Methods of Evaluating Stalk Quality in Corn

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ABSTRACT

Both the rind and pith contribute to stalk quality in corn (*Zea mays*). Thicker rinds and heavier wt of 5.1-cm sections, with and without pith, were found after inoculation with *Diplodia maydis*. Crushing strength, rind thickness and wt of 5.1-cm sections together gave the best estimate of stalk quality among the 15 possible single crosses of six inbred lines of known resistance or susceptibility to stalk lodging. All methods evaluated provided valid estimates of stalk quality. *Diplodia maydis* ratings have limitations because some hybrids may suffer considerable stalk rot but still retain satisfactory crushing strength. Inoculations lowered crushing strength except for single crosses involving the stalk-lodging resistant parent B14. Pith condition rating at 12 days after 50% silking gave valid estimates of stalk quality except for the first internode. Phytopathology 60:295-300.

Corn (*Zea mays* L.) hybrids currently grown resist lodging more than the open-pollinated varieties they replaced. Lodging in this paper refers to stalk lodging and not root lodging. However, stalk deterioration and breakage, as a result of a complex interaction of genetic and environmental effects, continues to be a major problem of corn production. The use of hybrids resistant to lodging is the principal method of control. Thompson (12) stated that the field evaluation method, which is dependent upon environmental forces, has served successfully in the past for upgrading stalk-lodging resistance of corn. He concluded, however, that continued improvement in stalk-lodging resistance may well depend upon selection procedures largely independent of environmental causes conducive to lodging.

Mechanical devices largely independent of environmental forces have been developed and are used for testing morphological characteristics associated with lodging resistance of corn and small grains (2, 5, 8, 12, 14). Studies with corn indicate that breaking strength of the lower internodes and resistance to various stalk rot pathogens are highly correlated with resistance to lodging (3, 4, 5, 7).

Zuber & Grogan (14) found a highly significant negative correlation between lodging and crushing strength of the second internode above the ground. Their results also showed significant, negative correlations between lodging and the morphological traits, crushing strength, rind thickness, and wt of 5.1-cm sections, for the third internode above the ground. Thompson (12) studied crushing strength and rind thickness in relation to lodging, and concluded that crushing strength was the better measure of lodging resistance.

Considerable effort has been devoted to artificial inoculation and rating resistance of breeding materials to stalk rot pathogens. *Diplodia maydis* (Berk.) Sacc. is one of the major causal organisms of stalk rot. Sprague (11) found that resistance to *D. maydis* did not insure a high level of resistance to stalk breakage, but on the average, that lines resistant to *D. maydis* lodged less frequently. Hooker (6) found that inoculations in the first or second elongated internode above the ground, 1 to 3 weeks following inoculation, resulted in the most accurate estimate of resistance to stalk rot.

Wysong & Hooker (13) studied the relationship of soluble solids content and pith condition to *D. maydis* stalk rot in corn hybrids. They found the rate of stalk rot infection to be similar to the rate of pith dehydration. Pappelis & Smith (10) found the spread of *D. maydis* in the first and fourth internodes as measured by stalk rot ratings to be highly correlated with pith condition ratings based on the area of dead internodal tissue. They found that inherent susceptibility was related to the dead parenchyma cells in the stalk pith.

The objective of this study was to determine the most effective method of evaluating stalk quality by comparing the stalk crushing method, the *Diplodia* stalk-rot rating method, and the pith-condition rating method, and to study the interrelationship of morphological and pathological characteristics associated with stalk quality.

MATERIALS AND METHODS.—Six inbred lines representing known resistance or susceptibility to lodging (B14 and C103 [resistant], H55 and 38-11 [intermediate] and Os420 and Mo940 [susceptible]) were crossed in all combinations to produce the 15 possible F_1 single crosses. The single crosses were space planted 32.2 cm between plants in rows replicated four times in a randomized complete block design. The six rows within each plot were then randomly assigned treatment numbers from 1 to 6. The treatment description and assigned number was as follows: 1) No *Diplodia* inoculation, crushed with pith intact. 2) No *Diplodia* inoculation, crushed with pith removed. 3) *Diplodia* inoculated, crushed with pith intact. 4) *Diplodia* inoculated, crushed with pith removed. 5) *Diplodia* inoculated, rated for percentage of stalk rot. 6) No *Diplodia* inoculation, rated for pith condition.

