EVALUATION OF SELECTED RICE LABORATORY SHELLING EQUIPMENT

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ABSTRACT. *The Satake THU-35A and Yamamoto FC2K laboratory rice shellers were evaluated and compared to the Grain Inspection, Packers, and Stockyard Administration (GIPSA)-specified McGill sheller using different rice types, harvest moisture contents (MCs), and hulling MCs. The mass percentage of unhulled rice, mass percentage of brokens, and the number percentage of fissured kernels in brown rice samples, as well as the head rice yield (HRY) and milled rice yield (MRY), were used to quantify sheller performance. The Satake and Yamamoto shellers performed similarly to the McGill when using medium-grain and short-grain varieties. For the long-grain lots, the Yamamoto sheller performed similar to the McGill in terms of HRY and MRY, while the Satake sheller produced HRYs that were greater than the McGill.*

Keywords. *Rice Laboratory Shelling Equipment.*

The official procedure for measuring rice milling quality requires the use of laboratory shellers (GIPSA, 1994). The McGill sheller is currently the only laboratory sheller approved for official use (GIPSA, 1996). Because laboratory shellers represent a low-volume business, the availability of new equipment and repair parts are major concerns of GIPSA official grading sites and other rice quality assessment laboratories. A study was thus conducted to compare the performance of the Satake THU-35A and Yamamoto FC2K shellers to that of the McGill. The objectives were to evaluate the performance of these shellers across a range of sheller settings using rice lots of various kernel types, harvest moisture contents (MCs), and hulling MCs.

MATERIALS AND METHODS

RICE LOTS

Calrose and Calmochi varieties, both harvested in October, 2002 at approximately 21% MC (Unless otherwise specified, all moisture contents are expressed on a wet basis.) in California, were used as medium- and short-grain types, respectively. Cocodrie was selected as the long-grain variety and was harvested in September, 2002 in Arkansas. The effects of harvest MC and hulling MC were evaluated using only the long-grain; the scope and intent of the project allowed testing the effects of these variables on only one rice type. As such, two lots of Cocodrie were harvested from the same field, one at 21% MC and another later in the season at 15%. The two harvest MCs of Cocodrie were used to determine if there was an effect of average kernel maturity at the time of harvest on sheller performance. Siebenmorgen and Bautista (2005) showed that rice kernel thickness distributions, which are reasoned to affect sheller performance, vary with harvest MC. After cleaning using a dockage tester (Carter-Day Co., Minneapolis, Minn.), each lot was stored at 1~5°C in sealed plastic containers until testing.

Sample MC at the time of milling is a critical factor determining rice milling behavior. In order to evaluate this factor, the Cocodrie rice harvested at 21% MC was dried in a chamber controlled at 21°C and relative humidities of 49%, 63%, and 74% for several days until the MC reached the target levels of 11.0%, 12.5% and 14.0%, respectively. The lots of Cocodrie (harvested at 15% MC), Calrose, and Calmochi were dried to a single, target rough rice hulling MC of 12.5%. Table 1 summarizes information regarding the rice lots.

DESCRIPTION OF SHELLERS

The McGill sheller comprises a steel shelling roll that rotates in a clockwise direction at approximately 1500 rpm, a rubber roll that counter rotates at approximately 90 rpm, and an aspirator assembly (GIPSA, 1996). Hulls are dislodged as kernels pass between the rolls and are then removed by an aspirator. Two duplicate McGill shellers were calibrated by GIPSA staff (Kansas City, Mo.) and used in this study. The Yamamoto FC2K is a centrifugal-type sheller, consisting of a rotor with eight impellers rotating at 3200 to 3900 rpm in a fixed enclosure. Through rotor centrifugal action, rough rice impacts the enclosure, thereby dislodging the hulls. A blower aspirates the brown rice to remove hulls. The Satake THU-35A is a rubber roll sheller comprising a rubber roll that rotates at 1900 rpm and an identical rubber roll that rotates in a counter rotation at 1000 rpm. The rubber rolls impart a shearing, frictional force to kernels passing through the gap between the rolls. A suction fan removes dislodged hulls.

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Table 1. Rice lots used in the laboratory rice sheller evaluation experiments.

