Stalk Rot Resistance and Strength of Maize Stalks from the Plant Introduction Collection

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ABSTRACT

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A sample of accessions from the Plant Introduction (PI) collection of maize germ plasm contained accessions more resistant to stalk rot than the check hybrid AES704. Stalk rot severity was measured by the extent of discoloration in the internodes and reduction in maximum rind strength. Differences in stalk rot ratings were mostly at the 8-wk rating, but some accessions had less than the maximum amount of rot at 10 wk. PI accessions with reduced stalk rot at 10 wk postinoculation included 221835, 270080, 270290, 279022, 357099, 357100, 357103, 357107, and 357116. In 1975, PI 269751, with a rot rating of 6 at 10 wk, also tested high in maximum fiber stress (MFS). The accession with the highest average MFS in all tests was PI 393711, with an MFS of 322 MPa, or 31% better than the check hybrid AES704. The PI accession with the highest mean MFS in relation to the check hybrid was 195757, with an MFS of 271 MPa, or 71% better than the check. The mean breaking force (K) of stalk rinds was negatively correlated with rot rating means of the accessions in all years. Either K or MFS could be used to measure stalk rot severity.

Additional key words: corn, *Diplodia maydis, Zea mays*

Stalk rot is one of the more persistent problems associated with the production of maize (*Zea mays* L.) (2,7,14,15,17,19). Indirect selection for stalk strength by discarding on the basis of broken stalks has improved the performance of hybrids, but progress has been slow. Hybrids of more recently developed inbred parents (e.g., B73, Mo17, H92, and A632) have less stalk breakage than hybrids with older inbred parents (e.g., WF9, Hy, I205, Os420, 38-11, and 187-2). The newer hybrids are commonly grown at populations in excess of 50,000 plants per hectare, whereas the older hybrids were grown at populations of fewer than 30,000 plants per hectare. Considerable progress has been made in reducing stalk breakage through selection (9,16).

Sleper and Russell (19) state that more precise methods of measuring stalk strength would accelerate the increase in hybrid performance. Methods have been developed (8,11,21) that are more precise than counting broken stalks or bending them slightly to induce failure of weakened stalks, the two most common methods. The most common method for evaluating stalk quality is to determine the incidence of broken and weakened stalks (1). Thus, except for a small percentage of programs, time is not devoted to accurate and time-consuming methods of evaluating for stalk rot resistance or measuring stalk strength. For a trait associated with stalk quality to be used as a selection criterion, it should be highly heritable and also genetically correlated with standing ability at harvest. This is evidently not the case for certain mechanical properties (for example, breaking strength of a stalk tested as a simple beam with midpoint loading [breaking strength]). Sleper and Russell (19) found that breaking strength was unsatisfactory for evaluation within segregating progenies, even though the heritability value for strength was 90%. Breaking strength was not highly correlated with natural stalk breakage ($r = -0.46$). Breaking strength accounted for only 21% of the stalk breakage variability in the testcrosses. Nonheritable plant-to-plant variability negated breaking strength or crushing strength as procedures to select for reduced stalk breakage in programs using large plant populations. Sleper and Russell also considered strength tests too time consuming and cumbersome for use as a routine procedure for evaluation within segregating populations. They concluded that the best procedure for reducing stalk breakage was to evaluate segregating populations by measuring stalk rot.

Unfortunately, the easier methods (stalk color and stalk breakage) of rating for stalk rot lead to selection for low kernel number and probably low yield (5,6). Campbell (3) noted that many of the best experimental high-yielding hybrids had to be discarded because of excessive stalk breakage. This observation has led to the assumption that stalk rot resistance is related to low yield. Thompson (20) found that after seven cycles of recurrent selection for lodging resistance based on lodging percentage at maturity, there was "a significant reduction in yield." He added that this was not detrimental because the lower yield was expressed in the population per se and not in the testcrosses. Jinahyon and Russell (13) found that recurrent selection for stalk rot resistance using a discoloration scale did not reduce yield; instead, they found a positive association between stalk rot resistance and grain yield. In early cycles of selection for increased stalk rot resistance, improvement was made; but in later cycles, a reduction in stalk lodging did not occur. They concluded that "selection must include some other measurement of stalk strength if continued progress for resistance to stalk lodging is to be achieved."

There is a need for maize populations with a desirable level of stalk traits from which breeders can select for grain yield. Breeding programs need and use materials from germ plasm collections, but these materials should be better described (10). If an accurate procedure for evaluation could be applied to populations per se so that they could be used without further strength measurements, the use of germ plasm in breeding programs would probably increase.

