Evaluation of the McGill No. 2 Rice Miller[1]

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ABSTRACT

The effects of moisture content (MC), milling time, pressure applied to rice, and sample size on head rice yield and degree of milling were evaluated with the McGill No. 2 miller. MC was 9–14% (wb), milling time was 0–60 sec (in 15-sec intervals), and sample sizes were 100, 125, and 150 g of rough rice. The pressure applied to the rice was adjusted by varying the position of a 1.5-kg weight on the weight lever. Samples produced by milling at the experimental combinations were graded by the Federal Grain Inspection Service. MC was found to be the most significant variable and sample size the least significant variable in affecting head rice yield (HRY). When MC was decreased or sample size was increased, HRY increased. It was also determined that when milling time or pressure applied to the rice was increased, HRY decreased. HRYs obtained with the No. 2 miller were compared to yields obtained with the McGill No. 3 miller at corresponding MCs. It may be possible to obtain equivalent results with the proper settings. However, no one combination was found to produce equivalent results across all four MCs for both varieties.

Head rice yield (HRY) is one of the primary factors determining the milling quality of rice. Head rice is milled rice that comprises kernels that are three fourths kernel or more in length (USDA 1979). HRY is the weight percentage of rough rice that remains as head rice throughout the milling process. This parameter is used in determining pricing schedules of rice and thus is critical to the producer, processor, and grader. Another parameter, used in determining the milling quality of rice, is the degree of milling. This indicates the amount of bran remaining on rice kernels after milling. The U.S. Department of Agriculture rice standards (USDA 1982) currently specify the use of the McGill No. 3 miller as part of the overall procedure in determining these parameters. However, a smaller miller, the McGill No. 2, is becoming more popular than the No. 3 in the rice industry.

One significant reason for the increasing popularity of the No. 2 miller is its lower initial cost. Other reasons include lower power and sample size requirements. The No. 2 miller is powered by a 0.25-kW (1/3 hp), single-phase motor, compared to the 2.24-kW (3 hp), three-phase motor of the No. 3 miller. Sample size is reduced from 1 kg of rough rice for the No. 3 miller (USDA 1982) to approximately 150 g for the No. 2 miller.

As the use of the No. 2 miller becomes more widespread, it is important that recommendations be made pertaining to the proper settings and procedure to be followed in using the miller. It is also important, if the No. 2 is to be accepted as an alternative miller, that a comparison of milling results between the two millers be made.

It is well documented that moisture content (MC) at the time of milling has a significant effect on HRY and the degree of milling (Wratten 1960; Wasserman 1960, 1961; Pominski et al 1961; Webb and Calderwood 1977; Banaszek et al 1989). Webb and Calderwood (1977) determined that as MC decreased, HRY increased and degree of milling decreased. They stated that to obtain a degree of milling at lower MCs equivalent to those observed at higher MCs, HRY is reduced. Banaszek et al (1989) determined HRY and degree of milling for rice ranging from 10 to 16% in MC. A No. 2 miller was used with milling time held constant at 30 sec. They stated that even within the MC range in which rice was classified as being well milled, MC accounted for more than 10 percentage points of change in HRY. In general, the above-cited studies indicate that when miller settings are not adjusted for MC, HRY is affected. No recommendations for MC of rice at the time of milling were made.

Few investigations as to the effects of milling time on HRY have been noted. Velupillai and Pandey (1987) associated the degree of milling with the milling time used on the No. 2 miller. This was done by milling samples for time periods of 0–60 sec in 5-sec increments. They determined that 65–73% of the bran was removed in the first 20 sec of milling. With the Newbonnet variety, as much as 84% of the breakage also occurred in the first 20 sec of milling. No recommendations for a standard milling time to be used in routine HRY determinations were made.

HRY and degree of milling can be influenced by the pressure applied to the rice during milling. The pressure applied in the milling chamber is controlled by the amount and location of the weight placed on the weight lever. Webb and Calderwood (1977) increased pressure settings on the miller to obtain equivalent degrees of milling. However, no mention was made of how or by what amount the pressure was increased. No other studies were found pertaining to the effect of pressure applied to the rice during milling.

It is speculated that still another factor may influence HRY and degree of milling. It has been observed that the amount of brown rice placed in the miller tends to alter HRY and degree of milling. No studies were found that suggest an amount of brown rice to be placed in the No. 2 miller when determining HRY.

The USDA rice-milling standards (USDA 1979) specify the use of the No. 3 miller or an "approved miller that produces the same results for determining head rice yield." However, the standards are written for use of the No. 3 miller. The USDA (1982) states that the milling yield shall not be determined when the MC of the rough rice exceeds 18.0%. An initial rough-rice sample of 1 kg is required. Since the weights for the No. 3 miller hang from the end of the weight lever, there is no adjustment for the position of the weights. Total weight on the weight holder is adjusted according to the type of rice (short-, medium-, or long-grain). The milling duration is usually set at 30 sec for all types of rice (USDA 1982). According to the USDA (1979), the time should be adjusted to 20 sec for Western Production rice. This time adjustment is not found in later publications. With the widespread use of the No. 2 miller, it is essential that standards be developed for its operation. It is well documented that MC significantly affects HRY and degree of milling. However, the effects of other variables, such as the pressure applied to the rice in the milling chamber, milling time, and the size of the sample being milled, are not documented. If standards for the No. 2 miller are to be developed, the effect of each of these variables and their interactive effects must be quantified.

The objectives of this study were as follows:

1. Determine the effects of the following variables of the McGill No. 2 miller on HRY and degree of milling of two varieties of long-grain rice: milling time (residence time of rice in the milling chamber), sample size (amount of rice to be used in the miller),

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and pressure applied to the rice (location of weight on the weight lever).

2. Determine the interactive effects of MC and the variables of objective 1 on the HRY and degree of milling of two varieties of long-grain rice.

3. Compare the HRYs obtained under the various experimental conditions investigated in objectives 1 and 2 to those obtained by milling with the No. 3 miller.

MATERIALS AND METHODS

Experimental Design

A McGill No. 2 miller equipped with an automatic timer and an adjustable weight to attain different degrees of milling was used. The pressure on the rice during milling was controlled by the placement of a 1.5-kg weight on the weight lever. The positions originally chosen for testing were 6, 12, 18, and 24 cm from the center of the saddle to the center of the weight. However, it was discovered that when the 1.5-kg weight was placed 24 cm from the center of the saddle, the pressure applied to the rice was too great for the miller to start. Thus, the 24-cm position was not included as part of the experimental design.

