Symposium on Sclerotinia

Control of Plant Diseases Caused by *Sclerotinia* Species

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Published with the approval of the Director as Journal Series Paper 5623, of the Nebraska Agricultural Experiment Station. The work reported was conducted under Nebraska Agricultural Experiment Station Project 21-15.

Most diseases caused by *Sclerotinia minor, S. sclerotiorum,* and *S. trifoliorum* have not been controlled consistently and economically. The explosive pathogenicity of these fungi under favorable conditions and the ability of their sclerotia to withstand adverse conditions allow them to be successful pathogens on many crops. Methods of control that have met with varying degrees of success include: protectant chemicals, materials that inhibit germination or destroy sclerotia, and cultural practices such as crop rotation, sanitation, and reduced irrigation. Other control methods, still under investigation and not widely used, include: sclerotium parasites, resistant or tolerant cultivars, and microclimate modification.

CHEMICAL CONTROL

Foliar protectants. As with the prevention of most diseases, chemicals to control those caused by *Sclerotinia* spp. must be applied before infection occurs. Because many Sclerotinia diseases are initiated by colonization of senescent plant organs, the fungicide must be applied to prevent colonization of these organs. For crops such as lettuce, in which *S. minor* is the major pathogen, myceliogenic germination of sclerotia causes direct infection. Thus, soil surface coverage near the plant and timing of fungicide application are the most important factors in obtaining control (24). The necessity for fungicide coverage at the soil-plant interface is well documented and even the use of black plastic mulch placed over the soil and under the lettuce leaves decreases *S. minor* infection (17). Benomyl (methyl 1-[butylcarbamoyl]-2-benzimidazole-carbamate), PCNB (pentachloronitrobenzene), and DCNA (2,6-dichloro-4-nitroaniline) were partially effective in California when applied as a single spray immediately after thinning (24). In contrast, in Florida and New Jersey, multiple applications of benomyl or DCNA are recommended every 10–14 days after transplanting to minimize lettuce drop. The reason for this difference in number of spray applications needed for control is not known. The method of spray application used in California may be superior to that used in other lettuce-growing areas. Also, although *S. minor* may be the major pathogen in lettuce as it is in California, *S. sclerotiorum* could be contributing ascosporic inoculum in Florida and New Jersey, and this would necessitate multiple sprays for adequate protection.

The growth habit or canopy density of a crop may influence the effectiveness of aerial application of fungicides against *S. sclerotiorum.* Gabrielson et al (14) reported that cabbage seed crops can be protected with benomyl if stem surface coverage of the upright open canopy is adequate. These workers also referred to unpublished work of Gabrielson indicating that poor deposition of benomyl on the lower portions of bean plants may be due to the vigorous viny growth and thus responsible for lack of control. In Florida, an aerial application of benomyl combined with an earlier ground spray and an in-furrow treatment at planting gave excellent control of white mold on pole beans, which have a more upright open canopy (R. T. McMillan, *personal communication*).

The relationship of inoculum density in the field and fungicidal control is demonstrated by the results of Gabrielson et al on cabbage discussed above and those of Letham et al (23) on cauliflower, a similar type of crop. Letham et al found that ground application of benomyl gave poor control of Sclerotinia rot in a plot with 20–40 apothecia per square meter. Gabrielson et al, who found no apothecia in their plot, achieved excellent control with aerial application of benomyl, although aerial infection was evident. Letham et al explained the lack of control by inadequate fungicide coverage with ground sprays; however, it seems unlikely that aerial application would give better coverage than ground sprays, especially near the soil. Thus, the lack of control with ground sprays seems to reflect the differences in inoculum density.

