

Stalk Quality and Stalk Rot Resistance of Tropical Hybrid Maize Derivatives

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ABSTRACT

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Temperate-adapted, 100% tropical maize inbreds were evaluated as inbreds and in hybrid combination with corn belt germ plasm for stalk quality and resistance to two stalk rot pathogens, *Stenocarpella maydis* and *Colletotrichum graminicola*. Plants were inoculated with one of the two pathogens and evaluated for stalk rot resistance via internode discoloration and lodging ratings. There was a wide range of resistance among the tropical inbreds to internode discoloration caused by the two pathogens. Most tropical inbreds had relatively high levels of resistance to *S. maydis* but were relatively susceptible to *C. graminicola*. Several experimental 50% tropical hybrids were superior to the commercial checks for stalk-lodging resistance. There was no correlation between internode discoloration ratings of the inbreds or hybrids and lodging resistance. The late-season internode discoloration data were limited, however, by a natural infestation of *Pythium* sp. that was associated with disintegration of pith in many plants. The importance of rind strength in lodging resistance was evident by the consistency of experimental hybrid performance over different pathogen tests. Poor stalk quality has been one of the major factors limiting the use of exotic maize germ plasm. The strong performance of some tropical inbreds used in this study, however, suggests that major progress has been made in some tropical breeding programs. No significant root lodging was observed in the study.

Additional key words: anthracnose, diplodia, *Zea mays*

Recently the potential for use of tropical maize germ plasm in U.S. breeding programs has increased markedly. The most important factor contributing to this increased potential is the development of some strong hybrid breeding programs in Latin America (12). As these breeding programs have progressed, the gap in agronomic potential between elite U.S. germ plasm and elite tropical materials has been reduced. However, many U.S. corn breeders are still very reluctant to work with exotic germ plasm. One major reason for this reluctance is the poor stalk quality in exotic populations of maize (*Zea mays* L.), especially those containing photoperiod-sensitive germ plasm (5,6).

The purpose of this study was to examine the stalk quality of tropical hybrid corn derivatives. Tropical inbred lines were generated from a diallel cross of 100% tropical maize hybrids as part of a germ plasm enhancement program. The pedigrees and early work involved in the development of these materials have been described by Goodman (5) and Holley and Goodman (7). This study was

designed to examine the response of tropical germ plasm to two common stalk rot pathogens of maize, *Stenocarpella maydis* (Berk.) Sutton (= *Diplodia maydis* (Berk.) Sacc.) and *Colletotrichum graminicola* (Ces.) G. W. Wils., and to evaluate durability of the stalks by harvesting very late in the season. Both stalk rot pathogens used in this study have been studied extensively in association with U.S. corn germ plasm. Most research on resistance to *S. maydis* was done in the 1960s, and resistance is present in most commonly used U.S. inbred lines (8,10). In contrast, development of *C. graminicola* as a major stalk rot pathogen occurred fairly recently (1,9,11). Resistance to both pathogens has been shown to be quantitatively inherited, with predominantly additive gene action involved in expression of resistance (1,8,9).

MATERIALS AND METHODS

Source of germ plasm. In an effort to enhance the germ plasm base of the U.S. maize crop, an adaptation program was initiated in 1975. Nine tropical hybrids were crossed in a half diallel with selfs. The hybrids were selected on the basis of performance in worldwide yield trials conducted by CIMMYT (2) during 1971-1973. The hybrids and the early adaptation work done with the cross progeny from the diallel have been previously described by Goodman (5) and Holley and Goodman (7). Inbred lines were developed via individual plant selection for earliness, low plant and ear

height, synchronous pollen shed-silk emergence, lodging resistance, and prolificacy. All of the adaptation work was done in Raleigh, North Carolina. Tropical hybrids used in the study included Agroceres 155 and Agroceres 504 from Brazil, H5 and H101 from El Salvador, and X105A, X304A, and X306B from the Pioneer Overseas program in Jamaica. These hybrids all represent 100% non-corn-belt germ plasm and contain a wide range of tropical germ plasm, including Cuban Flint, Tuxpeño, Tusón, Chandelle, and Coastal Tropical Flint.

