Assessment of Blast Disease and Yield Loss in Susceptible and Partially Resistant Rice Cultivars in Two Irrigated Lowland Environments

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ABSTRACT

Bonman, J. M., Estrada, B. A., Kim, C. K., Ra, D. S., and Lee, E. J. 1991. Assessment of blast disease and yield loss in susceptible and partially resistant rice cultivars in two irrigated lowland environments. Plant Dis. 75:462-466.

The importance of blast disease, caused by *Pyricularia oryzae*, varies with environment, and irrigated lowland rice in Korea is more prone to the disease than irrigated lowland rice in the Philippines. Rice cultivars with partial resistance can reduce losses from blast. Fungicide-protected and inoculated field plots were used to assess the effectiveness of locally adapted partially resistant cultivars in reducing leaf blast, neck blast, and yield losses. Over six trials conducted from 1987 to 1989, yield loss was positively correlated with the incidence of severe neck blast ($r^2 = 0.95$). The incidence of neck blast was low and yield losses negligible in partially resistant cultivars IR36 in the Philippines and Seomjin in Korea. Philippine cultivar IR66, which has partial resistance to neck blast but not to leaf blast, also showed a low incidence of neck blast and low yield losses. Partially resistant cultivar Bonggwang showed intermediate neck blast incidence of 16.2% and yield loss of 31.2% in Korea. The maximum losses measured in the susceptible checks were 20.9% in IR50 in the Philippines and 50.2% in Daechang in Korea. Under the less conducive irrigated lowland conditions in the Philippines, partial resistance alone can be used to manage blast disease. Under the highly conducive conditions in Korea, only cultivars with high levels of partial resistance will be effective alone, and cultivars with lower resistance may require the use of additional cultural and chemical control tactics.

Blast disease, caused by *Pyricularia oryzae* Cav., is common and destructive in irrigated rice (*Oryza sativa* L.) in temperate and subtropical areas of East Asia. Even in less blast-conducive environments, such as irrigated lowland rice areas in the tropics, serious epidemics have occurred where susceptible cultivars have been grown (16,19). In general, however, the disease is more destructive in temperate environments than in the tropics (16). The use of resistant cultivars is one of the key means of managing blast, and blast-resistant germ plasm has been deployed widely by national rice research programs. For irrigated rice in the tropics, it may be possible to manage blast with partially resistant cultivars (6,22). Partial resistance was previously defined as "a form of incomplete resistance in which spore production is reduced even though the host plants are susceptible to infection (susceptible infection type)" (17) but more recently has been called "quantitative resistance based on minor genes" (18). The earlier definition of partial resistance is adopted here because, except for IR36 (21), the genetic basis for it in the cultivars used in the present study is not known. Some cultivars with partial resistance to blast have shown durable resistance sensu Johnson (10), because for years they have been sown on large areas without appreciable damage from blast in environments where susceptible cultivars suffer high losses (6).

For irrigated lowland rice in temperate regions, the value of partial resistance for managing blast is not as clear as in the tropics. The perception is widely held among scientists in Japan that partial resistance, termed "field resistance" by Japanese workers, is a desirable trait (8). In the United States, such resistance has been recognized as one of the factors that limits the destructiveness of blast (15). In Korea, the strategy of using partial resistance was rejected in the past because, during the epidemic of 1978, partially resistant cultivars showed severe symptoms (7). Particularly because high rates of nitrogen fertilizer are used, Korea represents an environment where blast is unusually intense. Perhaps partial resistance that is agriculturally useful in less conducive environments is insufficient in areas favoring the disease, as suggested by Asaga (3) for various regions in Japan.

In small-plot seedling tests conducted in aerobic soil, it is well established that partially resistant cultivars can be severely diseased, but the level of disease is lower than that of susceptible cultivars (5,11,13,14,20). However, relatively little information is available from tests in flooded fields, which are more appropriate for estimating the likely disease levels of various cultivars under farm conditions and for measuring grain yields. The purpose of our study was to assess the value of partial resistance for blast management in Korea and the Philippines by measuring disease level and yield loss attributable to blast at both sites with locally adapted partially resistant and susceptible rice cultivars. The site in Korea represented a temperate lowland area highly conducive to the disease, and the Philippine site represented the less blast-prone tropical lowland environment.

