

# HARVEST LOCATION AND MOISTURE CONTENT EFFECTS ON RICE KERNEL-TO-KERNEL BREAKING FORCE DISTRIBUTIONS

G. Qin, T. J. Siebenmorgen

**ABSTRACT.** *One medium-grain rice variety, six long-grain varieties, and two long-grain hybrids, harvested from 13.4% to 26.0% moisture content (MC) from Keiser, Arkansas, Stuttgart, Arkansas, and Alvin, Texas, were used to determine the influence of harvest location and MC on kernel-to-kernel breaking force distributions (BFDs). Harvest moisture content (HMC) affected BFDs, however, a greater influence was imposed by the growing location. Breaking force distributions were generally characterized by primary and secondary modal populations, although in many instances a clear demarcation between these populations was not apparent. Head rice yield (HRY) was plotted against the percentage of kernels in a sample having breaking forces greater than 20 N, which was used as an estimate to define “strong” kernels. The strongest correlations between HRY and the percentage of strong kernels were found for growing location/variety lots having HRYs of 45% to 65%. Little to no correlation was observed for groups of samples having HRYs greater than 65%. One of the issues preventing a better HRY versus strong kernel percentage correlation was that the force level separating “weak” from “strong” kernels could not be accurately and consistently identified due to a lack of clear delineation between the modal populations.*

**Keywords.** *Rice, Harvest moisture content, Harvest location, Breaking force distributions, Head rice yield.*

Rice moisture content (MC) at harvest is one of the most important factors influencing milling quality and overall economic value of rice. Lu et al. (1995) demonstrated that HMC had a dramatic impact on the gross income to a producer, due to the fact that harvest moisture content (HMC) affected the field yield, drying charges, and milling quality. Significant losses in gross income could be incurred if HMC was less than 15% (all moisture contents are expressed on a wet basis) or greater than 22% in Arkansas.

## EFFECTS OF HARVEST MOISTURE CONTENT ON MILLING QUALITY

Numerous studies have addressed the effects of HMC on milling quality. Kester et al. (1963) reported the highest head rice yields (HRYs) at HMCs between 25% and 32% for medium-grain ‘Calrose’ and short-grain ‘Caloro’ in California. Morse et al. (1967) showed that the maximum HRY of ‘Caloro’ was obtained when the HMC was between 28% and 30% in California. Calderwood et al. (1980) evaluated two long-grain and two medium-grain cultivars in Texas and found that the HRY reached a maximum at an intermediate harvest date and then declined. Lu et al. (1992) also reported that HRY reached a maximum and then decreased for long-grain varieties in Arkansas.

More recently, Bautista and Siebenmorgen (2005) quantified variation in individual kernel MCs from rice panicles at various harvest MCs and grown at different locations. Also, Bautista and Siebenmorgen (2001) showed significant effects of HMC on HRY for two varieties grown in Arkansas. Peak HRYs were observed at HMCs that occurred near the intersection of curves quantifying the percentage of kernels with MCs less than 14% and greater than 22%, representing, respectively, the percentage of kernels that could fissure due to rapid moisture adsorption, which increases as HMC decreases, and the percentage of immature kernels, which increases as HMC increases. Both classes of kernels reduce HRYs.

## MOISTURE ADSORPTION EFFECTS

Kernel fissures are important in affecting the forces that rice kernels can withstand without breaking and reducing milling quality. The formation of fissures due to rapid moisture adsorption by low MC kernels is the primary reason for reductions in HRY often observed at low HMCs. Research has demonstrated this fissuring phenomenon (Kunze and Prasad, 1978) and that HRY reduction can occur due to various means of moisture adsorption (Calderwood et al., 1980; Siebenmorgen and Jindal, 1986; Jindal and Siebenmorgen, 1994). Exposure duration, initial MC, and air relative humidity (RH) were significant factors influencing HRY reductions caused by moisture adsorption (Banaszek and Siebenmorgen, 1990).

