Quantification of the Relationship Between Sheath Blight Severity and Yield Loss in Rice

M. A. MARCHETTI, Research Plant Pathologist, and C. N. BOLLICH, Research Agronomist, Agricultural Research Service, U.S. Department of Agriculture, Texas A&M University Agricultural Research and Extension Center, Beaumont 77713

ABSTRACT

Marchetti, M. A., and Bollich, C. N. 1991. Quantification of the relationship between sheath blight severity and yield loss in rice. Plant Dis. 75:773-775.

Breeding rice with resistance to sheath blight is difficult, because the resistance is expressed quantitatively, and the relationship between symptom expression and disease-induced yield losses is not clear. A 5-yr study to quantify this relationship showed a high correlation between a disease index (DI) and percent yield loss, $r^2 = 0.74$. The DI is calculated from visual estimates of the percent harvest area at prescribed disease severity levels. DIs across seven cultivars and 5 yr ranged from 1.7 to the maximum 9. A regression line is described by y (loss) = $-1.8 + 5.1\ x$ (DI). Evaluation of breeding lines for sheath blight resistance is based upon symptom expression. Two F_7 lines, selected solely on disease symptoms, from progeny of resistant x-susceptible crosses showed superior sheath blight resistance as regards effects of disease on yield.

Sheath blight caused by *Rhizoctonia solani* Kühn (anastomosis group AG-1 IA) has become the most serious disease of rice (*Oryza sativa* L.) in the southern United States. The etiology, epidemiology, and management of the disease in the United States were reviewed by Lee and Rush (3). Sheath blight was a minor disease of U.S. rice for decades, but it gained in importance in the 1970s with the widespread introduction of soybeans (*Glycine max* (L.) Merrill) into rice rotation. *R. solani* AG-1 IA also causes aerial blight of soybeans (3). The rapid adoption of high-yielding U.S. long-grain semidwarf cultivars and increased N-fertilization in the 1980s elevated sheath blight to its present status. Previous work with near-isogenic lines showed that semidwarfs sustain greater losses from the disease than do standard-height lines (5).

A major goal of southern United States rice breeding programs is the incorporation of sheath blight resistance into agronomically superior cultivars. Efforts have been hampered by a lack of germ plasm sources of high resistance. A continuum of disease symptoms from moderate to very severe has been observed among breeding lines over a decade of screening, with acceptable within-line consistency (M. A. Marchetti, *unpublished*). However, the relationship between symptom expression and loss of yield was not known. Symptoms indicating moderate susceptibility may represent functional field resistance as regards effects on yield and quality. We are reporting the results of a 5-yr study (1984–1988) to quantify the relationship between sheath blight severity and yield losses in U.S. long-grain cultivars. Also, we are reporting on two lines selected for improved sheath blight resistance from crosses of the very susceptible cultivar Lemont, a leading semidwarf cultivar, and an equally susceptible sister line (RU8003050) with the moderately resistant cultivar Leah (Table 1). Leah is considered a short-statured cultivar, although it does not possess a known dwarfing gene.

Accepted for publication 16 January 1991.

MATERIALS AND METHODS

All research was conducted at Beaumont, Texas, in field plots with six rows (6.1 m long and spaced 18 cm apart) that were drill-seeded at 90 kg/ha. The seven test cultivars listed in Table 1 are in order from most to least susceptible. Their pedigrees illustrate their high degree of relatedness, particularly among the Texas-bred cultivars (Rexmont, Lemont, Skybonnet, and Gulfmont). Plots of each cultivar were planted in pairs, with plot pairs replicated four times in a randomized complete block design.

Planting dates and nitrogenous fertilization varied among years because of weather. Plots were seeded 8–14 April, with seedling emergence 20–24 April. Preplant-incorporated ammonium sulfate (21% N) was applied with nitrogen at 100–112 kg/ha. Plots were topdressed, with nitrogen at 67 kg/ha, at the 2-mm panicle stage of Tebonnet, the earliest of the seven cultivars (Table 1). The permanent flood was applied 25–30 days after seedling emergence. The flood was maintained at a depth of 3–10 cm until 7–10 days before harvest of the earliest maturing lines, when the blocks were drained. Weeds were effectively controlled with a mix of bentazon (1.1 kg a.i./ha) and propanil (4.5 kg a.i./ha), applied 3–4 days before permanent flood.

