Correcting Head Rice Yield for Surface Lipid Content (Degree of Milling) Variation

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ABSTRACT

Head rice yield (HRY) is the primary parameter used to quantify rice milling quality. However, HRY is affected by the degree of milling (DOM) and thus HRY may not be comparable between different lots if the DOM is different. The objective of this study was to develop a method by which HRY values can be adjusted for varying DOM values when measured by surface lipid content (SLC). Seventeen rough rice lots including long-grain and medium-grain cultivars and hybrids were harvested from two 2003 and five 2004 locations. Duplicate subsamples of each lot were milled in a McGill No. 2 laboratory mill for 10, 15, 20, or 40 sec after zero, one, two, three, and six months of storage. HRY and SLC were measured. The average HRY versus SLC slope across all milling duration data sets was 9.4. As such, it is suggested that, when milling with a McGill No. 2 laboratory mill, the HRY of a rice lot can be adjusted by a factor of 9.4 percentage points for every percentage point difference between the rice lot SLC and a specified SLC.

Many factors, including rice moisture content (MC), temperature, and kernel surface topography, affect the relative ease by which bran is removed from rice kernels during milling. Therefore, the rate of bran removal can vary from one lot of rice to another (Siebenmorgen et al 2006). Ideally, rice samples are milled to a consistent, specified DOM, with DOM defined as the extent to which the germ and bran layers of brown rice kernels have been removed during the milling process. There are specific rice DOM grades established by the U.S. Department of Agriculture (USDA) that range from under-milled to hard-milled and are officially determined visually (USDA 1997). However, in commercial practice, DOM is often rapidly and objectively measured using light-transmittance or reflectance instruments such as milling meters and color meters or with NIR technology. A more time-consumptive, yet presumably more accurate, method of DOM determination measures the milled rice surface lipid content (SLC) through petroleum ether extraction (Mastler and Siebenmorgen 2005). This extraction method measures the amount of lipid remaining on a milled, whole rice kernel and thus is an indication of the amount of bran and germ remaining after milling, as rice bran is composed of ≈20% lipids.

Rice milling quality is usually expressed as HRY, the mass percentage of rough rice kernels that are ≥75% of the original kernel length after milling. As milling duration increases, DOM increases (thus SLC decreases) and HRY decreases linearly (Reid et al 1998; Siebenmorgen et al 2006). When comparing the milling quality of rice lots, HRY is the comparison parameter even though the DOM of the lots may be different, which ultimately results in inaccurate HRY comparisons. The ultimate objective of this study was to develop a method by which HRY values can be adjusted for varying DOM values when measured in the form of SLC.

One foreseen consideration was the effect of storage duration on HRY. Daniels et al (1998) found that as storage duration increased, milling duration had to be increased to achieve a consistent DOM as measured with a milling meter. Head rice yield also increased as storage duration increased for up to three months postdrying (Daniels et al 1998; Pearce et al 2001). Therefore, a parallel objective of this study was to determine whether storage duration should be considered when adjusting HRY for differences in SLC.

MATERIALS AND METHODS

Sample Procurement and Pretreatment Conditions

Seventeen rough rice lots (Fig. 1) were harvested from two 2003 and five 2004 locations as part of a field-scale variety testing program. Harvest MC range was 18–20%, wet basis. After harvest, samples were dried in a chamber maintained at 21°C and 62% relative humidity, corresponding to a rough rice equilibrium MC of 12.5% (ASAE 2004). Actual dried rough rice MC range was 11.5–13.0%, determined as the average MC of 50 kernels measured with an individual kernel MC meter (CTR 800E, Shizuoka Seiki, Shizuoka, Japan). After drying, samples were stored in Ziplock plastic storage bags at 4°C until treatment.

Head Rice Yield Determination

Samples were milled after 0, 1, 2, 3, and 6 months of storage. Before milling, samples from each of the 17 lots were removed from 4°C storage and equilibrated to room temperature, while in the sealed plastic bags, for at least one day. Eight rough rice samples (150 g) from each year/location/cultivar/storage period lot were then dehulled in a laboratory sheller (Type THU, Satake, Tokyo, Japan). Pairs (duplicates) of the resultant brown rice sam-

Fig. 1. Dataset samples of 17 lots of rice milled for four durations, in duplicate, after 0, 1, 2, 3, and 6 months of storage. In total, 680 head rice yield (HRY) and 680 surface lipid content (SLC) analyses were conducted.

