Stability of *Microsphaera diffusa* and the Effect of Powdery Mildew on Yield of Soybean

D. V. PHILLIPS, Department of Plant Pathology, Georgia Experiment Station, Experiment 30212

ABSTRACT

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Reactions of soybean cultivars to powdery mildew caused by *Microsphaera diffusa* collected in 1973, 1979, and 1982 were compared. There was no indication of any change in the strain of *M. diffusa* found in Georgia during this 9-yr period despite extensive planting of resistant cultivars and regular occurrence of the sexual stage of this fungus. A close negative correlation between powdery mildew rating and yield during one season indicated that yields in untreated control plots were 35% less than in plots where powdery mildew was controlled with fungicides. There was no significant difference between the yield of treated and control plots in three other years. During a 4-yr period when powdery mildew ranged from moderate to very severe, the powdery mildew ratings of plots treated with benomyl, chlorothalonil, or thiabendazole at registered rates and intervals of application were significantly reduced but yields of these plots were not increased. Comparisons of weather conditions with disease severity during a 5-yr period indicated that high humidity, moderate rainfall, and low temperature were most favorable for disease development. Blue lupine appears to be a more favorable host than soybean for development of cleistothecia of *M. diffusa*.

Additional key words: *Glycine max, Lupinus angustifolius*

In the past several years, powdery mildew of soybean (*Glycine max* (L.) Merr.), caused by *Microsphaera diffusa* Cke. & Pk., has been reported from several areas of North America (1,3–5, 11,13,15). In many of these areas, an outbreak in the field is unusual (1,11,13), but in parts of the southeastern United States, it has occurred frequently for many years (4,15,21).

The disease has become a problem more recently in Iowa (5,7,8), where 50% of the acreage in some areas is planted with susceptible cultivars (8). In Georgia, however, less than 10% of the acreage is planted with powdery mildew-susceptible cultivars (10).

Plant breeders in the Southeast have apparently selected against susceptibility to powdery mildew. As a result, there are very few widely planted susceptible cultivars in the Southeast despite the fact that nearly all have susceptible cultivars in their parentage (12). In the Midwest, where powdery mildew has been present for only a few years, a high percentage of the cultivars are susceptible (1,6,11).

The fact that selection has been effective in eliminating susceptible cultivars suggests that there has not been a proliferation of pathogenic races of *M. diffusa*. Arny et al (1) reported cultivar reactions in Wisconsin similar to those of Buzzell and Haas (3) in Ontario, where cultivar reactions observed in 1978 were identical to those of Lehman in 1947 from North Carolina (15). Grau and Laurence (11), however, reported that some cultivars reacted differently to different isolates, suggesting the presence of more than one pathogenic race.

Yield losses resulting from powdery mildew have been substantial (7,8,18,21). If new races of the pathogen attack resistant cultivars, control of powdery mildew with one of the several registered fungicides might be an alternative control.

The objectives of this research were to determine if there was any change in the pathogenic races of *M. diffusa* in Georgia, to evaluate the possibility of chemical control, and to estimate yield losses from powdery mildew.

MATERIALS AND METHODS

Forty soybean cultivars, including 11 tested in 1973 (4), were planted in a greenhouse in late summer of 1979 and inoculated by shaking conidia from diseased plants collected in the field over 4-wk-old plants. Four replicates of two or three plants each were inoculated for each cultivar. The same procedure was repeated with 39 cultivars, using inoculum from plants collected in the field in 1982. Cultivars were rated as resistant if mycelial development and sporulation were sparce and as susceptible if mycelium developed extensively and conidia were abundant. Ratings were made 4 wk after inoculation.

In field experiments, the highly susceptible cultivar Hampton 266A was planted between 14 and 29 May of each year (1974–1978). All experiments were arranged in randomized complete blocks with four replicates. Fungicides were applied in 187 L of water per hectare with a plot sprayer equipped with three nozzles per row operating at 4.9–5.3 kg/cm^2. The nozzles were suspended from an adjustable, tractor-mounted boom that could cover the four-row, 15-m-long plots without driving the tractor in the plot area. All data were taken on the interior two rows. One to three applications of fungicides were applied between early flowering and 6 wk after initial pod set, with most applications made at late flowering to early pod set and again 2–3 wk later (R_3 and R_5 as outlined by Fehr et al [9]). Fungicides and rates (active ingredients) used were benomyl, 140–560 g/ha; captafol, 560–3,360 g/ha; pyrazophos, 1,120 g/ha; mancozeb 1,795–3,585 g/ha; thiabendazole, 200–535 g/ha; fentin hydroxide, 140–560 g/ha; thiophanate methyl, 195–785 g/ha; chlorothalonil, 875–2,045 g/ha; several mixtures containing sulfur; several experimental fungicides; and combinations of fungicides.