Diplodia maydis inoculations were made in the second internode above the ground 20 days after 50% of

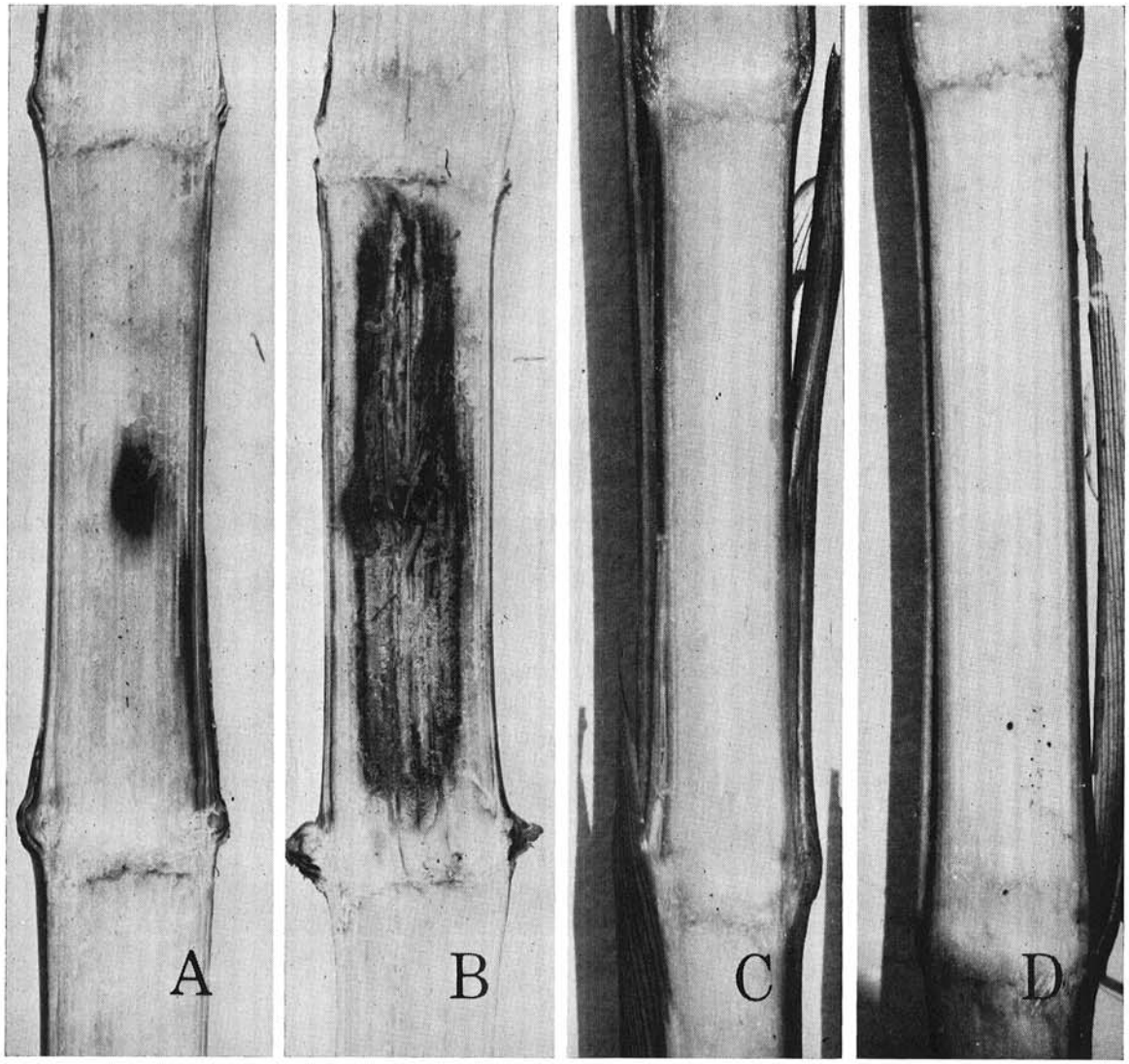

Fig. 1. Comparison of pith condition in stalks of single crosses of corn. **A)** Relatively low level of rotted pith in a corn stalk due to *Diplodia maydis* inoculation in the lodging-resistant single cross B14 × C103. **B)** High amount of rotted pith due to *D. maydis* inoculation in the lodging-susceptible single cross Os420 × Mo940. **C)** Pith condition of the third internode for the lodging-resistant single cross B14 × C103 characterized by the relatively large amount of "watery-like" pith. **D)** Pith condition of the third internode for the lodging-susceptible single cross Os420 × Mo940, characterized by the relatively large amount of chalky-white pith.

the plants had receptive silks (treatments 3, 4, and 5), by using the toothpick-cordless drill method (1). The second internode (treatments 1, 2, 3, and 4) was harvested 50 days after 50% silking by cutting through the internodes above and below the second internode with a linoleum knife. The stalk sections were placed in mesh bags and air-dried before processing.

Using a specially constructed saw (14), 5.1-cm stalk sections were cut from the air-dried, harvested internode and placed in a forced-air drier to bring all samples to a uniform moisture content. The samples were then weighed and processed. The pith was removed from treatments 2 and 4, and the rind weighed. Stalk sections from treatments 1, 2, 3, and 4 were crushed (14). Random samples of rind tissue were taken from each 5.1 section after crushing and measured for thickness using a micrometer caliper.