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ples were milled for 10, 15, 20, or 40 sec in a laboratory mill (McGill #2, Rapsco, Brookshire, TX) that was equipped with a 1.5 kg mass positioned on the mill lever arm 15 cm from the centerline of the mill chamber. HRY was measured using an image analysis system (2312 Grain Check, Foss North America, Eden Prairie, MN) and expressed as the mass percentage of head rice to initial mass of rough rice. Duplicate measurements were averaged before data analysis. Head rice was subsequently separated from brokens with a sizing device (Seedburo Equipment Co., Chicago, IL) and stored at 4°C in sealed plastic bags.

Surface Lipid Content Measurement

Samples were placed at room temperature for 2 hr before SLC determination. The SLC of each head rice subsample from each duplicate year/cultivar/storage duration/milling duration sample was measured using a lipid extraction system (Soxtec Avanti 2055, Foss) following the procedure of Matsler and Siebenmorgen (2005). In summary, this method used 5 g of head rice weighed into cellulose thimbles (Foss) that were first predried for 1 hr in an oven maintained at 100°C. Lipid was then extracted from the sample with 70 mL of petroleum ether (boiling point 35–60°C; VWR, Suwanee, GA). The hot plate below the extraction cups was heated to 135°C while the thimbles were immersed in the extraction cup solvent for a boiling duration of 20 min, then raised above the solvent and rinsed with petroleum ether condensate for 30 min. After rinsing, the extraction cups were placed into an oven maintained at 100°C for 30 min, then moved to a desiccator to cool to room temperature for ≈30 min before being weighed. The difference between the mass of the cups containing the extracted lipid and the original mass of the cups was then calculated to obtain the mass of the extracted lipid. SLC was expressed as the mass percentage of extracted lipid to the original head rice sample mass. Duplicate measurements were averaged before data analysis.

Data Analysis

Head rice yield (dependent variable) versus SLC (independent variable) regression equations were determined for each year/location/cultivar/storage duration data set. Each set included four HRY and four SLC data points corresponding to the HRY and SLC measured at each of the four milling durations. The effect of storage duration on HRY versus SLC slope was determined using the Student's t-test with statistical software (JMP 6, SAS Institute, Cary, NC).
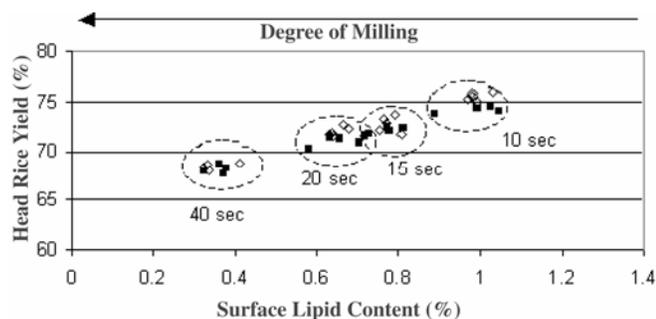
RESULTS AND DISCUSSION

As expected from previous studies (Reid et al 1998; Siebenmorgen et al 2006), SLC and HRY decreased linearly as milling duration increased and as more bran was removed. A typical response of HRY and SLC to increased milling duration is presented in Fig. 2. As SLC decreased through longer milling durations, HRY decreased linearly (Fig. 3). Reid et al (1998) and Sun and Siebenmorgen (1993) showed that HRY was linearly related to DOM, where DOM was measured instrumentally with a milling meter.
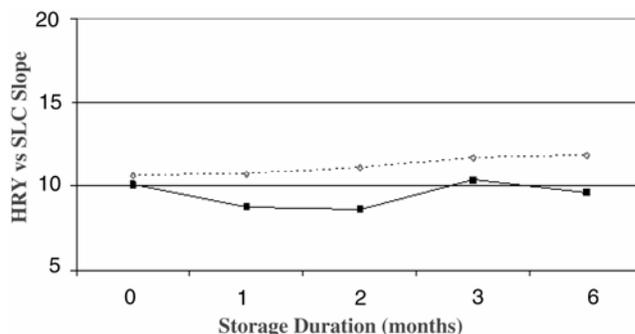
The HRY and SLC values (generated by varying milling durations) from each of the 85 year/cultivar/location/storage duration treatment combinations were well correlated. R^2 values were 0.85–1.00. However, the regression slope values varied considerably among the tested samples, with no consistent pattern due to harvest location or year (Fig. 4). Figure 5 shows that slope values ranged from 5.4 (month 1 of Cocodrie from Essex, MO, in 2004) to 15.7 (month 3 of Wells from Davidson, AR, in 2003). A greater slope
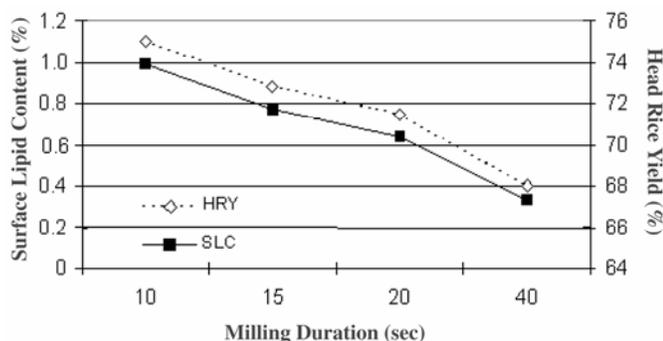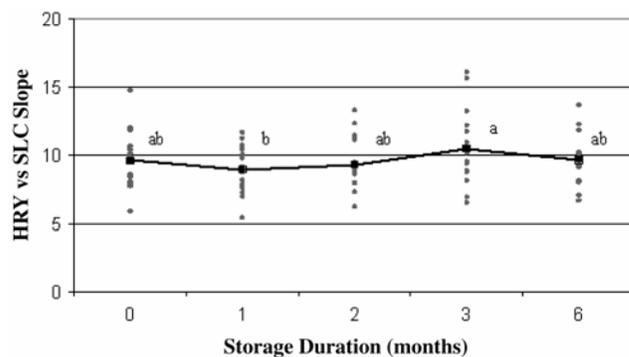
Fig. 2. Surface lipid content (SLC) and head rice yield (HRY) decrease of Bengal rice, harvested in 2004 from Jonesboro, AR, milled for the indicated milling durations.

