Relationships Among Reactions of Sweet Corn Hybrids to Goss' Wilt, Stewart's Bacterial Wilt, and Northern Corn Leaf Blight

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ABSTRACT

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Reactions to Goss' wilt and Stewart's bacterial wilt were highly correlated at the 1% level of probability for 75 midseason to late-season maturing sweet corn hybrids evaluated in the 1984 Illinois sweet corn disease nursery and as seedlings in greenhouse trials. In the disease nursery, correlation coefficients for comparisons of disease severity ratings of Goss' wilt and Stewart's wilt ranged from 0.64 to 0.77. Rank correlation coefficients for comparisons of hybrid rankings based on severity ratings for Goss' and Stewart's wilt ranged from 0.66 to 0.74 and agreed with correlations of severity ratings. Similar results were obtained in greenhouse trials. The similarity of hybrid reactions to the two bacterial diseases may have resulted from plant morphological characteristics, such as plant height, or from genetic resistance. Correlations between the two bacterial diseases and northern corn leaf blight (race 1 or 2 of *Exserohilum turcicum*) ranged from 0.34 to 0.63. Correlations between races 1 and 2 of northern corn leaf blight ranged from 0.61 to 0.83. The similarity of hybrid reactions to the two races of *E. turcicum* was probably due to polygenic resistance, which displayed little or no race specificity. Hybrid reaction to rust was not correlated with reactions to the other diseases.

Additional key words: *Corynebacterium nebraskense*, disease resistance, *Erwinia stewartii*, leaf freckles and wilt, *Puccinia sorghi*, *Zea mays*

Stewart's bacterial wilt, caused by *Erwinia stewartii* (E. F. Smith) Dye, has been recognized for several years as an important disease of corn (*Zea mays* L.). Resistance to Stewart's wilt was studied in the 1930s (10,11,23) and has been examined in more detail recently (2,6,14,18). Resistance to this disease was highly heritable and appeared to be dominant and controlled by relatively few genes (2,6,14,18,21). In evaluations of sweet corn and dent corn, responses to *E. stewartii* ranged from highly resistant to highly susceptible and included intermediate responses (2,10,11,14,15,18,21).

Goss' wilt, also known as leaf freckles and wilt, is caused by *Corynebacterium nebraskense* Vidaver & Mandel and is a relatively new disease of corn. First observed in Nebraska in the late 1960s, Goss' wilt has been observed in Iowa, Kansas, and Illinois (22). In evaluations of sweet corn, popcorn, and dent corn germ plasms, responses to *C. nebraskense* ranged from highly resistant to highly susceptible with intermediate responses (4,16,22). Preliminary reports of genetic studies of resistance to Goss' wilt stated that responses of offspring were intermediate to parents or were more susceptible than midparents (8,13). Probably more than one major gene locus was involved (8,13).

Inheritance of resistance to northern corn leaf blight, caused by *Exserohilum turcicum* (Pass.) Leonard & Suggs, has been observed to be of several types (9). A lesion-number form of resistance is inherited polygenically. Several chlorotic-lesion types of resistance are inherited as single, dominant genes. Currently, two races of *E. turcicum* (races 1 and 2) are prevalent in the corn belt (19,20). Single, dominant genes have been effective against race 1, but race 2 has been virulent on corn possessing the Ht_1 gene.

Disease reactions of corn genotypes to the bacterial wilts and other corn diseases have been observed to be correlated. In inbred and hybrid trials, Koehler (12) reported significant correlations between ratings of northern corn leaf blight and Stewart's wilt ($r = 0.41–0.54$) and between southern corn leaf blight (*Bipolaris maydis* (Nisik.) Shoem.) and Stewart's wilt ($r = 0.43–0.60$). Gardner (7) reported a similarity in reactions of 60 corn lines to *E. stewartii* and *E. zeae*. Wysong et al (23) reported a correlation between the severity of Goss' wilt and Fusarium stalk rot ($r = 0.48$).

This paper reports on relationships among reactions of sweet corn hybrids to Goss' wilt, Stewart's wilt, and northern corn leaf blight.

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MATERIALS AND METHODS

1984 Disease nursery. Seventy-five midseason to late-season maturing commercial sweet corn hybrids were planted in field plots at Urbana, IL, on 2 June. The hybrids represented a wide range of materials from 15 commercial companies (Table 1) and included four sugary types: three high-sugar types (sh_2, $sush_2$, and se) and standard sweet corn (su). Pathogens were treated as separate experiments with three replicates of the 75 hybrids arranged in a split-plot of a randomized complete block design with sugary types as main plots and hybrids as subplots. Subplots were one row wide and 3.4 m long with about 18 plants per row.