Rice Lot	Rice Variety	Harvest Location	Harvest MC (%w.b.)	Target Hulling MC (%w.b.)	Measured Hulling MC (%w.b.)
Long-grain, high HMC	Cocodrie	Arkansas	21	11.0	11.7
Long-grain, high HMC	Cocodrie	Arkansas	21	12.5	12.6
Long-grain, high HMC	Cocodrie	Arkansas	21	14.0	13.9
Long-grain, low HMC	Cocodrie	Arkansas	15	12.5	12.3
Medium-grain, high HMC	Calrose	California	21	12.5	12.6
Short-grain, high HMC	Calmochi	California	21	12.5	12.9

Experimental Procedure

A standard quantity of 1000 g of rough rice (GIPSA, 1994) at the desired MC was hulled for each experimental treatment combination, resulting in approximately 800 g of brown rice. One-sixteenth of this resulting brown rice sample (approximately 50 g) was removed using a Boerner divider. Both unshelled kernels and brokens in each of the 50-g brown rice subsamples were picked by hand and weighed using a digital scale (Explorer Pro, Ohaus Corporation, Pine Brook, N.J.). Fifty brown rice kernels were then taken randomly from the remainder of the 50-g subsample and the number of brown rice kernels with fissures was visually determined with the aid of a magnifier (GrainScope TX-200, Kett Electric Laboratory, Tokyo, Japan). After examination, the entire 50-g subsample was placed back into the original 800-g brown rice sample, which was subsequently milled.

A McGill No. 3 mill was used to mill the brown rice samples according to GIPSA guidelines (GIPSA, 1994). Milled rice yield was determined by dividing the mass of the resulting milled rice by 1000 g, the original rough rice sample mass. An imaging system (Model 2312 GrainCheck, Foss Tecator, Hoganas, Sweden) was used to assess brokens in the medium- and long-grain milled rice samples. Prior to the measurements, the imaging system was calibrated using standard medium- and long-grain samples provided by GIPSA. For assessing brokens in the short-grain samples, a shaker table was used because an imaging system calibration for short-grain inspection was not available. Head rice yield was calculated as the mass of head rice, milled kernels at least three-fourths the original kernel length, divided by the mass of the initial rough rice sample.

Laboratory Testing

Preliminary experiments were conducted to determine the range of operational settings to be used in the final, complete evaluation of the Satake and Yamamoto shellers. A complete analysis of this testing is given in Siebenmorgen et al. (2004). Table 2 indicates the settings that were used in the final testing. Since the McGill sheller served as a benchmark for comparison, the settings used for its operation were taken from GIPSA (1994). The final tests were conducted using two duplicate shellers of each model. The six rice lots described in table 1 were used and the experimental treatments were replicated six times. Therefore, there were 216 treatment combinations for the Satake sheller (3 sheller settings × 2 shellers × 6 rice lots × 6 replications), 432 for the Yamamoto (6 sheller settings × 2 shellers × 6 rice lots × 6 replications), and 72 for the McGill (2 shellers × 6 rice lots × 6 replications).

Table 2. Experimental operating settings used in evaluating the Satake THU-35A and Yamamoto FC2K laboratory rice shellers.

Sheller Type	Operational Parameter	Operational Settings	Evaluation Positions
Satake	Roll clearance	0.5, 0.8 and 1.0 mm	3
	Feed rate	1.2-mm feed rate valve gap	1
	Airflow rate	Midway position	1
Yamamoto	Rotor speed	3250 and 3500 rpm	2
	Feed rate	Low, medium, and high	3
	Airflow rate	Low	1
	Suction	Closed	1

Results and Discussion

Comparison of Duplicate Shellers

A variance analysis was conducted to determine if there were differences in performance between the duplicate shellers used. Table 3 reports the values of the performance indices, averaged across rice lots and sheller settings. For the Satake shellers, there were no significant differences in MRY or HRY, and there were no differences in the unhulled kernel percentage or the percentage of fissured kernels in the brown rice. Although the brokens percentage was statistically different, the similarity in the other performance indices was deemed sufficient to justify averaging the individual Satake sheller values for comparison to the McGill shellers.

There were no significant performance index differences between the duplicate Yamamoto shellers. Consequently, the

Table 3. Performance comparison of duplicate Satake THU-35A, Yamamoto FC2K, and McGill laboratory rice shellers.

