14	762	1.95	0.0187
Pltdate × Variety × Treatment	14	762	0.88	0.5793

† A total of 1200 observations (2 yr × 4 locations × 4 replicates × 2 planting dates × 6 varieties (7 at one location) × 3 treatments).
‡ Pltdate = planting date.

Table 2. Analysis of variance for total grain (total rice) milling yields from studies performed at four locations in 2 yr.†

Source	Numerator df	Denominator df	*F* value	*P* > *F*
Pltdate‡	1	12	0.00	0.9785
Variety	7	370	52.25	<0.0001
Pltdate × Variety	7	374	0.89	0.5167
Treatment	2	760	59.12	<0.0001
Pltdate × Treatment	2	760	0.74	0.4759
Variety × Treatment	14	761	5.47	<0.0001
Pltdate × Variety × Treatment	14	761	0.26	0.9972

† A total of 1200 observations (2 yr × 4 locations × 4 replicates × 2 planting dates × 6 varieties (7 at one location) × 3 treatments).
‡ Pltdate = planting date.

Table 3. Least squares means for whole grain (head rice) yield and total grain (total rice) milling yield by planting date and lodging treatment

Source	Planting date	Lodging treatment	Head rice yield		Total rice yield	
			Mean	SE	Mean	SE
			g kg^{-1}			
Pltdate†	early	–	518.72	15.91	695.62	10.13
Pltdate	late	–	527.75	15.91	695.50	10.13
Treatment	–	early	511.53	11.55	691.90	9.89
Treatment	–	late	507.78	11.55	693.20	9.89
Treatment	–	standing	550.40	11.55	701.58	9.89
Pltdate × Treatment	early	early	510.68	16.34	692.56	10.16
Pltdate × Treatment	early	late	495.33	16.34	693.25	10.16
Pltdate × Treatment	early	standing	550.26	16.34	701.06	10.16
Pltdate × Treatment	late	early	512.39	16.34	691.24	10.16
Pltdate × Treatment	late	late	520.34	16.34	693.15	10.16
Pltdate × Treatment	late	standing	550.53	16.34	702.10	10.16

† Pltdate = planting date.

695.50 g kg^{-1} of total grain per kilogram of rough rice milled. Neither of these differences in whole grain or total grain milling yield were found to be significant.

Differences were found in the least squares means estimates by lodging treatment ($p = 0.05$). Early lodged samples averaged 511.53 g kg^{-1} of whole grain rice and later lodged samples averaged 507.78 g kg^{-1} of whole grain rice over all planting dates, varieties, locations, and years (Table 3). These whole grain rice milling yields were different from the whole grain rice milling yield for the standing (not lodged) treatment. Standing rice samples averaged 550.40 g kg^{-1} of whole grain rice per kilogram of rough rice milled. The reduction in whole grain rice milling yield of 38.86 g kg^{-1} for early lodged rice and 42.62 g kg^{-1} for late lodged rice, although not statistically different from each other, were both found to be different from the whole grain rice yield on non-lodged rice (Table 4).

Similar results were found for the impacts of lodging on total rice grain milling yield. Total grain milling yield (whole grain and brokens) averaged 691.90 and 693.20 g kg^{-1} per kilogram of rough rice milled for the early lodged and late lodged treatments, respectively (Table 3). Although these total milling yields were not found to be different from each other, they were found to be different from the total milling yield of the standing, non-lodged treatment which yielded 701.58 g kg^{-1} of total rice grain.

Impacts of lodging on rice milling yields were found to be significant ($p = 0.05$) in the evaluation of the planting date × lodging treatment trials. Once again, no differences were found between the early and late lodging treatments. However, both

Table 4. Least squares means differences for whole grain (head rice) yield and total grain (total rice) milling yield by planting date and lodging treatment

Source	Planting date	Lodging treatment	Planting date	Lodging treatment	Head rice yield		Total rice yield	
					Diff.	$P > t$†	Diff.	$P > t$†
					g kg^{-1}	%	g kg^{-1}	%
Pltdate (PD)‡	early	–	late	–	–9.0310	0.6939	0.1252	0.9785
Treatment (TR)	–	early	–	late	3.7525	0.6861	–1.3030	0.3698
Treatment (TR)	–	early	–	standing	–38.8647	<0.0001	–9.6799	<0.0001
Treatment (TR)	–	late	–	standing	–42.6172	<0.0001	–8.3768	<0.0001
PD × TR	early	early	early	late	15.4528	0.1551	–0.6961	0.9959
PD × TR	early	early	early	standing	–39.5873	<0.0001	–8.5007	<0.0001
PD × TR	early	late	early	standing	–55.0401	<0.0001	–7.8046	<0.0001
PD × TR	early	early	late	early	–1.7126	1.0000	1.3159	0.9998
PD × TR	early	early	late	late	–9.6604	0.9984	–0.5940	1.0000
PD × TR	early	early	late	standing	–39.8546	0.5158	–9.5431	0.3213
PD × TR	early	late	late	early	–17.1654	0.9765	0.0120	0.9981
PD × TR	early	late	late	late	–25.1132	0.8866	0.1021	1.000
PD × TR	early	late	late	standing	–55.3074	0.1596	–8.8470	0.4087
PD × TR	early	standing	late	early	37.8747	0.5726	9.8166	0.2895
PD × TR	early	standing	late	late	29.9269	0.7877	7.9066	0.5390
PD × TR	early	standing	late	standing	–0.2673	1.000	–1.0425	0.9999
PD × TR	late	early	late	late	–7.9478	0.8168	–1.9100	0.7288
PD × TR	late	early	late	standing	–38.1420	<0.0001	–10.8591	<0.0001
PD × TR	late	late	late	standing	–30.1942	<0.0001	–8.9491	<0.0001

† Head rice and total rice milling yield differences evaluated using Tukey–Kramer method.