A selected group of inbred lines derived from the progeny of the diallel cross were used in a three-part study. The number of entries in each component of the study varied from 30 to 42 because of the use of different check inbreds or hybrids selected for the particular goals of each section.

Evaluation of inbred lines. Thirty-two tropical inbred lines were grouped with four public inbreds (B73, C103Ht, C123Ht, Mp305) in a randomized complete block design to form two tests with four replications. Plots consisted of two 3.66-m rows 0.96 m apart, with 22 plants in each row. The experiment was conducted at the Central Crops Research Station in Clayton, NC, in the summer of 1984, using standard cultural practices. A conidial suspension of *S. maydis* or *C. graminicola* was injected into the plants approximately 2 wk after the latest inbred flowered (28 July) using a 50-ml syringe. Each plant was inoculated at the first elongated internode above the ground with 1 ml of a liquid suspension containing 900,000 conidia per milliliter of *S. maydis* or 300,000 conidia per milliliter of *C. graminicola*. Stalks of six plants in the first row of each of the two-row plots were split in half and rated for the amount of internode discoloration (measured to the closest quarter of an internode). The stalk splitting was done at 4 and 6 wk after inoculation, with three plants selected at random each time. The second row of each plot was used to evaluate the effect of the stalk rot pathogens on lodging. Lodging ratings were done in mid-October to allow maximum symptom expression. Plants were counted as lodged when the angle of the stalk below the ear was greater than 45°.

Inoculated hybrid evaluation. Twenty-five of the tropical inbreds evaluated above were examined for resistance to *S.*

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maydis and *C. graminicola* in hybrid combination with (A632Ht × B73), a corn-belt single-cross tester. Thirty hybrids—22 experimental and eight check—were evaluated at two locations in 1985, using a randomized complete block design with four replications of each pathogen-location combination. Two check hybrids in each test were selected on the basis of previous work by D. G. White of the University of Illinois (*personal communication*). In the Diplodia test, B79 × Mo17 and B84 × Mo17 were included as susceptible checks. In the *Colletotrichum* test, B73 × L30 was the resistant check and B73 × LH24 was the susceptible check. The check hybrids included in both tests were Pioneer Brand 3369A, B73 × Mo17, B73 × Pa91, A632Ht × B73, C103 × (A632Ht × B73), and H103 × (A632Ht × B73). The two locations were the Central Crops Research Station, Clayton, NC, and Genetics Garden Research Station Unit No. 1, Raleigh, NC. All plants were inoculated approximately 2 wk after the latest flowering date, using a drip tube. The conidial concentrations for *S. maydis* and *C. graminicola* were 500,000 and 100,000 conidia per milliliter, respectively. As with the inbreds, two-row plots were used. In the first row, plant stalks were split and evaluated for internode discoloration. The second row was used for late-season lodging ratings. Stalk splitting was done at two time periods—replications one and two of each test at 4 wk after inoculation and replications three and four at 6 wk. Stalk lodging counts were done 3 mo after inoculation. In addition, a visual rating of premature plant death (PPD) was done approximately 6 wk after inoculation, using a 0–9 scale reflecting the

percentage of dead plants in the plot, from 0 to over 90%. Plant stand, ear and plant heights, and the number of days until 50% pollen shed were recorded for each plot. Analysis of variance was done by pathogen treatment, with locations and replications considered as random effects and hybrids considered as fixed effects.

Uninoculated hybrid evaluation. Thirty-four tropical inbreds were crossed to two corn-belt single-cross testers (A632Ht × B73 and Mo17 × (H95 × H99³)) and combined with eight commercial check hybrids to form two tests. The hybrids were grown at Genetics Garden Research Station Unit No. 1 in 1984 and 1985 using a randomized complete block design with three replications each year. Single-row plots were used, with 22 kernels placed in a 3.66-m row; spacing between rows was 0.96 m. The plants were left in the field until mid-November to allow for maximum expression of lodging resistance. Standard cultural practices were followed, and no stalk rot pathogens were artificially introduced. Statistical analyses of the tests were done separately.

