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Management of White Mold of White Beans in Ontario

White mold, also known as Sclerotinia rot and Sclerotinia wilt, is caused by *Sclerotinia sclerotiorum* (Lib.) de Bary. This fungus attacks a wide range of hosts and has a worldwide distribution on numerous field crops and vegetables (13). White mold frequently causes serious and unpredictable yield losses in beans (dry and green) (*Phaseolus vulgaris* L.) in southwestern Ontario, where the majority of Canadian white beans are grown (6,21).

This disease and its causal organism have been subjects of intensive investigation. The etiology, biology, and epidemiology of white mold in beans have been studied extensively and summarized in several reviews and symposia (1,2,8–10, 12,13,15). Despite this, the disease has not been controlled effectively and economically. Control measures commonly used include application of foliar protectants, seed treatments, sclerotial germination inhibitors, soil disinfectants, crop rotation, sanitation, moisture regulation, and microclimate regulation (15). These measures are ineffective, expensive, or improperly applied. Researchers are turning to biological control, hoping to use antagonistic microorganisms and resistant cultivars for disease control. Biological control of *S. sclerotiorum* is still in its infancy, and very few measures have proved to be practical (15).

This paper describes an integrated measure that has delivered successful control of white mold disease of white beans in Ontario. Before the control measures described were introduced, Ontario growers relied solely on preventive and eradicative foliar sprays of fungicides such as benomyl, chlorothalonil, dicloran, iprodione, and thiophanate-methyl for disease control. Foliar sprays proved to be ineffective and uneconomical, and most growers have abandoned the practice.

Occurrence and Etiology

Ontario bean production is centered within 60 km of Exeter in the southwestern part of the province. Approximately 60% of the bean fields in Ontario were surveyed during 1978–1980. The average incidence of bean crops with white mold during 1978, 1979, and 1980 was 16, 32, and 23%, respectively (18). The incidence of disease within fields ranged from a trace to 85%. These percentages, although somewhat lower, generally confirm those reported by Haas and Bolwyn (6) and Wallen and Sutton (21), who found that 22 and 44% of fields in 1969 and 1970, respectively, had white mold; within-field incidence ranged from 0 to 100%. Differences in incidence between fields were attributable to variations in precipitation, soil drainage, cultural practices, and sclerotial density in different localities. The important fact is that about one-half of the bean fields surveyed, representing one-third of the total acreage, were free from or have a low incidence of white mold infestation. These fields should be protected from inadvertent introduction of the fungus.

Fields planted with high populations of vine- or bush-type cultivars tend to have higher incidences of the disease than those planted with low populations of upright cultivars. At present, unfortunately, all recommended Ontario cultivars are bush-type.

The occurrence and severity of this disease are difficult to predict. However, the disease appears more frequently and is more severe in fields with a history of white mold, because *S. sclerotiorum* can survive in the soil for 6–8 years by means of sclerotia (2). Fields with a history of white mold are likely to have a high density of sclerotia.

In southwestern Ontario, the organism thrives from mid-July to late August, when weather conditions are warm and humid. This coincides with the blossom period of bean plants. Fallen petals that

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adhere to leaves or stems provide excellent sites for infection (1). Prolonged cool, wet periods preceding blossom are important to disease initiation because such weather promotes germination of sclerotia, with the production of apothecia (22) and discharge of ascospores that are responsible for primary infection (1). Boland and Hall (4) showed that the first appearance of disease coincides with closure of the canopy, appearance of apothecia, and presence of fallen petals in the crop after rain has provided plant surface wetness periods of 39–64 hours. Recently, I (19) showed that primary infection can also result from green leaves that come in direct contact with sclerotia on the soil surface. Secondary spread can be rapid and achieved by natural contact between healthy and diseased plant parts (1). Infected bean seeds are a primary source of introduction of the pathogen into fields previously not infested (19).

Symptoms

Infection usually occurs at the junction of the petiole and stem, approximately 10–15 cm above the soil level, where fallen flower petals or leaves have adhered. The infected petioles and leaves first show brown water-soaked lesions (Fig. 1A); these spread rapidly to the stems and branches. Later, the superficial cottony growth of white mold occurs on the infected petioles, stems, and pods (Fig. 1B). As the disease advances, the infected parts show a brown to chocolate-brown discoloration, and a soft rot results in dieback of the branches (Fig. 1C). At this stage, the fungus forms sclerotia, initially white but becoming black by maturity. The sclerotia on or inside the infected plants are slightly larger than a wheat grain (Fig. 2). Seeds from infected pods are infected to varying degrees (Fig. 3).