One of each pair of plots was inoculated 58–62 days after seedling emergence with 250 cc of a pathogen-infested mixture of rice hulls and rough (unhulled) rice (2:1, v/v). Inoculum was sprinkled between the center two rows along the interior 5 m.

Plots were rated weekly for disease incidence and severity, beginning 3 wk after heading of the earliest cultivar. A disease index (DI) was developed to take into account both disease incidence and severity. The DI was calculated from percentages of the 1.73-m^2 area to be harvested (expressed as decimals) rated 5 (40–60% of plant height diseased), 7 (61–90%), and 9 (>90%) (5). For example, the DI of a plot with 25% of the harvest area rated 5, 50% rated 7, and 15% rated 9 would be 6.1 $[(0.25 \times 5) + (0.50 \times 7) + (0.15 \times 9)]$. To simplify the rating procedure, any portion of the harvest area with less than 40% of plant height diseased was excluded from the DI equation. Mean DIs reported for each cultivar were derived from ratings recorded within 7 days of harvest, and we felt that plants less than 40% diseased at this time would not account for meaningful losses in the context of this study.

Plots were hand-harvested, and the grain threshed with a Vogel thresher (custom built by Bill's Welding, Pullman, WA), then dried to 12% moisture. Yields were calculated from grain harvested from the interior 4.8 m of the center two rows of each plot. Milling yields were determined on 125-g samples of grain according to standard rice milling procedures (1). Values for percent yield loss were calculated from yields of inoculated and check plots within plot pairs.

Data were summarized by year and subjected to analysis of variance (with years as replications). Differences among rice lines in DI, percent yield loss, and reductions in milling yield were identified by protected LSD analysis (7). The last two years include data from evaluation of two experimental lines with improved sheath blight resistance. They are F_7 lines from the crosses Leah/Lemont (RU8703153) and Leah/RU8003050

(RU8703196). RU8003050 is a sister line of the cultivars Lemont and Gulfmont and is similar in susceptibility to sheath blight. It was not included in this study because of lack of seed.

RESULTS

There was no evidence of movement of inoculum in floodwater from inoculated to check plots. The seven test cultivars differed significantly in DI, percent yield reduction, and reduction of whole-grain milling yield resulting from sheath blight (Table 2). The Texas-developed cultivars were the most severely affected, according to every measure of disease. The cultivar Leah was least affected by sheath blight but milled poorly, even in the absence of the disease.

Disease severity and associated yield reductions varied considerably among the five years (Table 3). Milling yields were so variable within years that the relationship between DI and milling yield reduction was not quantifiable. Percent yield reduction and DI were strongly correlated ($r^2 = 0.74$) (Fig. 1). The regression line is described by the following equation: percent yield reduction = −1.8 + 5.1 × DI. The percent yield loss increased by about five percentage points per unit increase in DI.

The two selections from the crosses were significantly more resistant to sheath blight than their respective susceptible parents and at least as resistant as Leah in two years of testing (Table 4). These two were selected because of other desirable agronomic traits from a greater number of lines rated as more resistant than the susceptible parent.

DISCUSSION

This information will be valuable to rice breeding programs with improved sheath blight resistance as an objective. Differences in cultivars with regard to both symptom expression and yield reductions resulting from the disease were quantified. The strong relationship between symptom severity and yield reduction is of practical importance, since almost all early-generation selection for sheath blight resistance is based primarily on symptomatology. Also, the relationship between disease severity and consequent yield reduction varies among cultivars. The ratios of percent loss to DI among cultivars tend to follow the trend of the DIs (i.e., the lower the DI, the lower the percent loss-DI ratio) (Table 2). In fact, the quadratic equation $y = 13.2 - 0.43x + 0.46x^2$ describes the regression curve slightly more accurately ($r^2 = 0.76$), within the limits of our data. The notable exception among the test cultivars is Newbonnet, with the lowest mean DI but the highest loss-DI ratio. Newbonnet sustained greater losses than disease symptoms indicated. This inconsistency may reflect a difference between Newbonnet and the other cultivars in relative availability, beyond the requirements of the pathogen, of nonstructural carbohydrate for grain filling. Differences among cultivars in carbohydrate