Yield increases from fungicides that could not be related to control of specific diseases have been observed in Georgia (20). To determine if this was happening at the test sites, a cultivar highly resistant to powdery mildew was planted adjacent to the susceptible Hampton 266A each year, and some, but not all, of the fungicide treatments were applied to the mildew-resistant cultivar. The resistant cultivars were Dare (1974), Bragg (1975 and 1978), and Coker 136 (1976 and 1977).

Each of four replicate plots was rated for powdery mildew severity at the late R_6 growth stage (9). Plants in each plot were assigned a rating from 0 = no powdery mildew to 5 = entire plot heavily and uniformly covered with powdery mildew. After maturity, the plants were harvested with a small-plot combine, the seed cleaned, and weight and percent moisture determined. All yields are reported on the basis of 13% moisture. Temperature and rainfall records were from a weather station less than 2 km from the test site and relative humidity records were from a station about 60 km away.

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To determine if powdery mildew inoculum from blue lupine would infect soybean and if that from soybean would infect blue lupine, bitter blue lupine (*Lupinus angustifolius* L.) and Hampton 266A soybean were planted in steam-pasteurized soil in a greenhouse free of powdery mildew. When the plants were 4 wk old, 10 replicates of two or three plants each of soybean were inoculated by shaking heavily infected blue lupine plants over the test plants. Uninoculated control plants were maintained in a separate section of the same greenhouse. In another greenhouse, the same procedure was used to inoculate blue lupine with inoculum from soybean.

A similar procedure was used to determine the relative abundance of cleistothecial development, except all plants were inoculated with inoculum from soybean and both blue lupine and soybean were kept on the same greenhouse bench. Plants were observed for cleistothecial development until the soybeans matured.

RESULTS AND DISCUSSION

Reactions of soybean cultivars of maturity groups V–VIII to *M. diffusa* collected in Georgia in 1979 and 1982 were as follows. Resistant: Bedford, Bienville, Bragg, Braxton, Cobb, Coker 136, CNS, Dare, Davis, Duocrop, Forrest, Ga Soy 17, Haberlandt, Hardee, Hill, Hood, Hood 75, Hutton, Improved Pelican, Jackson, Laredo, Lee, Lee 74, Majos, McNair 800, Palmetto, Patoka, PI 54610, Pickett, Roanoke, Semmes, S-100, Tanner, Tracy, Volstate, Wright, and Yelredo. Susceptible: Arksoy, Clemson, Coker 338, Dorman, Hale 7, Hampton 266A, Mammoth Yellow, Ogden, Ransom, Tokyo, and Essex. Cultivars Bragg, Cobb, Davis, Hardee, Hutton, Jackson, McNair 800, Hale 7, Hampton 266A, Ransom, and Essex tested with the same reaction in 1973 in Georgia by Demski and Phillips (4). Bienville, Coker 136, Hood 75, Lee 74, McNair 800, Pickett, Semmes, Hale 7, and Essex were not tested in 1982. Duocrop, Improved Pelican, Palmetto, Patoka, PI 54610, Clemson, Dorman, and Mammoth Yellow were not tested in 1979. Cultivar Clemson had both resistant and susceptible plants in the same seed lot. Reactions of 11 cultivars from the 1973 greenhouse test were the same as reactions to the 1979 inoculum, including Essex, which was intermediate between the highly resistant cultivars and the highly susceptible Hale 7, Ransom, and Hampton 266A. Essex has recently been reported to be infected in the field in Delaware (13). Eight of these cultivars were also included in the 39 tested with the 1982 inoculum, and all reacted as they did in 1973 and 1979. The 32 cultivars that were tested with both the 1979 and 1982 inoculum all gave the same reaction to both. Thus there was no evidence that the strain of the pathogen present in 1982 was any different from that present in 1973 and 1979.

The continuing resistance of the cultivars Lee, Bragg, and Davis (released in 1954, 1963, and 1965, respectively), despite being extensively planted throughout the southern United States, also indicates that this pathogen may be relatively stable.