## KERNEL MOISTURE CONTENT VARIABILITY AT HARVEST

Since rice kernels on panicles mature unevenly, the MCs of individual kernels at harvest varies (Chau and Kunze, 1987). Freshly harvested rice kernels exhibit a wide range of MCs, particularly during the early stages of the harvest season. Kocher et al. (1990) and Siebenmorgen et al. (1992) showed that the kernel MC frequency distributions from

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Article was submitted for review in February 2004; approved for publication by the Food & Process Engineering Institute Division of ASAE in June 2005.

The authors are **Guoqing Qin**, Visiting Scientist, Northwest Sci-Tech University of Agriculture and Forestry, Yangling, China; and **Terry J. Siebenmorgen**, **ASABE Member Engineer**, Professor, Department of Food Science, University of Arkansas, Fayetteville, Arkansas. **Corresponding author:** Terry J. Siebenmorgen, Department of Food Science, 2650 N. Young Ave., University of Arkansas, Fayetteville, AR 72704; phone: 479-575-2841; fax: 479-575-6936; e-mail: tsiebenm@uark.edu.

early harvest dates exhibited a tri-modal pattern while a single modal pattern characterized mature, low HMC rice. Bautista and Siebenmorgen (2005) reported that individual kernel MC distributions were different for various varieties. Siebenmorgen et al. (1998) showed that the percentage of kernels with MCs less than certain critical levels before moisture adsorption was related to the amount of HRY reduction incurred.

#### RELATING KERNEL-TO-KERNEL MECHANICAL PROPERTY DISTRIBUTIONS TO MILLING QUALITY

Nguyen and Kunze (1984) found that the average kernel breaking force was closely related to the percentage of fissured kernels in two rice varieties. Lu and Siebenmorgen (1995) found that the correlation between HRY and the average maximum compressive force to crush/break rough, brown, and white rice kernels was either insignificant or of a low order of magnitude. They found that the percentage of broken kernels from milling was closely related to the percentage of kernels that did not sustain approximately a 15-N breaking force in bending. Siebenmorgen and Qin (2005) reported bimodal breaking force distributions for several long-grain varieties. They further reported a linear relationship ( $R^2 = 0.90$ ) between HRY and the percentage of strong kernels, defined as kernels that withstood at least a 20-N force without breaking. These latter studies suggested a relationship between HRY and breaking force distributions.

#### RATIONALE FOR CURRENT STUDY

Rice HMC has an important influence on kernel-to-kernel MC variability; this variability in turn affects kernel property and mechanical strength distributions that ultimately determine milling quality. At higher HMCs, the presence of weak, immature kernels reduces HRY. At low HMCs, rapid moisture adsorption by low MC kernels can cause fissures, which also greatly reduces HRY. While it is known that HMC influences kernel MC variability, information is not available relating HMC to kernel-to-kernel mechanical strength distributions. This would lend a more direct and complete understanding of why HMC affects HRY. Further, differences in mechanical strength distributions of kernels among growing locations could possibly explain variability in HRYs due to growing location. The objectives were to determine: (1) the influence of growing location and HMC on kernel-to-kernel BFDs of rice lots, and (2) the relationships between BFDs and milling quality.

#### MATERIALS AND METHODS

Long-grain varieties 'Cypress,' 'Drew,' '1093,' 'Francis,' 'Wells,' 'Cocodrie,' and two hybrids 'XL7' and 'XL8,' and medium-grain variety, 'Bengal,' were harvested from three locations at various dates. Bengal, Cypress, and Drew were plot combine-harvested from Keiser, Arkansas, from 1 October to 31 October 2002 (fig. 1, right). Keiser is located in northeast Arkansas and is characterized by heavy clay soils (Sharkey clay). 1093, Francis, and Wells were harvested from Stuttgart, Arkansas, from 21 August to 12 September 2002 (fig. 1, middle). Stuttgart is located in southeast Arkansas and has primarily silt loam soil (Crowley silt loam). RiceTec Inc. at Alvin, Texas, similarly harvested Cocodrie, XL7, and XL8 samples from 30 July to 30 August 2002