Rough rice MCs of 9.5, 11, 12.5, and 14% (wb) were chosen. This range encompasses the normal range of MCs in long-grain rough rice typically encountered for milling.

Rough rice in amounts of 100, 125, and 150 g were milled for durations of 0, 15, 30, 45, and 60 sec. Two long-grain varieties, Lemont and Newbonnet, were used, and the experiment was replicated. Thus, 720 samples were milled (4 MCs × 3 weight placements × 3 rough rice weights × 5 milling durations × 2 varieties × 2 replications).

As a control for the experiment and a basis for comparison of the No. 2 and 3 millers, 40 1-kg samples of rough rice (five samples from each of the four MCs for both varieties) were milled by the Federal Grain Inspection Service (FGIS) at Stuttgart, Arkansas. The FGIS milled the samples in a No. 3 miller according to the USDA standard procedure and determined HRY and degree of milling.

Experimental Procedure

The two varieties of long-grain rice were combine-harvested at the Rice Research and Extension Center at Stuttgart. The harvest MC was approximately 18%. The rice was immediately placed in double-lined paper bags containing approximately 23 kg. The bags were placed in cold storage at 1°C for about 10 months before testing.

Cleaning and drying. Approximately 113 kg of Lemont rice was removed from cold storage, emptied from the paper bags onto a tarp in an air-conditioned laboratory, and allowed to air-dry. The ambient air conditions in the lab were approximately 26°C and 60% rh. While the rice was drying, it was removed from the tarp and cleaned with a Carter-Day Dockage Tester. No. 28, 23, and 22 sieves were used in the top, middle, and bottom sieve carriages, respectively. The No. 28 is a round-hole sieve, whereas the No. 23 and 22 sieves both have rectangular holes. No riddle was used in the riddle carriage. After cleaning, the rice was placed back on the tarp to continue drying.

During drying, the rice was stirred about every hour, and the MC was monitored with a Motomco Model 919A grain moisture meter. When the MC had decreased to 14%, 23 kg of the rice was placed in a double-lined paper bag and placed back in cold storage. The remaining rice was then transferred to a drying chamber. Use of the drying chamber was necessary to accurately obtain MCs lower than 14%. Drying air at 20°C and rh necessary to attain the desired MCs was supplied to the chamber by a rh and temperature control unit (Parameter Generation and Control, Inc., Model 300 CFM Climate-Lab-AA). Samples of the rice were dried to approximately 12.5, 11, and 9.5% MC. Approximately 23 kg of rice at each MC was placed in cold storage.

After the Lemont rice was dried, Newbonnet rice was taken from cold storage, cleaned, and dried by the same procedure. The rice was stored at 1°C for two to eight days before hulling. This storage period allowed the MC of the rice to equilibrate throughout the bag and within individual kernels.

Hulling. A McGill sample sheller (huller) was used for hulling the rough rice. The feed control of the hopper was adjusted to allow approximately 500 g/min to pass through the huller (USDA 1984). The clearance between the rollers was set at 0.048 cm (0.019 in.) (USDA 1982).

Before hulling was started, rough rice was allowed to adjust to room temperature, and 400–500 g of auxiliary rice was hulled to ensure proper warm-up of the huller. It was noticed in previous trials that without properly warming the huller, brown rice weights were considerably lower in initial samples and showed an increase as more samples were hulled. After warm-up, five samples each of 150, 125, and 100 g from one of the varieties at one of the MC levels were selected and hulled. After hulling, each brown rice sample was weighed. Unhulled kernels were not removed from the brown rice samples. The hulled samples were then placed in individual zip-lock plastic bags. The same procedure was followed for each of the three weight settings on the miller weight lever for each of the four MC levels and each of the two rice varieties.

The entire procedure was replicated twice. Between replications, an oven test was performed on the rough rice to determine the exact MC of the samples. The oven test consisted of drying 25-g samples at 130°C for 24 hr, as described by Jindal and Siebenmorgen (1987).

Milling. In the absence of a documented warm-up procedure for the No. 2 miller, the procedure used was analogous to that outlined in the Rice Equipment Handbook for the No. 3 miller (USDA 1984), which uses 750 g of brown rice. The warm-up consisted of milling approximately 120 g of brown rice in two consecutive 30-sec runs, one with a 1.5-kg weight and one without the weight.

The miller was thoroughly cleaned after each milling. Excess bran was removed from the cylinder, and broken rice kernels and dust were removed from the screen by brushing. Samples from all four MC levels were grouped in such a manner that samples requiring the same miller settings could be milled in consecutive runs. This was done to decrease the number of changes that had to be made in the miller settings between millings. Millings were performed in randomized order within each group. After milling, the white rice weight was recorded, and the milled samples were placed back in storage to await grading.

Grading. After all milling was completed, the white rice samples were sent to the FGIS, where the percentage of head rice and the degree of milling for each milled sample were determined. The procedure followed by the FGIS for grading the 720 samples milled in the No. 2 miller consisted of selecting a 40-g subsample from each milled sample through the use of a Boerner divider. The 40-g sample was then hand separated into head rice and brokens to determine the percentage of head rice for the 40-g milled sample. This percentage was multiplied by the total white rice weight to determine the head rice weight for the milled sample. The HRY was then calculated by dividing the head rice weight by the rough rice weight. The FGIS also determined the degree of milling through visual comparison with standard color line samples representing various degrees of milling classes. All hand separations and degrees of milling classification were performed by one experienced grader at the FGIS office.

RESULTS AND DISCUSSION

McGill No. 3 Miller

The 40 1-kg samples milled by the FGIS in the No. 3 miller were used as the basis of comparison for the HRYs determined under the experimental design settings of the No. 2 miller. HRY was inversely related to MC in both varieties (Table I). The change in MC from 9.5 to 14% accounted for a difference of 7.2 and 6.2 HRY percentage points in the Lemont and Newbonnet varieties, respectively. Table I indicates that milling yield was also inversely proportional to MC. This indicates that the performance of the No. 3 miller in removing bran, and possibly some endosperm layer, is greater at higher MCs.

McGill No. 2 Miller

The HRY and degree of milling for each combination of variables for the Lemont and Newbonnet varieties are shown in Figures 1–4 and 5–8, respectively. The figures show that MC and HRY are inversely related, just as they were with the No. 3 miller. The figures also show that as MC decreases, the rice becomes more difficult to mill to a well-milled degree, as indicated by the increasing number of samples that are not well milled.

