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Small Grain Cereal See

Beginning with its introduction in the 1930s, organic mercury seed treatment of small grain cereals, particularly wheat, barley, oats, and rye, was widely used over a period of 40 years. Materials such as Panogen and Ceresan were used throughout much of the world. Because of the increased awareness of the toxicity of the organic mercuries to animals, including man, the pesticide regulatory agencies have banned their use in many countries. In the United States, the alkyl mercury compounds were banned in 1970 by the Environmental Protection Agency (EPA) from interstate shipment, with the stipulation that existing stocks could be utilized. At that time, the less hazardous phenyl mercury formulations, such as phenylmercury ammonium acetate (PMAA), were still allowed to be manufactured and used. In 1978, the phenyl mercuries were also banned from interstate shipment in the United States, again with the provision that existing stocks could be used. The decade of the 1970s therefore saw a transition in cereal seed treatment practices as the alkyl and phenyl mercuries were gradually phased out and growers turned to other seed treatment materials.

Fig. 1. Commercial seed-treating station where growers bring their seed to be cleaned and treated with liquid or flowable formulations.

Current Status of Seed Treatment

To determine the current use of seed treatment on small grains, we contacted extension and research specialists in 18 states by letter in January 1981. These states planted 30.7 million hectares (75.9 million acres) to wheat, barley, and oats in 1978. This comprises 83% of the total U.S. acreage planted to these crops.

Of the area surveyed in 1980, an estimated 13.8 million hectares, or about 45%, were planted with treated seed. However, the amount of seed treatment in the different states surveyed varied greatly (Table 1). It is difficult to determine why the variation among states exists but it may be due in part to a history of smut problems.

Seed treatment materials currently being used are maneb (eg, Agsco DB Green, Cenex Drill Box G), hexachlorobenzene (HCB), pentachloronitrobenzene (PCNB; eg, Terra-Coat LT-2), and carboxin in combination with thiram (eg, Vitavax 200, Cargill RTU 1010) or captan (eg, Vitavax-Orthocide 20-20 Seed Protectant). No one material or formulation is used predominantly, but the formulation of the materials dictates their use to some extent. Equipment used by commercial treating stations (Fig. 1) requires liquid or flowable formulations. The individual grower can treat seed either with a drill box-endgate auger treater (Fig. 2), using a flowable or dust formulation, or directly in the drill box, which requires a dust formulation. One advantage to growers treating their own seed is that no treated seed is left over and stored until the next growing season.

Usefulness of Seed Treatment

Historically, the single most important small grain disease controlled by seed treatment is common stinking bunt of wheat caused by *Tilletia caries* (DC.) Tul. and *T. foetida* (Wallr.) Liro (Fig. 3). Fischer and Holton (1) indicate that one-fourth to one-half of the winter wheat crop in Kansas was destroyed by common bunt in 1890. Between 1900 and 1930, losses to common bunt in the Pacific Northwest were also high, as much as 87% in some fields. In 1928, 12% of the wheat shipped out of Montana was graded smutty. In addition to production losses, growers suffered from price dockage at the elevator for wheat graded smutty.

By 1933, the release of a few bunt-resistant wheat cultivars plus the introduction of Ceresan mercury seed treatment reduced the losses from common bunt in most areas of the United States, with the exception of the Pacific Northwest (1). This practice certainly rates as one of plant pathology's major success stories of this century. However, mercury seed treatments controlled only the seedborne phase of common bunt. In the Pacific Northwest, soilborne bunt continued to be a problem until the introduction and use of HCB in 1956, followed by release of resistant cultivars, such as Gaines in 1961.

Because the mercury seed treatments were toxic to a broad spectrum of organisms, including fungi and bacteria, they were useful in controlling a number of seed and seedling diseases. These included covered smut of oats (*Ustilago avenae* (Pers.) Rostr.) and of barley (*U. hordei* (Pers.) Lagerh.), semiloose smut of barley (*U. nigra* Tapke), barley stripe caused by *Pyrenophora graminea* Ito & Kurib., and bacterial leaf streak caused by *Xanthomonas translucens*, as well as seed decay and seedling blights caused by a number of fungi.