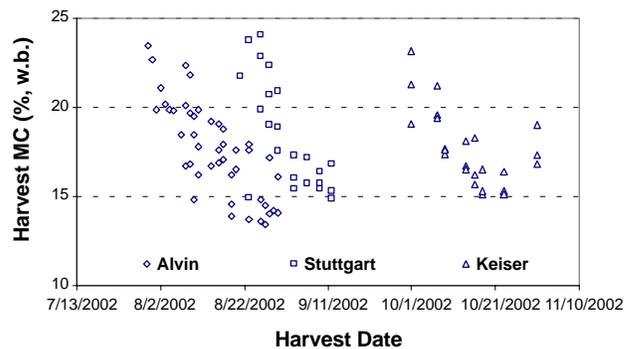


Figure 1. Moisture contents of samples harvested on the indicated dates from the indicated locations.

(fig. 1, left). Alvin is located along the Texas gulf coast and is characterized by heavy, dark clay soils (typically either Bernard or Lake Charles clays). Immediately after harvest, samples were cleaned using a dockage tester (Carter-Day Co., Minneapolis, Minn.). The HMCs of the samples were measured using an individual kernel moisture meter (CTR-800E, Shizuoka Seiki, Shizuoka, Japan). Two-kg samples of each lot were dried slowly by spreading the rice on screened trays in a chamber maintained at approximately 21°C and 65% RH (rough rice equilibrium MC of 12.8%) by a temperature and RH control unit (Climate Lab AA, Parameter Generation & Control, Inc., Black Mountain, N.C.). The samples were then sealed in plastic bags and stored at 2°C until milling and mechanical property tests.

Two hundred kernels were randomly selected from each location/variety/HMC lot and hulled by hand. Three-point bending tests were conducted on each brown rice kernel using a texture analyzer (TA.XT2i, Texture Technologies Corp., Scarsdale, N.Y.) with a flat-faced loading head, having a thickness of 1.5 mm and a width of 9.9 mm (fig. 2). The distance between the two supporting points was set at 3.4 mm and the deformation rate was 0.5 mm/s. The 3.4-mm supporting point distance was selected based on observations reported by Siebenmorgen and Qin (2005) in which some rice kernels, particularly shorter kernels, were cut at the ends if distances greater than 4 mm were used. The 3.4-mm distance was chosen to accommodate both long- and medium-grain kernels. After placing a kernel across the supports, a bending test was initiated and the maximum force attained before the kernel failed was recorded as the breaking force.

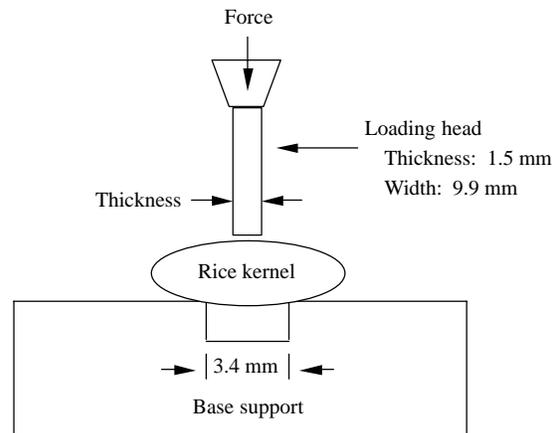


Figure 2. Schematic of the three-point bending test device.

Two 150-g subsamples from each lot were milled to determine HRY. Prior to milling, samples were allowed to warm to approximately 21°C. The rough rice was first shelled using a laboratory huller (THU, Satake Engineering Co., Tokyo, Japan) with a roller clearance of 0.48 mm. The resulting brown rice was milled for 30 s using a laboratory mill (McGill No. 2, Rapsco, Brookshire, Tex.) with a 1.5-kg mass placed on the lever arm 15 cm from the center of the milling chamber. All samples were milled at approximately 12.5% rough rice MC. The percentage head rice in each milled sample was determined using an image analyzer (2312 Graincheck, FOSS North America, Minneapolis, Minn.).