Statistical Analysis

Preliminary analysis showed significant interactions of a higher order between variety and the other independent variables. For this reason, models were fitted independently for the two varieties. The effects of MC, milling time, weight placement, and rough rice weight were evaluated initially by analysis of variance for a four-way classification in which MC, milling time, weight placement, and rough rice weight were the respective factors. The individual factor, source of variation, was partitioned into components of one degree of freedom, representing the regressions on that factor. The interactions between factors were partitioned in a corresponding way. None of the parts of the three- or four-way interaction components were found to be significant for either variety.

A full quadratic response surface in the four independent variables (MC, milling time, weight placement, rough rice weight) was fitted using the RSREG (response surface for regression) procedure of SAS (SAS 1987) for each variety. The results proved to represent the HRY data adequately. The details of the fit plus the coefficients of the equations that could be used to predict HRY are given in Table II. All the effects in Table II were statistically significant at the 5% significance level. The linear effects of the four variables explained most of the variability in the HRYs when using the No. 2 miller.

The influence that each of these variables has on HRY is illustrated for both varieties in Figure 9. MC was found to be the most important factor affecting HRY. Rough rice weight was found to be the least important but statistically significant. Figure 9 illustrates that the relative influence of the experimental variables on HRY was different for the two varieties. In an effort to explain this difference, 100 kernels were measured from each variety. The average length, width, and thickness for the Lemont variety were 7.08, 2.35, and 1.73 mm, respectively. The average length, width, and thickness for the Newbonnet variety were 6.82, 2.06, and 1.59 mm, respectively. A t test showed significant differences at the 5% significance level between corresponding dimensions of the two varieties. From this, it was postulated that the differences in contributions shown in Figure 9 are due to differences in kernel dimensions between the varieties.

In an attempt to plot the response surface for both varieties, two variables (weight placement and rough rice weight) were fixed. The surfaces are given in Figures 10 and 11 for the Lemont and Newbonnet varieties, respectively. In general, the contours show that for both varieties, HRY decreases as either MC or milling time is increased.

Rough Rice Weight Effects

In general, increasing rough rice weight resulted in fewer broken kernels and thus an increase in HRY. The rotor action in the No. 2 miller is such that the more kernels present in the milling chamber, the less each kernel is milled. Thus, as rough rice weight is increased, the interactions from one kernel to another are decreased. This is supported by Figures 1–8, which show that as rough rice weight is increased, the number of well-milled samples decreases. However, there were interactive effects between rough rice weight and the other experimental variables.

TABLE I
Data for 40 1-kg Samples Milled by the Federal Grain Inspection Service Using a McGill No. 3 Miller

Variety	Moisture Content (%, wb)	Milling Yield[a] (%)	Head Rice Yield[a] (%)	Standard Deviation[b] (%)
Lemont	9.5	73.3	64.6	0.553
	11.0	72.4	62.9	0.793
	12.5	71.6	60.4	0.785
	14.0	70.7	57.4	0.532
Newbonnet	9.5	72.6	67.9	0.262
	11.0	71.4	65.7	0.380
	12.5	70.4	64.0	0.385
	14.0	69.1	61.7	0.174

[a]Average of five replications.
[b]Standard deviation of the five head rice yields comprising the average.

TABLE II
Coefficients for Equation Predicting Head Rice Yields for Lemont and Newbonnet Varieties[a,b]

		Rice Variety			
Independent Variables	Experimental Settings	Lemont Coefficient	Standard Error	Newbonnet Coefficient	Standard Error
Intercept		21.1352	6.2708	106.7517	5.947
Linear components					
MC, %	(9.5, 11, 12.5, 14)	13.226	0.7329	−1.4099	0.5126
MT, sec	(15, 30, 45, 60)	0.2784	0.0434	0.2088	0.043
WP, cm	(6, 12, 18)	0.3371	0.1576	−0.1104	0.1565
RRW, g	(100, 125, 150)	−0.4363	0.0606	−0.4299	0.0644
Quadratic components					
MC^2		−0.5983	0.0289	0.041	0.019
MT^2		0.0013	0.0003	0.0005	0.0003
WP^2		0.01	0.0038	0.0436	0.0039
RRW^2		0.0025	0.0002	0.0019	0.0002
Interactions					
MC × MT		−0.0175	0.0023	−0.0153	0.0019
MC × WP		−0.0194	0.0079	−0.1037	0.0066
MC × RRW		−0.0055	0.0019	−0.0028	0.0017
MT × WP		−0.0024	0.0008	0.0027	0.0008
MT × RRW		−0.0022	0.0002	−0.0011	0.0002
WP × RRW		−0.0051	0.0007	−0.0019	0.0006
Overall mean		Y = 58.5332		Y = 60.8527	
Residual mean square		1.22 with 273 degrees of freedom		1.25 with 273 degrees of freedom	
R^2		$R^2 = 96.10\%$		$R^2 = 96.38\%$	

[a]Determined using RSREG (response surface for regression) procedure of SAS (1987).
[b]MC = moisture content, MT = milling time, WP = weight placement, RRW = rough rice weight.

1

Moisture Content = 9.5%						
Rough Rice Weight (grams)	Weight Placement (cm)	Milling Time (sec)				
		0	15	30	45	60
100	6	70.9 UM (6.28)	65.2 WM (0.56)	64.8 WM (0.16)	63.8 WM (-0.76)	64.2 WM (-0.43)
	12	69.9 UM (5.35)	64.5 WM (-0.06)	63.0 WM (-1.56)	62.6 WM (-2.02)	62.6 WM (-2.02)
	18	70.4 UM (5.77)	63.1 WM (-1.49)	62.3 WM (-2.30)	61.9 WM (-2.69)	61.1 WM (-3.53)
125	6	70.9 UM (6.27)	66.9 RWM (2.26)	63.9 WM (-0.68)	62.8 WM (-1.82)	61.3 WM (-3.31)
	12	71.1 UM (6.49)	63.5 WM (-1.07)	62.0 WM (-2.55)	60.8 WM (-3.83)	60.2 WM (-4.38)
	18	70.6 UM (6.03)	62.8 WM (-1.82)	59.8 WM (-4.84)	57.2 WM (-7.41)	56.5 WM (-8.09)
150	6	70.8 UM (6.21)	68.7 RWM (4.11)	66.0 RWM (1.42)	64.1 WM (-0.51)	63.1 WM (-1.49)
	12	70.8 UM (6.19)	65.9 RWM (1.35)	63.4 WM (-1.22)	61.5 WM (-3.12)	60.2 WM (-4.44)
	18	70.3 UM (5.67)	63.5 RWM (-1.09)	62.8 WM (-1.80)	59.2 WM (-5.35)	56.4 WM (-8.16)