Epidemiology

S. sclerotiorum is a soil-inhabiting fungus. Ascospores are forcefully ejected into the air from apothecia produced from sclerotia (Fig. 4). The majority of ascospores become lodged within the canopy of the bean plants, but a few are ejected above the bean canopy and reportedly travel several meters to several kilometers (1). Ascospore density, and thus the probability of infection, probably declines with distance from the point of origin. This assumption is supported by the results of disease monitoring and field surveys showing that apothecia within the fields were a major source of inoculum and that low levels of white mold in fields were generally associated with low numbers of endogenous apothecia (4,7). In addition, many bean fields located less than 30 m from a bean field with severe white mold had little or no disease.

Primary infections are initiated by ascospores with the help of exogenous energy sources. As mentioned previously, fallen flower petals that attach to stems, petioles, or pods are ideal loci for infection (15). Necrotic tissues resulting from injury or pathogenesis are likewise ideal locations for infection. A free moisture period of 48–72 hours is required for establishment of infection and lesion expansion. If free moisture is not available, lesion expansion quickly stops. The fungus, however, appears to remain quiescent in the infected tissues and can be reactivated upon the return of free moisture. Secondary infections are achieved by natural contact of healthy plant parts with diseased ones. Therefore, factors such as frequency and duration of rain and dew, wind, aeration, row width, and plant morphology that can affect the duration of free moisture and plant contact will have a profound effect on disease incidence as well as severity.

An investigation of a field with heavy *S. sclerotiorum* infestation in Mitchell, Ontario, revealed that white mold was severe in 1981 and 1982 but negligible in 1983 and 1984. Severe symptoms occurred only when initial incidence was high and when conditions were suitable for rapid spread. The high incidence of disease initiation in 1981, 1982, and 1984 coincided with a high frequency (11 days) of rainfall early in the season. The low incidence of disease initiation in 1983 was associated with a low frequency (5 days) of rainfall between 15 June and 14 July.

Disease spread was associated with the amount and frequency of rainfall between 15 July and 15 September, with frequency being more important than amount. For example, white mold incidence was high in 1984 and low in 1983. The total amount and frequency of rainfall between 15 July and 15 September for 1983 and 1984 was 325.6 and 232.1 mm, respectively, and 22 and 25 days, respectively. Temperature did not appear to be a restrictive factor in the spread of disease in any year. Moisture records can be used to predict disease initiation and subsequent spread with reasonable success in fields infested with the white mold fungus.

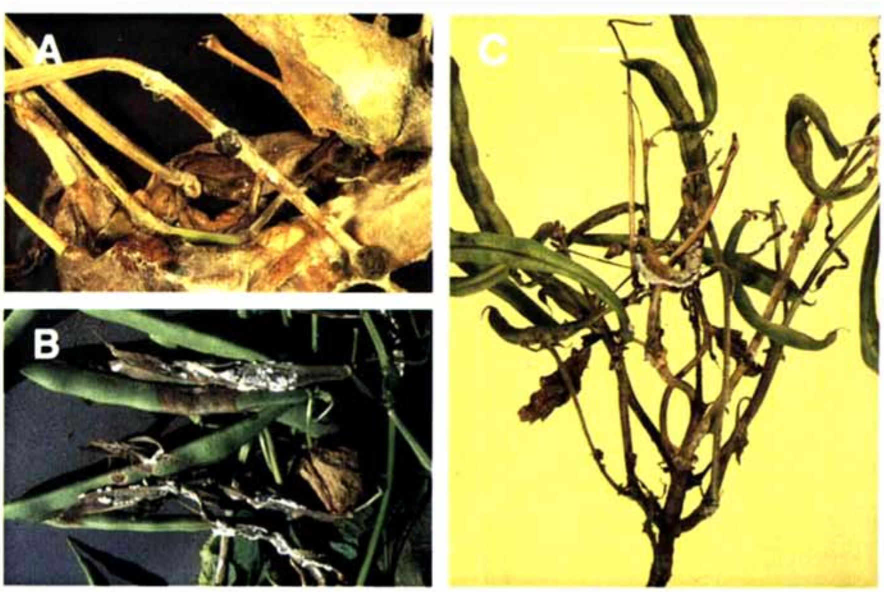

Fig. 1. Symptoms of white mold progress from (A) brown water-soaked lesions on infected petioles and leaves, to (B) a superficial cottony growth on petioles, stems, and pods, to (C) a brown to chocolate-brown discoloration and a soft rot resulting in dieback of the branches.