It is fortunate that strains of *M. diffusa* capable of attacking these resistant cultivars have not developed, because 5 yr of tests indicate that control of powdery mildew with fungicides is probably not a competitive alternative. In one of the 5 yr (1978), the weather was hot and dry and disease development was too light and scattered to evaluate the fungicide treatments. From 1974 through 1977, powdery mildew developed uniformly throughout the test site and was rated from moderate to very heavy (Table 1) on the basis of the disease ratings of untreated control plots. Disease ratings were reduced to low levels (below 1.0) by at least one fungicide each year except 1975, when the heaviest mildew development occurred. No more than two applications of any fungicide were made that year and the lowest mean disease rating was 2.5.

Dunleavy kept susceptible cultivars free of powdery mildew by weekly applications of benomyl (7,8). In this study, good control was obtained each year except 1975 by two or three applications of a fungicide; however, in all years except 1974, the best control was obtained by a fungicide or combination of fungicides at rates and application intervals not registered for use on soybeans. Fungicides applied according to the label were considerably less effective in mildew control each year except 1974, when mildew severity was rated moderate (Table 1). Therefore, fungicide treatments available to growers were not highly effective against powdery mildew when conditions favored heavy disease development.

In the 4 yr (1974 through 1977) when powdery mildew was severe (rated 3–5, Table 1), there was a close negative relationship ($r = -0.81$) between powdery mildew severity and yield only in 1976 (Fig. 1). When the disease ratings were made (late R_6) in 1976, other foliar

Table 1. Powdery mildew severity ratings, temperature, rainfall, and relative humidity during September of 1974 through 1978

Variables	Year 1974	1975	1976	1977	1978
Powdery mildew severity	Moderate	Very heavy	Heavy	Heavy	Very light
Mean disease rating of untreated plots[a]	3.0	5.0	3.8	4.3	...[b]
Lowest mean rating with a fungicide at any rate or interval of application[a]	0.2	2.5	0.3	0.5	...
Lowest mean rating with a fungicide at labeled rates and intervals of application[a]	0.2	3.8	2.0	2.5	...
No. of days of rain[c]	8	7	9	7	1
No. of days of relative humidity[d] above					
99%	3	10	9	3	2
95%	5	19	12	15	10
90%	13	23	20	23	15
Mean temperature departure from normal (degrees C)	−2.0	−0.6	−1.6	+0.2	+0.7

[a]Rating scale: 0 = no powdery mildew to 5 = entire plot heavily and uniformly covered with powdery mildew.
[b]Powdery mildew very light and scattered, so numerical ratings not made.
[c]Rainfall of 2.5 mm or more recorded.
[d]Recorded every 3 hr; relative humidity higher than the indicated percentage for periods shorter than 3 hr might not have been detected.

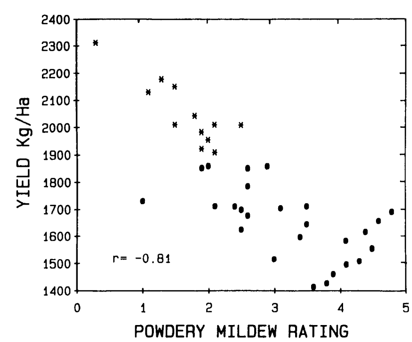

Fig. 1. Relationship between yield and powdery mildew severity on Hampton 266A soybeans at Experiment, GA, in 1976. Each point is the mean of four replicate plots that received two or three applications of a fungicide or a combination of fungicides (fungicides and rates listed in text). * = Yield was significantly higher ($P = 0.05$) than the untreated control; • = yield was not significantly higher than the control.

Table 2. Influence of fungicides applied at labeled rates and intervals on powdery mildew and yield of soybean cultivars resistant or susceptible to powdery mildew

	1974–1977 Average		
	Susceptible[v]		Resistant[w]
Treatment	Yield (kg/ha)	Powdery mildew rating[x]	Yield (kg/ha)
Control	1,734 a[y]	4.0 a	2,527 a
Thiabendazole	1,882 a	2.9 b	2,521 a
Benomyl	1,983 a	2.4 b	2,709[z]
Chlorothalonil	1,869 a	2.7 b	2,588[z]

[v] Cultivar Hampton 266A.

[w] Cultivars Dare (1974), Bragg (1975), and Coker 136 (1976 and 1977).