## RESULTS AND DISCUSSION

### BREAKING FORCE DISTRIBUTION TRENDS

Figure 3 shows the BFDs for Bengal, Cypress, and Drew samples with high, medium, and low HMCs harvested at

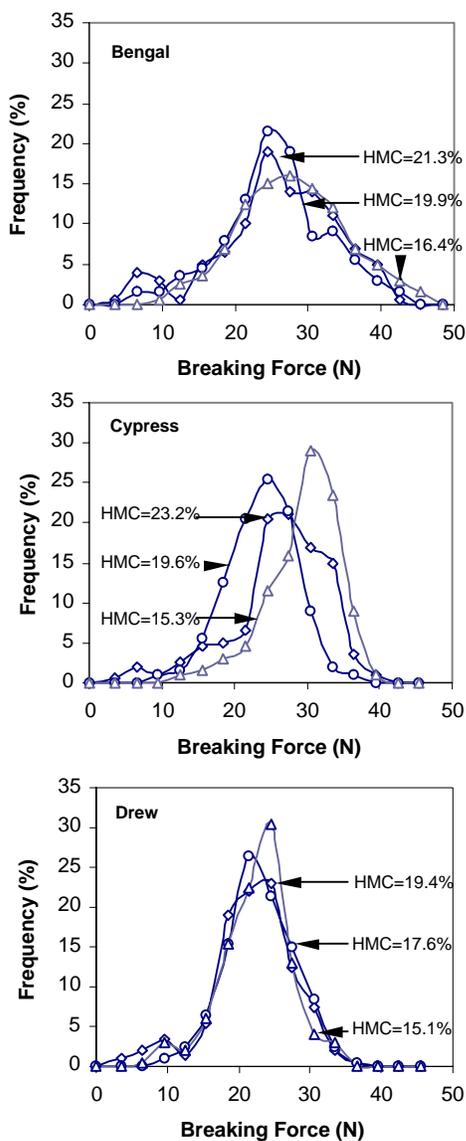


Figure 3. Kernel breaking force frequency distributions at selected harvest moisture contents (HMCs) in 2002 for ‘Bengal,’ ‘Cypress,’ and ‘Drew’ from Keiser, Ark. Each curve was generated from 2001 brown rice kernels.

Keiser, Arkansas. While not as apparent with Bengal or Drew, there was a tendency, as illustrated with Cypress in figure 3, for the peak breaking force mode to shift to greater breaking forces as HMC decreased. This would indicate that the overall average strength of kernels increased as HMC decreased. This could be explained by the hypothesis that as HMC decreases, the overall kernel filling and maturity level increases. Matthews and Spadaro (1976) and Lu and Siebenmorgen (1995) showed that kernel thickness increases as the kernel matures; this increase in thickness would be expected to produce greater kernel breaking forces. However, as the MC decreases to critically low levels, kernels become susceptible to fissuring by rapid moisture adsorption, which can drastically lower kernel breaking force.

Figure 4 shows selected BFDs for lots harvested from Stuttgart, Arkansas. For all varieties from this location, the BFDs showed a much different pattern than those from