Control Measures

Among the reported control measures, foliar sprays of fungicides have been recommended in Ontario. Most foliar protectants are applied by airplane. Benomyl, for example, has been applied at 2 kg a.i./ha in 45 L of water. Generally, with air applications the water volume is insufficient and the spray droplets are too large to penetrate the canopy where white mold is active. Ground application of fungicides by means of boom sprayers with 450 L of water and a delivery pressure of 3.6 kg/cm^2 is a more effective alternative but is also more time-consuming and involves the risk of damage to vines and stems by tractor wheels or spray equipment. The average yield increase from fungicide application in Ontario is approximately 100 kg/ha per spray, representing approximately $35 (U.S.). The cost per spray at the recommended rate, however, is approximately $75/ha per spray, making fungicide applications uneconomical. In fact, the majority of growers with white mold are not spraying their fields. Applications of sclerotial germination inhibitors and soil disinfectants are extremely expensive and are not being made at present nor will they be in the foreseeable future.

A 3-year crop rotation is routinely practiced, but, unfortunately, crop rotation is not an effective control measure, since sclerotia are known to survive 6–8 years in the soil (2). Sanitation is important but will not help fields that are already infested. Biological control with hyperparasites or antagonistic microorganisms appears to be impractical for the near future. Moisture regulation is not relevant because all beans are planted in nonirrigated land in Ontario. The alternatives for control of white mold that remain are seed treatment, use of disease-resistant cultivars, and changes in row width and plant density.

Seed treatment. I (19) demonstrated that *S. sclerotiorum* could survive in infected seeds as dormant mycelia in testae and cotyledons for 3 years or longer. When infected seeds were sowed in soil or sand, 88–100% failed to germinate, depending on severity of the infection. Seedlings from infected seeds subsequently died from damping-off or white mold at an early stage. Seeds that failed to germinate were rotted by *S. sclerotiorum*, and three to six sclerotia were formed in place of each seed. A low percentage of these sclerotia germinated carpogenically with (2.5%) or without (11.5%) preconditioning. It must be noted in this connection that freshly harvested sclerotia were normally preconditioned at 4 C for 4 weeks to stimulate carpogenic germination (16). Myceliogenic germination of sclerotia with and without preconditioning was 35.5 and 70.5% on water agar and 81 and 93% on glucose agar, respectively. Both preconditioned and nonconditioned sclerotia scattered on the soil surface germinated myceliogenically. The conclusion is, therefore, that dormant mycelia in the infected seeds play an important role not only in dissemination of the fungus but also in epidemiology of the disease. Only disease-free seed should be planted in fields that are free from white mold infestation.

In Ontario, all commercial white bean seeds are treated with DCT (diazinon 6%, captan 18%, thiophanate-methyl 14%) for the control of bean anthracnose (5). This treatment was also found to be effective in preventing introduction of white mold into noninfested fields via infected seeds. Tests conducted in potted soil in the greenhouse showed that with DCT treatment, no sclerotia were produced and seeds that were not severely infected germinated and produced normal seedlings. The captan and thiophanate-methyl in the DCT are probably sufficient to control seedborne white mold.

Tolerant and resistant cultivars. *S. sclerotiorum* has a wide host range without known strain specificity in pathogenicity (15). Many researchers formerly believed that resistance to *S. sclerotiorum* did not exist. More recently, however, field resistance to this fungus was observed in several crops (15). In beans, some Great Northern and Black Turtle Soup varieties were reported to have intrinsic disease resistance that appears to be quantitatively inherited (14). Unfortunately, because commercial white beans have many specific traits that must be maintained, attempts to use these materials in breeding commercial white bean cultivars for white mold resistance have met with limited success. More recently, tolerance to white mold was discovered in the white bean ExRico 23 in Ontario (20).