The Plant Introduction (PI) maize collection at Ames, IA, contains more than 2,700 accessions and includes germ plasm from all parts of the United States and the temperate zones of the world. The oldest accessions were put into this collection in 1948, and new accessions are added each year. The seed is available to scientists on request.

The objectives of this study were to investigate the utility of measuring the severity of stalk rot by the reduction in rind strength that occurs in rotted stalks and to identify germ plasm with resistance to stalk rot decay and with high ultimate strength in the stalk rind.

MATERIALS AND METHODS

In 1973, 1975, 1976, 1977, and 1978,

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about 100 accessions per year, selected for an unrelated study, were grown as 10 data plants per plot, which measured 1 × 3 m in a completely randomized design with eight replicates. Six replicates were used to evaluate internal stalk discoloration caused by *Diplodia maydis* (Berk.) Sacc. Two replicates were used for stalk strength tests, except in 1976 and 1977, when one replicate was used for strength tests. The hybrid AES704, grown each year as a check, was selected because of its low rate of stalk breakage (16). The PI accessions grown each year were different except that the plantings of 1976 and 1977 were duplicates and 32 of the accessions grown in 1973 were repeated in 1975. Seven PI accessions were tested during 3 yr (1973, 1975, and 1978). The plants were grown in the field at Ames.

Ten plants from each plot were inoculated with conidia (8×10^6/ml) of *D. maydis* grown on sterilized oat kernels. Plants were inoculated 2 wk after flowering in the second internode above the main brace roots (4). The inoculator was a gravity-flow brass tube fitted with a 2-mm-diameter steel needle that delivered about 0.5 ml of suspension per inoculation. Inoculated plants were rated for stalk rot by splitting the stalk and estimating the amount of the inoculated internode that was discolored on a scale of 1–9, where 1 = no discoloration and 9 = entire internode discolored. Plants were rated 8 and 10 wk after flowering and the ratings averaged.

Plants tested for stalk strength were cut at the third elongated internode above the ground at maturity, and the internode was dried and stored at room temperature, except in 1973, when the stalk sections were stored moist at −16 C soon after cutting. Test strips 0.6 cm in width were prepared and tested on an Instron materials tester (model TTBM) as described previously (12).

The force to break (Px) and the force to cause 1% strain (P1) were determined from the stress-strain diagram. Breaking force (K) was Px/0.6, or the force to break a strip 1 cm wide (uncorrected for thickness). The maximum fiber stress (MFS) was calculated by dividing Px by the area (thickness × width) to correct for variation in rind thickness. Because thickness was based on strength at 1% strain, the calculation of MFS was reduced to 98Px/P1 (12). Results for K were expressed in Newtons per centimeter (N/cm) and, for MFS, in megaPascals (MPa). Plant values were averaged to give plot means, then analyzed for variance by the general linear models procedure and listed as subsets at the 95% confidence level (18). Stalk rot rating means and K means were correlated within years, and duplicate accession means were correlated across years.

Table 1. Diplodia stalk rot ratings[a] of the 20 best maize PI accessions of each test

Year									
1973		1975		1976		1977		1978	
PI	Rot rating	PI	Rot rating	PI	Rot rating	PI	Rot rating	PI	Rot rating
279022	5	267203	3	357128	5	357128	3	406218	5
221835	5	372161	4	357103	5	357103	3	406199	5
210404	5	363067	4	357093	5	414178	4	194384	5
276376	6	360877	4	357100	5	357125	4	186189	5
270290	6	358282	4	357118	5	357116	4	172333	5
270080	6	358276	4	357096	5	357107	4	171921	5
269751	6	358274	4	393757	5	357102	4	406232	6
222645	6	274011	4	357125	6	357101	4	406222	6
218137	6	270080	4	357116	6	357099	4	406221	6
186189	6	269751	4	357101	6	357098	4	406220	6
172331	6	262495	4	357099	6	357093	4	406202	6
163559	6	262484	4	357126	6	414180	5	406195	6
274011	7	222629	4	357123	6	401763	5	406193	6
270289	7	222618	4	357108	6	357127	5	406185	6
262588	7	210404	4	357097	6	357126	5	406175	6
222629	7	186189	4	357095	6	357123	5	406173	6
193901	7	186187	4	393739	6	357121	5	195115	6
186231	7	372167	5	357129	6	357110	5	195117	6
186210	7	370609	5	357120	6	357109	5	194385	6
186198	7	368845	5	357119	6	357108	5	194389	6
AES704	7		4		4		6		6
Mean[b]	7.8		5.9		7.0		6.9		7.2

[a] Averages of two ratings made 8 and 10 wk after flowering. Ratings on a scale of 1–9, where 1 = no discoloration and 9 = entire internode discolored.
[b] Mean of all entries tested in indicated year.