Diplodia ratings (treatment 5) were made 30 days after inoculation (50 days after silking). The stalk was split longitudinally. Using the scale reported by Wysong & Hooker (13), the spread of the fungus as measured by the amount of discolored tissue surrounding the point of inoculation was rated visually. A rating 0.1 indicated less than 3.0% of rotted internodal tissue, and 6.0 indicated that the plant was prematurely killed. Comparative areas of rotted pith due to inoculation by *D. maydis* are shown in Fig. 1-A for the lodging-resistant single cross B14 × C103, and in Fig. 1-B for the lodging-susceptible single cross Os420 × Mo940.

Pith condition ratings were made 10-12 days after

TABLE 1. Mean crushing strength values for the 15 possible single crosses among six inbred corn lines by *Diplodia maydis* and pith removal treatments for experiments conducted in 1966 and 1967

Single cross	Stalk lodging classification	Pith intact, treatment 1[a]	Pith removed, treatment 2	Pith intact, treatment 3	Pith removed, treatment 4
		(*kg*)	(*kg*)	(*kg*)	(*kg*)
B14 × C103	R × R	559[b]	393	561	390
B14 × H55	R × I	515	350	519	333
B14 × 38-11	R × I	371	242	409	247
B14 × Os420	R × S	365	218	348	223
B14 × Mo940	R × S	363	203	318	224
C103 × H55	R × I	481	328	434	299
C103 × 38-11	R × I	376	228	323	197
C103 × Os420	R × S	294	210	281	203
C103 × Mo940	R × S	387	221	364	214
H55 × 38-11	I × I	373	268	350	209
H55 × Os420	I × S	260	212	255	183
H55 × Mo940	I × S	379	188	273	160
38-11 × Os420	I × S	269	195	264	138
38-11 × Mo940	I × S	297	158	271	142
Os420 × Mo940	S × S	238	152	218	127
Mean		368[c]	238	346	219

[a] Treatments: 1) No Diplodia inoculation, crushed with pith intact; 2) No *Diplodia* inoculation, crushed with pith removed; 3) *Diplodia* inoculated, crushed with pith intact; 4) *Diplodia* inoculated, crushed with pith removed.

[b] Differences greater than 62 kg between any two F_1 single crosses are significant at the 5% level.

[c] Differences greater than 16 kg between any two treatment means are significant at the 5% level.