Fig. 4. Effect of storage duration on head rice yield (HRY) vs. surface lipid content (SLC) slope. Effect of storage duration was not consistent between sample lots. Data from Bengal rice grown in 2004 in Jonesboro, AR (■) and Lodge Corner, AR (◇).

Fig. 3. Effect of surface lipid content (SLC) on head rice yield (HRY) of Bengal rice grown in 2004 in Jonesboro, AR (◇) and Lodge Corner, AR (■). Circled data points represent rice milled for 10, 15, 20, 40 sec, with degree of milling increasing with decreasing SLC. Each point is the mean HRY and SLC of duplicate samples milled after 0, 1, 2, 3, or 6 months of storage.

Fig. 5. Effect of storage duration on the head rice yield (HRY) vs. surface lipid content (SLC) slope, showing the averages (■) of all slopes (✳) after 0, 1, 2, 3, and 6 months of storage. Mean pairs denoted with the same letter are not significantly different ($P < 0.05$) (unnormalized data).

value implies that there was a greater reduction in HRY for a given decrease in SLC. The differences in the HRY versus SLC slopes could be due to inherent differences among cultivars such as kernel dimensions and surface topography. When milling a cultivar that features deep kernel surface grooves, it would be expected that the ridges could be removed while a greater amount of bran could remain on the kernel, as opposed to a kernel with a smoother surface, which would be expected to mill more uniformly (Bhashyam and Srinivas 1984). The presence of deep kernel surface grooves would then result in a greater HRY versus SLC slope; that is, a relatively small reduction in SLC corresponds to a large reduction in HRY. Differences in kernel thickness distributions from sample to sample could also have played a role in the slope differences as thick and thin kernels experience different bran removal rates (Chen and Siebenmorgen 1997; Chen et al 1998). Finally, Reid et al (1998) showed that the MC of the rice at the time of milling affects the rate of bran removal and the HRY versus DOM slope. In this study, milling MC range was 11.5–13% and were not correlated with HRY versus SLC slope.

The average HRY versus SLC slope values for storage durations of 0, 1, 2, 3, and 6 months were 9.6, 9.0, 9.3, 10.5, and 9.6, respectively (Fig. 5). With the large range in slope data displayed in Fig. 5, it is not surprising that storage duration did not have a significant effect ($P > 0.05$) on the HRY versus SLC slope in an ANOVA analysis, though in a comparison of means, the mean value at 3 months of storage was significantly greater than the values at 1 month of storage. In other words, there was a significantly greater reduction in HRY for a given change in SLC at 3 months of storage compared with that at 1 month. These changes in kernel milling behavior due to storage duration are supported by Pearce et al (2001).

Normalization was performed by taking the difference between the mean slope value obtained at each storage duration and the average slope value over all storage duration for each year/location/cultivar combination. In an ANOVA analysis, the normalized values showed that the effect of storage durations was significant ($P < 0.05$) and the same mean pairs as in the unnormalized

analysis were different. Further studies into the effects of storage on grain hardness and bran properties are necessary to fully understand this phenomenon.