MATERIALS AND METHODS

The experiments were conducted from 1987 to 1989 in Magdalena, Laguna, Philippines, and at the Icheon experiment station (Rural Development Administration), Korea. Philippine trials were sown in June at the beginning of the wet season and harvested in September. The trials in Korea were sown in April and harvested in early October.

The cultivars were chosen based on results from previous experiments, including blast nursery screening trials. The test cultivars are all grown commercially. For the Philippine trials, three indica cultivars that are widely grown in tropical Asia were selected. IR36 was chosen because it has partial resistance to leaf and neck blast, IR66 because it is susceptible to leaf blast but has partial resistance to neck blast, and IR50 because it is susceptible to both leaf and neck blast (5). For the Korean trials, japonica cultivars grown locally were selected. Seomjin and Bonggwang were chosen to represent partially resistant cultivars. In more than 30 blast nursery tests conducted at several locations in Korea, Seomjin and Bonggwang had blast scores ranging from 4 to 8 with means of 5.0 and 5.6, respectively. The nurseries were scored on a scale where 4 = an entry with typical lesions but less than 2% diseased leaf area, and 9 = more than 75% diseased leaf area (2). Chucheong and Daechang were chosen to represent susceptible cultivars. In 40 nursery trials in Korea, Chucheong had scores of 4–9 with a mean of 8.2, and Daechang had scores of 5–9 with a mean of 8.1. Seomjin, Chucheong, and Daechang were tested in all trials; Bonggwang was tested in 1988 and 1989

Accepted for publication 17 October 1990 (submitted for electronic processing).

only.

A split-plot experimental design with three replications was used in all trials with fungicide-protected and unprotected treatments as main plots and cultivars as subplots. Subplot size was 36 m^2 in the Philippine trials and 6–21 m^2 in Korea, depending on the year.

Locally recommended agronomic practices were followed with higher nitrogen (N) fertilizer rates used in Korea (220–300 kg/ha) than in the Philippines (120–150 kg/ha). N was applied as ammonium sulfate, 50% at transplanting and 50% at 45 days after transplanting (DAT) in the Philippines and 50% at transplanting, 40% at 30 DAT, and 10% at heading in Korea. The area harvested for grain yield assessment was at least 5 m^2 in Korea and 18 m^2 in the Philippines.

Philippines. Unprotected treatments were inoculated by transplanting infected seedlings into the plots. The inoculum source in each year was a natural population of *P. oryzae* maintained for screening purposes on a mixed sowing of many rice cultivars and lines. In the 1987 trial, 25-day-old infected seedlings of the susceptible line IR442-2-58 were placed inside the subplots at about 45 DAT. In the 1988 trial, inoculation was done beginning at 21 DAT. In the center of the subplot, two trays (23 × 10 × 10 cm) of infected seedlings of IR442-2-58 were placed at canopy height on a wooden stand. The sources were replaced weekly and allowed to remain in the field until booting. At 14 DAT in 1989, a mixture of infected seedlings of IR50, IR36, and IR66 were transplanted into 32 points in each subplot and allowed to remain until booting.

At 45 DAT in 1987 and 21 DAT in 1988 and 1989, pyroquilon (Coratop 2.7G) was applied at 0.6 kg a.i./ha in the protected plots. At booting, pyroquilon was applied at 1.2 kg a.i./ha.

Because inoculation was conducted relatively late in 1987, leaf blast was not evaluated. In 1988, leaf blast severity was assessed once at 38 DAT by estimating the percentage of diseased leaf area in five 1-m^2 quadrats per plot. In 1989, leaf blast was evaluated six times from 32 to 57 DAT by estimating the percentage of diseased leaf area on 20 hills in each subplot chosen at random points along an x-pattern.

Neck blast severity was assessed about 1 wk before harvest by evaluating all panicles taken from 20 randomly chosen hills in the 1987 trial and 20 random hills along an x-pattern in the 1988 and 1989 trials. Disease was scored with the scale of Ahn and Mukelar (1) and was expressed as percentage of severe neck blast (SNB) as described by Bonman et al (5).