Sheller Type		Observations	Unhulled Kernels[a] (mass %)	Brokens (mass %)	Fissured Kernels (no. %)	MRY (%)	HRY (%)
Satake	A	108	4.4[a]	5.3[d]	3.5[a]	69.9[a]	61.0[a]
	B	108	4.2[a]	4.6[e]	4.3[a]	70.0[a]	61.2[a]
Yamamoto	A	216	1.5[b]	11.8[a]	2.7[c]	69.7[a]	59.1[c]
	B	216	1.4[b]	12.2[a]	2.8[c]	69.5[a]	58.6[cd]
McGill	A	36	1.7[b]	10.1[b]	3.4[ab]	69.3[a]	59.2[c]
	B	36	1.9[b]	7.4[c]	3.0[b]	69.6[a]	60.1[b]

[a] Values in a column with the same superscripted letter are not significantly different at the 5% probability level according to an LSD test.

individual Yamamoto sheller values were averaged for comparison to the McGill shellers. Conversely, the duplicate McGill shellers presented significant differences in HRY and the percentage of broken kernels in the brown rice; the cause of which is unknown. However, from a practical standpoint, there was little difference in sheller performance, so the average McGill sheller performance was used for comparisons.

Analysis of Sheller Performance

Roll clearance did not significantly affect Satake sheller performance in terms of MRY and HRY (table 4). The one aspect of performance that was affected by roll clearance was the percentage of unhulled kernels in the brown rice. This effect was only observed in the long-grain rice, and there was no difference in this parameter between the 0.8- and 1.0-mm roll clearances.

The Yamamoto sheller analysis (table 5) indicates that feed rate did not significantly affect MRY, and from a practical standpoint, HRY as well. However, the high feed rate caused more unhulled rice and less broken rice in the brown rice stream than did the lower rates. Therefore, the high feed rate can be chosen to produce more desirable results than the lower feed rates. There was no effect of rotor speed on MRY. However, the low rotor speed of 3250 rpm produced a slightly higher HRY than the 3500-rpm rotor speed, and it also resulted in more unhulled kernels, but less broken kernels, in the brown rice. Therefore, the low rotor speed would be preferred over the higher speed.

Sheller Performance Comparison

Table 6 compares the performance of the Satake and Yamamoto shellers against that of the McGill shellers. For medium-grain Calrose and short-grain Calmochi, there were no statistical differences in HRY across all shellers. For the long-grain lots, there was never a statistical difference in HRY between the Yamamoto and McGill shellers. The Satake shellers, however, consistently produced higher HRYs than the Yamamoto and McGill shellers.

In regards to MRY, there were essentially no differences across shellers within any of the rice lots. There were statistically significant differences in MRY within the Cocodrie lot having a hulling MC of 14.0%. However, the differences were practically small.

For the Cocodrie 11.0% and 14.0% hulling MC lots, the Satake shellers produced greater brown rice percentages than the Yamamoto and McGill shellers. There were no differences in brown rice and unhulled percentages across shellers in the medium-grain Calrose. This finding also held true for the Satake and Yamamoto shellers in short-grain Calmochi; however, there was a greater amount of unhulled kernels produced by the McGill sheller with the Calmochi rice.

The Yamamoto sheller produced the greatest percentage of broken kernels across all rice lots, while the Satake sheller produced the least. There were essentially no fissured brown rice kernels produced by any sheller across the long- and short-grain lots. However, for medium-grain Calrose, there were high values of fissure percentages for all shellers and the Satake shellers produced a greater number of fissured kernels than the other two shellers.

Table 4. Mean performance of two Satake THU-35A laboratory rice shellers.[a]

Rice Variety	Harvest MC(%)	Hulling MC (%)	RC[b] (mm)	Mean Percentage[c] (%)				
				Unhulled[d]	Broken[e]	Fissured[f]	MRY[g]	HRY[h]
Cocodrie	21.0	11.0	0.5	4.4 c	4.7 c	0.5 c	70.7 b	65.8 a
			0.8	6.8 ab	4.7 c	0.3 c	70.4 b	65.1 ab
			1.0	6.6 ab	4.4 c	0.3 c	70.8 b	65.6 a
	21.0	12.5	0.5	3.9 c	5.0 c	0.5 c	70.0 bc	63.5 c
			0.8	6.5 ab	4.7 c	0.0 c	70.1 bc	63.6 c
			1.0	6.6 ab	4.7 c	0.2 c	70.1 bc	64.3 b
	21.0	14.0	0.5	4.5 c	5.1 c	0.2 c	69.7 c	62.9 d
			0.8	7.5 a	4.7 c	0.0 c	69.6 c	62.6 d
			1.0	7.6 a	4.6 c	0.3 c	69.6 c	62.7 d
	15.0	12.5	0.5	3.7 c	7.3 a	0.5 c	71.7 a	64.7 b
			0.8	6.1 b	7.2 a	0.1 c	71.7 a	64.6 b
			1.0	6.2 b	7.4 a	0.3 c	71.7 a	64.8 b
Calrose	21.0	12.5	0.5	1.5 d	5.6 b	21.7 b	69.6 c	58.0 e
			0.8	1.4 d	5.7 b	23.9 a	69.8 c	57.6 e
			1.0	1.3 d	5.4 b	22.2 ab	69.7 c	57.6 e
Calmochi	21.0	12.5	0.5	0.8 d	2.7 d	0.0 c	68.1 d	52.4 f
			0.8	0.8 d	2.5 d	0.0 c	68.0 d	52.2 f
			1.0	0.7 d	2.5 d	0.0 c	67.9 d	51.9 f