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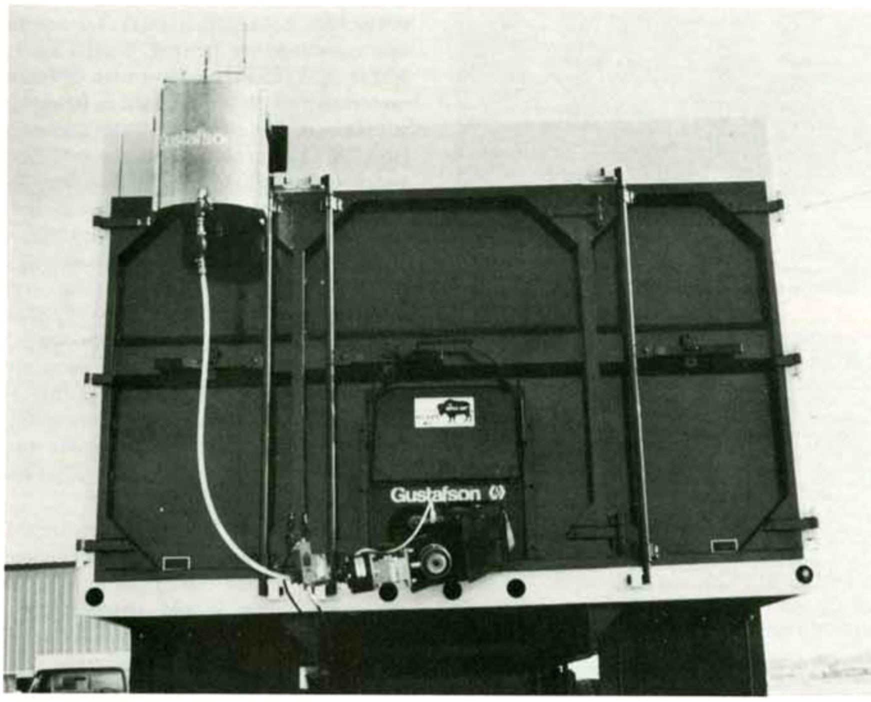
reatment in the Postmercury Era



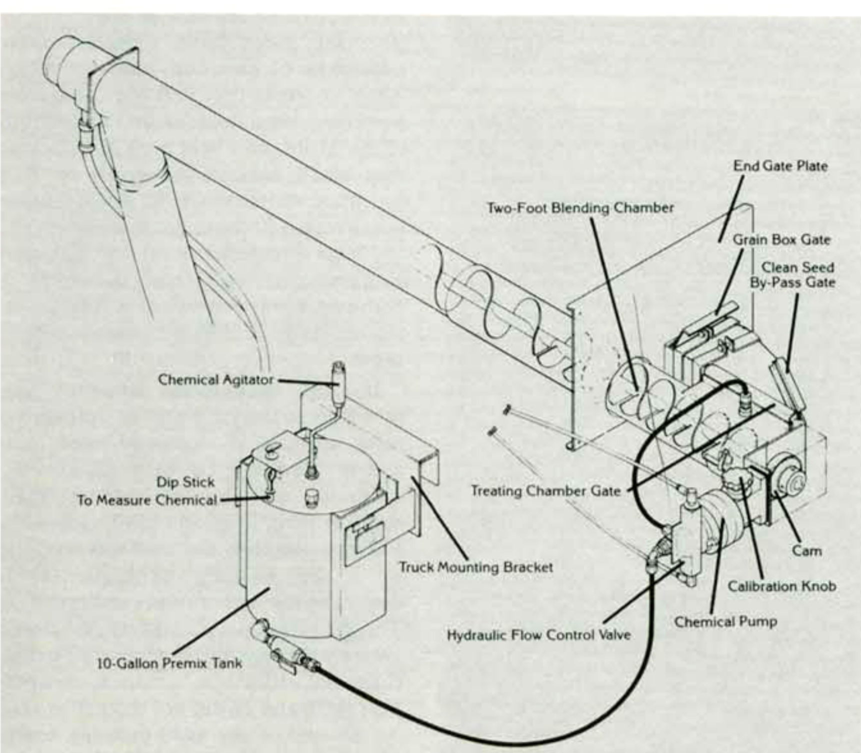


Fig. 2. With an endgate auger seed treater, treatment materials are added to the grain as it moves through the auger from the truck box into the grain drill. (Courtesy Gustafson, Inc., Dallas, TX)

Fig. 3. (Left) Wheat kernels destroyed by common bunt of wheat compared with (right) healthy kernels.