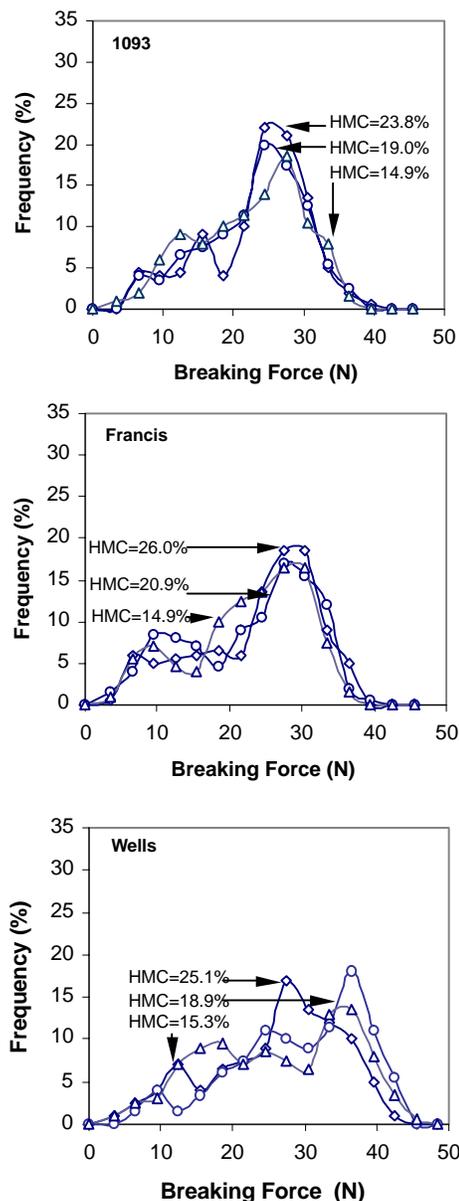


Figure 4. Kernel breaking force frequency distributions at selected harvest moisture contents (HMCs) in 2002 for ‘1093,’ ‘Francis,’ and ‘Wells’ from Stuttgart, Ark. Each curve was generated from 200 brown rice kernels.

Keiser in that the Stuttgart distributions were skewed to low breaking force levels. Associated with this distributional pattern was an increased variation in breaking forces relative to those from Keiser (fig. 3). This significant difference in BFDs could have ramifications in milling quality as it is hypothesized that kernels with low breaking forces, resulting from either being thin due to immaturity or fissured due to moisture adsorption, will be prone to breaking during milling.

Figure 5 shows selected BFDs for samples of hybrids/varieties from Alvin, Texas. Overall, the BFDs from Alvin more closely resembled those from Stuttgart, Arkansas (fig. 4) than Keiser, Arkansas (fig. 3). The Alvin distributions tended to be heavily skewed to low breaking force levels. In general, samples with HMCs greater than 20% produced a

bi-modal and in some cases a tri-modal BFD. As HMC decreased, the distributions became more uniform, transforming into a bi-modal and then practically a single-modal distribution. The “shifting” from multi- to single-modal distributions was not consistent, which could have been due to in-field variability. The occurrence of moisture adsorption fissuring due to weather conditions could also have played a role in this inconsistency. The distributions for XL7 in figure 5, in particular, illustrate moisture adsorption as a potential factor, as the distribution for the sample harvested at 13.6% MC produced a primary mode at a much lower breaking force than the samples at higher HMCs. This trend was much more apparent in the Alvin samples than those from either Keiser or Stuttgart. For example, the Cypress distribution in figure 3 showed a tendency for the primary peak to increase in breaking force level at low HMC.