RESULTS

Inbred evaluation. Analysis of the data obtained by stalk splitting revealed significant differences among the inbred lines for resistance to the two pathogens (Table 1). After we determined there was no genotype-by-date interaction (analysis not presented), data from both stalk-splitting dates were combined to form plot means. There was a 2-wk spread in flowering dates among the inbreds, with the tropical materials generally flowering about 1 wk later than the check inbreds, but the lack of a genotype-by-date interaction indicates that any bias in the results due to differences in maturity was relatively small. Most tropical inbreds showed moderate levels of resistance to *S. maydis* and were about equal to the four check inbreds in that all had mean values of about one internode discolored. Five tropical inbreds had mean values of 0.75 or less and were significantly more resistant than any check. Four of the five resistant inbreds were progeny from the cross of X105A × H5; the fifth was a straight X105A derivative. There were also five tropical inbreds significantly

more susceptible than the checks, with mean values in the range of 1.25 to 2.00 internodes discolored. The susceptible inbreds covered a wide range of tropical pedigrees but did not include any X105A × H5 derivatives.

The mean number of internodes discolored for all inbreds inoculated with *C. graminicola* was 2.52, with a wide range of values in both checks and tropical inbreds. Mp305, the most resistant check, had a mean of 1.25 internodes discolored, whereas B73 and C123Ht had ratings of 2.12 and 2.97, respectively. These results are in agreement with those of previous studies (1,9). The tropical inbreds appeared to be relatively susceptible to development of anthracnose; only two inbreds had resistance levels about equal to those of Mp305, and eight were significantly more susceptible than B73, with more than 3.0 internodes discolored. Again, the most resistant inbreds were X105A × H5 derivatives, although some of these derivatives were among the highly susceptible inbreds. Because of a lack of favorable weather conditions for lodging late in the season, there was no significant lodging in either of the two pathogen tests.

Inoculated hybrid evaluation. The evaluation of internode damage caused by pathogen development was limited because of a high level of natural stalk rot associated with a high incidence of *Pythium* sp. in lower internodes (K. J. Leonard, *personal communication*). The disintegration of pith made unbiased ratings of damage caused by the two introduced pathogens impossible. The incidence of natural infestation was low during the first rating period when the first two replications of the tests were evaluated, and for this reason only the internode discoloration data for the first two replications were used in the analysis. This limited data base indicated there were significant location effects in the development of both pathogens (Table 2). However, entry effects were significant only in the development of *S. maydis*. Development of both pathogens was limited at the time of the first rating period, with test mean values of 0.51 and 0.99 internodes discolored for *S. maydis* and *C. graminicola*, respectively. All 50% tropical hybrids had mean values within the range of those of the check hybrids for development of Diplodia stalk rot. B73 × Mo17 was the most resistant hybrid and B79 × Mo17 the most susceptible, with mean values of 0.31 and 0.86 internodes discolored, respectively.

Analysis of variance for PPD indicated presence of significant entry effects in both pathogen tests and significant location and hybrid-by-location interaction effects in the *C. graminicola* test (Table 3). Rapid PPD occurred predominantly during a 2-wk period, 5 wk after flowering, after extended soil

Table 1. Analysis of variance for number of internodes discolored in inbred lines due to development of *Stenocarpella maydis* or *Colletotrichum graminicola*

Source	df	Mean squares	
		<i>S. maydis</i>	<i>C. graminicola</i>
Replications	3	0.061	3.945** ^a
Inbreds	35	0.359**	2.852**
Residual	95	0.033	0.313

^a** = Significant at the 0.01 level.

