Smut Expression and Resistance of Corn to *Sphacelotheca reiliana* in Minnesota

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ABSTRACT

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Head smut caused by *Sphacelotheca reiliana* occurred in 1980–1983 in only four counties in north central Minnesota. In resistance trials in 1981 and 1982, 56% of 238 inbreds and hybrids had at least 5% smutted plants. Of 168 elite hybrids, 113 were resistant or moderately resistant to *S. reiliana*. Planting date within a given year did not significantly affect smut incidence; however, more plants were smutted in 1982 than in 1981. Twice as many ears as tassels were smutted and about half of the smutted plants were stunted. Leaf infection and phyllody occurred sporadically. Single crosses were intermediate in smut incidence between their resistant and susceptible inbred parents. Applying teliospore-infested soil to kernels at planting was an effective method to evaluate resistance of inbreds and hybrids in the field.

Head smut of corn (*Zea mays* L.) is caused by *Sphacelotheca reiliana* (Kühn) Clint., or according to Langdon and Fullerton (8), by *Sporisorium reiliana* (Kühn) Langdon & Fullerton. This smut was first discovered in Minnesota in Wadena County in 1980 by Stromberg (11), and it was subsequently identified as occurring sporadically in about 1,200 ha in four counties (Ottertail, Stearns, Todd, and Wadena) (11). Surveys made from 1981 through 1983, however, detected no spread from the four original counties (R. M. Sushak, *unpublished*).

This smut attracted attention partly because of an outbreak in 1979 in Ontario (9), a first report for Canada, and a seed corn directive dated 10 December 1980, issued by B. E. Hopper, Associate Director, Plant Quarantine, Food Production and Inspection Branch, Agriculture Canada, restricting seed corn importation.

Previously, head smut of corn had been known to occur in river deltas and intermountain valleys of the Pacific Coast states and Mexico (5,6,10,12). In 1975, however, it was reported for the first time in seven counties in Texas, with losses in some fields reaching 30–50% (4). Details of signs, symptoms, and worldwide geographic distribution were given by Halisky (5,6) and Frederiksen et al (4), and factors affecting infection were reported by Krüger (7) and Baier and Krüger (1).

Because of an incidence of head smut in the University of Minnesota field plots at the Area Vocational Technical Institute farm at Staples (Wadena County), all field trials were made there in soil already contaminated with smut teliospores.

Our objectives were to 1) develop a field inoculation technique to ensure uniform infection pressure to evaluate hybrids for resistance, 2) study typical and atypical signs and symptoms of smut, and 3) evaluate resistance of inbreds and hybrids (public and private) to smut.

MATERIALS AND METHODS

All experiments were done at the University of Minnesota plots at Staples in a field where head smut was found in 1980. Three planting dates were chosen: 27–28 April, 11–12 May, and 26–27 May 1981; and 26 April, 11 May, and 24 May 1982. There were three replicates of a randomized, complete-block design at each planting for each year per entry.

Corn kernels were planted singly in 6-m rows with 30 kernels sown per row to give a plant population of 11,300 plants per hectare. Some seed lots had been treated with captan when received and no attempt was made to remove the fungicide. The soil was a sandy loam and was irrigated weekly as needed by overhead sprinklers during the growing season. The herbicide alachlor was applied at planting for weed control.

To prepare inoculum, smutted ears from the previous year were collected, stored in burlap sacks, and hung in a corncrib over the winter. One week before planting, teliospores from the smutted ears were mixed with moist sandy loam from an adjacent field in a concrete mixer using the ratio 200 parts soil to one part teliospores (v/v). About 120 cc of inoculum was placed over each kernel after it was dropped into a hand-jab planter. This effectively covered each kernel with soilborne teliospores.

Plant stand, incidence of smutted tassel and ear (and combinations thereof), stunting, and any other signs or symptoms of smut infection were recorded.

In the 2 yr, 238 public and private inbreds and hybrids were evaluated. Private hybrids and inbreds were contributed by the seed industry; public hybrids were obtained from the Minnesota

Fig. 1. Signs and symptoms of head smut in corn tassels, showing the variation in branching habit from **(A–C)** compact types to **(D)** more open branching and **(E)** excessive proliferation of bracts that subtend the inflorescence.