Table 1. Some characteristics of rice cultivars evaluated for sheath blight resistance, 1984–1988, Beaumont, Texas

Line	Pedigree	Height (cm)	Days to head
Rexmont	Newrex/Bellemont[u]	92	86
Lemont	CI 9881[v]/PI 331581[w]//Lebonnet[v]	99	92
Skybonnet	Bluebelle//Belle Patna/Dawn	132	89
Gulfmont	CI 9881/PI 331581//Lebonnet	101	88
Tebonnet	Bonnet 73[x]/CI 9841[y]	138	85
Leah	CI 9902[z]/unknown outcross selection	102	90
Newbonnet	Dawn/Bonnet 73	127	95
RU8703153	Leah/Lemont	104	91
RU8703196	Leah/3/CI 9881/PI 331581//Lebonnet	87	90

[u] Bellemont = CI 9881/PI 331581.
[v] Bluebelle//Belle Patna/Dawn; sister lines of Skybonnet.
[w] Bluebelle*6/Taichung Native No. 1.
[x] Lacrosse//Zenith/Nira/3/Bluebonnet 50/CI 9187.
[y] Vegold/CI 9556//Dawn.
[z] Dawn/PI 245717/3/13-D//Rexoro/unknown red rice.

Table 2. Mean effects of sheath blight on yield and milling of seven rice cultivars in paired inoculated and check field plots, 1984–1988, Beaumont, Texas

		Yield (kg/ha)				Whole grain (%)		
Cultivar	DI[x,y]	Check	Inoculated	Yield loss (%)[y]	L/DI[z]	Check	Inoculated	Milling loss (%)[y]
Rexmont	7.8 a	6,864	3,856	44 a	5.6	54.0	43.6	18 ab
Lemont	7.2 ab	6,601	4,362	34 b	4.7	56.6	43.5	23 a
Skybonnet	7.2 ab	6,127	4,089	33 b	4.6	57.9	53.0	9 bc
Gulfmont	6.8 b	6,710	4,627	31 b	4.6	53.9	44.8	17 ab
Tebonnet	5.3 c	6,324	4,952	22 c	4.1	57.6	55.9	2 c
Leah	4.1 c	6,154	5,210	15 c	3.7	44.3	43.1	2 c
Newbonnet	3.8 c	6,325	4,933	22 c	5.7	60.9	59.3	2 c
$LSD_{0.05}$	1.0			7.5				13.9

[x] Disease index, calculated from portions of harvested area (in decimals) rated 5 (41–60% of plant height diseased), 7 (61–90%), and 9 (>90%). For example, the DI of a plot with 25% rated 5, 50% rated 7, and 15% rated 9 is 6.1 [(0.25 × 5) + (0.50 × 7) + (0.15 × 9)].
[y] Values in the same column followed by the same letter are not significantly different (P = 0.05), according to protected LSD analysis of mean values of four replications per year.
[z] Ratio of percent yield loss to DI.

Table 3. Yearly variation in sheath blight severity and its impact on yield of rice, 1984–1988, Beaumont, Texas

Year	Mean disease index[y,z]	Mean yield loss (%)[z]
1988	7.6 a	40.9 a
1985	6.8 ab	29.1 b
1986	6.5 b	27.8 b
1987	4.6 c	25.3 bc
1984	4.6 c	19.4 c
$LSD_{0.05}$	0.9	6.4

[y] Calculated from portions of the harvested area (in decimals) rated 5 (41–60% of plant height diseased), 7 (61–90%), and 9 (>90%). For example, the disease index of a plot with 25% rated 5, 50% rated 7, and 15% rated 9 is 6.1 [(0.25 × 5) + (0.50 × 7) + (0.15 × 9)].
[z] Values are means of disease ratings or yield losses of the seven cultivars listed in Table 2, each replicated four times per year. Values in the same column followed by the same letter are not significantly different (P = 0.05), according to protected LSD analysis.