Korea. In 1987, the protected plots were sprayed with Kasugamycin (2WP) at 25 g a.i./ha 1 wk after transplanting, 7 days before heading, and 7 days after heading. In 1988 and 1989, Kasugamycin plus Fthalide (Allta 21.2% WP) was applied at 250 g a.i./ha at 36 and 43 DAT, and at 340 g a.i./ha at heading. Disease was allowed to develop naturally in 1987. In 1988 and 1989, inoculations were made to ensure the presence of races compatible with all four test cultivars. Seedlings of Chucheong were grown in pots and artificially inoculated with race KJ-101 in 1988 and race KJ-105 in 1989. In 1988, plots were inoculated at 29 DAT by transplanting infected seedlings at two points inside each plot. In 1989, the center of each plot was inoculated at 35 DAT.

Leaf blast was evaluated five times beginning at 51 DAT in 1987 and at 41 DAT in 1988. Leaf blast was evaluated twice in 1989, at 57 and 64 DAT. The percentage of diseased leaf area was estimated visually on 20 randomly selected hills per plot.

Unlike in the Philippine tests, infection of panicle branches in Korea was common even in the absence of panicle base infection and was easily scored because of the contrast between green, healthy spikelets and white, damaged spikelets. To make the scoring at both sites comparable, panicles having more than 30% damaged spikelets were considered severely affected. The percentage of SNB was determined from 20 randomly selected hills per plot.

RESULTS AND DISCUSSION

Although plants were inoculated at tillering in the 1988 trial in the Philippines, leaf blast development was low, with less than 1% diseased leaf area recorded on IR50. In the 1989 trial, though, more severe leaf blast developed, with nearly 10% diseased leaf area recorded on IR50 by 42 DAT (Fig. 1). Aside from differences in weather between the 2 yr, the lower disease development in 1988 could have been because less initial inoculum was present. Infected seedlings were placed only at the center of each subplot in 1988 but were placed at many points in 1989.

In contrast to the 1989 Philippine trial, leaf blast in the trials in Korea was lower, reaching a maximum of about 4% diseased leaf area in 1987 (Fig. 2). In 1988 and 1989, less than 2% diseased leaf area occurred. Also, the disease peaked later in the season in Korea, reaching maximum severity from 65 to 80 DAT compared with about 40–45 DAT in the Philippines. Presumably, the later peak in Korea was related to weather differences rather than to differences in crop development, because maximum tillering occurred at about 40–45 DAT at both sites.

As in previous experiments (5), IR66 showed susceptibility to leaf blast (Fig. 1) but resistance to neck blast (Table 1). Based on comparison of fungicide-protected and unprotected plots, no significant yield loss was found for IR66, even in 1989 when leaf blast severity was relatively high. Little yield loss attributable to leaf blast was also observed in field experiments in Japan (9). Considering results from all six trials, the occurrence of SNB was positively correlated with the percentage of yield loss. This result was consistent in the following two situations: 1) when yield loss was estimated as the yield difference between fungicide-protected and unprotected plots ($r^2 = 0.95$) and 2) when yield loss of the Korean entries was estimated as the difference between the treatment