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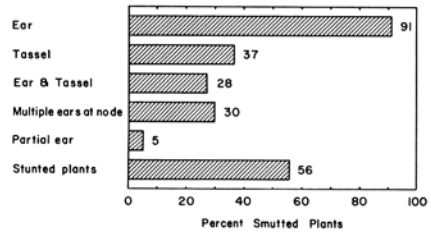

Fig. 2. Percentage of corn plants infected with *Sphacelotheca reiliana* in which signs or symptoms of smut were apparent, based on 1,976 smut-infected plants in 1981. Plants with ear smut included those partially smutted and those with tassel smut; similarly, the tassel smut category included plants that also had ear smut.

Crop Improvement Association. The 25 inbreds evaluated in 1982 included 20 of the 25 most popular public lines in 1979, as listed by Zuber and Darrah (13). Inbreds A554, A654, A665, CO109, ND203, W59E, W117, and W182B are popular early lines and were the parents of the diallel set of 28 F_1 single-cross hybrids tested in 1982.

RESULTS

Tassel smut. Typically, head smut is characterized by sori that appear in the microgametophyte inflorescence (tassel) in which florets are replaced by teliospores without the formation of a gall that characterizes common smut (*Ustilago maydis* (DC.) Cda.). This may result in a compact inflorescence (Fig. 1A–C), some proliferation of spikelets on the rachis and branching (Fig. 1D), and infrequently, some proliferation of bracts or leaves that subtend the inflorescence (Fig. 1E). Where there are multiple tillers, one or more, but not necessarily all, may have signs and symptoms of tassel smut.

Infected tassels occurred in 134 of 168 smutted hybrids (80%) and in 37% of smutted plants (Fig. 2). Tassel infection may be accompanied by ear infection. Both signs were found on the same plant in 128 of the 168 hybrids (76%) and in 28% of the smutted plants (Fig. 2).

Ear smut. Ear infection is a conspicuous sign of head smut and occurred in 164 of 168 hybrids (98%) and on 91% of the smutted plants (Fig. 2). Most often, a single ear was smutted (Fig. 3A), but not infrequently, two or more ears on the same stalk were smutted (Fig. 3B) or one ear was smutted and one was not. Ears that were partially smutted (Fig. 3C) were seen in 53 of 168 smutted hybrids (32%) and on 5% of smutted plants (Fig. 2). Instead of a sorus, there may be a proliferation of leaves or husks at the node (Fig. 3D), with scant appearance of teliospores in the tissues. Ear proliferation (Fig. 3B,D) attributable to smut infection occurred in 79% of the 168 infected hybrids and on 30% of smutted plants (Fig. 2).

Another less frequently occurring variation in symptoms is the substitution of tubular leaves (phyllody) for kernels on the cob (Fig. 3E,F). Teliospores were not always present in those tissues. These symptoms superficially resemble vivipary as described for Diplodia ear rot (2); however, the structures in Figure 3E,F were not plumules of germinating kernels.