2

Moisture Content = 11.0%						
Rough Rice Weight (grams)	Weight Placement (cm)	Milling Time (sec)				
		0	15	30	45	60
100	6	69.7 UM (6.77)	65.7 RWM (2.82)	64.4 WM (1.51)	63.8 WM (0.92)	62.3 WM (-0.58)
	12	69.5 UM (6.56)	64.2 WM (1.28)	63.0 WM (0.12)	61.8 WM (-1.05)	62.1 WM (-0.81)
	18	69.9 UM (7.00)	62.8 WM (-0.09)	61.7 WM (-1.22)	61.3 WM (-1.59)	59.7 WM (-3.24)
125	6	69.7 UM (6.82)	66.4 LIM (3.51)	64.4 WM (1.49)	61.7 WM (-1.16)	61.6 WM (-1.29)
	12	69.4 UM (6.46)	64.4 RWM (1.46)	61.6 WM (-1.34)	60.2 WM (-2.72)	59.0 WM (-3.91)
	18	69.5 UM (6.59)	62.1 WM (-0.81)	59.8 WM (-3.13)	57.4 WM (-5.48)	54.4 WM (-8.48)
150	6	70.1 UM (7.17)	67.4 LIM (4.47)	65.3 RWM (2.37)	63.5 WM (0.58)	62.5 WM (-0.40)
	12	70.6 UM (7.66)	65.6 LIM (2.72)	62.1 WM (-0.82)	60.8 WM (-2.07)	58.6 WM (-4.29)
	18	70.4 UM (7.50)	64.1 RWM (1.19)	59.6 WM (-3.33)	58.6 WM (-4.28)	53.8 WM (-9.12)

3

Moisture Content = 12.5%						
Rough Rice Weight (grams)	Weight Placement (cm)	Milling Time (sec)				
		0	15	30	45	60
100	6	68.7 UM (8.27)	63.8 WM (3.45)	60.3 WM (-0.14)	59.6 WM (-0.84)	58.2 WM (-2.19)
	12	68.0 UM (7.62)	60.7 WM (0.32)	59.5 WM (-0.87)	58.3 WM (-2.13)	57.6 WM (-2.79)
	18	67.9 UM (7.48)	59.5 WM (-0.87)	58.0 WM (-2.44)	57.1 WM (-3.30)	56.3 WM (-4.13)
125	6	68.2 UM (7.84)	62.8 RWM (2.40)	60.5 WM (0.05)	58.6 WM (-1.79)	56.8 WM (-3.61)
	12	67.4 UM (7.05)	60.8 WM (0.38)	58.1 WM (-2.32)	54.8 WM (-5.59)	54.2 WM (-6.20)
	18	68.8 UM (8.39)	57.7 WM (-2.69)	54.8 WM (-5.56)	53.6 WM (-6.83)	51.7 WM (-8.66)
150	6	67.2 UM (6.78)	65.0 RWM (4.60)	61.6 WM (1.23)	59.4 WM (-1.04)	57.5 WM (-2.89)
	12	68.9 UM (8.52)	61.0 RWM (0.60)	56.8 WM (-3.62)	55.2 WM (-5.20)	54.2 WM (-6.18)
	18	68.4 UM (7.96)	60.4 WM (-0.05)	56.2 WM (-4.25)	53.5 WM (-6.91)	49.8 WM (-10.63)

4

Moisture Content = 14.0%						
Rough Rice Weight (grams)	Weight Placement (cm)	Milling Time (sec)				
		0	15	30	45	60
100	6	65.1 UM (7.72)	57.5 WM (0.13)	55.7 WM (-1.72)	53.4 WM (-4.05)	52.9 WM (-4.48)
	12	65.7 UM (8.33)	56.0 WM (-1.42)	52.5 WM (-4.91)	51.2 WM (-6.25)	52.3 WM (-5.05)
	18	65.9 UM (8.49)	55.0 WM (-2.42)	51.8 WM (-5.64)	52.1 WM (-5.27)	49.2 WM (-8.17)
125	6	65.6 UM (8.17)	57.9 WM (0.47)	55.0 WM (-2.42)	52.7 WM (-4.70)	50.6 WM (-6.76)
	12	66.1 UM (8.74)	55.2 WM (-2.24)	49.0 WM (8.37)	46.7 WM (-10.73)	45.9 WM (-11.46)
	18	65.9 UM (8.45)	53.2 WM (-4.23)	48.4 WM (-9.02)	46.4 WM (-10.97)	43.9 WM (-13.53)
150	6	65.5 UM (8.07)	60.3 RWM (2.94)	57.5 WM (0.13)	52.9 WM (-4.48)	51.0 WM (-6.39)
	12	65.0 UM (7.58)	57.4 WM (0.04)	53.1 WM (-4.31)	48.2 WM (-9.17)	45.6 WM (-11.76)
	18	66.8 UM (9.36)	55.0 WM (-2.45)	50.3 WM (-7.10)	47.8 WM (-9.57)	42.6 WM (-14.84)

Figs. 1–4. Milling data for Lemont rice milled in the McGill No. 2 miller. Head rice yields (HRYs) are shown as the first number in each block and are the average of two replications. Degree of milling is classified as follows: UM = undermilled, LIM = lightly milled, RM = reasonably well milled, WM = well milled. The number in parentheses is the difference between the HRYFs obtained with the No. 2 miller and those obtained with the McGill No. 3 miller (Table I). Blocks in gray are below the WM classification; blocks in black are WM, and the HRYs deviate less than two percentage points from the No. 3 HRYs; blocks in white are well milled but deviate more than two percentage points from the No. 3 miller HRYs.