Need for Seed Treatment

Seed decay. One stated value of seed treatment has been to increase stand, and thereby yield, by preventing seed and seedling decay. Is this in fact true? Studies between 1930 and 1960 often showed a definite increase in stand but most did not include yield evaluations. The few studies that did combine stand and yield data indicated a highly variable response. In 1971, Line et al (5) reported that for 10 locations in eastern Washington and Oregon, the stand and yield of Nugaines winter wheat were not increased by the use of various mercury and nonmercury seed treatments. Similar results were obtained by Line on spring wheat and spring barley in 1972. In Virginia, only stands from damaged seed were increased by use of mercury seed treatment. In Montana, a greenhouse study using soil from 38 locations showed a 91% emergence from Panogen-treated wheat seed compared with 88% from untreated seed (7).

Most field studies in Montana using both winter and spring wheat have failed to show any statistically significant effects of treatment on stand or yield, regardless of the treatment used (7). The lack of yield response to seed treatment when soil moisture at seeding is adequate and wireworms (*Aeolus dorsalis* Say) are not a factor probably lies in the fact that many growers plant more seed than is needed for optimum yields. Thus, the loss of some plants to seed decay is compensated for by the surviving plants producing extra tillers. However, studies in eastern Canada (9,10) where infestation of seed by *Cochliobolus sativus* (Ito &

Table 1. Status in 1980 of small grain cereal seed treatment in 18 states

State	Total hectares seeded ($\times 10^3$)	Estimated hectares planted with treated seed ($\times 10^3$)	Percentage of hectares treated
California	920	874	95
Ohio	680	612	90
Oregon	640	512	80
Montana	2,800	2,240	80
Washington	1,440	1,152	80
Indiana	640	448	70
Michigan	360	216	60
Minnesota	2,440	1,110	50
North Dakota	5,440	2,611	48
Texas	3,040	1,064	35
Kansas	4,600	1,610	35
Colorado	1,360	408	30
Oklahoma	2,960	592	20
Georgia	120	24	20
Iowa	760	76	10
Nebraska	1,400	70	5
North Carolina	200	0.2	0.1
Virginia	160	0.16	0.1
Total	29,960	13,619.36	

Table 2. Efficacy of nonmercury seed treatments in controlling wheat seed decay in dry soil[x]

Seed treatment	Rate (ml or g/kg)	Emergence (%)				
		BSL[y]	CFC	MFSaL	MFSiL	$\bar{x}$
Maneb	2.1 g	37	56	47	73	53 a[z]
Thiram	2.1 g	34	40	28	81	46 a
Captan	1.3 g	32	38	37	81	47 a
PCNB	2.2 ml	28	24	33	36	30 b
Untreated	...	32	22	24	42	30 b

[x] Wared spring wheat seed was treated and incubated in the four soil types at −50 bars water potential for 1 month, then the soil was moistened and the percentage of emergence determined 10 days later.
[y] BSL = Bozeman silt loam; CFC = Conrad fine clay; MFSaL = Manhattan fine sandy loam; MFSiL = Manhattan fine silt loam.
[z] Column means followed by the same letter are not significantly different at $P = 0.05$, Student—Newman's Keuls test.

Table 3. Efficacy of currently registered nonmercury seed treatment formulations in controlling common bunt of wheat

Fungicide	Formulation[a]	Rate (g or ml/kg)	Bunted heads (%)[b]			
			Seedborne			Seedborne and soilborne
			OR	MT	MI	OR
PCNB	L	2.2 ml	0	1	0	3
HCB	WP	0.5 g	1	0	...	6
Maneb	WP	2.1 g	18	1	...	78
Captan	WP	1.3 g	80	40	...	95
Thiram	WP	2.1 g	48	6	3	88
TCMTB (Nusan 30)	L	0.8 ml	9	8	...	90
Copper hydroxide (Kocide SD)	F	2.6 ml	...	9	...	...
Carboxin + thiram (Vitavax 200)	F	2.6 ml	8	1	2	59
Carboxin + captan (Vitavax-Orthocide Seed Protectant)	WP	3.1 g	0	2	...	8[c]
Thiabendazole (Mertect LSP)	F	1.0 ml	2	...	1	23
Untreated	...	...	89	63	38	88

[a] L = true solution; WP = wettable powder; F = liquid flowable suspension.
[b] OR = Oregon (data from Hoffmann and Waldher [3]); MT = Montana; MI = Michigan (data from Wiese and Ravenscroft [11]).
[c] Formulation was 37.5% carboxin + 37.5% captan wettable powder.

