Effects of Bactericide Treatments on Bacterial Spot Severity and Yield of Different Pepper Genotypes and on Populations of Certain Insects

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ABSTRACT

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In a 3-yr study, bell pepper genotypes with different levels of susceptibility to *Xanthomonas campestris* pv. *vesicatoria* were treated with bactericides to study disease and yield responses. At Blairsville, Georgia, under moderate disease pressure, a cupric (Cu) hydroxide + mancozeb combination applied at weekly intervals provided moderate disease control and increased yields 76, 117, and 83% during 1987, 1988, and 1989, respectively, on the highly susceptible cultivar Yolo Wonder B. In 1988, at Athens, Georgia, under low disease pressure, the same treatment resulted in a 15% yield reduction on Yolo Wonder B due to stimulation of insect activity. The Cu hydroxide + mancozeb treatment also reduced disease severity on the moderately susceptible genotype C44-NV22 but significantly increased yield (21%) in only one of three years. The treatment also reduced disease on more resistant genotypes but did not increase yields. Season-long use of copper compounds alone or in combination with fungicides resulted in significant increases in populations of aphids (at Blairsville) or fall armyworms (at Athens).

Additional keywords: chemical control, host resistance, *Myzus persicae, Spodotera frugiperda*

Bacterial spot caused by *Xanthomonas campestris* pv. *vesicatoria* (Doidge) Dye is a serious disease of pepper (*Capsicum annum* L.) in many areas of the world (2,29). The disease is particularly damaging to bell pepper grown commercially in the mountainous areas of northeastern Georgia, where frequent late afternoon and evening showers and heavy dews and fog provide prolonged periods of free moisture. Growers in this area use only limited measures to control bacterial spot. Few horticulturally acceptable, bacterial spot resistant bell pepper cultivars are available. Growers are reluctant to use chemical control measures on a routine basis because of erratic disease occurrence from farm to farm and from year to year, and especially because they question the value of available bactericides in increasing yields under conditions conducive to disease development. Yield reduction from disease is the primary concern, as fruit infection that may lead to quality reduction rarely occurs in northeastern Georgia, although it is a common problem elsewhere (2,12,29).

In 1986, a program was initiated to screen commercial pepper varieties and breeding lines for resistance to strains of *X. c. vesicatoria* and tobacco etch virus (another important pathogen of pepper in northeastern Georgia) prevalent in the area, and different levels of resistance to both pathogens were identified (*unpublished*). Yolo Wonder B (hereafter YWB), the most commonly grown cultivar in the area, was one of the most susceptible of 14 genotypes tested. The genotypes least susceptible to both pathogens were selections designated as a C44 series that originated from crosses including Truhart Perfection, Yolo Wonder, PI 163192, and PI 264281 (10). Some genotypes tested had high resistance to tobacco etch virus but only moderate resistance to *X. c. vesicatoria.*

A series of experiments was conducted to determine yield losses caused by bacterial spot on genotypes with different levels of susceptibility and assess the value of a systematic bactericide spray program in controlling disease and increasing yield on these genotypes. In preliminary work, certain chemical treatments resulted in marked increases in populations of certain insects. Data on this phenomenon also were recorded and are reported here. A portion of this work has appeared in abstract form (17).

MATERIALS AND METHODS

Most studies were conducted at the University of Georgia Mountain Branch Experiment Station near Blairsville. In 1988, studies also were conducted near Athens, Georgia, in the piedmont area, where disease pressure was less because weather conditions were less conducive to disease development. At both locations, routine land preparation practices were used, and plots were fertilized according to soil test results and recommendations of the Georgia Cooperative Extension Service. Weeds were controlled with trifluralin (Treflan, 1.2 L/ha) and routine cultivation. Sprinkler irrigation was used as needed to promote normal crop growth.

Except where indicated otherwise, treatments were arranged in a randomized complete block design with five replications. Each replication consisted of paired rows 0.96-m apart, with 22–24 plants per row spaced 0.3-m apart. The two center plants in each row were always YWB and served as inoculum loci within each plot.