5

Rough Rice Weight (grams)	Weight Placement (cm)	Moisture Content = 9.5% — Milling Time (sec) 0	15	30	45	60
100	6	74.3 UM (6.35)	68.4 RWM (0.53)	67.9 WM (0.01)	67.6 WM (-0.31)	66.8 WM (-1.05)
	12	74.8 UM (6.93)	67.6 WM (-0.29)	67.0 WM (-0.90)	66.7 WM (-1.23)	65.3 WM (-2.63)
	18	74.6 UM (6.68)	66.3 RWM (-1.59)	66.3 WM (-1.58)	65.7 WM (-2.16)	64.8 WM (-3.13)
125	6	73.8 UM (5.95)	70.2 RWM (2.30)	68.5 RWM (0.65)	68.1 WM (0.25)	67.7 WM (-0.20)
	12	74.6 UM (6.66)	68.4 RWM (0.46)	67.7 WM (-0.16)	66.4 WM (-1.52)	64.6 WM (-3.25)
	18	74.0 UM (6.06)	67.7 RWM (-0.17)	65.8 WM (-2.13)	62.9 WM (-4.98)	62.9 WM (-4.98)
150	6	74.3 UM (6.45)	71.5 LIM (3.63)	70.4 RWM (2.46)	68.5 RWM (0.65)	68.3 RWM (0.42)
	12	73.4 UM (5.53)	69.7 LIM (1.84)	69.3 RWM (1.40)	67.9 RWM (0.05)	66.8 WM (-1.06)
	18	74.4 UM (6.53)	68.8 RWM (0.94)	67.3 RWM (-0.62)	66.9 WM (-1.01)	65.1 WM (-2.83)

6

Rough Rice Weight (grams)	Weight Placement (cm)	Moisture Content = 11.0% — Milling Time (sec) 0	15	30	45	60
100	6	73.8 UM (8.05)	68.2 RWM (2.53)	65.5 WM (-0.20)	65.3 WM (-0.15)	64.7 WM (-1.00)
	12	73.6 UM (7.92)	61.5 RWM (-4.20)	60.4 WM (-5.34)	59.4 WM (-6.28)	59.1 WM (-6.58)
	18	73.9 UM (8.21)	59.7 WM (-6.04)	59.2 WM (-6.45)	58.5 WM (-7.15)	58.3 WM (-7.45)
125	6	73.5 UM (7.78)	68.1 RWM (2.43)	65.5 WM (-0.18)	64.6 WM (-1.07)	63.4 WM (-2.32)
	12	73.5 UM (7.83)	61.6 RWM (-4.14)	58.8 WM (-6.90)	57.3 WM (-8.36)	56.5 WM (-9.15)
	18	73.3 UM (7.55)	60.3 RWM (-5.37)	57.7 WM (-8.02)	55.7 WM (-9.99)	53.7 WM (-12.04)
150	6	74.2 UM (8.47)	70.4 RWM (4.67)	67.7 RWM (2.01)	66.4 WM (0.65)	65.0 WM (-0.67)
	12	73.5 UM (7.77)	63.6 RWM (-2.12)	60.3 WM (-5.37)	59.1 WM (-6.59)	56.8 WM (-8.93)
	18	73.2 UM (7.49)	61.6 RWM (-4.10)	58.6 WM (-7.10)	56.6 WM (-9.15)	55.6 WM (-10.14)

7

Rough Rice Weight (grams)	Weight Placement (cm)	Moisture Content = 12.5% — Milling Time (sec) 0	15	30	45	60
100	6	72.6 UM (8.64)	65.0 RWM (1.01)	64.3 WM (0.29)	62.9 WM (-1.11)	61.7 WM (-2.26)
	12	72.1 UM (8.05)	59.1 RWM (-4.86)	57.8 WM (-6.25)	57.5 WM (-6.47)	56.4 WM (-7.56)
	18	72.3 UM (8.28)	57.6 WM (-6.41)	56.8 WM (-7.21)	56.7 WM (-7.32)	55.6 WM (-8.41)
125	6	72.7 UM (8.74)	66.0 RWM (2.00)	63.2 RWM (-0.84)	63.0 WM (-1.03)	60.7 WM (-3.26)
	12	72.1 UM (8.08)	59.6 RWM (-4.42)	58.0 WM (-6.03)	55.5 WM (-8.47)	55.3 WM (-8.66)
	18	72.1 UM (8.11)	58.0 RWM (-6.01)	56.3 WM (-7.68)	53.7 WM (-10.24)	51.7 WM (-12.27)
150	6	72.4 UM (8.44)	68.0 RWM (4.00)	64.5 RWM (0.55)	63.5 WM (-0.47)	62.3 WM (-1.73)
	12	72.5 UM (8.50)	60.3 RWM (-3.70)	58.8 WM (-5.25)	57.0 WM (-7.05)	56.4 WM (-7.60)
	18	72.6 UM (8.56)	59.6 RWM (-4.45)	57.5 WM (-6.48)	53.0 WM (-11.04)	52.5 WM (-11.49)

8

Rough Rice Weight (grams)	Weight Placement (cm)	Moisture Content = 14.0% — Milling Time (sec) 0	15	30	45	60
100	6	71.5 UM (9.82)	62.9 RWM (1.25)	61.7 WM (0.03)	60.9 WM (-0.75)	58.7 WM (-2.98)
	12	71.4 UM (9.68)	57.1 WM (-4.58)	56.5 WM (-5.24)	54.7 WM (-6.95)	54.1 WM (-7.63)
	18	70.2 UM (8.52)	55.0 RWM (-6.70)	54.1 WM (-7.57)	50.8 WM (-10.91)	46.8 WM (-14.93)
125	6	71.5 UM (9.85)	63.4 WM (1.70)	61.0 WM (-0.69)	60.2 WM (-1.47)	57.2 WM (-4.55)
	12	70.5 UM (8.76)	56.5 WM (-5.17)	54.1 WM (-7.58)	52.3 WM (-9.43)	50.4 WM (-11.28)
	18	70.7 UM (9.03)	55.7 WM (-6.04)	51.9 WM (-9.84)	48.0 WM (-13.73)	45.4 WM (-16.33)
150	6	71.7 UM (10.03)	65.6 RWM (3.92)	62.9 WM (1.24)	61.8 WM (0.07)	59.3 WM (-2.45)
	12	70.9 UM (9.16)	59.5 WM (-2.18)	56.2 WM (-5.51)	54.0 WM (-7.74)	51.7 WM (-9.96)
	18	70.7 UM (8.99)	56.5 WM (-5.15)	54.4 WM (-7.27)	49.9 WM (-11.80)	48.9 WM (-12.84)

Figs. 5-8. Milling data for Newbonnet rice milled in the McGill No. 2 miller. Head rice yields (HRYs) are shown as the first number in each block and are the average of two replications. Degree of milling is classified as follows: UM = undermilled, LIM = lightly milled, RWM = reasonably well milled, WM = well milled. The number in parentheses is the difference between the HRYFs obtained with the No. 2 miller and those obtained with the McGill No. 3 miller (Table I). Blocks in gray are below the WM classification; blocks in black are WM, and the HRYs deviate less than two percentage points from the No. 3 HRYs; blocks in white are well milled but deviate more than two percentage points from the No. 3 miller HRYs.