Kurib.) ex Dastur. is often a problem have shown that seed treatment of spring-sown cereals does result in higher yields.

In many areas of the semiarid Great Plains and Pacific Northwest, fall-seeded winter wheat may be planted in dry soil. In some cases the seed may lay ungerminated in this dry soil for 4–6 weeks or longer before it rains. A number of fungi, particularly *Penicillium* spp., are able to invade seed in very dry soil (eg, water potential of −50 bars or lower). One value of seed treatment is to protect this seed from decay. Can nonmercury fungicides accomplish this? To answer this question, we treated Wared spring wheat seed (95% viability) with different materials and placed the seed in Bozeman silt loam soil at −50 bars water potential (too low for the seed to imbibe sufficient water to germinate). After 1 month the soil was moistened to allow seed germination or the seed was extracted from the soil and plated on malt-salt agar to determine the percentage of seed invaded by *Penicillium* spp. Captan, thiram, and maneb were able to provide some protection against seed decay and invasion by *Penicillium* spp. (Table 2). This may be why some growers in dry areas insist on a seed treatment that contains one or the other of these materials.

Smut control. With the remarkable control of the covered smuts of wheat, oats, and barley using mercury seed treatments, one would speculate that these diseases have been nearly eliminated. From the standpoint of economic loss, this is no doubt true, but whether this will continue to be the case is uncertain. At least six states have reported recent outbreaks of common bunt on winter wheat in areas that had been free from bunt for several decades. In 1975, a study of the Montana wheat crop (6) indicated that small background levels of bunt inoculum still exist. Of 302 wheat samples taken from 140 commercial elevators and 162 farm storage facilities, over 70% were contaminated with trace quantities of common bunt. Results of a smaller but similar study in 1980 were essentially the same.

If small background levels of bunt inoculum still exist, could an outbreak of bunt develop if untreated seed were widely planted? To help answer this question, we obtained winter wheat seedlots from Montana growers in 1979. Prior to planting, the seed was analyzed by a seed-washing technique (6) to determine the level of smut contamination. This seed was then planted by 28 different growers throughout Montana; 12 treated their seed with PMAA, maneb, or captan plus HCB and 16 did not treat their seed. At the end of the 1980 growing season samples were obtained from the growers and the harvested seed reanalyzed for the presence of bunt. Only one of the 12 treated seedlots showed an increase in bunt, and that was only a 10-fold increase; bunt decreased in seven lots. Of the 16 untreated seedlots, five showed an increase in bunt—a 100,000-fold increase in one lot; 11 showed either no change or a decrease in bunt. Therefore, while bunt did not always increase, the only sizable increases occurred with untreated seed.

Were these increases of sufficient magnitude to lead to an epidemic of bunt? Our studies and earlier findings by Fischer and Holton (1) suggest that it takes at least 2,000 bunt spores per seed to cause a significant bunt outbreak. Some of the seedlots we tested had about 600 spores per seed, not enough to cause an outbreak of bunt. If this seed were planted without being treated, however, and bunt spores increased 10-fold on the harvested seed, the stage would be set for development of a smutty crop. Apparently, sufficient numbers of bunt spores survive at low levels even when seed is treated. Therefore, if growers were to abandon seed treatment for several years, the potential would exist for development of smutty wheat.

Studies by many individuals, including Hoffmann in Utah (2,3), Wiese in Michigan (11), and us in Montana (7), have shown that a number of nonmercury fungicides and combinations of fungicides provide adequate control of bunt. The efficacy of currently registered materials in controlling common bunt is shown in

Table 4. Efficacy of nonmercury seed treatments in controlling a variety of seedborne pathogens of small grains

	Relative disease control[a]		
Fungicide	Wheat and barley loose smut	Barley covered smut	Wheat common bunt
PCNB	–	+	+++
HCB	–	–	+++
Maneb	–	+	++
Captan	–	–	+
Thiram	–	–	+
TCMTB	?	+	++
Copper hydroxide	–	–	+
Carboxin + thiram	+++	+++	+++
Carboxin + captan	+++	+++	+++

[a] – = no control; + = low level of control; +++ = excellent control.