50% silking (treatment 6). The stalk was split longitudinally, and the first, third and fifth internodes above the uppermost brace roots were visually rated on the percentage of dehydrated internodal tissue (13). A rating of 0.3 represented little or no dehydration. A rating of 6.0 indicated that the dehydration of the pith enclosed by the rind was complete. Differences in pith conditions are shown in Fig. 1-C, D for B14 × C103 and Os420 × Mo940, respectively.

RESULTS AND DISCUSSION.—*Crushing strength.*—The single crosses involving the lodging-resistant parents, in general, had the highest crushing strength (Table 1). Strength progressively decreased, depending on whether the other parent was an intermediate or lodging-susceptible parent. Single crosses involving susceptible parents generally had the lowest crushing strength. *Diplodia maydis*-inoculated treatments 3 and 4, in general, had lower crushing values than their noninoculated counterparts treatments 1 and 2 (Table 1). Inoculation did not affect the crushing strength of the single crosses involving lodging-resistant parent B14.

Previous investigators (12, 14) have shown the rind to be a major component of crushing strength. An assumption was made that no differences existed for rind thickness between the two noninoculated treatments 1 and 2, except for pith removal in treatment 2. The percentage of the total crushing strength contributed by the rind was computed by comparing the crushing strength for a given single cross in treatment 2 with the same single cross in treatment 1. This same comparison was made for the inoculated treatments 3 and 4. The percentages of the total stalk strength contributed by the rind (Table 2) were higher for crosses involving certain inbred lines than for others. The two inbred lines classified as lodging-susceptible were involved in crosses with low crushing strength, but had both the highest (Os420) and the lowest (Mo940) percentages contributed by the rind for the noninoculated treatments.

The percentages of the total crushing strength contributed by the rind were generally different for the inoculated and noninoculated treatments. Crosses involving the lodging resistant inbred lines B14 and C103 were not appreciably changed when inoculated. However, the percentage of the total crushing strength contributed by the rind, for crosses involving the inbred line 38-11 with intermediate lodging resistance, was reduced by inoculation, indicating that both rind and pith contributed important characteristics to stalk quality. The contribution of the rind to crushing strength was approximately 65% for the noninoculated and 63% for the inoculated treatments for all F_1 single crosses. The percentages for the noninoculated treatments ranged from a high of 82% for H55 × Os420 to a low of 50% for H55 × Mo940. For the inoculated treatments, the percentages ranged from a high of 72% for C103 × Os420 to a low of 52% for 38-11 × Os420.

Rind thickness.—In general, crosses involving lodging-resistant inbred lines had thicker rinds than crosses involving lodging-susceptible inbred lines. The rind thickness mean for all crosses involving the two lodging-resistant parents B14 and C103 was 1.196 mm; for the two intermediate parents H55 and 38-11 the mean was 1.101 mm; and for the two susceptible parents Os420 and Mo940 the mean was 1.039 mm. The *D. maydis*-inoculated treatments had significantly thicker rinds (1.122 mm) than the noninoculated treatments (1.102 mm). The cause for thicker rinds on *D. maydis*-inoculated plants is not known. One possible explanation may involve a host-plant response to infection that results in increased mechanical tissue being laid down by the plant. Further evidence that a reaction occurs due to *D. maydis* inoculation is reflected in the heavier 5.1-cm sections weights.

TABLE 2. Percentages of the total stalk crushing strength contributed by the rind for the 15 possible single crosses among six inbred corn lines for experiments conducted in 1966 and 1967 combined

Inbred lines	B14	C103	H55	38-11	Os420	Mo940	Mean	Rank
	%	%	%	%	%	%	%	%
B14		70/70[a]	64/68	60/65	64/60	70/56	66/64	2/5
C103	70/70		69/68	61/61	72/71	59/57	66/65	1/3
H55	64/68	69/68		60/72	72/82	58/50	65/68	3/2
38-11	60/65	61/61	60/72		52/72	52/53	57/65	6/4
Os420	64/60	72/71	72/82	52/72		58/64	64/70	4/1
Mo940	70/56	59/57	58/50	52/53	58/64		59/56	5/6

[a] Numerator = % of total stalk strength in rind of inoculated stalks; denominator = % of total stalk strength in rind of noninoculated stalks.