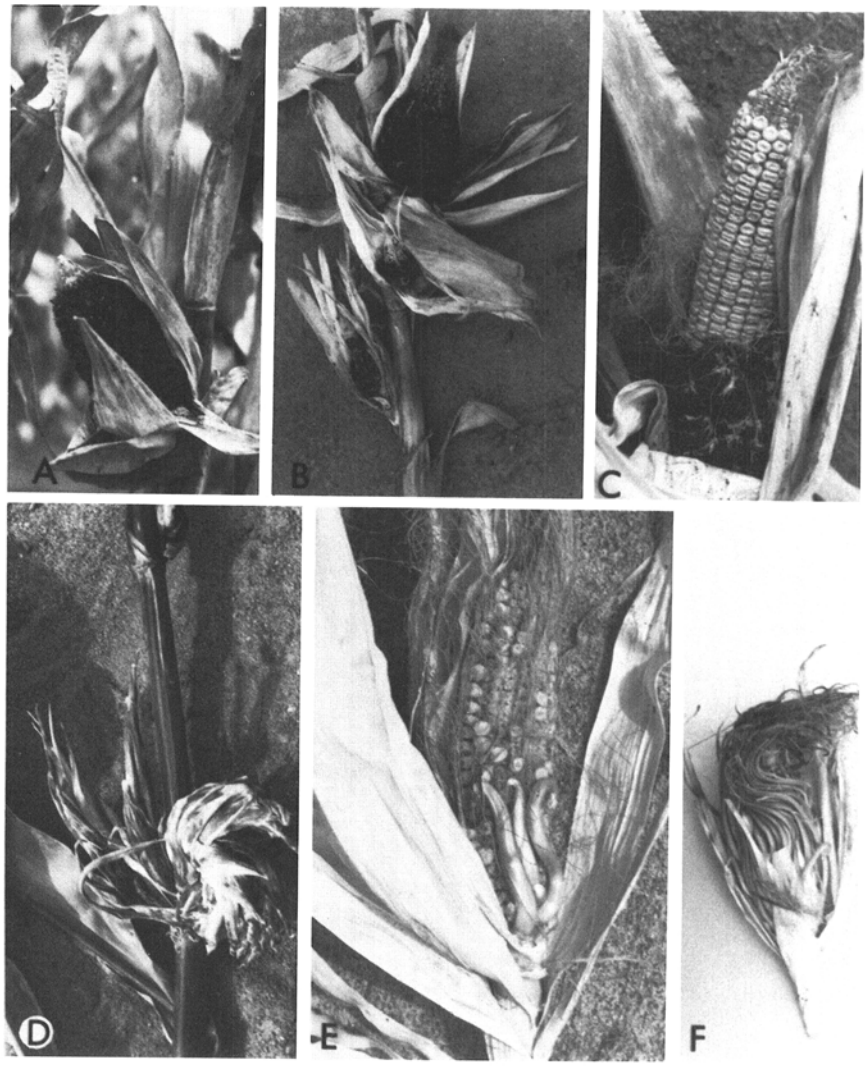

Fig. 3. Signs and symptoms of head smut in corn ears, showing the variation from **(A)** single ears per stalk and **(B)** multiple ears, **(C)** partial ear smut, **(D)** proliferation of husks and leaves of an ear, and **(E and F)** phyllody in an ear.

Leaf smut. In fewer than 1% of smutted plants, smut sori appeared on the distal ends of leaf blades, not as a gall but as an open eruption of teliospores along the veins accompanied by some tissue necrosis (Fig. 4). Confirmation as *S. reliana* was determined by microscopic examination of teliospores. Leaf smut did not occur as a sole sign of disease but mainly in association with ear or tassel smut.

Stunted plants. Often, infected plants can be recognized in the field by stunted growth; however, smutted tassels and ears are sometimes found on plants of normal height. Stunted plants were observed in 151 of the 168 infected cultivars (90%) and in 56% of the infected plants (Fig. 2). Stunting is frequently

Fig. 4. Signs and symptoms of head smut of corn in which sori erupt on the leaf blade.

associated with multiple tillers in which one or more show both tassel and ear smut.

Genotype reaction. During 1981 and 1982, 238 hybrids or inbred lines of corn were evaluated for resistance to *S. reiliana* and 136 (58%) sustained not more than 5% incidence of smutted plants (Table 1). Of 168 private hybrids, 64% had no more than 5% smutted plants, whereas 38% of the inbreds and 25% of the single-cross hybrids were in this group (Table 1). Of 38,928 plants in 152 smutted private hybrid lines tested in 1981, 4.9% of the plants were smutted.

Private hybrids. A list of 168 hybrids were classified as resistant (no smutted plants), moderately resistant (0.1–5.0% smutted plants), moderately susceptible (5.1–10.0% smutted plants), and susceptible (>10.0% smutted plants) and are listed by their brand-variety designation as follows:

Resistant. Cenex 2203, 3015, 3139; Dekalb XL14AA; Funk's G-4256; Lester Pfister 1430; McCurdy Big M-X956; and Northrup, King & Co. PX37.