Efficacy of fungicidal control of white mold of beans is determined by coverage of blossoms with a chemical such as benomyl. Hunter et al (20) found that if the whole plant or only bean blossoms were sprayed with benomyl, effective control

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resulted when plants subsequently were inoculated with a suspension of *S. sclerotiorum* ascospores. On the other hand, if all aboveground plant parts except blossoms were covered with benomyl, no control was achieved. Erratic control by benomyl could result, however, from inadequate blossom coverage because of indeterminate flowering and growth habit and/or location and frequency of inoculum production. Snap beans have a determinate growth and flowering habit and need protective fungicide coverage for about 2 wk after flowering. Dry edible beans are indeterminate and produce blossoms for at least 4 wk after initial flowering. In Nebraska, when two applications of benomyl were made to dry edible beans at first bloom and 7 days later, and just before canopy coverage precluded further ground applications, residues were detected on or in blossoms by a bioassay technique for only 2 wk after the last spray (Steadman, *unpublished*). In the test location, apothecia were found both within (an average of 10–34 apothecia/m^2) and outside (an average of 5–15 apothecia/m^2) irrigated bean fields from 2 wk after first bloom to near harvest (31). Thus, erratic control in Nebraksa compared with consistent control in New York may reflect the difficulty in protecting indeterminate bean cultivars that produce flowers (potential infection sites) until maturity and during a period when inoculum production is intense. Where chemical control has been effective, timely blossom coverage probably has been achieved.

Seed treatment. Seed treatment is advocated to control Sclerotinia foot rot of sunflower and to eliminate Sclerotinia from infested rapeseed (4). However, benefits of seed treatment are questionable because of the low incidence of disease resulting from sunflower (4) or bean seed (33) inoculum.

Sclerotial germination inhibitors and soil disinfectants. Many diverse compounds inhibited germination of sclerotia of *Sclerotinia* spp. in laboratory or greenhouse tests (35). Materials such as methyl bromide or formaldehyde were effective preplant treatments for destroying sclerotia in the soil (4). Cyanamide, although no longer manufactured in the USA, and expensive when imported, has been widely reported to prevent sclerotial germination and subsequent ascospore production. Gabrielson et al (14) reported significant reduction of *S. sclerotiorum* infection in cabbage seed plants with a single ground application of 1,123 kg/ha cyanamide. The treatment provided control even when plots were located within 30 m of untreated infested areas. These results indicate that most ascospore dispersal was from within the treated field. In many cases, however, airborne ascospores originating from outside the treated area will nullify any disease control conferred by germination inhibitor treatments. In Germany, experiments designed to study the efficacy of soil applications of PCNB for control of Sclerotinia on rape were confounded by aerial inoculum from outside the treated areas. Even in the absence of aerial spore showers, furrow-irrigated disinfested fields can be reinfested by sclerotia or ascospores in reused irrigation runoff water. In dry edible beans, application of PCNB resulted in a reduction of apothecial inoculum produced within the same filed, but there was no concomitant reduction in disease or yield increase. Use of soil fumigants not only has been ineffective in controlling diseases caused by *S. sclerotiorum*, but Partyka and Mai (28) reported that fumigation with dichloropropene-containing compounds actually increased the incidence of lettuce drop. Where lettuce drop is caused by *S. minor*, methyl bromide, as a result of its destruction of inoculum, could reduce disease.

A recent study of Sclerotinia disease of greenhouse-grown eggplant and cucumber demonstrated disease control by the use of a light filter that inhibited apothecial development. Covering the plants with UV-absorbing vinyl film (lower limit of transmission, 390 nm) reduced the total number of apothecia when compared with covering plants with common agricultural vinyl film (lower limit of transmission, 300 nm). Disease also was reduced under UV-absorbing vinyl film. This technique has great promise for greenhouse crops where ascospores produced within the house initiate infection, but it would be impractical for use on a field-grown crop (18).