Table 5. Efficacy of seed treatment in controlling barley stripe disease and increasing yield of Summit barley[x]

Fungicide	Rate[y] (g or ml/kg)	Infected plants (%)	Yield (kg/ha)
Carboxin + thiram	2.6 ml	30 b	4,239 b[z]
TCMTB	1.0 ml	36 b	4,724 b
Fenapronil	0.6 ml	1 a	5,978 b
Ceresan M-DB	2.6 g	31 b	5,110 b
Untreated	···	72 c	1,799 a

[x] Seedlot was >90% infected.
[y] Rate is given as formulated product.
[z] Column means followed by the same letter are not significantly different at $P = 0.05$ according to Duncan's multiple range test.

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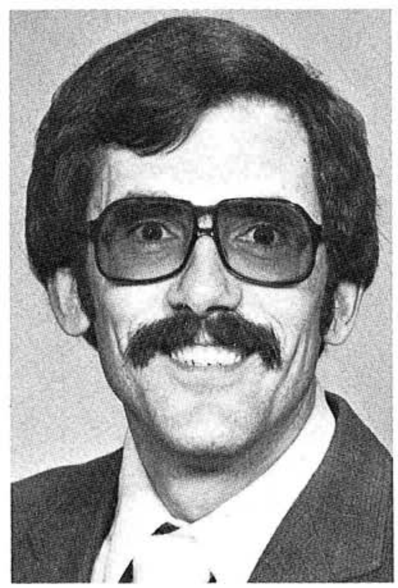

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Table 3. In some areas, particularly the Pacific Northwest, bunt inoculum survives in the soil as well as on the seed. Not all materials will control both seedborne and soilborne bunt. In spite of this, materials that effectively control only seedborne inoculum are finding widespread use, particularly the treatments combining carboxin with thiram or captan. Carboxin plus captan will control both seedborne and soilborne bunt at rates above those that control just seedborne bunt (3).

Because many small grain producers grow barley and/or oats in addition to wheat, it would be very helpful to them if one seed treatment material would be effective against pathogens affecting all three crops. Are there such materials? Table 4 outlines the relative effectiveness of nonmercury treatments against seedborne pathogens affecting wheat and barley. With the exception of barley stripe and bacterial leaf streak, the combination treatments involving carboxin plus thiram or captan appear to offer the broadest control. These materials are available as either flowable formulations (eg, Vitavax 200, Cargill RTU 1010) that can be applied by commercial high-volume treaters or as a dry drill box formulation (eg, Vitavax-Orthocide 20-20 Seed Protectant) that a grower can apply directly to seed in the drill box. If loose smut is not a problem, the grower can choose materials for controlling common bunt of wheat or covered smut of barley that do not contain carboxin (eg, maneb, PCNB, HCB, 2-[thiocyanomethylthio] benzothiazole [TCMTB]).

Loose smut. Loose smut of wheat and barley caused by *Ustilago tritici* (Pers.) Rostr. and *U. nuda* (Jens.) Rostr., respectively, is easily recognized because it appears at heading (Figs. 4 and 5). Until the 1970s, loose smut was controlled by soaking seed in hot water or using resistant cultivars. With the development and use of carboxin in the 1960s and 1970s, control of loose smut by seed treatment became practical. Today, most breeder, foundation, registered, or certified seed classes specify a zero or near-zero tolerance for loose smut. This can easily be met by treating the seed with formulations containing an adequate level of carboxin.

In 1976, we observed a striking case of loose smut of wheat in a hybrid winter wheat field in Kansas. The necessity of open flowers for cross-pollination to produce the hybrid seed is ideal for loose smut infection. This may suggest that if hybrid wheat and barley are eventually produced, the seed of such cultivars will need to be treated with carboxin or other systemic fungicides for loose smut control.

Flag smut. Flag smut of wheat caused by *Urocystis agropyri* (Preuss) Schroet. is currently geographically limited in the United States to a few areas of Oregon and Washington. Line's studies (4) indicate that carboxin alone or in combination with thiram or captan effectively controls flag smut.