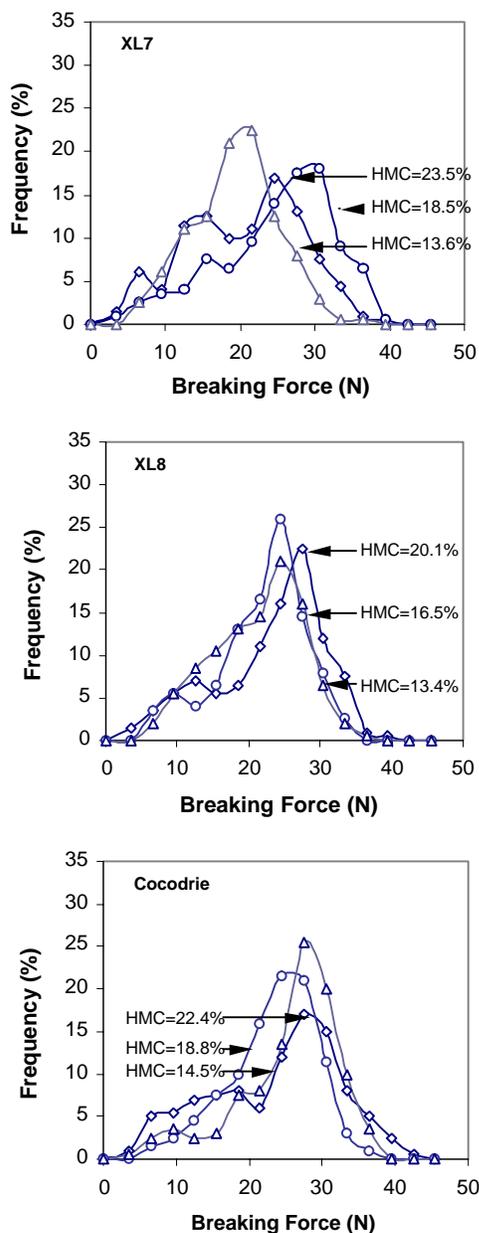


Figure 5. Kernel breaking force frequency distributions at selected harvest moisture contents (HMCs) in 2002 for ‘XL7,’ ‘XL8,’ and ‘Cocodrie’ from Alvin, Tex. Each curve was generated from 200 brown rice kernels.

### BREAKING FORCE DISTRIBUTION VS. HARVEST MOISTURE CONTENT

Table 1 shows the correlation of HMC to average breaking force for the rice lots. The average breaking force ranged from 17 to 28 N over the HMC range of the samples (fig. 6). There were inconsistent trends and large levels of variability in average breaking force values across HMCs. Some varieties showed general trends of increasing average breaking force as HMC decreased, while others showed the opposite trend; this may have depended some on the scope of the HMC range for a given variety. Some varieties, such as XL7 from Alvin, Texas, and Wells from Stuttgart, Arkansas, produced a trend of increasing average breaking force from a high to mid-HMC, but then decreased as HMC decreased to low levels (data not shown). This pattern was expected due to lowered breaking forces of immature kernels at high HMCs and fissured kernels at low HMCs. Bengal, as a representative medium-grain variety, displayed a narrower average breaking force range than those of the long-grain varieties, as can be seen in figure 6.

### HEAD RICE YIELD VS. AVERAGE BREAKING FORCE

Figure 6 indicates the relationship between HRY and the average breaking force of brown rice kernels for all samples. The correlation coefficients between average breaking force and HRY are shown in table 1. For samples from Keiser, there was no relationship between HRY and average breaking

Table 1. Correlation coefficients between the indicated parameters.

Location	Variety	HMC <sup>[a]</sup>	ABF <sup>[b]</sup>	P of S <sup>[c]</sup>
		ABF <sup>[b]</sup>	HRV <sup>[d]</sup>	HRV <sup>[d]</sup>
Keiser, Arkansas	Bengal	-0.0905	0.1790	0.4277
	Cypress	-0.5887	0.3495	0.6509
	Drew	-0.3987	-0.6308	-0.4253
Stuttgart, Arkansas	I093	0.5951	0.4203	0.4624
	Francis	0.4627	0.2983	0.5752
	Wells	-0.2379	0.3932	0.6162
Alvin, Texas	XL7	0.1108	0.7916	0.8136 <sup>[e]</sup>
	XL8	0.6193	0.9153 <sup>[e]</sup>	0.9074 <sup>[e]</sup>
	Cocodrie	-0.5182	0.4861	0.6620 <sup>[e]</sup>

<sup>[a]</sup> Harvest moisture content (% w.b.).

<sup>[b]</sup> Average breaking force of 200 brown rice kernels (N).

<sup>[c]</sup> Percentage of strong kernels (breaking force greater than 20 N) in a 200 kernel sample (%).

<sup>[d]</sup> Head rice yield (%), mean of two 150-g subsamples.

<sup>[e]</sup> Significant at P < 0.01.