The nursery included five pathogens: *C. nebraskense*, *E. stewartii*, *E. turcicum* races 1 and 2, and *Puccinia sorghi* Schw., causal agent of common rust. Plants were inoculated twice at about the fifth-leaf stage.

Bacterial inoculations were made at dusk on 20 June and 5 July using a slight modification of the techniques described by Blanco et al (1). Both bacterial pathogens were cultured from infected corn leaves collected in central Illinois. Cultures were preserved at −80 C as described by Sleesman and Leben (17). Stock cultures were used to increase inoculum by growing the bacteria for 2 days at room temperature in nutrient broth in Erlenmeyer flasks on shakers. Shake cultures were then streaked on nutrient broth/yeast-extract agar in petri plates and incubated for 3–4 days at room temperature. Bacterial concentrations were adjusted to about 10^7 colony-forming units per milliliter ($A_{590} = 0.05$) before inoculation.

Inoculations with *E. turcicum* were

Table 1. Sources of sweet corn hybrid seed

Seed source	No. of hybrids
Abbott and Cobb, Inc.	4
Agrigenetics Corp.	8
Agway, Inc.	2
Asgrow Seed Co.	10
Crookham Co.	12
Ferry Morse Seed Co.	3
Harris Moran Seed Co.	7
Illinois Foundation Seeds, Inc.	5
J. R. Jung's Seed Co.	1
Musser Seed Co., Inc.	3
Robson Seed Farms	5
Rogers Brothers Seed Co.	8
Seed Way, Inc.	1
Stokes Seeds, Ltd.	3
Twilley Seed Co.	3

done on 2 and 3 July. Ground corn leaf tissue infected with *E. turcicum* (race 1 or 2) was placed into plant whorls on 2 July. Conidial suspensions were sprayed into whorls at dusk on 3 July. Conidia were produced by culturing both races of *E. turcicum* on potato-dextrose agar at room temperature for 2–3 wk. Cultures were flooded with water and rubbed gently to remove spores. Spore suspensions were adjusted to about 10^3 conidia per milliliter before inoculations.

Urediniospore suspensions of *P. sorghi* (3 g of urediniospores suspended in 36 L of water and 5 ml of Tween 80) were sprayed into whorls of plants at dusk on 5 and 12 July. Urediniospores were collected from infected corn leaves at various locations in Illinois in 1983 and increased in the greenhouse on 15 sweet corn hybrids and two dent corn inbred lines.

Disease assessments were made twice for both bacterial diseases and both races of northern corn leaf blight (NLB-1 and NLB-2). Disease ratings for rust were made at four different times.

Both bacterial diseases were rated on 8 July and 1 August. Each plant in a plot was categorized into one of five classes, where 1 = trace to slight chlorosis of lower leaves, 0–5% severity; 2 = slight chlorosis of lower leaves, 5–25% severity; 3 = chlorosis of lower and upper leaves, 25–50% severity; 4 = chlorosis, necrosis, and stunting, 50–80% severity; and 5 = severe stunting and necrosis, nearly dead, 80–100% severity. Severity of Stewart's wilt and Goss' wilt was calculated as the mean severity of all plants per plot.

For NLB-1 and NLB-2, percentage of total leaf area diseased per plot was estimated on 28 July and 15 August. For rust, percentage of total leaf area diseased was estimated using a modified-Cobb scale on 18 July and 1, 10, and 24 August.

Mean disease severity of each hybrid was calculated for each disease at each rating date. Pearson's product-moment correlations (r) between mean disease severity ratings were calculated. Hybrids were ranked from 1 to 75 by mean disease severity ratings for each disease at each rating date. Spearman's rank correlations (r_s) of hybrid rankings were calculated. For Goss' wilt and Stewart's wilt, frequency distributions of plants per rating category were compared by hybrid using chi-square contingency tests. For the bacterial ratings on 8 July, categories 1 and 2 and categories 4 and 5 were combined in the chi-square analyses.

Greenhouse evaluations. Four greenhouse trials were conducted for Goss' wilt and for Stewart's wilt. Each trial included four replicates of 65 hybrids that had been included in the 1984 nursery. Each replicate consisted of five plants of each hybrid in rows in flats and inoculated at the fifth-leaf stage with either *C. nebraskense* or *E. stewartii*. Plants were placed in a mist chamber overnight to ensure adequate moisture after inoculations.