Table 2. Analysis of variance for number of internodes discolored in hybrids due to development of *Stenocarpella maydis* or *Colletotrichum graminicola*, using only the first two replications^a

Source	df	Mean squares	
		<i>S. maydis</i>	<i>C. graminicola</i>
Locations	1	1.185** ^b	7.781**
Replications/locations	2	0.008	0.068
Hybrids	29	0.064**	0.104
Hybrids × locations	29	0.020	0.137
Residual	58	0.037	0.090

^aData from only the first two replications were used because of a large number of missing plots at the second stalk-splitting date associated with disintegration of the pith tissue.

^b** = Significant at the 0.01 level.

water saturation. PPD appeared to be due to damage associated with *Pythium* sp. rather than either introduced pathogen. Differences in relative magnitude of the location and replication effects between the two tests, however, suggest there may have been an interaction associated with pathogen combinations. Rank correlations of hybrids over locations and/or pathogen tests ranged from 0.69** to 0.86**, suggesting that genotype-by-environment effects would not cause serious bias if resistant genotypes were selected using data from a small number of environments. There was a tendency toward greater resistance to PPD in later maturing hybrids, albeit all hybrids flowered within a 1-wk period. As a group, most corn-belt check hybrids appeared to be very susceptible to PPD, with such notable exceptions as Pioneer 3369A and B73 × Pa91 (Table 4). There was a wide range in resistance among the tropical materials, with very high levels of resistance in hybrids containing X105A × X306B germ plasm and very little resistance in hybrids containing X105A or X105A × H5 inbreds in their pedigrees.

The analysis of variance for stalk lodging indicated the presence of significant differences among hybrids and significant hybrid-by-location effects in both pathogen tests (Table 3). In addition, there were significant location effects in the *S. maydis* test. The presence of a high level of natural stalk rot development caused some bias in the evaluation of the effects of introduced pathogen in terms of lodging data. The average Spearman rank correlation for stalk lodging and PPD, for hybrid means by locations, was 0.50** in the *S. maydis* test and 0.29 (NS) in the *C. graminicola* test. Incidence of stalk lodging was high, an average of 26 and 50% in the Diplodia and anthracnose tests, respectively. In the Diplodia test, seven experimental hybrids had less than 20% stalk lodging and compared favorably with check hybrids (Table 4). As in the case of PPD, the two hybrids with X105A × X306B inbreds in their background were the best entries in the test, although the resistant tropical materials covered a wide range of pedigrees.

In the *Colletotrichum* test, only four experimental hybrids appeared to be highly resistant to stalk lodging in comparison to the checks, and once again hybrids with X105A × X306B inbreds were the best (Table 4). The performance of the checks resistant (B73 × L30) and susceptible (B73 × LH24) to anthracnose stalk rot was in agreement with results of previous work (D. G. White, *personal communication*). The tester appeared to have an intermediate level of resistance, with a mean value of 35% lodging. Many of the 50% tropical hybrids appeared very susceptible, with mean values of

Table 3. Analysis of variance for stalk lodging (%SL) and premature plant death (PPD) ratings for hybrids inoculated with *Stenocarpella maydis* or *Colletotrichum graminicola*

Source	df	Mean squares			
		<i>S. maydis</i>		<i>C. graminicola</i>	
		%SL	PPD ^a	%SL	PPD
Locations	1	10,537 ^{ab}	4.82	10,481	576.60 ^{**}
Replications/locations	6	767 ^{**}	7.75 ^{**}	1,789 ^{**}	43.97 ^{**}
Hybrids	29	1,585 ^{**}	25.49 ^{**}	3,085 ^{**}	12.51 ^{**}
Hybrids × locations	29	592 ^{**}	2.09	527 ^{**}	4.13 ^{**}
Residual	174	241	2.14	287	1.57

^a Rated on a scale of 0–9, with 0 = no dead plants and 9 = over 90% of plants dead.

^b * = Significant at the 0.05 level, ** = significant at the 0.01 level.