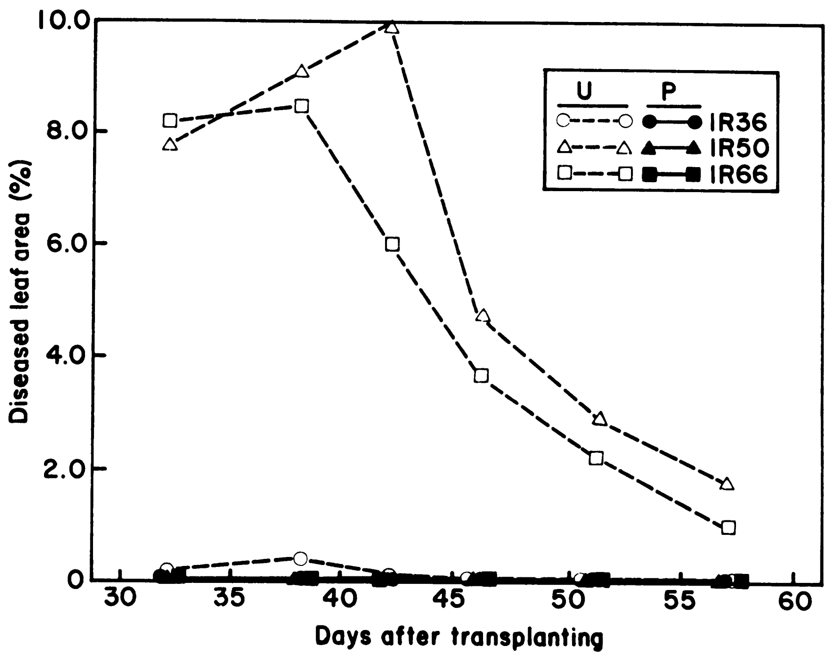

Fig. 1. Leaf blast development in three Philippine cultivars in fungicide-protected (P) and unprotected (U) treatments in the 1989 trial.

Table 1. Percentage of severe neck blast, grain yield, and yield loss from blast of susceptible and partially resistant rice cultivars tested for 3 yr in the Philippines and Korea

Location and cultivar	Trial year	Severe neck blast		Yield (t/ha)		Yield loss[y] (%)
		Inoculated	Protected	Inoculated	Protected	
Philippines						
IR36	1987	1.0 b[z]	0.0 a	3.4 b	3.4 b	1.7 NS
IR66	1987	0.5 b	0.0 a	4.2 a	4.2 a	−1.4 NS
IR50	1987	28.3 a	0.8 a	3.0 c	3.7 b	17.8 **
IR36	1988	0.4 b	0.2 a	4.4 a	4.3 a	−2.3 NS
IR66	1988	3.0 a	0.4 a	4.1 a	4.2 a	2.2 NS
IR50	1988	2.5 a	0.0 a	3.7 a	3.8 a	3.2 NS
IR36	1989	0.7 b	0.0 a	4.5 a	4.7 a	3.2 NS
IR66	1989	0.5 b	0.0 a	4.9 a	5.0 a	1.0 NS
IR50	1989	45.8 a	0.1 a	3.9 b	4.9 a	20.9 **
Korea						
Seomjin	1987	0.0 b	0.0 c	6.6 a	6.5 a	−1.1 NS
Chucheong	1987	90.2 a	14.6 b	3.7 b	5.8 b	35.8 *
Daechang	1987	98.2 a	49.6 a	2.4 c	4.7 c	49.0 **
Seomjin	1988	0.0 d	0.0 c	6.2 a	6.6 a	6.5 NS
Bonggwang	1988	43.1 c	4.6 b	4.2 a	6.0 a	31.2 NS
Chucheong	1988	75.8 b	1.2 bc	4.0 a	6.1 a	34.0 *
Daechang	1988	99.8 a	14.8 a	3.3 a	6.6 a	50.2 **
Seomjin	1989	0.0 c	0.0 b	6.2 a	6.6 ab	6.8 NS
Bonggwang	1989	37.6 b	13.4 a	5.0 b	5.9 b	16.2 NS
Chucheong	1989	74.9 a	6.1 a	4.4 b	6.5 ab	33.1 **
Daechang	1989	81.5 a	6.7 a	4.8 b	7.3 a	34.5 **

[y] Yield loss estimate based on difference between fungicide-protected and unprotected treatments, NS = Not significant, * = significant at the 5% level, ** = significant at the 1% level.
[z] In a column, means followed by a common letter are not significantly different at the 5% level by LSD.