The reaction of each plant 7–11 days after inoculation was classified into one of three disease rating categories, where 1 = healthy or mild, 2 = intermediate, and 3 = severe. To compare reactions of hybrids to Goss' wilt and Stewart's wilt, frequency distributions of plants per category for Goss' wilt were compared by hybrid with frequency distributions for Stewart's wilt using chi-square contingency tests. Means of disease ratings for both bacteria also were calculated by hybrid over all trials, and hybrids were ranked by mean reaction. Pearson's correlation coefficients of mean reaction and Spearman's correlation coefficients of hybrid rank were calculated. All reported correlations were at the 1% level of probability.

RESULTS

1984 Disease nursery. All diseases in the nursery developed sufficiently to evaluate hybrid reactions. Disease severity ranged from 1 to 65% for Goss' wilt, from 1 to 51% for Stewart's wilt, from 1 to 43% for NLB-1, from 2 to 37% for NLB-2, and from 3 to 37% for rust. The range of disease reactions reflects the diversity of genotypes in the nursery.

Early and late disease ratings were highly correlated for all diseases, and correlation coefficients (r) between early and late severity ratings were 0.87, 0.86, 0.77, and 0.63 for Goss' wilt, Stewart's wilt, NLB-1, and NLB-2, respectively (Table 2). Rank correlation coefficients (r_s) between early and late hybrid rankings were 0.87, 0.85, 0.80, and 0.70 for Goss' wilt, Stewart's wilt, NLB-1, and NLB-2, respectively (Table 2). The correlations between rust severity ratings at different dates ranged from 0.51 to 0.95 and rank correlations ranged from 0.46 to 0.95 (Table 3).

Hybrids reacted similarly to Goss' wilt and Stewart's wilt. Correlations between Goss' wilt and Stewart's wilt severity ratings were 0.77 and 0.64 for early and late ratings, respectively, and 0.64 and 0.76 for combinations of ratings, i.e., Goss' wilt on 8 July and Stewart's wilt on 1 August and Goss' wilt on 1 August and Stewart's wilt on 8 July (Table 2). Rank correlations were 0.74 and 0.66 for early and late rankings, respectively, and 0.67 and 0.72 for combinations of rankings (Table 2). The correlation between Goss' wilt and Stewart's wilt mean disease severity (means of 8 July and 1 August ratings) was 0.74 (Fig. 1A). The correlation of hybrid rankings based on mean severity was 0.72 (Fig. 1B). For 53 of the 75 chi-square contingency tests of ratings on 8 July, the null hypothesis failed to be rejected ($P = 0.05$), indicating that the distributions of plants infected with Goss' wilt and Stewart's wilt were the same for those 53 hybrids. For the ratings on 1 August, 20 of the 75 hybrids had the same distributions of infected plants on the basis of the chi-square analyses.

Reactions of hybrids were similar for races 1 and 2 of *E. turcicum*. Correlations between severity of NLB-1 and NLB-2 were 0.76 and 0.83 for 28 July and 15 August ratings, respectively, and 0.66 and 0.61 for combinations of ratings (Table 2). Rank correlations were 0.77 and 0.83 for 28 July and 15 August rankings, respectively, and 0.70 and 0.66 for combinations of ratings (Table 2).

Northern corn leaf blight severity was significantly correlated with severity of Goss' wilt and Stewart's wilt. Correlations were below 0.50 for the early rating of northern corn leaf blight (28 July) but ranged from 0.34 to 0.63 for the 15 August rating, when NLB-1 and NLB-2 were more severe (Table 2). Rank

Table 2. Correlations between Goss' wilt, Stewart's bacterial wilt, and northern corn leaf blight severity and rank correlations between hybrid rankings for 75 hybrids evaluated in the 1984 Illinois sweet corn disease nursery

Disease	Rating date	Goss' wilt		Stewart's wilt		NLB-1		NLB-2	
		8 Jul.	1 Aug.	8 Jul.	1 Aug.	28 Jul.	15 Aug.	28 Jul.	15 Aug.
Goss's wilt	8 Jul.	···	0.87[a]	0.77	0.64	0.38	0.53	0.42	0.61
	1 Aug.	0.87[b]	···	0.76	0.64	0.34	0.48	0.36	0.58
Stewart's wilt	8 Jul.	0.74	0.72	···	0.86	0.37	0.46	0.42	0.63
	1 Aug.	0.67	0.66	0.85	···	NS	0.34	NS	0.49
NLB-1	28 Jul.	0.39	0.42	0.40	NS	···	0.77	0.76	0.66
	15 Aug.	0.50	0.46	0.49	0.38	0.80	···	0.61	0.83
NLB-2	28 Jul.	0.41	0.37	0.47	0.27	0.77	0.66	···	0.63
	15 Aug.	0.53	0.50	0.54	0.44	0.70	0.83	0.70	···

[a] Correlation coefficients above the diagonal are for correlations of severity ratings.
[b] Spearman's rank correlation coefficients below the diagonal are for rank correlations of hybrid rankings.