Moderately resistant. Blaney B101, B606, S2101wx, S2184, S2202, S2322, S3306, S4402, S4406wx, S5602, S6389, S6595A; Cenex 2004, 2091, 2093, 2106, 2108, 2110, 2111, 2119, 2134, 3011, 3018, 3094, 3103, 3121, 3123; Dekalb EX505, EX1212, EX2929, EX3333, XL6, XL13, XL15, XL18, XL23, XL25A, XL32A, XL36; Funk's G-4085, G-4141A, G-4143, G-4180, G-4224, G-4315, G-4323, G-4424, G-4426, G-4435; Kaltenberg KX33, KX44, KX47, KX54A, KX59; Lester Pfister 7801; McCurdy Big M-46, M-3410, M-4436, M-4664, M-4855, M-5596; Midland M-1001B, M-1051DR, M-1080, M-1085A, M-1088, M-1090B, M-3090B, M-3093, M-3095A; Northrup, King & Co. PX419, PX443, X6392, X6668; Payco SX-386-N, SX-431-N, SX-442-N, SX-620-N, SX-680-N; Pfizer T-950, T-1000, T-1058, T-1069; Ramy X-13, X-14, X-20, X-22, X-33; RBA 94, 94+, 104+, 105+, 3040, S3060, Super 4; Sokota 78-A, MS27, TS20; Stauffer 2184, 3306, 3406wx; and sweet corn hybrids Green Giant Code 8, Code 48, and Code 97.

Moderately susceptible. Blaney B607, S3242; Cenex 3138; Dekalb EX1112, XL11, XL314; Kaltenberg KX31, KX53, KX58, KX390; Lester Pfister 1222, 1428; Midland M-1051TY, M-2087, M-3080; Northrup, King & Co. PX11; Payco SX-411-N, SX-555-N, SX-637-N, SX-711-N; Pfizer T-X90, T-930; Ramy X-16, X-150, X-200; RBA Super 4+, Super 80; Stauffer 101, 302wx, 2101wx, 2202, 4402, 5602; and Wilson 1100B, 1300.

Susceptible. Blaney S4800; Cenex 2155; Dekalb XL8, XL12, XL13; Funk's G-5048; Kaltenberg KX362; Northrup, King & Co. PX7, PX24, PX449, PX485; Payco 3X-155-N, 3X-227-N, SX-599-N; Pioneer 3975A; Ramy EX14739, X-135; Stauffer 3242, 5260; and sweet corn hybrids Green Giant Code 7 and Code 47.

Planting date effect. The smut ratings and resistance classifications of private hybrids represent averages of three planting dates. These values were combined because there were no significant differences among the three dates. This is illustrated with public inbreds and hybrids to show the amount of variation (Table 2). Although the average for smut incidence is greater in the first than in subsequent planting dates, it was not consistent for each hybrid tested. Therefore, we averaged data for the three planting dates.

Season effect. Only seven inbreds and six hybrids were evaluated in both years, and the incidence of smutted plants was consistently greater in 1982 than in 1981 (Table 3). Smut incidence among inbreds was not greatly increased in 1982 although some doubled (W117) or tripled (A654). Because the inoculation method and location were the same in both years, the difference was attributed to the environment. Although naturally occurring inoculum might have been greater in the second year, the amount of inoculum added to each kernel sown would have been much greater than the possible difference in naturally occurring inoculum.

Inbreds and derived hybrids. In 1982, 25 public inbreds and 28 F_1 single-cross hybrids using eight of these inbreds for parents were evaluated. The contribution to resistance by the inbred is shown by comparing inbreds and hybrids (Table 4). For example, A554 had 8% smutted plants and A654 had 24%, whereas the hybrid of these two inbreds gave 24% smutted plants. A554 combined with A665 gave only 1% smutted plants, however. Note also that A654 (24% incidence) crossed with A665 (1%) resulted in a hybrid with 10% smutted plants. Other comparisons show the inbred contribution to hybrid resistance (Table 4). In general, smut incidence among the derived hybrids was less than that of the more susceptible inbred but

Table 1. Incidence of smutted plants of private and public hybrids and inbreds and public single crosses and inbreds tested in 1981, 1982, or in both years

Cultivar	No. entries	No. entries/incidences of smutted plants			
		0	0.1–5%	5.1–10%	>10%
Private hybrids[a]	168	8	105	35	20
Public hybrids[b]	9	0	5	2	2
Single crosses[c]	28	0	7	7	14
Public inbreds[d]	28	0	8	6	14
Private inbreds[e]	5	0	3	0	0
Total	238	8	128	50	52

[a] One hundred forty-four tested in 1981, 18 in 1982, and six in both years.
[b] Tested only in 1981 (see Table 2).
[c] F_1 of diallel single crosses tested in 1982 (see Table 4).
[d] Three tested in 1981, 18 tested in 1982 (see Tables 3 and 4), and seven tested in both years.
[e] Five tested in 1981.