Table 4. Mean values of hybrids, uninoculated or inoculated with *Stenocarpella maydis* (*S.m.*) or *Colletotrichum graminicola* (*C.g.*), for percent stalk lodging (%SL) and premature plant death (PPD), over locations or years

Entry no.	Pedigree		%SL		%SL		PPD ^a	
			Uninoculated		Inoculated		Inoculated	
			T1 ^b	T2	<i>S.m.</i>	<i>C.g.</i>	<i>S.m.</i>	<i>C.g.</i>
1	(X105A)	× T	33	41	58	70	5.5	5.6
2	(X105A)	× T	28	31	...	...	...	...
3	(X105A)	× T	35	32	53	75	5.1	4.0
4	(X105A)	× T	38	23	...	...	...	...
5	(X105A × H5)	× T	38	32	...	...	...	...
6	(X105A × H5)	× T	27	35	46	56	4.0	3.6
7	(X105A × H5)	× T	26	37	25	30	5.4	4.5
8	(X105A × H5)	× T	19	21	...	...	...	...
9	(X105A × H5)	× T	21	30	14	36	1.9	2.5
10	(X105A × H5)	× T	21	12	22	41	3.3	4.5
11	(X105A × H5)	× T	43	18	...	...	...	...
12	(X105A × H5)	× T	39	14	28	50	4.5	4.5
13	(X105A × H5)	× T	22	14	...	...	...	...
14	(X105A × X306B)	× T	3	1	...	...	...	...
15	(X105A × X306B)	× T	3	2	3	8	0.8	0.9
16	(X015A × X306B)	× T	8	5	8	14	0.9	1.1
17	(Ag155)	× T	17	22	37	74	1.8	2.6
18	(H5)	× T	43	20	26	60	1.5	1.9
19	(H5)	× T	41	38	...	...	...	...
20	(H101)	× T	12	8	15	36	1.1	1.5
21	(X105A)	× T	13	19	23	34	3.0	3.8
22	(Ag155 × Ag504)	× T	33	21	...	...	...	...
23	(Ag155 × Ag504)	× T	35	13	41	66	1.0	1.1
24	(H5 × Ag155)	× T	53	36	59	92	1.4	3.4
25	(X105A × Ag155)	× T	25	19	37	55	2.6	2.9
26	(X105A × Ag155)	× T	20	11	...	...	...	...
27	(X105A × Ag155)	× T	19	20	...	...	...	...
28	(X105A × Ag155)	× T	9	10	17	46	1.5	2.8
29	(X304A × Ag504)	× T	7	5	13	26	1.4	1.8
30	(X105A × H5)	× T	22	20	28	54	2.8	3.1
31	(X306B × H5)	× T	15	8	21	40	2.0	2.3
32	(X105A × H101)	× T	19	19	13	47	0.9	1.4
33	(X304A × H101)	× T	14	22	17	26	1.6	2.3
34	(X304A × H101)	× T	10	7	...	...	...	...
35	Pioneer Brand 3369A		8	8	19	36	2.0	1.6
36	Pioneer Brand 3165		7	5	...	...	...	...
37	Pioneer Brand 3055		12	3	...	...	...	...
38	Pioneer Brand 3389		6	3	...	...	...	...
39	Pioneer Brand 3358		2	8	...	...	...	...
40	USS 9001		21	7	...	...	...	...
41	B73 × Mo17		6	10	22	26	3.9	3.3
42	B73 × Pa91		...	...	13	26	1.3	1.8
44a	B79 × Mo17		...	...	34	...	6.8	...
44b	B73 × L30		...	...	...	19	...	2.0
45a	B84 × Mo17		...	...	28	...	6.3	...
45b	B73 × LH24		...	...	...	51	...	3.6
46	A632Ht × B73		...	...	18	35	5.0	5.1
47	C103 × (A632Ht × B73)		...	...	27	41	3.9	2.9
48	H103 × (A632Ht × B73)		...	...	25	62	1.5	2.6
LSD (0.05)			28	21	25	23	1.5	2.1

^a T = Single-cross tester. In inoculated hybrid evaluation, tester was A632Ht × B73. In uninoculated hybrid evaluation, T1 tester was A632Ht × B73 and T2 tester was Mo17 × (H95 × H99³).

^b Rated on a scale of 0–9, with 0 = no dead plants and 9 = over 90% of plants dead.