Table 3. Correlations between rust severity and rank correlations between hybrid ranking at four rating dates for 75 hybrids evaluated in the 1984 Illinois sweet corn disease nursery

Rating date	18 Jul.	1 Aug.	10 Aug.	24 Aug.
18 Jul.	···	0.62[a]	0.59	0.51
1 Aug.	0.61[b]	···	0.95	0.84
10 Aug.	0.56	0.95	···	0.85
24 Aug.	0.46	0.76	0.83	···

[a] Correlation coefficients above the diagonal are for correlations of severity ratings.
[b] Spearman's rank correlations coefficients below diagonal are for rank correlations of hybrid rankings.

correlations among northern corn leaf blight and the two bacterial wilts were similar to correlations of severity ratings (Table 2).

Reactions of hybrids to rust were not correlated with reactions to other diseases. No significant correlations were observed between severity of rust and Goss' wilt, Stewart's wilt, or northern corn leaf blight except for the 25 July severity ratings for NLB-2 and the 18 July severity ratings for rust ($r = -0.23$).

Greenhouse evaluations. Goss' wilt was more severe than Stewart's wilt in greenhouse trials. The mean disease rating for Goss' wilt was 2.12, and hybrid means ranged from 1.55 to 2.61 (Fig. 2A). The mean disease rating for Stewart's wilt was 1.61, and hybrid means ranged from 1.16 to 2.51 (Fig. 2A).

Hybrid reactions to Goss' wilt and Stewart's wilt were correlated, but the relationship was not as strong as for field observations. Correlations of hybrid mean disease ratings and rank correlations of hybrid rankings were 0.58 (Fig. 2). Rank correlations among greenhouse and field hybrid rankings were 0.68 and 0.66 for Goss' wilt and Stewart's wilt, respectively. Rank correlations of greenhouse and field hybrid rankings between Goss' wilt and Stewart's wilt (i.e., Goss' wilt in the greenhouse and Stewart's wilt in the field and Stewart's wilt in the greenhouse and Goss' wilt in the field) were 0.54 and 0.69, respectively. For the 65 chi-square contingency tests, the null hypothesis failed to be rejected for only 10 hybrids, indicating that the distributions of plants infected with Goss' wilt and Stewart's wilt were similar for those 10 hybrids.

DISCUSSION

Reactions of sweet corn hybrids to races 1 and 2 of *E. turcicum* and to *E. stewartii* and *C. nebraskense* were highly correlated. The similarity of hybrid reactions to the two races of *E. turcicum* was probably due to genetic resistance of a polygenic nature that displayed little or no race specificity. The correlations between reactions of sweet corn hybrids to Goss' wilt and Stewart's wilt could have resulted from plant morphological characteristics, such as plant height or maturity, or from a genetic resistance mechanism, such as a host response that localized the pathogens.

Reactions of corn genotypes to *E. stewartii* have been related to plant height, plant maturity, and genetic resistance. Ivanoff (10) and Ivanhoff and Riker (11) reported that tall, late-maturing varieties were more resistant to *E. stewartii* than short, early-maturing varieties. They observed correlations between resistance and height and between resistance and maturity to be 0.78 and 0.86, respectively, for 96 open-pollinated sweet corn varieties. Low correlations between resistance, height, and maturity were observed for hybrids derived from short, early, resistant materials. Wellhausen (21) also observed that short, early varieties were more susceptible to *E. stewartii* than tall, late varieties; however, he proposed that the existence of tall, late, susceptible and short, early, resistant varieties indicated that genes for height and maturity did not have much effect on resistance. No relationship between maturity and reaction to the bacterial wilts was observed among the 75 sweet corn hybrids evaluated in the 1984 nursery, although all of the genotypes were of relatively late maturity.

Considering the responses of early and late sweet corn varieties to Stewart's wilt, a similar phenomenon may be occurring in reactions of hybrids to Goss' wilt and Stewart's wilt. Ford and Mikel (5) suggested that morphological factors may allow *E. stewartii* and *C. nebraskense* to move and develop more readily in some plants than in others. Braun (3) reported that resistance to *E. stewartii* in a field corn inbred, C123, was apparently due to a host response that localized the pathogen.