Table 2. Incidence of corn plants infected with head smut in 10 inbreds and nine public hybrids at three planting dates in 1981

Corn line	Infected plants per planting date[a]							
	28 April		12 May		27 May			
	Percent	*SD*	Percent	*SD*	Percent	*SD*	Avg.	*SD*
Inbred								
A554	6.8	5.4	2.6	3.6	9.4	4.5	6.3	5.4
A632	0.0	0.0	0.0	0.0	1.1	1.6	0.4	1.0
A634	4.2	3.6	0.0	0.0	0.0	0.0	1.4	2.9
A654	10.7	9.9	7.4	5.8	5.2	1.6	7.8	7.1
A661	2.6	3.6	5.0	1.7	2.2	3.1	3.3	3.2
A671	29.5	8.7	28.9	7.7	29.9	5.1	29.4	7.4
CM105	4.2	5.9	3.9	3.3	0.0	0.0	2.7	4.3
CO109	12.8	5.4	12.3	1.8	6.6	6.3	10.6	5.6
W117	10.6	5.7	1.3	1.8	0.0	0.0	4.0	5.8
W153R	10.6	2.1	0.0	0.0	9.5	2.1	6.7	5.1
Hybrid								
A661 × A665	2.5	1.7	4.8	4.5	0.0	0.0	2.4	3.4
CO109 × CM105	0.0	0.0	1.3	1.8	2.3	3.3	1.2	2.3
MN 4201	35.5	6.7	20.3	4.8	20.1	2.5	25.3	8.8
MN 4202	0.0	0.0	0.0	0.0	1.1	1.6	0.4	1.0
MN 5202	0.0	0.0	0.0	0.0	1.1	1.6	0.4	1.1
MN 5301	10.3	4.5	21.5	8.6	5.7	3.3	12.5	8.9
MN 6305	12.6	2.4	4.0	3.4	1.3	1.9	6.0	5.5
MN 7301	6.0	3.6	13.3	10.3	3.8	3.0	7.7	7.7
MN 8301	9.3	4.5	1.1	1.6	3.5	2.9	4.6	4.7
Control[b]	28.1	2.1	32.1	2.5	23.5	3.7	27.9	5.1
Average	9.8		8.0		6.3			

[a] Average of three replicates per date, 30 plants per replicate. *SD* = standard deviation.
[b] Susceptible private hybrid.

more than that of the more resistant inbred.

DISCUSSION

The signs and symptoms we described and illustrated are similar to and more complete than those shown by Halisky (5,6), Frederiksen et al (4), and Lynch (9). Both Halisky (5,6) and Frederiksen et al (4) also reported independent infections of tassels and ears. The predominance of ear over tassel smut was striking in that more than twice as many ears as tassels were smutted. With 91% of the ears in infected plants with smut, the loss in yield can be substantial. Tassel infection has greater visibility than ear infection in the field so its presence tends to be overemphasized in detection compared with ear smut. Linear sori on leaves, reported by Halisky (6), were found occasionally (< 1%) on smutted plants in Minnesota.

Stunting to half the normal height was cited by Halisky (6) but this degree of severity was not usually found by Frederiksen et al (4). We observed considerable variation in stunting; some plants were slightly below normal in height and others were less than half normal in height. Stunting occurred in about half of all smutted plants.

The fact that all signs and symptoms were not present in each infected plant suggests, as it has to several others (4–7), that systemic infection by smut hyphae depends on the stage of meristem differentiation at the time of infection. Soil factors may also be an important determining factor (1,5–7).

Soil moisture and temperature were reported to be critical factors affecting smut incidence (1,5). Soil texture, however, apparently has little or no influence because head smut was severe in clay or clay-loam soil in Ontario (9), occurred in peat soil in California (5,6), and was present in sandy-loam soil in Minnesota.