Barley stripe. Barley stripe caused by *P. graminea* (Fig. 6) has not been a serious disease in the United States for many years because of the use of mercury seed treatments and resistant cultivars. Recently, however, this disease has "reappeared" in seedlots from Europe. The availability of a highly infected seedlot ($>$ 90%) allowed us to determine whether nonmercury materials (registered for use or experimental) applied as a seed treatment can control this disease. As seen in Table 5, only the experimental material fenapronil provided complete control. However, both TCMTB and carboxin plus thiram reduced infection and increased yield in a manner comparable to that of Ceresan mercury. If seed is produced in semiarid areas without irrigation (8) and resistant cultivars and/or seed treatment with TCMTB or carboxin plus thiram is used, barley stripe disease should not be a threat to barley producers.

Conclusions and Considerations

Seed treatment of small grain cereals has been of great economic benefit by

Fig. 4. (Left) Loose smut of barley compared with (right) healthy head.

preventing serious losses to a variety of diseases, particularly the smuts. The cost of treatment is relatively low, and with proper attention to label directions, nonmercury materials are less hazardous to man and the environment than mercury materials. In many cases, seed treatment must be viewed as an insurance policy against disease, since most seedlots are not tested for pathogens prior to planting. The fact that various states have reported new outbreaks of common bunt in winter wheat, plus our work in Montana indicating that wheat seed is carrying low levels of bunt inoculum, suggests that seed treatment should continue to be a recommended practice. In addition, growers will need to be aware of other seedborne diseases, such as barley stripe and loose smut, that can be controlled by seed treatment. As the mercury seed treatments fade from the scene, nonmercury formulations are available that do provide satisfactory control of most seedborne diseases caused by fungi.

The future for seed treatment contains several unknowns, however. Certainly, cost is one factor. As recently as 10 years ago, seed treatment costs were as low as 15¢/ha, whereas now the cost can run as high as $2.50/ha. While still very low in comparison to other production costs, seed treatment as an insurance policy may be one area that is cut back as growers are faced with spiraling prices. This trend is already evident in some areas of the United States. If this continues, growers may have to rely more on the use of resistant cultivars as a control measure. For this to be effective, plant breeders must begin immediately to put more effort into this aspect of their already complicated breeding programs.

Other areas of concern surround the formulation of seed treatments. The flowable formulations are not as easy and convenient to use as the "true liquid solutions" of the past. This provides a challenge to private industry to develop new materials that can be formulated as true solutions or as flowables approximating true solutions in their handling characteristics.

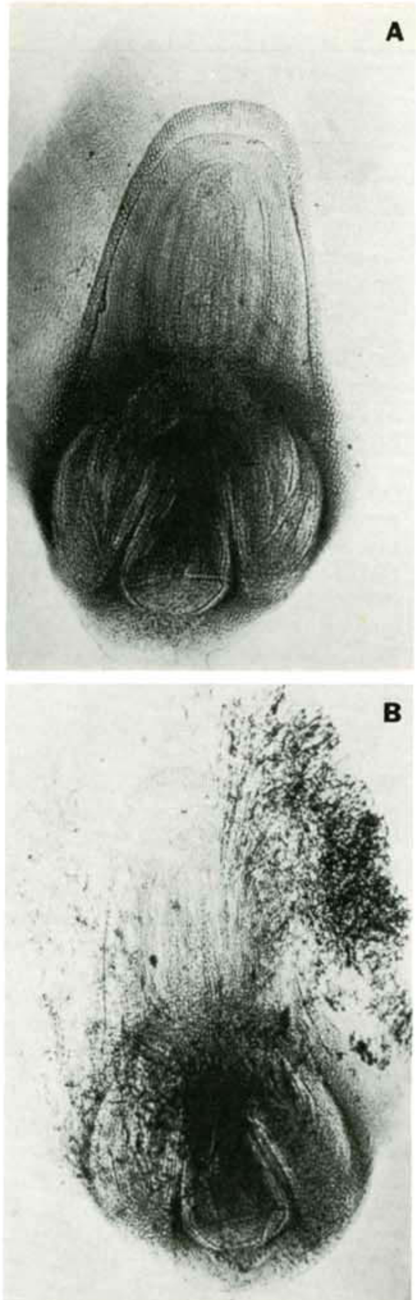

Fig. 5. (A) Healthy embryo of barley compared with (B) embryo infected with loose smut, with mycelial growth of *Ustilago nuda*.

Acknowledgments

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Fig. 6. Leaf symptoms in barley infected by seedborne inoculum of *Pyrenophora graminea*.

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