[x] Rating scale: 0 = no powdery mildew to 5 = entire plot heavily and uniformly covered with powdery mildew.

[y] Numbers in a column followed by the same letter are not significantly different ($P = 0.05$) according to Duncan's new multiple range test.

[z] Benomyl was not included on the resistant cultivar in 1974 and chlorothalonil was not included in 1976. The appropriate mean control yield was 2,621 kg/ha (for comparison with benomyl) and 2,480 kg/ha (for comparison with chlorothalonil). Neither difference is significant ($P = 0.05$).

diseases were present in no more than trace amounts and none of the treatments increased yield when applied to a powdery mildew-resistant cultivar growing nearby. A pod and stem blight severity rating (20) made at maturity indicated no significant difference between fungicide-treated and control plots. Thus, the difference in yield between fungicide-treated and control plots appears to be due to powdery mildew.

In 1974, 1975, and 1977, powdery mildew was reduced significantly by some fungicide treatments but there were no significant differences between the yields of treated and control plots in those years.

Although several treatments increased yields significantly in 1976 (Fig. 1), only one of these was a registered fungicide used according to the label. Chlorothalonil (1,260 g/ha) applied three times produced a yield of 2,009 kg/ha compared with the control yield of 1,485 kg/ha. However, none of the registered fungicides applied at rates and intervals consistent with the label produced a significant yield increase during a 4-yr period (Table 2). All three fungicides (Table 2) significantly lowered disease but apparently not enough to produce a yield increase.

Dunleavy (7,8) reported differences averaging 10 and 13% (maximum difference of 26%) between untreated plots and those receiving weekly fungicide applications. In 1976, the most effective treatment (DPX 110 [benomyl + sulfur] applied three times) reduced the powdery mildew rating from 3.8 to 0.3, and the yield of the untreated control was 35% lower than that of the treated plots. In 1977, however, the most effective treatment (EL 222) reduced the mildew rating from 4.3 to 0.5 but did not increase yield significantly. In 1975, triphenyltin hydroxide reduced the mildew rating from 5.0 to 2.5 without a significant yield increase, and in 1974, benomyl reduced the disease rating from 3.0 to 0.2 without a significant yield increase. Powdery mildew can cause serious yield reductions (7,8,19,21), but it can apparently also be present and cause little yield loss.

Powdery mildew was first detected during late August each year and reached its maximum level by the end of September. Development of powdery mildews in general is often considered to be inhibited by high rainfall or high temperature and aided by high humidity and low temperature (2,23–26). Comparisons of mildew development with weather conditions in September during 5 yr (Table 2) indicate that high humidity and temperatures near or below normal were common in years of extensive disease development. It appears that a moderate amount of rainfall did not inhibit disease development and the hot and very dry conditions in 1978 were not conducive to powdery mildew development. The rate of disease progress during the early part of this period, which may be the critical factor in determining if a yield loss will occur, was not closely monitored in this study.

Most recent reports (1,4,11,13,17,19) have described *M. diffusa* as the causal agent of powdery mildew on soybeans, but there is no firm evidence that reports of *Erysiphe polygoni* (14,22) are in error. Therefore, identification of the pathogen by examination of the perfect stage is important. The cleistothecial stage of *M. diffusa* develops abundantly in the field in Georgia, has been observed each year since 1973, and probably has been present for many years (4,15). In the greenhouse, the perfect stage was abundant throughout the winter in 1973 (4) but has been sparce and erratic each year since then. Others (1,6,11,14,16,17,19) have reported erratic cleistothecial production on soybeans.

While testing the cultivar reaction to the 1979 inoculum, blue lupine in the same greenhouse became heavily infected and cleistothecia of *M. diffusa* developed. Inoculum from blue lupine readily infected soybean and that from soybean readily infected blue lupine. On five separate occasions, blue lupine was planted next to susceptible soybeans in the greenhouse and both were inoculated with *M. diffusa* from soybean. On two occasions, sparce cleistothecial development occurred on the soybeans while abundant cleistothecia developed on the blue lupine. On the other three occasions, cleistothecia were sparce on the blue lupine and failed to develop on the soybeans. The conidial stage was always abundant on both hosts. The conidial and cleistothecial stages of *M. diffusa* on blue lupine were indistinguishable from those on soybean. Thus, blue lupine appears to be a more favorable host for cleistothecial development and might be useful as an indicator for the presence of *M. diffusa*.

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