‡ Pltdate = planting date.

lodging treatments were different from the standing crop treatment in both whole grain and total grain milling yield for each planting date. In the early rice planting date trials, early and late lodged treatments averaged 510.68 and 495.22 g kg^{-1} in whole grain rice yield, respectively, and 692.56 and 693.20 g kg^{-1} in total rice milling yield (Table 3). The milling yield for the standing crop treatment was 550.26 g kg^{-1} of whole grain rice and 701.06 g kg^{-1} of total grain, both of which were higher than the milling yields for the lodged treatments. The greatest differences were in the whole grain rice milling yield. Reduction in whole grain rice yield from lodging of 39.58 and 55.04 g kg^{-1} for the early and late lodging treatments were both different from the standing crop whole grain rice yield (Table 4). In the late planting date trials, whole grain rice milling yields were 512.39 and 520.34 g kg^{-1} for early and late lodging. Differences from the standing crop of 38.14 and 30.19 g kg^{-1} were statistically significant. The impact of lodging on total grain milling yield of late planted rice compared to the standing crop were statistically significant, although much smaller. The larger observed impact of lodging on whole grain rice milling yield is important because whole grains are valued higher than broken grains in a milled rice sample. If lodging impacts head rice yield more than total grain yield, lodging will have a greater impact on the market price of rough rice received by the producer.

The rough rice market price based on milling yield was estimated for each rice sample using Eq. [1] along with the estimated values of whole grain and broken grain rice for long and medium grain rice varieties. Least squares mean values for rough rice market price along with least squares differences are shown in Table 5 for planting date and lodging treatments. Since there were no differences in rice milling yields by planting date, the estimated mean rough rice market prices for those two treatments of \$0.3021 and \$0.3032 kg were also not different ($p = 0.05$). However, impacts from lodging on market price, as was the case in milling yield, were found to be significant. For the evaluation of lodging over all planting dates, the estimated rough rice market prices for early and late lodged rice, based on milling yield, of \$0.2995 and \$0.2994 kg, were different from the estimate market price of \$0.3091 kg for the standing crop. Mean market price reductions due to lodging of \$0.0095 kg (early lodged) and \$0.0097 (late lodged) were significant. Similar results were found by evaluating different planting dates. Early and late lodging on early planted rice reduced mean rough rice market prices by \$0.2992 and \$0.3015 kg. Early and late lodging on later planted rice reduced mean rough rice market prices by \$0.0098 and \$0.0075 kg. These reductions in market price due to lodging result from the comparatively larger reduction in whole grain rice milling yield compared to total grain milling yield.

SUMMARY AND CONCLUSIONS

Lodging of rice plants just before harvest has been known to negatively impact harvest yield. Primary potential impacts from lodging can occur in quantity of grain recovered from affected areas, the milling yield of lodged rice, as well as the quality of lodged rice. The objective of this study was to quantify the impact of rice lodging on milling yield and rough rice market

Table 5. Rough rice market price and total revenue by planting date and lodging treatment

Source	Planting date	Lodging treatment	Market price	SE	Price difference†	Difference $P > t$‡
			$ kg^{-1}			%
Pltdate§	early	–	0.3021	0.0127	–0.0011	0.8175
Pltdate	late	–	0.3032	0.0127	–	–
Treatment	–	early	0.2995	0.0125	–0.0095	<0.0001
Treatment	–	late	0.2994	0.0125	–0.0097	<0.0001
Treatment	–	standing	0.3091	0.0125	–	–
Pltdate × Treatment	early	early	0.2999	0.0128	–0.0092	<0.0001
Pltdate × Treatment	early	late	0.2972	0.0128	–0.0119	<0.0001
Pltdate × Treatment	early	standing	0.3091	0.0128	–	–
Pltdate × Treatment	late	early	0.2992	0.0128	–0.0098	<0.0001
Pltdate × Treatment	late	late	0.3015	0.0128	–0.0075	<0.0001
Pltdate × Treatment	late	standing	0.3090	0.0128	–	–

† Differences in market prices determined from comparison to standing crop for lodging treatments.

‡ Differences in market prices evaluated using Tukey–Kramer method.

§ Pltdate = planting date.

price. A 2-yr study was conducted to address this question with research trials locations in four of the major rice growing areas of the southeastern United States. Two rice lodging treatments were specified to evaluate with comparisons to a standing non-lodged treatment. A range of rice varieties were included in the study which also evaluated potential differences from planting dates. An early lodged treatment was conducted with the rice crop manually lodged approximately 5 to 7 d before field drainage. A later lodged treatment was conducted with the rice crop manually lodged approximately 1 wk before harvest maturity. These two lodging treatments were used to represent the range of time over which a rice crop could lodge before harvest.

Results from this study indicated that crop lodging just before harvest does have a significant impact on rice milling yield and rough rice market price. There were no observed differences in milling yield or market price which resulted from the timing the lodging. However, lodging was observed to have a greater impact on the whole grain (head rice) milling yield than on the total grain milling yield compared to a non-lodged crop, although reductions in both were significant. Whole grain rice milling yields were estimated to be reduced by 30.19 to 55.30 g kg^{-1} and total rice grain milling yields were estimated to be reduced by 7.80 to 10.85 g kg^{-1} from lodging. These milling yield reductions were estimated to reduce rough rice market price by $0.0075 to $0.0119 kg, due to changes in milling yield alone. Other impacts from lodging related to rice quality and actual yield recovered would also impact market price received and crop revenue per hectare harvested.

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