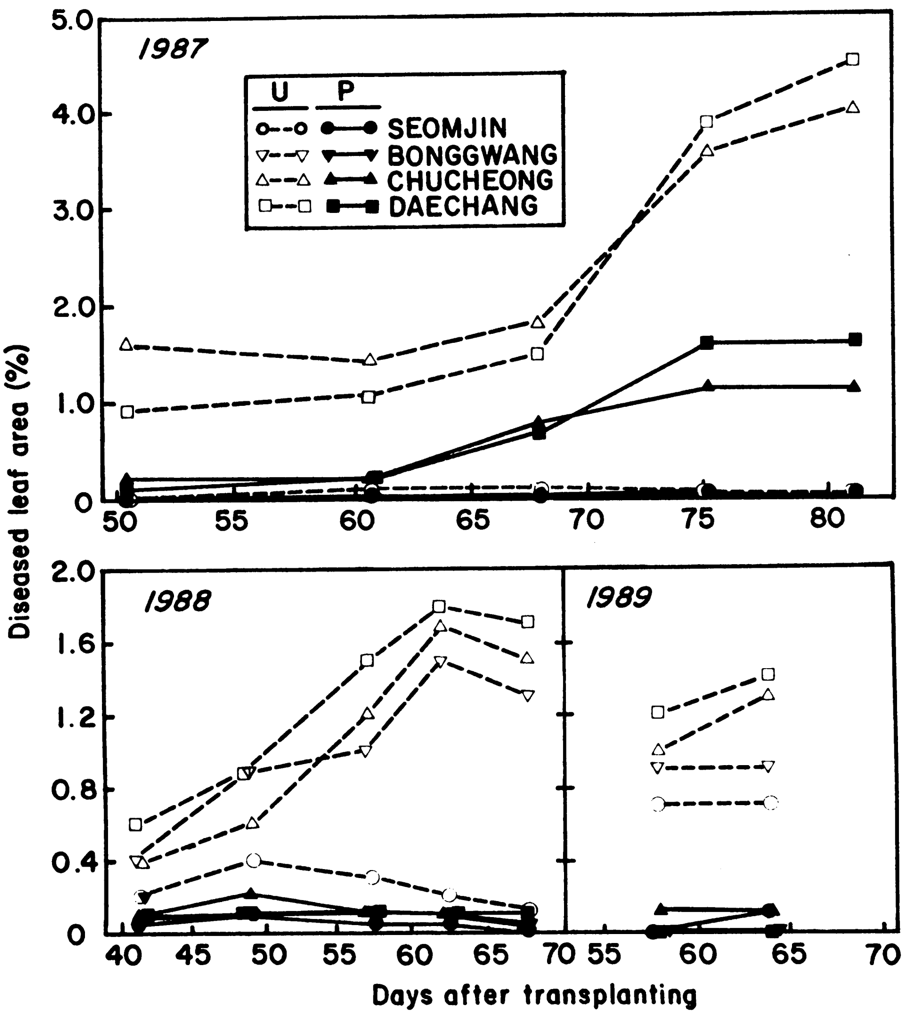

Fig. 2. Leaf blast development in four Korean cultivars in fungicide-protected (P) and unprotected (U) treatments in the 1987–1989 trials.

yield and the highest yield measured for the trial ($r^2 = 0.89$) (Fig. 3). These results indicate the importance of neck blast occurrence to yield reductions and the value of resistance to neck blast in preventing such reductions. Fortunately, resistance to leaf and neck blast is associated in most cultivars, and screening plants for resistance at 3–5 wk of age is probably sufficient to ensure the presence of neck blast resistance in breeding lines (5).

The partially resistant cv. IR36 also showed no significant yield loss attributable to blast in the three Philippine trials (Table 1). Although typical leaf blast lesions were present each year, leaf blast severity was consistently low, as was the incidence of SNB infection (Table 1). Under the conditions of the three trials, the level of partial resistance of IR36 was sufficient to reduce SNB to low levels and prevent yield losses. This result is supported by the history of IR36 and IR50 under commercial production. Blast epidemics have occurred on IR50 in several countries in tropical Asia (12,19), whereas blast has not been a problem on IR36 (6,22).

In previous tests where inoculations were made at flowering, we recorded up to 23% SNB on IR36 and other partially resistant cultivars (5). Thus, in instances where high inoculum influx from nearby fields occurs at flowering, the level of partial resistance of IR36 would be insufficient to prevent losses.

Because rice environments are highly diverse and vary in their conduciveness to blast, the target environment must be considered when assessing the relative durability of blast resistance in rice cultivars and when choosing resistant parents for breeding purposes (6). Resistance that is of practical value for less conducive environments, for example, might be useless in upland rice areas where blast is more intense.