[a] Values in a column with the same superscripted letter are not significantly different at the 5% probability level according to an LSD test.
[b] Roll clearance.
[c] All values are the mean of 12 observations.
[d] Mass percentage of unhulled rice in brown rice samples.
[e] Mass percentage of broken rice in brown rice samples.
[f] Number percentage of fissured kernels in brown rice samples.
[g] Milled rice yield.
[h] Head rice yield.

Table 5. Mean performance of two Yamamoto FC2K laboratory rice shellers[a] .

Rice Variety	Harvest MC (%)	Hulling MC (%)	RS[b] (rpm)	FR[c]	Mean Percentage[d] (%) Unhulled[e]	Broken[f]	Fissured[g]	MRY[h]	HRY[i]
Cocodrie	21.0	11.0	3250	Low	1.3 cd	11.4 d	0.0 e	70.1 b	62.6ab
				Medium	1.7 c	10.4 e	0.0 e	70.4 b	63.4a
				High	2.4 b	10.3 e	0.0 e	70.1 b	63.3a
			3500	Low	0.5 d	13.5 b	0.0 e	69.6 b	61.5 c
				Medium	0.8 d	13.0 bc	0.0 e	69.8 b	61.9 bc
				High	1.2 cd	11.8 d	0.0 e	70.1 b	62.8 ab
	21.0	12.5	3250	Low	1.9 c	11.7 d	0.3 e	69.6 b	61.4 c
				Medium	2.5 b	10.9 de	0.0 e	70.0 b	62.1 b
				High	3.2ab	10.6 e	0.2 e	70.0 b	62.4 b
			3500	Low	1.1 cd	12.8 c	0.2 e	69.6 b	61.0 c
				Medium	1.4 c	12.6 c	0.0 e	69.5 b	61.0 c
				High	2.2 b	12.1 cd	0.0 e	69.6 b	61.3 c
	21.0	14.0	3250	Low	2.8 b	12.5 c	0.0 e	69.0 bc	59.3 de
				Medium	3.3ab	11.3 d	0.2 e	68.9 bc	59.4 de
				High	4.1a	11.3 d	0.0 e	69.5 b	60.0 d
			3500	Low	1.2 cd	14.4 b	0.0 e	68.4 c	57.8 e
				Medium	1.6 c	14.1 b	0.0 e	68.6 bc	58.1 e
				High	2.6 b	12.9 cd	0.0 e	68.7 bc	58.8 e
	15.0	12.5	3250	Low	1.4 c	14.0 b	0.0 e	71.5 a	61.7 c
				Medium	1.7 c	13.8 b	0.0 e	71.7 a	62.4 b
				High	2.5 b	12.9 c	0.2 e	71.3 a	62.2 b
			3500	Low	0.6 d	15.8 a	0.0 e	71.2 a	60.3 d
				Medium	0.8 d	15.4 a	0.3 e	71.3 a	60.7 cd
				High	1.3 cd	14.7 ab	0.0 e	71.5 a	61.6 c
Calrose	21.0	12.5	3250	Low	0.8 d	12.7 c	16.7 bc	69.8 b	57.5 ef
				Medium	1.1 cd	12.1 c	19.3 a	69.9 b	57.8 ef
				High	1.4 c	12.4 c	17.5 b	69.7 b	57.3 ef
			3500	Low	0.3 d	14.6 ab	15.0 c	69.6 b	56.9 f
				Medium	0.5 d	14.1 b	13.3 d	69.5 b	57.4 ef
				High	0.8 d	13.8 b	16.3 bc	69.6 b	57.2 f
Calmochi	21.0	12.5	3250	Low	0.3 d	7.3 g	0.0 e	67.9 c	51.5 g
				Medium	0.4 d	7.1 g	0.0 e	67.6 c	51.4 g
				High	0.7 d	6.9 g	0.0 e	68.6 c	51.8 g
			3500	Low	0.2 d	8.6 f	0.0 e	68.0 c	51.5 g
				Medium	0.3 d	8.5 f	0.0 e	67.6 c	50.9 gh
				High	0.3 d	8.3 f	0.0 e	67.6 c	50.3 h

[a] Values in a column with the same superscripted letter are not significantly different at the 5% probability level according to an LSD test.
[b] Rotor speed.
[c] Feed rate.
[d] All values are the mean of 12 observations.
[e] Mass of unhulled rice in brown rice samples.
[f] Mass percentage of broken rice in brown rice samples.
[g] Number percentage of fissured kernels in brown rice samples.
[h] Milled rice yield.
[i] Head rice yield.