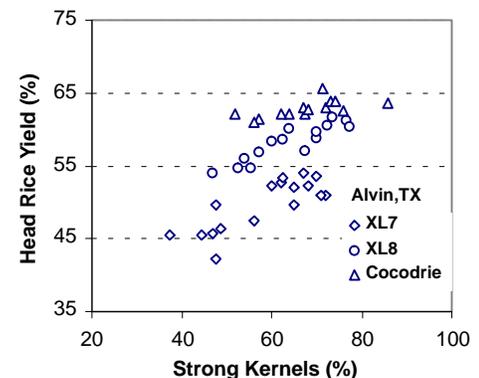
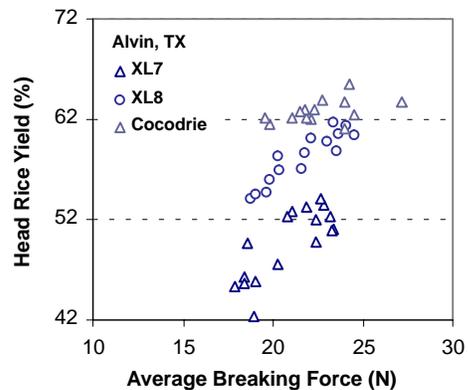
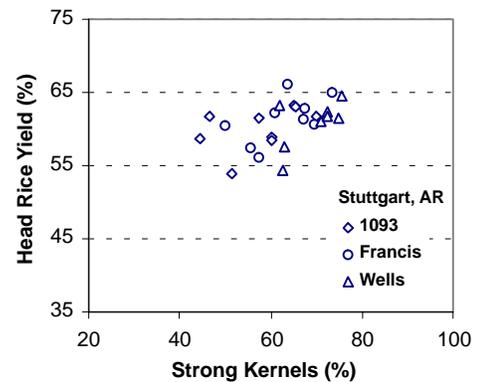
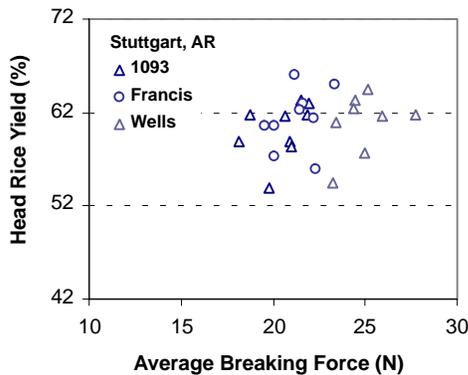
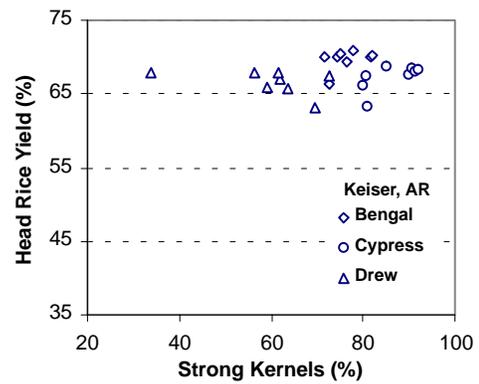
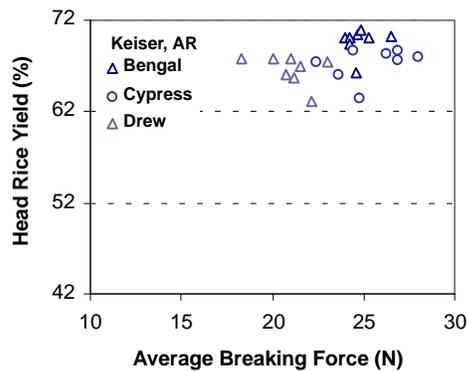


Figure 6. Correlation of head rice yield to average breaking force for samples harvested in 2002 from Keiser, Ark., Stuttgart, Ark., and Alvin, Tex. Each point was generated from a 200 kernel brown rice sample. Correlation coefficients are given in table 1.

force in that HRY did not dramatically vary over the range of average breaking forces. The samples from Stuttgart and Alvin generally showed a direct, linear relationship between HRY and average breaking force, although, due to variability in the data, table 1 shows generally low correlation coefficient values. Figure 6 indicates that such a linear relationship held for those location/variety combinations having generally lower overall HRYs; all samples from Keiser were noted to have exceptionally high HRYs.