Table 5. Analysis of variance for percent stalk lodging in uninoculated hybrid evaluation

Source	df	Mean squares	
		Tester 1	Tester 2
Year	1	34,582***	22,562**
Replication (yr)	4	1,278**	373**
Hybrid	41	1,031*	744**
Hybrid × year	41	575**	318**
Residual	164	214	161

*** = Significant at the 0.05 level, ** = significant at the 0.01 level.

over 50% lodged plants.

The average Spearman rank correlation of hybrid stalk lodging over the two pathogens was 0.65** using test-location means. This suggests that degree of susceptibility to the pathogens as measured by internode discoloration was a secondary factor in determining the susceptibility to stalk lodging. Levels of root lodging were very low in both tests, and the data were not used in the analysis.

Uninoculated hybrid evaluation. Use of late-season lodging counts provided a good estimate of hybrid stalk durability and produced a wide range of significantly different mean values for individual hybrids (Table 4). Performance of tropical inbreds in hybrid combination was fairly constant across testers, with a rank correlation of 0.75** for hybrid means over testers. As a group, the 50% tropical hybrids were more susceptible to stalk lodging than most commercial hybrids, but seven tropical hybrids compared favorably with commercial checks. The two hybrids with the lowest lodging percentages in the experiment, entries 14 and 15, contained tropical germ plasm. As in the inoculated part of the study, hybrids with X105A × X306B in their background were superior, albeit several of the tropical pedigrees generated hybrids that were competitive with commercial checks. In the analysis of variance, there were significant year, hybrid, and hybrid-by-year effects in both tests (Table 5). The mean lodging ratings for the two years were much different—8.4% in 1984 and 29.6% in 1985. This difference in lodging severity between the two years is partially responsible for the highly significant

hybrid-by-year effects, due to the associated heterogeneous variances. When log transformed data for stalk lodging are used, hybrid effects are highly significant (0.01) and hybrid-by-year effects are nonsignificant in the first test, albeit there is no change in the significance of effects in the second test. Rank correlations for hybrid means across years were 0.55** and 0.67** for testers 1 and 2, respectively.

DISCUSSION

A relatively short-term adaptation program has produced inbreds of purely tropical origin that, in hybrid combination with corn-belt germ plasm, are competitive with some of the standard, purely corn-belt hybrids for stalk quality. The mean performance of the tropical materials is still significantly below the average performance of a group of lines from purely corn-belt germ plasm, but the magnitude of the difference is less than that found in many other studies involving use of exotic germ plasm.

Many of the inbreds of tropical origin have levels of resistance to *S. maydis* that are comparable with those of standard U.S. materials. In most cases, resistance to *C. graminicola* appears to be low in the tropical materials; some recurrent selection will be needed before many inbreds of tropical origin can be used in an area where this pathogen is prevalent. Most of the resistance to stalk lodging appeared to be due to rind strength, as opposed to resistance to pathogen development in the pith. This is reflected in the fact that the rank correlations for lodging in inoculated hybrid evaluations were very high across pathogens. The results of the uninoculated hybrid evaluation also support similar rankings of tropical pedigrees for lodging resistance (Table 4). In addition, some of the most lodging-resistant pedigrees, including X105A × X306B, had high levels of internode discoloration as inbreds and as hybrids in the Diplodia test. Rind strength has been previously shown to be more important than pith characters in terms of stalk lodging (3,4,13). There was no significant correlation between internode discoloration of inbred lines and the lodging

resistance of the inbreds in hybrid combination. In the initial inbred line evaluation, high levels of resistance to both pathogens were common in the lines derived from X105A × H5 (*data not presented*). In the hybrid evaluations, lines derived from X105A × H5 performed very poorly (Table 4). At the same time, the inbred lines that did best in hybrid combination, lines from X105A × X306B and X304A × Ag504, had relatively high levels of internode discoloration as inbreds. It is encouraging to note that the most lodging-resistant experimental hybrids performed well in yield trials (7).

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