Inbreds reported by Frederiksen (3) to be resistant to head smut in Texas (B73, Mo17, and W64A) were also resistant in Minnesota, whereas inbred Va26 proved susceptible in both states. Several other inbreds also showed good resistance in our evaluation (Tables 2–4). Of the crosses made from inbreds (Table 4), the percentage of smutted plants in the single-cross hybrid was almost always intermediate between that of the parent inbreds. This is not consistent with Frederiksen's finding (3), where resistance was reported to be dominant or partially dominant.

We have identified resistances in popular inbreds and public and private hybrids that enable farmers to reduce losses to head smut in the irrigated sandy loam soils of Minnesota and perhaps elsewhere. It is not likely that a field evaluation of such a number of hybrids and inbreds will be tried again soon because of the considerable amount of inoculum required (8.4 t in 1981) for such an evaluation.

Table 3. Incidence of corn plants infected with head smut in seven inbred lines and six hybrids tested in the field in 1981 and 1982

	Infected plants[a]			
	1981		1982	
Corn line	Percent	*SD*	Percent	*SD*
Inbred				
A554	6.2	5.4	8.5	5.7
A632	0.4	1.0	4.6	5.0
A634	1.4	2.9	2.6	3.2
A654	7.8	7.1	24.5	10.0
CM105	2.7	4.3	7.7	6.5
CO109	10.6	5.6	13.7	13.1
W117	4.0	5.8	10.7	6.6
Hybrid (brand-variety)				
Dekalb				
XL6	0.8	1.5	5.0	5.4
XL13	2.4	3.8	12.8	6.4
XL14AA	0.0	0.0	6.9	4.9
XL18	0.6	1.6	5.1	3.8
XL25A	0.4	1.1	1.6	3.0
Control[b]	28.7	5.1	37.0	15.7

[a] Average of three planting dates each year, three replicates per date, 30 plants per replicate. *SD* = standard deviation of grand mean.
[b] Susceptible private hybrid.

Table 4. Incidence of smut-infected plants of 25 inbreds and 28 single-cross hybrids tested in the field in 1982

Inbred[a,b]	Percent	*SD*[c]	Hybrid[b]	Percent	*SD*
A554	8	5.7	A554 × A654[r]	19	14.1
A619	49	10.3	A554 × A665[r]	1	1.4
A632	5	5.0	A554 × CO109	6	4.7
A634	3	3.2	A554 × ND203	14	9.1
A635	3	4.6	A554 × W59E	7	4.0
A654	24	10.0	A554 × W117	4	3.1
A665	1	1.7	A554 × W182B[r]	8	6.3
B37	24	11.2	A654 × A665	10	6.5
B68	34	27.6	A654 × CO109	14	14.0
B73	6	4.9	A654 × ND203	19	16.1
B84	2	2.6	A654 × W59E	18	16.2
CM105	8	6.5	A654 × W117	10	5.8
CO109	14	13.1	A654 × W128B	16	7.5
H84	17	10.7	A665 × CO109[r]	6	8.3
H99	9	5.8	A665 × ND203	15	10.5
H100	11	6.5	A665 × W59E[r]	4	3.0
Mo17	3	1.2	A665 × W117	5	5.7
N28	7	6.7	A665 × W182B	5	5.8
ND203	22	14.9	CO109 × ND203	23	13.7
PA762	41	18.1	CO109 × W59E	14	13.2
Va26	56	27.6	CO109 × W117	9	9.2
W59E	16	8.8	CO109 × W182B[r]	5	2.9
W64A	5	5.9	ND203 × W59E	19	10.0
W117	11	6.6	ND203 × W117[r]	14	9.4
W182B	25	10.2	ND203 × W182B[r]	14	7.0
			W59E × W117	3	2.1
			W59E × W182E	16	10.6
			W117 × W128B	14	6.6

[a] Parents of the diallel set of 28 F_1 hybrids.
[b] Average of three planting dates, three replicates per planting date, and 30 plants per replicate. [r] = Cross made in reciprocal direction to that listed.
[c] *SD* = standard deviation.

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