In 1980, ExRico 23 was compared with Fleetwood, a cultivar of similar yield and maturity, in a field at Mitchell with a history of severe white mold. The results showed that ExRico 23 had a consistently lower disease incidence than Fleetwood (Table 1). White mold and yield loss were less in the short-row (5-m) plantings than in the long-row (30-m) plantings (Table 1). Also, whereas the initial disease incidence in ExRico 23 and Fleetwood on 5 August was the same, the progression of disease was considerably slower in ExRico 23 than in Fleetwood (Table 2).

A possible explanation for the resistance of ExRico 23 was found in experiments in which oxalic acid was supplied to plants (17). Oxalic acid is secreted by *S. sclerotiorum* during pathogenesis. ExRico 23 had higher cellular tolerance to oxalic acid than susceptible cultivars, such as Fleetwood.

In 1981, ExRico 23 was registered for commercial planting in Ontario. Growers were initially skeptical because ExRico

Table 1. Incidence of white mold and yield in white bean cultivars Fleetwood and ExRico 23 in short-row (5-m) and long-row (30-m) plantings, 1980

Plot type	Yield (kg/ha) Fleetwood	Yield (kg/ha) ExRico 23	White mold incidence[y] (%) Fleetwood	White mold incidence[y] (%) ExRico 23
Short-row planting	2,297 a[z]	2,937 b	67.3 a	16.7 a
Long-row planting	1,329 b	2,746 b	99.6 b	34.3 b

[y] Determined the week of 3 September.
[z] Means within a column followed by the same letter are not significantly different ($P>0.05$) according to Student's t test.

Table 2. Progression of incidence of white mold in white bean cultivars Fleetwood and ExRico 23 in short-row (5-m) and long-row (30-m) plantings, 1980

Plot type	Cultivar	White mold incidence (%) 5 Aug.	10 Aug.	20 Aug.	3 Sept.
Short-row planting	ExRico 23	1	1	2	16.7
	Fleetwood	3	7	35	68.0
Long-row planting	ExRico 23	1	2	6	34.3
	Fleetwood	3	13	75	100.0

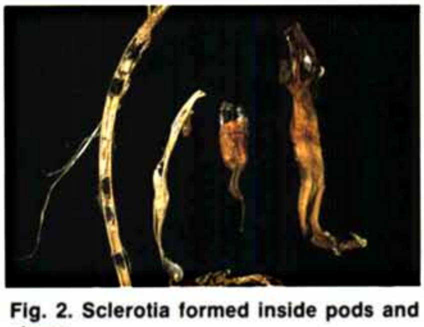

Fig. 2. Sclerotia formed inside pods and stems.

Fig. 3. Different degrees of infection of seeds from infected pods.

Fig. 4. Apothecia produced from sclerotia.

23 is a full-season cultivar requiring 98–101 days to mature. Growers were afraid that fall rain might impede the harvest. The skepticism proved to be unwarranted, however. Today, ExRico 23 is one of the most widely accepted cultivars in Ontario, and a large number of fields infested with *S. sclerotiorum* have been planted with this cultivar. Field tours conducted in 1986 and 1987 showed that incidence of white mold in Ontario fields averaged about 8 and 6%, respectively, and was substantially reduced from the incidence recorded in the 1978–1980 survey.

Most recently, Ontario bean breeders have released OAC Rico (3), Crestwood (J. W. Aylesworth, *personal communication*), and Centralia (11). All three were developed from crosses with ExRico 23. These cultivars show a high degree of field tolerance to white mold (Table 3). Several other new cultivars with ExRico 23 heredity are being developed.

In 1986, M. H. Dickson of New York, J. R. Steadman of Nebraska, and I collaborated in testing 10 highly resistant bean cultivars and lines from various parts of the world. Among them, MO162, Laureat, PI 165.787, A55, 8BP266, and Rabia de Gato appeared more resistant than ExRico 23 in Ontario fields. Unfortunately, except for ExRico 23, OAC Rico, Crestwood, and Centralia, these cultivars are either colored bean or non-navy bean types. Nevertheless, further research into the genetics of these resistant cultivars and lines should be beneficial to the practical breeding of white beans resistant to white mold.