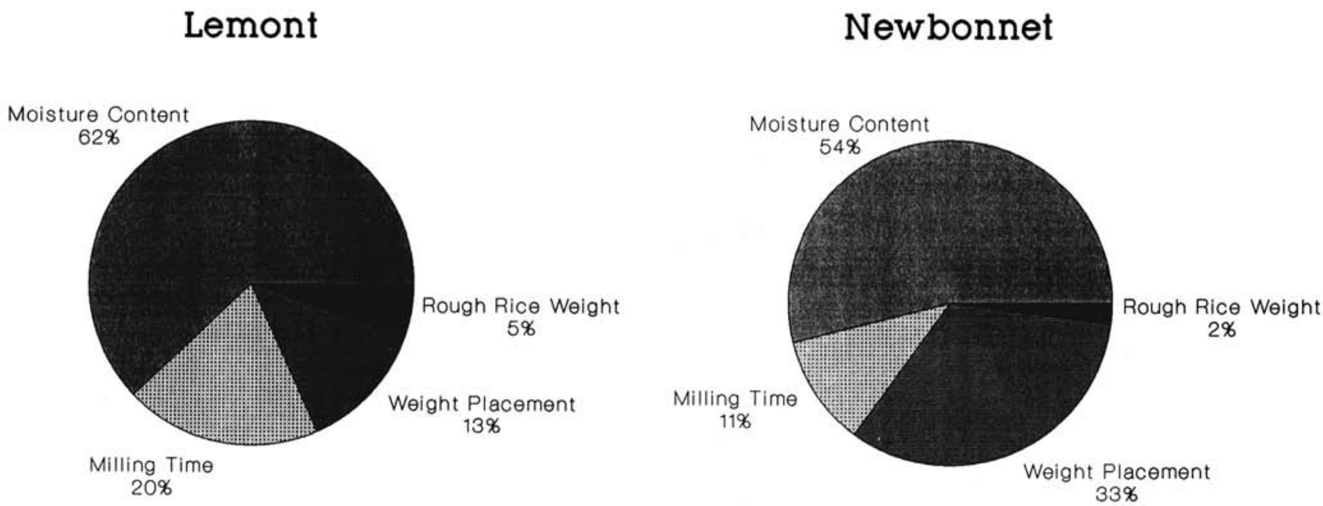

Fig. 9. Contributions (percent) of experimental variables accounting for changes in head rice yield as indicated by sum of squares.

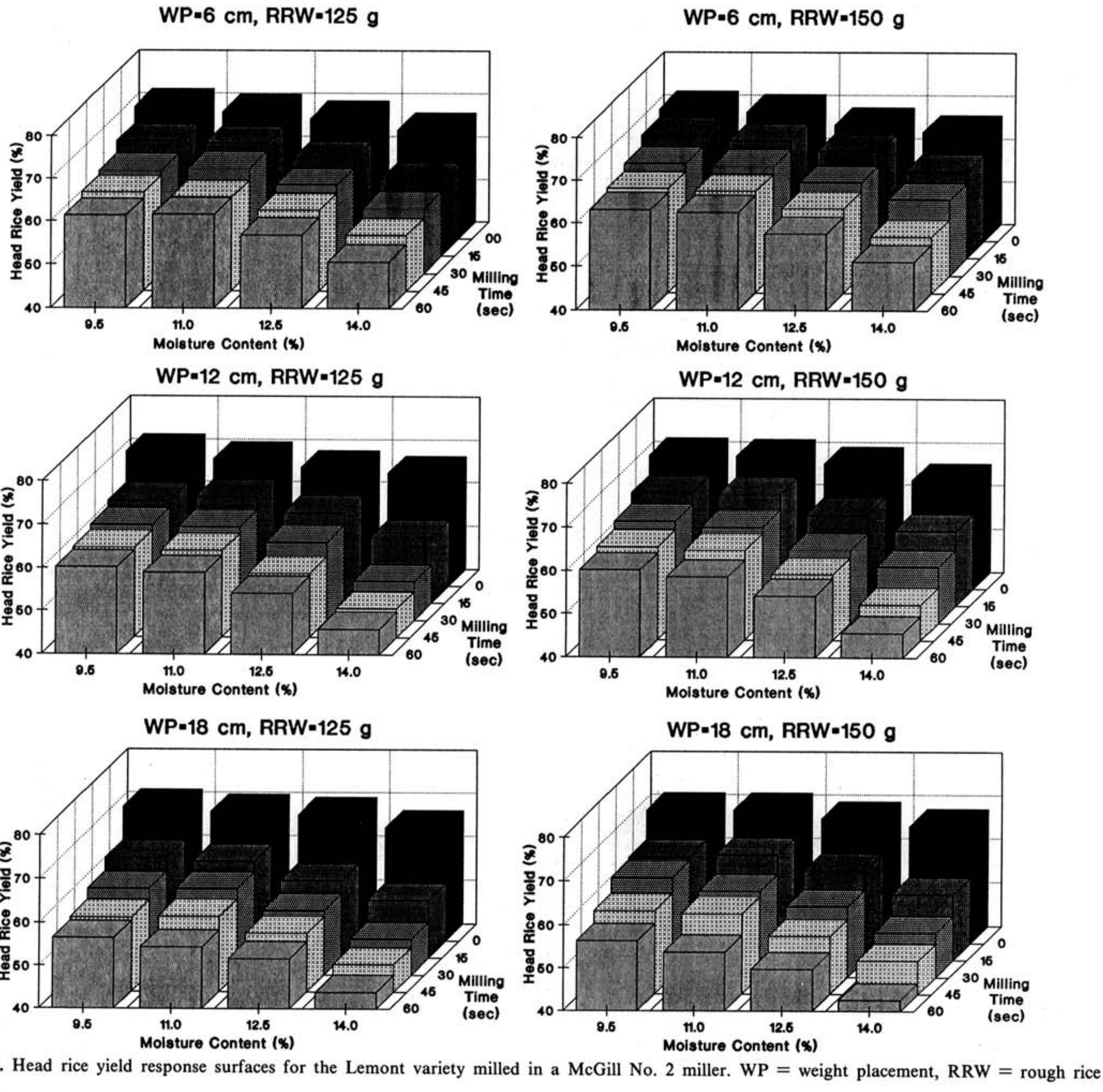

Fig. 10. Head rice yield response surfaces for the Lemont variety milled in a McGill No. 2 miller. WP = weight placement, RRW = rough rice weight.