Table 2. Maximum fiber stress (MPa) of stalk rinds of the 20 best maize PI accessions of each year[a]

Year									
1973		1975		1976		1977		1978	
PI	MPa	PI	MPa	PI	MPa	PI	MPa	PI	MPa
270289	318	358279	301	393711	322	357094	292	195757	271
276376	316	172331	293	414185	304	357106	280	194389	252
221835	313	269751	290	393744	302	393725	276	163597	252
270080	309	358534	288	357096	299	401763	270	406234	246
269751	309	162701	286	393777	297	357109	268	186212	239
267203	307	343058	286	393741	294	414176	268	194385	229
163558	304	368842	285	393749	291	357124	268	406214	219
186198	304	358272	283	357125	286	357096	266	195233	217
172330	304	372170	283	393750	282	357129	265	183741	217
172331	300	372161	279	393721	279	357098	262	406177	215
274011	299	213702	278	393735	278	357120	258	406211	210
200179	297	270080	278	393764	278	357114	255	406226	208
218149	295	186189	273	393719	276	401754	255	183646	206
279022	294	186229	270	393751	276	357107	254	406236	206
222629	294	372157	270	357106	276	357128	253	194384	202
167962	293	177651	268	393731	273	393733	253	195117	198
222645	292	368829	268	357127	273	357127	253	166161	197
210404	291	368830	263	357099	272	357102	252	183778	193
180165	291	370608	263	357110	267	357118	251	172330	192
162702	290	222618	263	401762	267	393756	251	181844	192
AES704	290		229		245		211		158
Mean[b]	272		248		243		218		173

[a] All accessions are in the best subset (95% confidence level) except 12 accessions of 1978.
[b] Mean of all entries tested in indicated year.

RESULTS

This sample of the PI collection contained accessions more resistant to Diplodia stalk rot than the check hybrid AES704. The 20 best PI accessions for each year are listed in Table 1. Twelve, 1, 24, and 6 accessions in 1973, 1975, 1977, and 1978, respectively, had less rot than AES704. Accessions 357093, 357103, and 357128 averaged less rot over 2 yr (1976 and 1977) than AES704. Differences among the accession means came mostly at the 8-wk reading; by 10 wk, most accessions were rated 9, the maximum value. The PI accessions noted in 1973 with reduced rot at 10 wk were 221835, 270080, 270290, and 279022. PI 172331 had a low rating at 10 wk in 1973 and 1975 but not in 1978. Accessions with ratings less than 9 at 10 wk in 1976 and 1977 were 357099, 357100, 357103, 357107, and

357116—all from Ethiopia. In 1975, PI 269751, with a rot rating of 6 at 10 wk, also tested high in MFS (Table 2). The response of the duplicate accessions of 1976 and 1977 to stalk rot was similar. The highest rated accessions of 1976 were also high (above average) in 1977.

Differences in MFS among the accession means were highly significant in all years (tests). The best or highest testing accessions (Table 2) were equal to or greater than AES704. In all years, the stalks of accessions with the highest MFS values were less rotted as indicated by the stalk rot ratings than the stalks of accessions with low MFS values. In 1973, all but six of the 20 accessions listed in Table 2 had a reaction lower than 9 to Diplodia rot at the 10-wk reading. Thirty accessions from the subsets with the least rotted stalks (Table 1) were also in the subsets with the highest MFS (Table 2). A few accessions had a low P1 (less than 98 N) but had an average Px (about 400 N) that resulted in a high calculated MFS; such accessions are not included in Table 2.

Accessions with high MFS values came from a diversity of sources; the two countries with the most accessions having high MFS values were Ethiopia and Yugoslavia. High MFS was not associated with any particular endosperm type. PI 195757 (China H.N.1) had the highest MFS value (271MPa) in 1978 in relation to AES704 (71% better than the check). PI 393711 (Yugoslavia) had the highest average MFS (322 MPa, 31% greater than AES704) in all tests in 1976, a year in which AES704 rated 4, or moderately rotted (Table 2). PI 393711 was low in strength in 1977, with an MFS of 196 MPa (well below average). The K of PI 393711 was also below average (617 N/cm). Although the MFS means of duplicate accessions were different in the different tests, the deviation and variability were similar. The standard deviations for the five tests were 51, 54, 56, 47, and 50 in 1973, 1975, 1976, 1977, and 1978, respectively. The coefficients of variability of MFS for the five respective tests were 19, 22, 23, 22, and 29%.