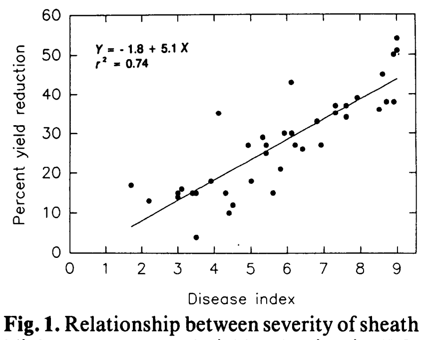

Fig. 1. Relationship between severity of sheath blight symptoms and yield reduction in U.S. long-grain rice. Points represent four-replicate means of each of seven rice cultivars in each of 5 yr (1984–1988) and of each of two experimental lines in each of 2 yr (1987–1988). Disease index was calculated from portions of harvested area (in decimals) rated 5 (41–60% of plant height diseased), 7 (61–90%), and 9 (>90%). For example, the disease index of a plot with 25% rated 5, 50% rated 7, and 15% rated 9 is 6.1 [(0.25 × 5) + (0.50 × 7) + (0.15 × 9)].

reserves during grain filling have been documented, but Newbonnet was not among those studied (2).

There has been little progress toward breeding for sheath blight resistance reported in the international literature, possibly because other diseases of greater regional importance are being targeted for resistance breeding (for instance, blast, bacterial leaf blight, and tungro). But the difficulty in evaluating resistance in sheath blight is also a factor. No sources of strong qualitative resistance are known to date, and differences in resistance tend to be less than definitive under typical screening conditions. Plants with 40–60% of their height diseased do not appear to have meaningful resistance. Yield reductions of 15–20% do not seem indicative of acceptable resistance, especially to growers for whom that level of damage is unacceptable. But quantitative resistance is at its worst in small plots (8). The responses reported here occurred under conditions that resulted in 95–100% diseased plants and 30–40% yield losses in cultivars that nonetheless have produced record yields in recent years. Our plots were artificially inoculated to ensure uniform exposure to the pathogen. Such measures are required to provide reliable comparative data, but they do not necessarily represent field conditions.

The observed level of resistance could have long-term effects on disease incidence by reducing inoculum production on less susceptible cultivars. Initial results of an ongoing study showed sclerotial production was reduced by 50% and average sclerotial size by 18% in diseased plots of RU8703196 compared to those of Lemont (6). Reduced inoculum should result in reduced disease incidence in subsequent seasons. Other workers have reported a direct relationship between sclerotial size and survivability (4). Therefore, fewer of the sclerotia produced on the more resistant RU8703196 should be infectious in the following season. The ongoing study is concerned with these conjectures.

RU8703196 has been used as a parent resistant to sheath blight in the rice breeding program at Beaumont, and it will be registered as elite germ plasm. It possesses good field resistance to blast, typical U.S. long-grain cooking quality, and a semidwarf plant type. Although RU8703196 compared favorably in yield and milling quality to Lemont in this study, it has not demonstrated the yield potential of Lemont and newer cultivars in extensive regional trials (C. N. Bollich, *unpublished*). Therefore, its release as a commercial cultivar is unlikely.

Table 4. Comparison of effects of sheath blight in two rice lines selected for improved resistance and their parental cultivars, 1987–1988, Beaumont, Texas

		Yield (kg/ha)			Whole grain (%)		
Cultivar	Disease index[y,z]	Check	Inoculated	Loss (%)[z]	Check	Inoculated	Loss[z] (%)
Lemont	7.6 a	6,857	4,072	40 a	55.7	46.4	17 a
Leah	5.2 b	6,122	4,756	22 b	45.4	44.5	1 a
RU8703153	4.4 b	6,725	5,250	22 b	39.1	35.3	10 a
RU8703196	3.3 b	7,027	5,954	15 b	55.4	52.0	7 a
$LSD_{0.05}$	2.0			12			28

[y] Calculated from portions of harvested area (in decimals) rated 5 (41–60% of plant height diseased), 7 (61–90%), and 9 (>90%). For example, the disease index for a plot with 25% rated 5, 50% rated 7, and 15% rated 9 is 6.1 [(0.25 × 5) + (0.50 × 7) + (0.15 × 9)].

[z] Values in the same column followed by the same letter are not significantly different ($P = 0.05$), according to protected LSD analysis of four replicate means per year.

ACKNOWLEDGMENT

We wish to thank R. C. Kolander for technical assistance.

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