#### HEAD RICE YIELD VS. PERCENTAGE OF STRONG KERNELS

Lu and Siebenmorgen (1995) showed that while HRY was related to average breaking force, there was a stronger relationship between HRY and the percentage of kernels that withstood a certain breaking force. Lu and Siebenmorgen reported this breaking force level to vary from 14.5 to 16 N depending on the rice variety. More recently, Siebenmorgen

Figure 7. Correlation of head rice yield to percentage of strong kernels for samples harvested in 2002 from Keiser, Ark., Stuttgart, Ark., and Alvin, Tex. Each point was generated from a 200 kernel brown rice sample. “Strong” kernels are defined as those kernels that withstood more than a 20-N force in a bending test. Correlation coefficients are given in table 1.

and Qin (2005) showed a significant relationship between HRY and the percentage of kernels that withstood a breaking force greater than 20 N.

Using the 20-N breaking force as the level that separated strong from weak kernels, the percentage of strong kernels for each sample was calculated. Figure 7 indicates the relationships between HRY and the percentage of strong kernels for each location/variety/HMC lot. As with the average breaking force relationships, the Keiser varieties showed no relationship between HRY and percentage of strong kernels; all of the samples from Keiser had very high HRYs, even though the percentage of strong kernels varied (fig. 7). However, a potential reason for this lack of correlation is the choice of force level used to differentiate strong from weak kernels. The frequency distributions in figure 3 indicate that the force level separating the two

breaking force modal populations was approximately 12 to 13 N. Thus, using the selected level of 20 N would classify some strong kernels as being weak.

Head rice yields were better correlated with the strong kernel percentages at Stuttgart and Alvin than Keiser. The frequency distributions for Stuttgart in figure 4 indicate that 20 N was a reasonable estimate of the force level separating the breaking force modal populations, although some of the BFDs from Stuttgart, particularly those from 1093 with 19.0% and 14.9% HMCs, did not reveal a definitive mode separation. As such, some of the kernels classified as weak could have indeed survived milling intact and contributed to HRY.

Figure 7 and table 1 indicate relatively strong correlation coefficients between HRY and percentage of strong kernels for the Alvin samples. Similar to figure 3 for Keiser, figure 5 for Alvin indicates that 20 N may not be the optimal value to use for defining a strong kernel.

In summary, the breaking force distributions, measured across a range of HMCs and growing locations, did not reveal a consistent demarcation between high and low kernel breaking force modal populations. Furthermore, the magnitude of this demarcation force was dependent on the production location, thereby precluding the use of a universal force level to differentiate weak from strong kernels. It is speculated that incorporating a measure of the cross-sectional area of the kernel, from which a failure stress level could be calculated, into the procedure used to define strong kernels could improve the prediction of HRY. However, adding such a parameter would greatly add to the procedural complexity of the approach, particularly with regards to developing automated instruments to perform HRY predictions.

## SUMMARY AND CONCLUSIONS

The effects of growing location and HMC on kernel-to-kernel three-point breaking force distributions were investigated. The BFD patterns were affected by HMC, but were most notably affected by growing location. The distributional patterns for a variety were characteristic for a given growing location, and varied greatly across locations. The breaking force frequency distributions were generally bimodal, although in many instances a clear demarcation between modal populations was not apparent.

Head rice yield was plotted against the percentage of kernels in a sample having breaking forces greater than 20 N, which was used as an estimate to define "strong" kernels. The strongest correlations between HRY and the percentage of strong kernels were found for location/variety/HMC lots having low to mid-level HRY levels. Little to no correlation was observed for samples having high HRYs. These low correlations were due in large part to the lack of a clear separation between breaking force modal populations.

## ACKNOWLEDGEMENTS

The authors wish to thank the Arkansas Rice Research and Promotion Board and the corporate sponsors of the University of Arkansas Rice Processing Program for the financial support of this research.

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