The mean K of stalk rinds was negatively correlated with mean rot rating of the accessions in all years (Table 3). Some correlations were low; only in 1977 were the r values above 0.75. The best correlation was obtained between the stalk rot ratings of 1977 and the K values of 1976 (r = 0.81). The converse relation or the correlation of K values of 1977 with the stalk rot ratings of 1976 was lower (r = 0.60). Also, the K values did not correspond to the averages of the rot ratings when compared by years. The respective yearly means for rot ratings were 7.8, 5.9, 7.0, 6.9, and 7.2; for K, they were 1,157, 774, 1,000, 726, and 755 N/cm; for MFS, they were 272, 248, 243, 218, and 173 MPa. The high values of MFS in 1973 were not the result of overcorrection for rind thickness because the mean K value of 1,157 N/cm was also the highest mean of all tests.

Table 3. Simple correlation of Diplodia stalk rot means with breaking force means in maize stalks over 5 yr

Stalk rot (yr)	Breaking force (yr) 1973	1975	1976	1977	1978
1973	−0.43*[a]	−0.49	...	...	−0.71
	(86)[b]	(31)	...	...	(15)
1975	−0.07	−0.68*	...	...	−0.17
	(32)	(86)	...	...	(7)
1976	...	...	−0.61*	−0.60*	...
	...	...	(129)	(129)	...
1977	...	...	−0.81*	−0.80*	...
	...	...	(129)	(129)	...
1978	−0.57	...	...	...	−0.49*
	(15)	...	...	...	(140)

[a] * Significant at $P = 0.01$.
[b] Number of means compared.

DISCUSSION

Many potential sources of useful maize germ plasm in the PI collection with good resistance to stalk rot have been identified. This study verified the resistance of certain accessions previously identified as resistant to Diplodia stalk rot (4).

Although *D. maydis* was injected into the stalks, other organisms were probably present. Some accessions had little visible rot (low *Diplodia* ratings), but the low MFS values indicated severe decay. This could have resulted from other organisms causing deterioration but not discoloration. Other accessions with a susceptible *Diplodia* rating but a high MFS might indicate that the rind was not attacked in those accessions. MFS is not a sensitive measurement of the effects of stalk rot because it takes severe stalk rot to reduce the MFS of the rind. Conversely, if MFS is increased by selection, the severity of rot should be reduced substantially. Thus the measurement of MFS is useful as a means to evaluate progress in stalk quality improvement in a selection program rather than as a selection criterion. Another advantage of measuring MFS is that it can be used to compare rot severity in inbred lines and hybrids, because MFS corrects for differences in rind thickness. In 1978, many accessions were of early maturity (60–70 days to midsilk), which might explain the low MFS values; nevertheless, the check AES704 also had a low MFS value in 1978.

Even though MFS presumably measures the effect of general decay on the rind, this is the first report that MFS can be correlated with stalk rot ratings of an inoculated organism. Nevertheless, it may not always reflect the level of discoloration of the internodal parenchyma caused by an inoculated organism. In 1973, for example, the mean MFS was 272 MPa (the strongest) and the mean rot was 7.8 (the most rotted). A more accurate method for calculating MFS would be to use thickness values taken from healthy plants (2–4 wk after flowering) and measure maximum breaking force at harvest. This is because thickness values taken at harvest can be reduced by rot but not as much as breaking force (12). MFS is not a practical method for routine evaluation of stalk rot resistance as defined by Sleper and Russell (19) because it is more time consuming than their stalk strength tests.

Severe natural stalk rot reduces yield; thus selection of parents of high-yielding crosses has reduced stalk rot severity, resulting in an increased standing ability. How much of the increase in stalk quality is due to reduced rot and how much is due to increased strength is not known. Severe natural stalk rot does not occur with sufficient frequency to be a dependable selection criterion. Thus, an accurate procedure for measuring decay is needed to increase effectiveness of selection for stalk rot resistance.

The perceived association between low yield and nonrotted plants has led to emphasis on yield while accepting some stalk breakage. The increase in stalk rot resistance has been a slow process, possibly because of the inadequate methods for measuring stalk rot severity. The PI accessions identified in this study should make a broad-based synthetic population of widely different maturities from which resistant phenotypes could be extracted without having to conduct extensive stalk rot tests.

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