In most crops one application of a fungicide such as benomyl, DCNA, or PCNB can be economical if disease reduction is satisfactory. For example, in Nebraska bean fields, losses due to *S. sclerotiorum* averaged 13% over 4 yr (21). This would result in a $100/ha loss at the present price of beans and would be slightly more than twice the estimated cost of a fungicide application. In lettuce, a 5% incidence of lettuce drop was estimated to result in a $185/ha loss (24), and this level of disease would make multiple fungicide applications economically feasible if control was achieved. In New York, in addition to direct losses in the field, detection of more than 2% snap bean pod infection can result in rejection of the entire truckload at the processing plant (1). In this instance, chemical control may be very critical. In all cases, chemical applications must precede the onset of disease, and if epidemics could be predicted, the expense of routine fungicide applications could be obviated or reduced. Haas and Bolwyn (16) reported some guidelines for predicting white mold epidemics in navy bean fields. However, 44% of randomly chosen fields and 60% of predicted fields had the disease. In another attempt at forecasting, numbers of sclerotia (inoculum potential) in bean fields were not correlated with epidemic potential (31). With airborne and waterborne inoculum available and microclimate as well as macroclimate regulating disease development, the factors that limit or prevent infection need to be determined for each crop production area.

In addition to economical considerations, repeated applications of specific chemicals within a growing season or a succession of growing seasons may select for a fungicide-tolerant strain of the fungus. Such a selection or mutant has not been reported for *S. minor*, *S. sclerotiorum*, or *S. trifoliorum*, but fungicide tolerance has occurred in other fungi and could develop sooner or later in *Sclerotinia* spp.

BIOLOGICAL CONTROL

At least 30 species of fungi and bacteria as well as insects and other organisms have been reported to be parasites or antagonists of *Sclerotinia* spp. In most instances, although these organisms have been associated with sclerotia of *Sclerotinia* spp., their parasitic nature has not been assessed. Also, most reports have been based on laboratory observations or tests, and little information is available on their activity and effectiveness under natural or field situations. *Coniothyrium minitans* and *Trichoderma* spp. are the only parasites that have been studied to any extent, and Huang and Hoes (19) indicated that *C. minitans* could effectively control the population of *S. sclerotiorum* in sunflower fields. Turner and Tribe (37) reported that up to 65% of sclerotia of *S. trifoliorum* were destroyed in field soil by application of a pycnidial dust preparation of *C. minitans*; however, disease control studies were not attempted. P. B. Adams (*personal communication*) found three mycoparasites of *S. sclerotiorum* that appear to be involved in the natural destruction of sclerotia in soil. The potential for biological control of Sclerotinia diseases exists; however, at present, no practical recommendations are available.

CULTURAL MODIFICATIONS

Crop rotation. Crop rotation is a disease-control recommendation and often has been advocated for control of Sclerotinia diseases. However, sclerotia survive in the soil at least 3 yr and tillage operations generally assure the presence of sclerotia at or near the soil surface (9). In Nebraska, sclerotial populations were comparable in all fields sampled in various crop rotations despite differences in occurrence of the host in the previous crop history (31). In addition, apothecia were found in fields of nonhost crops. This would assure that airborne or irrigation-waterborne ascospore dissemination could occur. Although not effective for control of Sclerotinia diseases caused by the large-sclerotia types, crop rotation is a necessary practice for minimizing many other plant diseases and should be used. Also, crop rotation may be more effective on *S. minor* that infects from sclerotia rather than from ascospores. Deep plowing also has been recommended for control of white mold of bean, but plowing to a depth of 25 cm did not affect disease severity in Nebraska (9). Thus, it may not be a valid general recommendation.

Sanitation. Any method that reduces sclerotial inoculum could contribute to a control program, but as with chemical soil treatments, reinfestation possibilities always exist and reduction of sclerotial numbers per se in a field may not lead to control. Sclerotia sometimes are harvested along with sunflower, pea, bean, or other seeds; the use of certified seed will reduce chances of introduction of the pathogens into clean fields. Redistribution of inoculum in infested bean straw, cull seeds, or other residue into fields should be avoided.