TABLE 3. The percentage of the 5.1-cm corn stalk section wt due to the rind for the 15 possible single crosses among six inbred lines for 1966 and 1967 experiments combined

Inbred lines	B14	C103	H55	38-11	Os420	Mo940	Mean	Rank
	%	%	%	%	%	%	%	%
B14		71/73	69/74	72/75	70/76	68/75	70/75	2/1
C103	71/73		69/73	70/75	70/70	69/72	70/73	4/3
H55	69/74	69/73		71/73	70/72	64/69	69/72	5/5
38-11	72/75	70/75	71/73		73/74	69/69	71/73	1/2
Os420	70/76	70/70	70/72	73/74		67/72	70/73	3/4
Mo940	68/75	69/71	64/69	69/69	67/72		67/71	6/6

[a] Numerator = % of total wt contributed by the rind in inoculated stalks; denominator = % of total wt contributed by the rind in noninoculated stalks.

Comparative wt of 5.1-cm sections with and without pith.—The mean wt for 5.1-cm sections, with and without pith, were heavier for crosses involving the inbred lines classified as lodging-resistant than for crosses involving lines classified as lodging-susceptible. The mean wt with the pith intact for all crosses involving the two lodging-resistant parents was 3.2 g; for the lodging-intermediate parents the mean wt was 2.9 g; and for the lodging-susceptible parents the mean weight was 2.9 g. Similar trends were found for 5.1-cm sections without the pith. The wt of 5.1-cm sections, with and without pith, provides estimates of wt contributed by the rind and pith. The calculated percentage of the 5.1-cm section wt due to the rind is summarized in Table 3. In general, the percentage of weight due to rind was approximately 73% for the noninoculated treatments and 70% for the inoculated treatments. No trend was found for percentage of rind contribution to stalk section wt among crosses involving either lodging-susceptible or -resistant lines.

The stalk sections with and without pith were heavier for the inoculated treatments. With pith intact, the 5.1-cm section wt were 3.2 g for the inoculated treatments and 2.8 g for the noninoculated treatments. The wt without pith were 3.4 g for inoculated treatment and 2.0 g for the noninoculated treatment.

Diplodia rating.—Sprague (11) found that *D. maydis* resistance did not insure a high level of resistance to stalk breakage, but, on the average, lines resistant to *D. maydis* exhibited less lodging. Our data (Table 4) support his conclusions. Stalk-crushing strength was associated with stalk-rot resistance, but some crosses susceptible to stalk rot had strong stalks. For example, the single cross B14 × H55 had a *Diplodia* rating of 2.60 and a crushing strength of 519 kg, whereas, C103 × Mo940 had a rating of 2.01 and a crushing strength of only 364 kg.

Pith condition rating.—Pappelis & Smith (9) suggested that the spread of *D. maydis* was confined to dead internodal tissue. Wysong & Hooker (13) found significant positive correlations between stalk-rot development within internodal tissue and rate of dehydration, indicating that the rate of stalk-rot infection was similar to the rate of pith dehydration. We found that pith condition ratings were lower for the first and third internode than for the fifth internode when ratings were made 12 days after 50% silking. Although significant

TABLE 4. Mean *Diplodia* rating for the 15 possible single crosses among six inbred lines for experiments conducted in 1966 and 1967 combined

Single cross	Stalk-lodging classification	*Diplodia* rating
B14 × C103	R × R	1.40 a[a]
B14 × H55	R × I	2.60 bc
B14 × 38-11	R × I	2.81 bcd
B14 × Os420	R × S	3.89 e
B14 × Mo940	R × S	3.70 e
C103 × H55	R × I	2.03 ab
C103 × 38-11	R × I	2.78 bcd
C103 × Os420	R × S	3.41 cde
C103 × Mo940	R × S	2.01 ab
H55 × 38-11	I × I	3.98 e
H55 × Os420	I × S	4.26 e
H55 × Mo940	I × S	4.01 e
38-11 × Os420	I × S	3.61 de
38-11 × Mo940	I × S	3.79 e
Os420 × Mo940	S × S	3.85 e

[a] 0.1 Rating = less than 3% rotted tissue (resistant); 6.0 Rating = plant prematurely dead (susceptible). Any two means followed by the same letter are not significantly different at the 5% level (Duncan's new multiple range test).