Significance of Findings

The performance of the Satake THU-35A and Yamamoto FC2K laboratory rice shellers was similar to the GIPSA-specified McGill sheller when using the selected medium- and short-grain rice varieties. For the long-grain lots, the Yamamoto shellers performed statistically similar to the McGill shellers in terms of HRY and MRY, while the Satake shellers produced HRYs that were greater than those of the McGill.

This study provides preliminary evaluation information for choosing alternative laboratory shellers for use in measuring rice milling quality. However, in order to officially introduce alternative laboratory shellers to the McGill, further testing is required to validate the optimum settings used in this study for both the Satake and Yamamoto shellers. Additionally, further comparative tests to the McGill are needed.

Table 6. Comparison of the Satake THU-35A, Yamamoto FC2K, and McGill laboratory rice shellers under optimum settings[a].

Rice Variety	Harvest MC (%)	Hulling MC (%)	Sheller Type	Mean Percentage[b] (%)					
				Brown Rice[c]	Unhulled[d]	Broken[e]	Fissured[f]	MRY[g]	HRY[h]
Cocodrie	21.0	11.0	Satake	83.3 a	6.6 b	4.4 h	0.3 c	70.8 bc	65.6 a
			Yamamoto	81.9 bc	2.4 e	10.3 c	0.0 c	70.1 b	63.3 c
			McGill	81.6 bc	1.3 f	8.6 e	0.0 c	69.7 b	63.3 c
	21.0	12.5	Satake	83.0 ab	6.6 b	4.7 gh	0.2 c	70.1 b	64.3 b
			Yamamoto	81.9 bc	3.2 d	10.6 c	0.2 c	70.0 b	62.4 d
			McGill	81.6 bc	1.2 f	9.3 d	0.0 c	69.4 b	62.5 d
	21.0	14.0	Satake	83.4 a	7.6 a	4.6 gh	0.3 c	69.6 b	62.7 cd
			Yamamoto	82.5 b	4.1 c	11.3 b	0.0 c	69.5 b	60.0 e
			McGill	82.0 bc	1.6 f	10.6 c	0.0 c	68.4 c	59.4 e
	15.0	12.5	Satake	83.8 a	6.2 b	7.4 f	0.3 c	71.7 a	64.8 ab
			Yamamoto	82.8 ab	2.5 e	12.9 a	0.2 c	71.3 a	62.2 d
			McGill	82.7 ab	1.0 g	11.5 b	0.3 c	71.2 a	62.7 cd
Calrose	21.0	12.5	Satake	81.1 c	1.3 f	5.4 g	22.2 a	69.7 b	57.6 f
			Yamamoto	80.6 cd	1.4 f	12.4 ab	17.5 b	69.7 b	57.3 f
			McGill	80.8 c	1.8 ef	9.2 d	18.9 b	69.9 b	57.9 f
Calmochi	21.0	12.5	Satake	79.9 d	0.7 g	2.5 j	0.0 c	67.9 d	51.9 g
			Yamamoto	79.6 d	0.7 g	6.9 fg	0.0 c	68.6 c	51.8 g
			McGill	80.2 d	3.9 cd	3.2 i	0.0 c	68.0 cd	52.2 g

[a] A roll clearance of 1.0 mm, a 1.2-mm feed rate valve gap, and the midway airflow rate position were chosen as optimum settings for the Satake shellers.
A rotor speed of 3250 rpm, the high feed rate setting, and the low airflow rate position were chosen as optimum settings for the Yamamoto shellers.
Values in a column with the same superscripted letter are not significantly different at the 5% probability level according to an LSD test.
[b] All values are the mean of 12 observations.
[c] Mass percentage of the 1000-g rough rice sample remaining as brown rice.
[d] Mass percentage of unhulled rice in brown rice samples.
[e] Mass percentage of broken rice in brown rice samples.
[f] Number percentage of fissured rice kernels in brown rice samples.
[g] Milled rice yield.
[h] Head rice yield.

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