Moisture regulation. Moore (25) reported that flooding a field continuously for 23–45 days or cycles of alternate flooding and drying led to destruction of sclerotia of *S. sclerotiorum* and reduced disease in Florida. However, this technique would have only limited usefulness in most nonirrigated areas. Smith (36) found that sclerotia of *S. sclerotiorum* and *S. minor*, when dried for short periods and remoistened in soil, leaked nutrients, were rapidly colonized by microorganisms, and decayed in 2–3 wk. Although the implications for disease control were obvious, sclerotia had to lose 90% of their moisture before survival was affected. It would be difficult to reduce moisture in field soil enough to allow sclerotia to lose that amount of water. Furthermore, drying of *S. minor* stimulates mycelial germination (36); thus, infection may be increased. For irrigated crops such as lettuce, there is usually less drop if beds are made higher to provide for rapid drainage of water (R. G. Grogan, *personal communication*). Reduction in the number of irrigations, especially those at the end of the season, can reduce disease in the absence of rainfall. However, reducing irrigation often results in a decrease in yield in dry edible beans. Thus, the final irrigation should not be eliminated unless the disease is present in the field or disease potential is great. Studies have been conducted over the past 3 yr in Nebraska on irrigation frequency and white mold disease development. Results from these studies (8,31) showed that both apothecium production and disease severity were reduced by less frequent irrigation of a Great Northern bean cultivar. Yield increases at the lower water rates were correlated with lower disease severity. Elimination of reuse of surface irrigation runoff water can reduce the chances of spreading sclerotia, mycelia, or ascospores from one field to another. However, recent Environmental Protection Agency regulations require reuse of irrigation runoff water. Research on the treatment of reuse water to eliminate plant pathogenic microorganism contamination indicates that when combined with filtration and sedimentation, chlorine (as hypochlorite) can be effective on ascospores (Steadman, *unpublished*). Sclerotia are not killed, however, and chlorine treatment may not be economical.

Microclimate modification. An association between plant canopy development and Sclerotinia disease incidence and severity has been observed in various crops. Susceptible lettuce cultivars produced a canopy that created a favorable microclimate and also provided senescent leaf tissue for infection by *S. minor* (17), although it also can attack from below ground (24). Similarly, the effects of row spacing, growth habit, and plant density on bean and potato canopy development, disease incidence, and severity were reported in Nebraska (10,34) and New York (29), respectively. A study comparing the microclimates of two dry edible bean canopy types in a semiarid region revealed that the vigorous viny cultivar produced the most dense canopy and when irrigated heavily was the coolest and wettest and had the highest disease severity (8). In another study comparing growth habit and flowering of bean cultivars, white mold severity was not always correlated with frequency or pattern of colonizable sites (blossoms). Canopy structures, and more specifically, distribution of leaf area near the ground in terms of leaf area × dry weight/height, affected white mold incidence and severity (32). The growth habit (ie, determinate or indeterminate) did not exclusively influence infection. Upright indeterminate and open bush types also resulted in reduced production of apothecia as compared with that under dense compact bush or vine types (32).

Several methods for modification of canopy structure can influence Sclerotinia diseases. A growth regulator, TIBA (2,3,5-triiodobenzoic acid), caused reduced bean stem internode elongation and a compact dense plant that had severe white mold (10). Pruning "runners" did not reduce white mold, but growth of beans on a trellis (10) and wide row spacing (34) reduced canopy density and white mold disease. When the bean cultivar Aurora and cultivars of Great Northern type were grown at a within-row spacing of 30.5 cm, both were equally susceptible to *S. sclerotiorum*. However, at a spacing of 4.5 cm, Aurora had less disease symptoms than did the Great Northern cultivars (12). Bennett and Elliot (7) reported differences in incidence and severity of forage crown rot caused by *S. trifoliorum* on north- and south-facing slopes. Similarly, Haas and Bolwyn (16) indicated effects of row orientation on bean white mold severity in Canada.