TABLE 5. Correlation coefficients among four corn stalk traits, *Diplodia* stalk rot rating, and pith condition ratings of three internodes above the soil and uppermost brace roots for experiments conducted in 1966 and 1967

	Rind thickness	Wt 5.1-cm section	Wt of 5.1-cm rind section	*Diplodia* rating	Pith condition ratings		
					1st Internode above the soil	3rd Internode above the soil	5th Internode above the soil
Crushing strength	0.95[b]	0.89[b]	0.86[b]	−0.79[b]	−0.59[a]	−0.75[b]	−0.79[b]
Rind thickness		0.82[b]	0.85[b]	−0.77[b]	−0.62[a]	−0.86[b]	−0.85[b]
Weight of 5.1 cm section			0.89[b]	−0.75[b]	−0.43	−0.67[b]	−0.70[b]
Weight of 5.1 rind section				−0.74[b]	−0.53[a]	−0.73[b]	−0.77[b]
Diplodia rating					0.71[b]	0.89[b]	0.87[b]
Pith condition rating							
1st Internode above the soil						0.88[a]	0.82[b]
3rd Internode above the soil							0.99[b]

[a] Significant at the 5% level.
[b] Significant at the 1% level.

differences were found between entries for the first internode, a later rating date probably would have increased the range of differences observed. However, the differences for the fifth internode would have decreased at the later date too, since dehydration begins in the central region of a given internode and progresses from the higher internodes toward the base of the plant. Further investigation is needed to find the optimum pith-condition-rating time and the internode from which maximum information can be obtained.

In general, the crosses involving the lodging-resistant inbred lines had the lowest pith condition ratings, and those involving lodging-susceptible inbred lines had the highest ratings. The only exception was the lodging intermediate inbred line H55 that was involved in crosses having the highest pith condition ratings for the first and third internodes. The means of the first, third, and fifth internode ratings for all single crosses involving the two lodging-resistant inbred lines were 1.96; for the two lodging-intermediate inbred lines, 2.64; and for the two lodging-susceptible inbred lines, 2.71.

Correlation coefficients.—All possible correlation coefficients among the four morphological stalk traits, *Diplodia* stalk-rot rating, and pith condition rating for the first, third, and fifth internodes are given in Table 5. The majority of the correlations are significant at the 1% level. The only exceptions are those involving the pith condition rating of the first internode. These results suggest that rind thickness and 5.1-cm section wt are the major components of crushing strength, with rind thickness and crushing strength being very closely related. The *Diplodia* rating and pith condition rating are also reliable estimations of stalk quality. The high correlation between *Diplodia* ratings and pith condition ratings supports the conclusions reported by Pappelis & Smith (9) suggesting that the spread of *D. maydis* is restricted largely to dead pith tissue.

Crushing strength, rind thickness, 5.1-cm stalk section wt, *Diplodia* rating and pith condition ratings provide valid estimates of stalk quality, with the exception of pith-condition rating for the first internode. Crushing strength, rind thickness, and wt of 5.1-cm sections gave the most precise and complete estimate of stalk quality. Crushing strength, in general, was lower in the inoculated treatments than in the noninoculated treatments. The reduction in crushing strength attributed to inoculation per se involved inbred lines from all three lodging classifications. Rind thickness was a major component of crushing strength. Crosses with thicker rinds had higher crushing strength for both the inoculated and noninoculated treatments.

This study indicated that *Diplodia* ratings are useful in making selections for lodging resistance, but the rating method has limitations, since some hybrids permit the spread of stalk rot and still exhibit satisfactory crushing strength. Pith condition ratings at 12 days after 50% silking would not be satisfactory in a breeding program because it is necessary to destroy the plants before the seed has reached maturity. Further investigation is needed to determine the optimum pith-condition-rating time and internode from which maximum information can be obtained.

The quality of both the rind and pith contribute to stalk quality.

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