Figure 12 reveals the results of a physical limitation of the No. 2 miller that was observed during milling. The figure indicates that at the 100-g rough rice weight, varying the milling time minimally affected HRY. When using 100 g of rough rice, which results in approximately 80 g of brown rice being milled after hulling, it was observed that the weight lever of the miller rested on the milling chamber frame instead of entirely on the rice. It was concluded that the No. 2 miller requires a brown rice sample larger than 80 g to prevent the miller from bottoming out. In other words, a rough rice weight of 100 g is below the lower limit of the No. 2 miller. However, it should be noted that the data in Figure 12 were obtained with a weight placement of 18 cm, which was the highest setting, and thus produced the greatest pressure on the rice. As a result, Figure 12 represents the worst-case scenario for illustrating the bottoming-out action.

Figure 12 also illustrates the interactive effects of milling time and rough rice weight. It is shown that the relative changes in HRY obtained when varying milling time are dependent on rough rice weight. As rough rice weight was increased from 125 to 150 g, HRYs actually increased for low milling times, indicating that there was less force per kernel. However, as milling time was increased at the 150-g rough rice level, HRYs decreased. This decrease in HRY reflects the increase in the exposure of the rice to the milling or frictional forces per kernel.

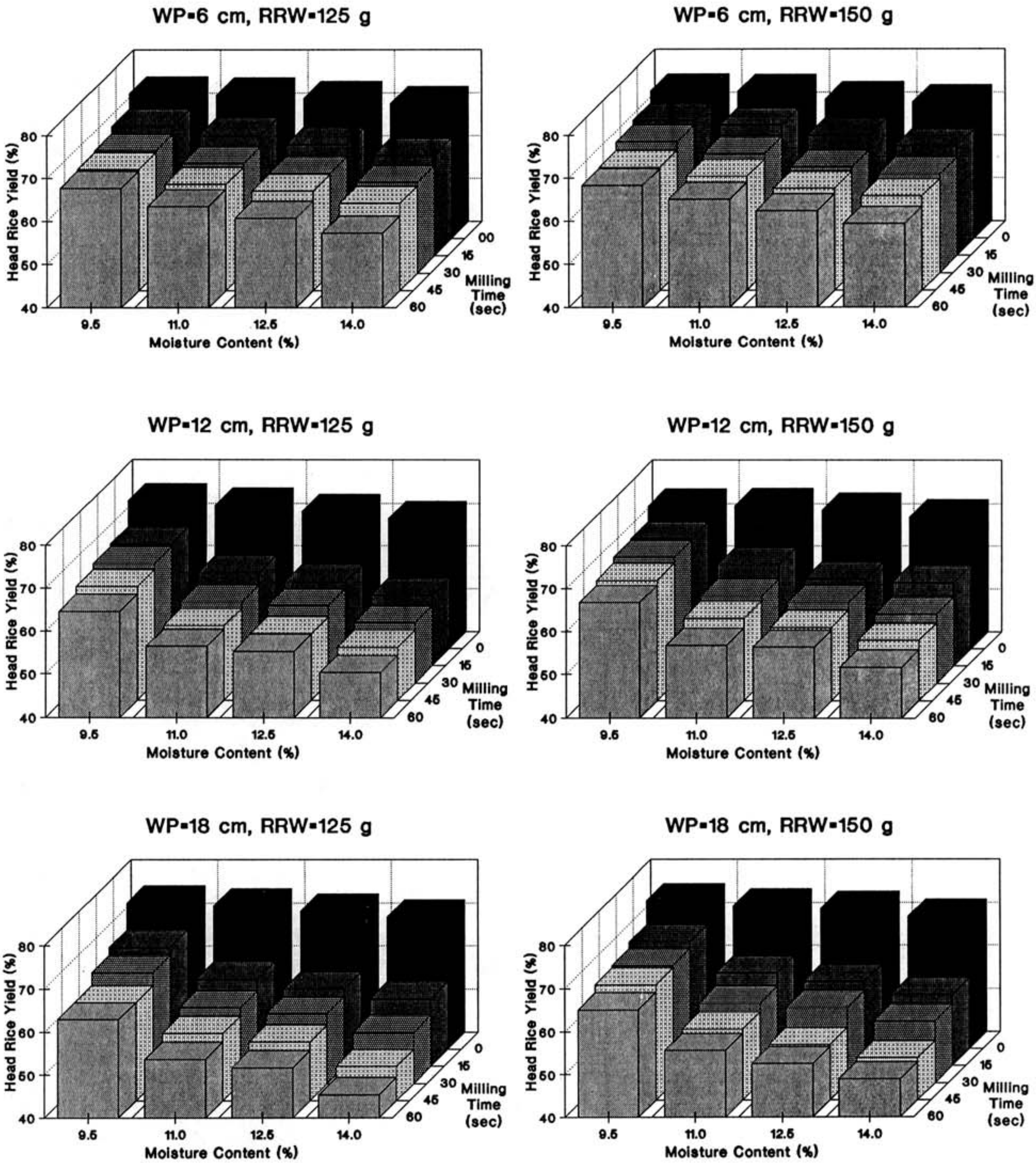

Fig. 11. Head rice yield response surfaces for the Newbonnet variety milled in a McGill No. 2 miller. WP = weight placement, RRW = rough rice weight.