If genetic resistance factors were responsible for the correlation of reactions among sweet corn hybrids to the two bacterial wilts, this may have resulted from linkage or pleiotrophy, and resistance to one of the bacterial diseases may be improved by selection for resistance to the other bacterial disease. If the correlation was not due to genetically related factors, concomitant improvement would not be expected. Inheritance of resistance to *E. stewartii* has been observed to be dominant (2,6,11,14,18,21), whereas preliminary reports of genetic studies on Goss' wilt indicated that crosses tended to be intermediate between their parents (8), or for some crosses, dominance for susceptibility was indicated when disease severity of F_1s exceeded midparent values (13). Further studies on the inheritance of resistance to both bacteria are needed to establish the genetic nature of reactions.

Correlations between reactions to the two bacterial diseases and both races of *E. turcicum* were of a magnitude similar to those reported by Koehler (12) for Stewart's wilt and northern corn leaf blight. Although these similar reactions may have some related genetic basis, multiple disease resistance to the bacterial wilts, northern corn leaf blight, and rust probably will require selection for each trait.

The use of Pearson's (r) and Spearman's rank (r_s) correlations in the analyses of these data produced similar results and inferences. The chi-square analyses,

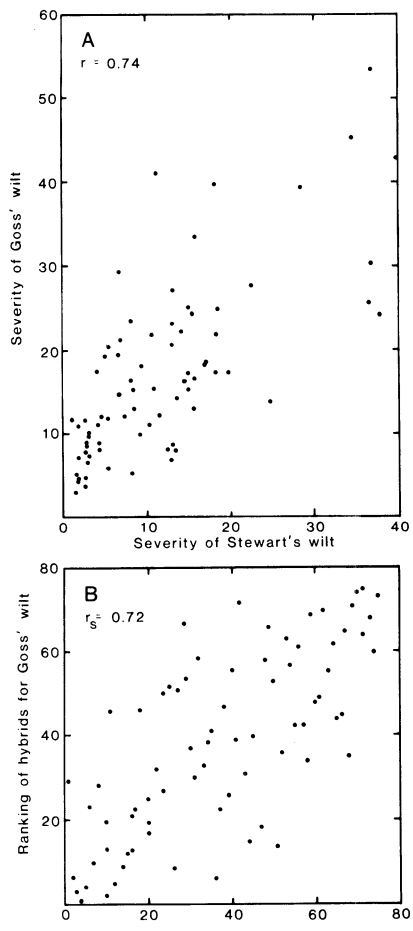

Fig. 1. (A) Mean disease severity (mean of 8 July and 1 August ratings) of Goss' and Stewart's bacterial wilts and **(B)** hybrid ranking based on mean disease severity for 75 sweet corn hybrids evaluated in the 1984 Illinois sweet corn disease nursery.

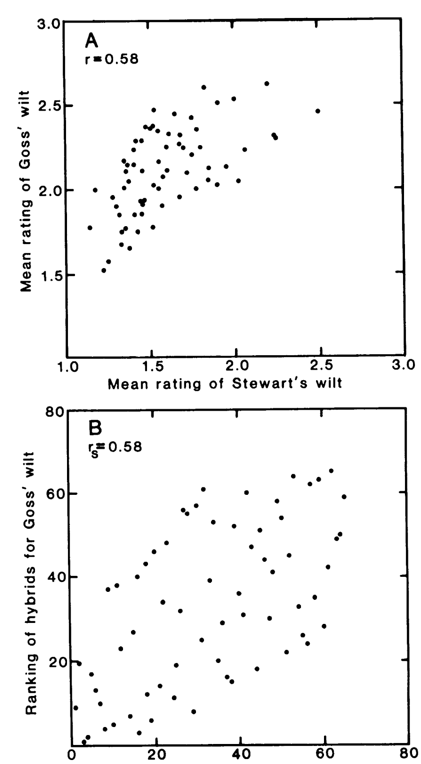

Fig. 2. (A) Mean disease rating (mean of all plants in all trials) for Goss' and Stewart's bacterial wilts and **(B)** hybrid ranking based on mean disease rating for 65 sweet corn hybrids evaluated in four greenhouse trials.

however, suggested that the distributions of Goss' wilt and Stewart's wilt usually were dissimilar for individual hybrids. These dissimilarities of distributions probably occurred because Goss' wilt generally was more severe than Stewart's wilt in the nursery and in greenhouse trials.

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