Plants for the experiments were produced on a greenhouse bench in 180-ml paper cups filled with a fertilized soil mix (soil, sand, peat moss, perlite, vermiculite; 2:1:1:1:1, v/v). Plants were fertilized as needed with a 20-20-20 water-soluble fertilizer (2.4 g/L) to maintain normal growth until transplanted 7–8 wk (20 cm tall) after seeding. Each plant was given 0.3 L of a 20-20-20 water-soluble fertilizer solution (2.4 g/L) at transplanting on 9 June 1987, 24 May (Athens) and 30 May (Blairsville) 1988, and 12 June 1989.

To supplement natural inoculum and to ensure uniform disease development, *X. c. vesicatoria* was introduced into each plot by inoculating the two center YWB plants in each row 2 to 3 wk after transplanting. Inoculum was produced by growing a pepper strain (race 2, resistant to copper and sensitive to streptomycin) of *X. c. vesicatoria* on plates of YDC (10 g of yeast extract, 20 g of dextrose, 20 g of calcium carbonate, 20 g of agar, 1 L of distilled water) for 72 hr at 25 C. Suspensions in sterile distilled water containing 10^7 to 10^8 cfu/ml were prepared based on turbidity measurements with a spectrophotometer. Plants were irrigated in late afternoon before inoculation so that the foliage remained wet during and at least 14 hr after inoculation. Leaves were rubbed gently with sterilized moist sand to provide wounds and water-soaking, and then inoculum was applied to the entire foliar surface of the two YWB plants until runoff using a hand-held garden sprayer at a pressure of 1.8–2.0 kg/cm^2.

Effectiveness of the inoculation method was determined at Blairsville in 1988. The inoculum levels within the plots were measured three times during the growing season by plating washings from asymptomatic leaves collected from control plots. Leaves were collected from the eight plants at the end of each row to avoid the inoculated plants at the center. Samples were collected, held over ice during transport, and assayed the same

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day. Composite leaf samples (10 g) from each plot were placed in 500-ml flasks containing 200 ml of sterile 0.1-m phosphate buffer (1:2, v/v, of KH_2PO_8 [13.6 g/L] and K_2HPO_4 [17.8 g/L], pH 7.1, amended with 0.1% peptone, w/v). The flasks were placed on a wrist-action shaker for 30 min at medium speed. Serial dilutions were prepared in sterile distilled water, and dilutions predicted to give countable plates were plated, 0.1 ml/plate, on five plates of Tween A medium (18). Plates were incubated at 28 C for 3 days, and colonies were counted.

Chemical treatments were started 1 wk after inoculation and were continued at 7-day intervals throughout the growing season. The sprays were applied at recommended rates until runoff with a back-mounted, motorized mist blower (Solo Motors, Newport News, Virginia). Polyethylene shields (1-m high) were held between plots during chemical application to minimize spray drift.

Disease ratings were recorded periodically each year to follow the progress of disease. Disease severity was recorded on a scale of 0 to 5 that reflected lesion number and lesion size on retained leaves and numbers of leaves on the ground resulting from disease. Plus and minus readings were used with the scale to provide increased flexibility. Yields were determined by making weekly harvests of mature fruit.

Rating scales (0–5) were used to record green peach aphid (*Myzus persicae* (Sulzer)) numbers at Blairsville in 1988 and 1989 and for fall armyworm (*Spodoptera frugiperda* (J. E. Smith)) damage at Athens during 1988. Armyworm counts also were made by shaking plants vigorously and collecting the worms on a cloth placed under the plants. No attempt was made to control the insects chemically so the effect of the chemical treatments could be studied.

1987 Tests. Five genotypes that differed in susceptibility to bacterial spot in previous tests were grown as previously described and were either sprayed with water (check) or with a Cu hydroxide (Kocide 101, 3.6 g/L) + mancozeb (Dithane M-45, 1.8 g/L) combination. The genotypes, in increasing order of susceptibility, were C44-14-19, C44-14-16, C44-NV22, XVR3-25, and YWB.

1988 Tests. Genotypes C44-14-19, C44-NV22, and YWB were used, and each was sprayed with water (check), Cu hydroxide + mancozeb, or streptomycin sulfate (Agri-mycin 17, 1.2 g/L). In a second experiment, six chemical treatments were applied to C44-14-19 plants to determine their effect on insect populations. The treatments were Cu hydroxide, mancozeb, Cu hydroxide + mancozeb, chlorothalonil (Bravo 720, 2.4 ml/L), chlorothalonil + Cu oxychloride + maneb (Bravo CM, 4.8 g/L), and streptomycin. The design was a randomized complete block with split plots. One row of 22 plants was sprayed with the chemical mixtures and the other with water. Ratings for insect populations or damage were made at 2-wk intervals beginning at midseason. Yield data were not taken in the second experiment.