IR50 was the only test cultivar to show significant incidence of SNB and yield loss in the Philippine trials (Table 1). The level of SNB in IR50 was lower, however, than that found in Korea on susceptible cvs. Chucheong and Daechang. SNB ranged from 74.9 to 99.8% on these two cultivars, and yield losses were correspondingly high (33.1–50.2%) (Table 1). Similar losses (40–50%) were measured in Japan with the susceptible cv. Sasanishiki when severe panicle infection occurred (9).

In contrast to the two susceptible cultivars in the Korean trials, the partially resistant cv. Seomjin consistently showed low leaf blast, no incidence of SNB, and low yield loss (Table 1). Thus, the partial resistance level of Seomjin was sufficient to prevent serious loss attributable to blast in the absence of fungicide protection under conditions where susceptible cultivars were heavily damaged. In Japan, Higashi and Saito

(9) reported losses of about 7% in partially resistant cv. Toyonishiki under moderate disease pressure, and 19% loss under severe conditions where losses in susceptible checks were more than 50%. Seomjin has been grown commercially in Korea since 1982, and in 1989 it was cultivated on 160,000 ha (S. Y. Cho, *personal communication*). There is no assurance that the resistance of partially resistant cvs. like Seomjin and Toyonishiki will continue to be effective, though, especially because other japonica cultivars have shown partial resistance specific to certain races of *P. oryzae* (4). Scientists are monitoring the blast pathogen population in Korea yearly to detect possible changes in aggressiveness on partially resistant cultivars such as Seomjin.

The partially resistant cv. Bonggwang proved to be more susceptible than Seomjin. Although incidence of SNB on Bonggwang was lower than on the two susceptible cultivars, yield loss tended to be higher than in Seomjin (Table 1). Bonggwang was introduced to Korea from Japan, where its original name is Minehikari, and it is reported to have an intermediate level of field resistance (8). The results from the Korean field tests agree with the classification of resistance in Japan, because Bonggwang was more resistant than the susceptible cultivars yet had partial resistance insufficient to prevent losses in small plot tests.

If anything, these field trials should have underestimated the effectiveness of partial resistance in Seomjin and Bonggwang, because the plot size was relatively small and inoculum from adjacent plots of the two heavily diseased cvs. Daechang and Chucheong would have entered the plots. Such interplot interference can occur when testing for partial resistance against windborne pathogens (18). Perhaps the level of partial resistance of Bonggwang is of practical value in commercial fields, and field surveys (taking into account fungicide and N level) or further experiments (using large plots) should be conducted to test this hypothesis.

Incidence of SNB and consequent yield losses were much lower in the trials in the Philippines than in Korea (Table 1). This result fits with the observation that tropical lowland environments are less conducive to blast in general than are temperate environments. At present, our understanding of the factors responsible for this difference in blast conduciveness is incomplete. Differences in the nightly duration of leaf wetness from dew deposition may be important, and, perhaps, leaf wetness duration limits blast development in many tropical lowland rice-growing areas (16). Also, in the present study, the earlier peak of leaf blast severity compared with Korea could have contributed to the lower incidence of SNB in the Philippines (Fig. 2). Regardless of the underlying mechanisms, if the experimental site in the Philippines is representative of less blast-conducive tropical environments, cultivars with partial resistance to leaf and neck blast or to neck blast alone can be used to manage blast in such environments.

Differences in cultivar resistance could have affected the relative loss measured in the Korean and Philippine trials. Although some cultivars produced from crosses between indica and japonica rices are grown in Korea, japonica cultivars are better adapted to temperate conditions and are grown on most of the Korean rice area. Indica cultivars are widely grown in the tropics. Thus, there are no commercial cultivars common to both environments, and we have no direct comparisons of levels of partial resistance levels between these two groups of cultivars in general or among the specific indica and japonica cultivars used in the present study. Such comparisons may be confounded by differences among populations of *P. oryzae* from different sites (4) but could be attempted in future work if cultivars susceptible at both sites are identified and grown experimentally with the same crop management.