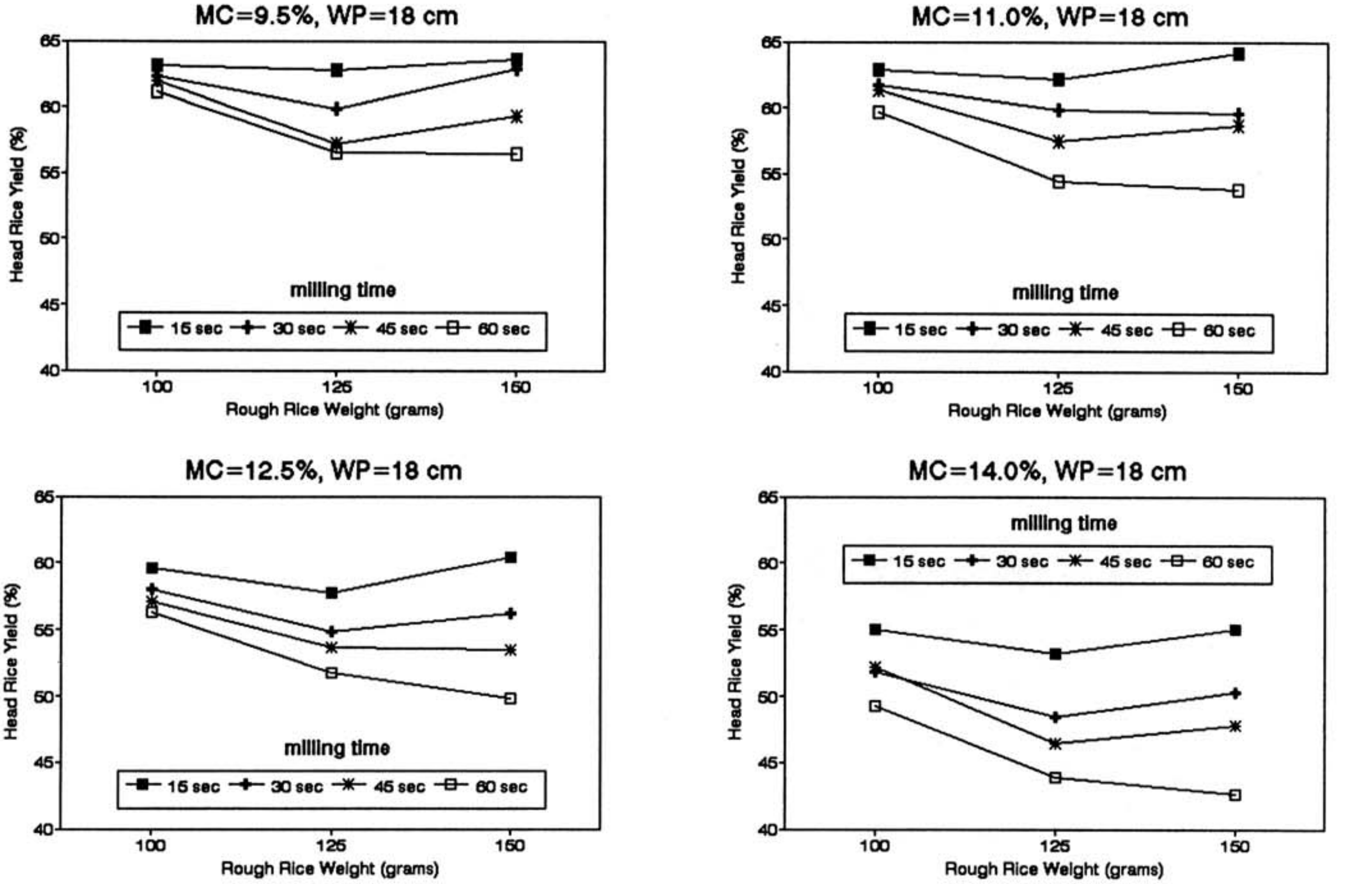

Fig. 12. Head rice yields produced with McGill No. 2 miller for the Lemont variety and the given variables. MC = moisture content, WP = weight placement.

Effects of MC

Figures 9–11 show that MC is a major factor in determining HRYs. A change in MC from 9.5 to 14% accounted for a change in HRY of up to 14.6 percentage points in the Lemont variety and 17 percentage points in the Newbonnet variety. These figures reinforce the observations made from the No. 3 millings. Figures 1–8 show that as MC decreases, so does the number of well-milled samples. This is an indication that bran removal becomes more difficult at lower MCs.

Weight Placement and Milling Time

Weight placement and milling time affected HRY in the same manner. As either was increased, HRY decreased (Figs. 10 and 11). A change in weight placement from 6 to 18 cm accounted for a reduction in HRY of 8.7 percentage points in the Lemont variety and up to 12.2 percentage points in the Newbonnet variety. This inverse relationship was consistent throughout the study. An analogous trend was found for milling time, in that as milling time was increased, HRYs decreased. However, milling for given time periods was necessary to attain a well-milled sample. Figures 1–8 show that many of the samples milled for the 15-sec duration were not well-milled samples.

Comparison of No. 2 and 3 Millers

Figures 1–8 show that a large portion of the samples having a rough rice weight of 100 g were well milled and deviated less than two percentage points in HRY from the FGIS millings. Two percentage points was assumed to account for typical variations associated with grading. However, as previously stated, rough rice weights of 100 g were below the lower limit of the No. 2 miller and therefore will not be discussed in comparing the two millers.

In the Newbonnet variety, if samples with a rough rice weight of 100 g are disregarded, only two experimental combinations produced equivalent results at the 12.5% MC level (samples that were both well milled and had HRYs within two percentage points of the No. 3 miller). These two combinations are at a weight placement of 6 cm, a milling time of 45 sec, and a rough rice weight of 125 or 150 g. These same two combinations will produce results equivalent to those of the No. 3 miller at the 11.0 and 14% MC levels. In the Lemont variety, more combinations will produce equivalent results, but no single combination is sufficient at all four MC levels.

A weight placement of 6 cm tended to produce equivalent results in more experimental combinations than did the 12- or 18-cm weight placements. Aside from weight placement, MC plays such a large role in determining the ease or difficulty in bran removal that a consistent milling time did not produce equivalent results across all MCs. At 12.5% MC, a weight placement of 6 cm and a milling time of 45 sec produced results equivalent to those of the No. 3 miller for both varieties. In the Lemont variety, changing the milling time to 30 sec also produced equivalent results. When the milling time was set at 30 sec in the Newbonnet variety and weight placement at 6 cm, there was a difference of less than two percentage points from the No. 3 miller at the 12.5% MC level, but the samples were only reasonably well milled.

CONCLUSIONS

The effects of milling time, sample size (rough rice weight), and the pressure applied to the rice (weight placement) were found to be critical when determining HRYs. Milling time was found to have an inverse effect on HRY and played an important role in determining degree of milling. A rough rice weight of 100 g was found to produce an insufficient amount of brown rice for the No. 2 miller. Rough rice weights of 125 and 150 g were adequate for the No. 2 miller, and 150 g usually produced higher HRYs.

Weight placement had an inverse effect on HRY in both varieties.

MC was found to be the most significant variable affecting HRY. As MC decreased, bran removal became more difficult and HRYs increased. The interactive effects of MC with milling time, weight placement, and rough rice weights were found to be significant and greatly influenced the degree of milling in both varieties.

HRYs from the No. 2 miller were compared to HRYs of the No. 3 miller. Results of the comparison indicate that it may possible to obtain equivalent results with the proper settings. However, no one combination was found to produce equivalent results across all four MCs for both varieties. It is recommended that additional research be conducted on the effects of different varieties, locations, and crop years before conclusive statements regarding equivalency of the two millers are made.

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