Table 3. Incidence of white mold[x] among some currently recommended Ontario cultivars

Cultivar	White mold incidence[y] (%)
Mitchell	15
Crestwood[z]	12
Centralia[z]	2
Midland	22
Westland	20
Kentwood	21
Suncrest	19
Dresden	13
ExRico 23	9
OAC Rico[z]	11
Harofleet	25

[x] Determined in mid-August at seven official Ontario field bean trial sites, where beans were planted in 4.8-m rows 75 cm apart, 18 seeds per meter.
[y] Three-year average over five tests except for cvs. Mitchell, Suncrest, and Dresden (three tests) and Centralia (two tests).
[z] Developed from crosses with ExRico 23.

Row width and plant density. The introduction of resistant cultivars may permit growers to reduce row widths in order to increase bean yields. Although row width and plant density are correlated with the incidence of white mold, their effects on resistant cultivars had not been determined. A 3-year (1982–1984) field study was conducted to ascertain these effects, using Fleetwood (susceptible) and ExRico 23 (tolerant), cultivars with similar growth habits, maturity dates, and yields. In the absence of fungicidal sprays and at a constant plant population, the narrower the row width, the higher the incidence of white mold (Table 4). This response was very apparent in susceptible Fleetwood but less so in tolerant ExRico 23. For ExRico 23, a notable increase in the incidence of white mold occurred only at the narrowest row width (20 cm). When plants were sprayed with a fungicide (benomyl 50WP, 2.2 kg a.i/ha), the average yield increase was approximately 6% over all row widths. This amount of return would not compensate for the cost of the spray.

Table 4. Effects of different row widths on incidence of white mold and yield in white bean cultivars Fleetwood and ExRico 23 over 3 years (1982–1984) at constant plant density[x]

Cultivar	Row width (cm)	White mold incidence[y] (%)	Yield[z] (g)
Fleetwood	20	37	486
	40	30	675
	60	22	881
	80	29	738
ExRico 23	20	17	593
	40	8	738
	60	6	1,025
	80	10	958

[x] At 96 seeds per 4.8-m row, or 384 seeds per four-row plot.
[y] Determined on or around 30 August of each year.
[z] Dry beans per 11.76 m^2 based on 18% moisture content in beans.

Reductions in row width accompanied by increases in plant population magnified the effect of row width on the incidence of white mold (Table 5). As a result of the increasing incidence of white mold, yield of the susceptible cultivar Fleetwood did not increase as seeding rate increased from 384 to 1,536 seeds per plot. In contrast, the tolerant cultivar ExRico 23 showed a substantial increase in yield (from 1,053 to 1,274 g per plot) when row width was reduced from 80 to 60 cm, with no significant increase in white mold incidence.

When plants were sprayed with benomyl, increases in yield were less than 5% at 60- and 80-cm row widths and approximately 15% at 20- and 40-cm row widths. The latter increases in yield barely compensated for the cost of the spray. Unfortunately, high seeding rates are impractical and costly. At present, the cost-return ratio makes chemical sprays uneconomical regardless of cultivar and row width used.

Conclusions

White mold of white bean in Ontario is controlled by a combination of seed treatment and use of resistant cultivars. Seed treatment has prevented the introduction of seedborne white mold to disease-free fields. The selection and introduction of the tolerant cultivar ExRico 23 and subsequent backcross breeding have resulted in the licensing of several high-yielding cultivars, such as Crestwood and Centralia, that are resistant to white mold. Chemical sprays are not an economical alternative control measure.

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Table 5. Effects of different row widths and seeding rates on incidence of white mold and yield in white bean cultivars Fleetwood and ExRico 23 over 3 years (1982–1984)

Cultivar	Row width (cm)	Seed/plot[x]	White mold incidence[y] (%)	Yield[z] (g)
Fleetwood	20	1,536	47	1,050
	40	768	35	961
	60	512	27	978
	80	384	25	989
ExRico 23	20	1,536	20	1,274
	40	768	14	1,304
	60	512	8	1,236
	80	384	10	1,053

[x] At 96 seeds per 4.8-m row, with seeds per 3.2 × 4.8 m plot varying according to number of rows planted.
[y] Determined on or around 30 August of each year.
[z] Dry beans per 11.76 m^2 based on 18% moisture content in beans.

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