Some determinate bean types had less white mold than most common Great Northern and Pinto cultivars. A study was conducted in Nebraska to determine whether white mold was reduced and bean yields increased by blending determinate with indeterminate cultivars (11). The indeterminate plants in the blend, however, were affected by white mold when conditions were very favorable for disease development even though apothecial production was less than when the indeterminate type was planted alone. The inoculum apparently was not reduced below a critical threshold level, or alternatively, outside ascospore inoculum nullified any affects. Under less favorable conditions for disease, some reduction of infection was obtained in the blend, but no concomitant yield response was observed.

DISEASE RESISTANCE

S. sclerotiorum has an extremely wide host range. In addition, strain specificity in regard to pathogenicity to various hosts has not been reported. The dearth of reports before 1968 indicates that many researchers formerly accepted the idea that resistance to *S. sclerotiorum* did not exist. Field resistance to *S. minor* was found in red and white clover (5) and alfalfa (13). Escape from *S. sclerotiorum* infection due to type of growth habit was reported in lettuce (26), sunflower (22), and bean, as discussed. Differences in susceptibility of cultivars, breeding lines, and plant introductions were noted in soybean (15), peanut (30), and sunflower (27). Orellana (27) reported that tolerance of sunflower was attributable to enhanced growth and lignification of host tissue in response to long-day treatment.

Genetic resistance to *S. sclerotiorum* was observed first by Anton de Bary in 1887 when he found that *Phaseolus multiflorus* (*P. coccineus*) was seldom attacked whereas *P. vulgaris* (common bean) cultivars were destroyed by the fungus. Adams et al in 1973 (3) confirmed that *P. coccineus* (scarlet runner bean) is resistant; they inoculated bean stems with mycelial inoculum and incubated in a greenhouse. Abawi et al in 1975 (2) also reported resistance in *P. coccineus* and *P. coccineus* × *P. vulgaris* hybrids; they inoculated with ascospores at time of flowering and incubated the plants in a growth chamber at conditions optimum for disease development. These workers reported that all *P. vulgaris* accessions were relatively susceptible. In irrigated bean nurseries, however, Anderson et al (6) and Coyne et al (12) identified *P. vulgaris* cultivars with resistance or tolerance that was not due entirely to maturity or disease avoidance mechanisms (11). Thus, in *P. vulgaris*, inherent and architectural escape-type of resistances exist that can be used in breeding for resistance to white mold.

Inheritance of resistance in bean to *S. sclerotiorum* was studied in Nebraska (11) and New York (2). In the *P. vulgaris* crosses of resistant Black Turtle Soup × Great Northern cultivars and lines, heritability of the disease reaction was low. Thus, selection for disease resistance would be more effective in later generations. Although late maturity was linked with resistance, moderately early maturing, resistant recombinants were identified. From limited populations of *P. vulgaris* × *P. coccineus*, B-3749, Abawi (2) found that resistance appeared to be controlled by a single dominant gene. Breeding strategy for *P. vulgaris* recommended by Coyne et al (11) would be to combine a high level of inherent resistance with architectural disease escape mechanisms. Yield trials of advanced lines have not been conducted in Nebraska.

However, Abawi (2) was able to transfer resistance to *S. sclerotiorum* through several backcross generations in snap bean (*P. vulgaris*).

CONCLUSIONS

The control method(s) chosen to combat Sclerotinia diseases depends on the crop. In high cash value crops such as lettuce, tomato, peanuts, and other vegetables, chemical control may be feasible. However, the high cost and threat of development of fungicide-resistance strains of the pathogen indicate that cultural practices or resistance should be investigated. Tolerant peanut and clover cultivars are available. Because of year-to-year and field-to-field variation in disease severity in field crops such as rape, sunflower, dry edible bean, and forage, use of routine chemical control may be uneconomical unless a forecasting system is devised. Cultural practice modifications can reduce disease in most crops but often are not compatible with high yield, especially in semiarid irrigated areas. Resistance and microclimate modification appear to be the most useful control measures for field crops, utilizing chemical control where high disease pressure is expected. Effective and practical biological control of Sclerotinia diseases remains to be developed.

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