The high nitrogen rates used by Korean farmers favor blast. If it becomes possible to use high nitrogen fertilizer rates over large areas of the lowland tropics, blast could become more intense, and higher levels of partial resistance would be required to manage the disease. Similarly, for cultivars with levels of partial resistance levels lower than that of Seomjin, other cultural and chemical control tactics may be required in temperate areas to supplement cultivar resistance.

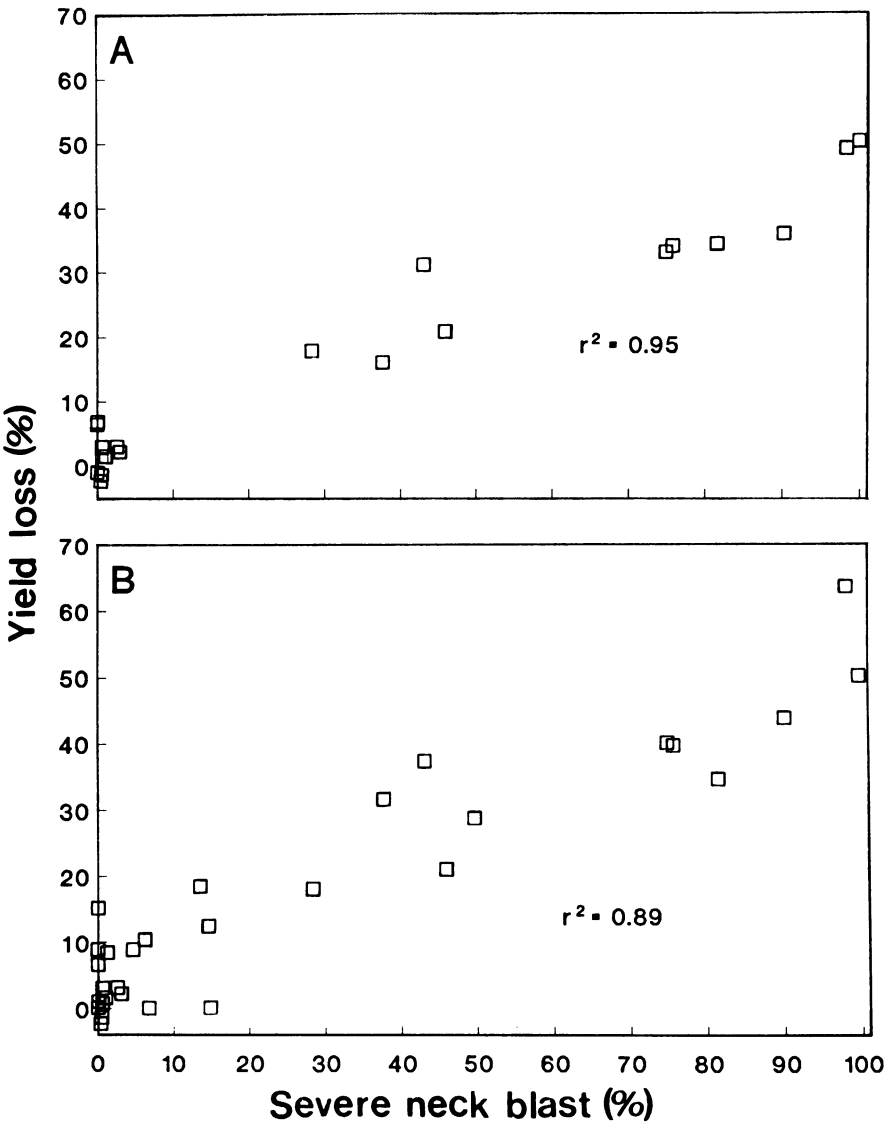

Fig. 3. Correlation between incidence of severe neck blast and percentage of yield loss for six trials in Korea and the Philippines. Yield loss calculation based on **(A)** difference between fungicide-protected and unprotected treatments for all entries ($n = 20$), and **(B)** yield loss of Korean entries estimated as difference between treatment yield and highest yielding entry in the trial ($n = 31$).

ACKNOWLEDGMENTS

We thank J. M. Bandong, T. Vergel de Dios-Mew, and Jae Dang Ryu for technical assistance. We also thank D. Ledesma for help with data analysis and Juan Lazaro for help with graphics.

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