For practical implementation of a technique to meet this study's objective, the HRY and SLC data of each of the 17 year/location/cultivar lots were regressed across storage duration. In this manner, effects of storage duration on the HRY versus SLC slopes were incorporated into the calculated adjustment equation. Table I shows the regression equations and respective R^2 values obtained for each of the 17 lots. The regression equations explained 89–97% of the data variation and the HRY versus SLC slopes (ppHRY/ppSLC) were 7.0–13.4. The average of all the HRY versus SLC slope values was 9.4.

Equation 1 represents an approach that can be used to adjust the HRY of a sample for SLC

$$\text{HRY}_{adjusted} = \text{HRY}_{sample} - 9.4\,(\text{SLC}_{sample} - \text{SLC}_{standard}) \qquad (1)$$

where $\text{HRY}_{adjusted}$ = HRY of a lot adjusted for differences in SLC between the lot SLC and the desired, specified SLC value (%); HRY_{sample} = HRY of a rice lot with a given DOM (SLC_{sample}) (%); SLC_{sample} = SLC of a rice lot (%); $\text{SLC}_{standard}$ = predetermined, specified SLC of a standard or processing application (%).

For example, if 0.5% SLC was determined to be the standard DOM for a particular application, a rice lot with a HRY of 62.0% and a SLC 0.7% would have a $\text{HRY}_{adjusted}$ value of 60.1%. If the SLC in the previous example were 0.2%, the lot would have a $\text{HRY}_{adjusted}$ value of 64.8%. A sample with a SLC of 0.5% would not have to be adjusted.

CONCLUSIONS

To correct HRY for differing SLC, a given HRY can be adjusted by subtracting $9.4 \times \Delta\text{SLC}$, where ΔSLC is the difference in SLC of a rice lot and a predetermined standard or desired SLC (Equation 1). The value of 9.4 is the average slope of the regression lines correlating HRY and SLC for 17 lots of rice, with subsamples of each lot milled for either 10, 15, 20, or 40 sec after 0, 1, 2, 3, and 6 months of storage. The approach used to obtain the 9.4 factor incorporated storage duration effects into the HRY versus SLC slopes. It is proposed that HRY adjusted by this factor, for differences between a sample's SLC and that of a standard value, would give a more accurate value of the true milling quality of a rice lot. Further studies are needed to fully understand the HRY versus SLC slope differences observed between locations and storage durations and the universal appropriateness of the 9.4 factor.

TABLE I
Regression Equations Relating Head Rice Yield (HRY, *y*) and Surface Lipid Content (SLC, *x*) of 17 Lots of Rice[a]

Cultivar	Type[b]	Location	Regression Eq[c]	R^2
2003				
Cocodrie	LG	Davidson	$y = 8.6x + 62.4$	0.95
Cocodrie	LG	Riggs	$y = 7.1x + 65.5$	0.90
Francis	LG	Davidson	$y = 11.4x + 57.1$	0.90
Wells	LG	Davidson	$y = 12.6x + 53.2$	0.92
2004				
Bengal	MG	Jonesboro	$y = 10.8x + 64.7$	0.96
Bengal	MG	Lodge Corner	$y = 9.4x + 64.8$	0.97
Cocodrie	LG	Essex	$y = 7.0x + 65.4$	0.93
Cocodrie	LG	Hazen	$y = 7.2x + 67.2$	0.94
Cocodrie	LG	Newport	$y = 9.3x + 63.3$	0.93
Wells	LG	Essex	$y = 9.1x + 61.1$	0.89
Wells	LG	Hazen	$y = 9.0x + 64.8$	0.95
Wells	LG	Newport	$y = 8.4x + 64.3$	0.97
XP716	LGH	Jonesboro	$y = 8.6x + 68.5$	0.95
XP716	LGH	Lodge Corner	$y = 9.4x + 64.8$	0.97
XP723	MGH	Essex	$y = 13.4x + 62.3$	0.97
XP723	MGH	Hazen	$y = 9.3x + 64.9$	0.97
XP723	MGH	Newport	$y = 9.9x + 67.1$	0.94

[a] Rice harvested over two years from various locations and milled for 10, 15, 20, and 40 sec after 0, 1, 2, 3, and 6 months of storage. Equations were fit through points for all milling and storage durations. Slope of the regression equations represents the change in HRY (percentage points) for a one percentage point change in SLC.
[b] LG, long grain; MG, medium grain; LGH, long grain hybrid; MGH, medium grain hybrid.
[c] Average HRY vs. SLC slope 9.4.

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