1989 Test. The same three genotypes as in 1988 were used, and each was sprayed with either water (check) or Cu hydroxide + mancozeb. Data on disease severity, aphid populations, and yield were recorded as in 1988.

RESULTS

At Blairsville, bacterial spot was moderately severe on the highly susceptible cultivar YWB for all three years (Tables 1–3) despite generally drier than normal conditions. The severity of disease on the less susceptible cultivars varied somewhat from year to year but was always less severe than on YWB. The genotype C44-14-19, which was highly resistant in earlier tests, had little disease in these tests despite moderate disease pressure. C44-NV22 had more disease than C44-14-19 but less than YWB.

Inoculation of the two YWB plants in each plot row resulted in excellent distribution of inoculum in all plots throughout the growing season. For example, on 5 August 1988 bacterial populations of 1.3×10^6, 2.7×10^6, and 1.2×10^6 cfu/g of fresh tissue were detected on the YWB, C44-NV22, and C44-14-19 genotypes when washings from asymptomatic leaves were plated. Counts made in a similar way on C44-14-19 and YWB plants were 1.0×10^6 and 6.3×10^6 cfu/g on 15 August and 5.5×10^4 and 3.9×10^5 cfu/g on 8 September in the same year.

At Blairsville during all three years, weekly applications of Cu hydroxide + mancozeb applied to YWB plants resulted in moderate to good disease control and in significant yield increases (76 to 117%) (Tables 1–3). In 1988, the streptomycin treatment reduced disease and increased yield on YWB plants similar to the Cu hydroxide + mancozeb treatment. In 1987, the Cu hydroxide + mancozeb treatment significantly reduced disease on four genotypes in addition to YWB but only increased yield on the moderately susceptible genotype XVR3-25 (Table 1). In 1988, both the Cu hydroxide + mancozeb and the streptomycin treatments resulted in a significant disease reduction and a significant yield increase on the moderately susceptible cultivar C44-NV22 (Table 2). The same year, both treatments significantly reduced disease on the C44-14-19 genotype, but neither increased yield. In 1989, the Cu hydroxide + mancozeb treatment significantly reduced disease levels on both the C44-NV22 and C44-14-19 genotypes but did not significantly increase yields of either (Table 3).

At Athens in 1988, little bacterial spot developed even though inoculum was introduced into the plots as at Blairsville. The Cu hydroxide + mancozeb and streptomycin treatments reduced disease levels on all genotypes but did not increase yield (Table 2). In fact, the Cu hydroxide + mancozeb treatment significantly reduced yields of all three genotypes, presumably because of stimulation of high populations of fall armyworms.

The effect of a Cu hydroxide + mancozeb treatment on populations of aphids was first observed in 1986 in field plots at Blairsville (*unpublished*). Plants receiving season-long applications of this mixture eventually became heavily covered with sooty mold because of honeydew accumulation, whereas adjacent plants receiving water (check) or chlorothalonil were mostly free of aphids and sooty mold. The same observations were made in 1987, but no data were recorded. In 1988, high numbers of green peach aphids occurred on all genotypes treated with Cu hydroxide + mancozeb (Table 2). Similar results were obtained in 1989 (Table 3). In both years, aphid populations increased as the season progressed. Despite relatively high aphid populations, the yields of plants treated with the chemical mixture were equal to or greater than nontreated plants because of control of bacterial spot.

Table 1. Effect of a scheduled spray program on disease severity and yield of five pepper genotypes with different levels of resistance to bacterial spot at Blairsville, Georgia, in 1987

Genotype[a] Treatment[b]	Disease reading[c]	Mean yield[d] (kg/plot)
C44-14-19		
Sprayed	<0.1*[e]	28.2
Unsprayed	0.1	30.5
C44-14-16		
Sprayed	0.6*	25.6
Unsprayed	1.2	27.5
C44-NV22		
Sprayed	1.1*	28.0
Unsprayed	2.0	31.5
XVR3-25		
Sprayed	1.0*	25.3
Unsprayed	1.8	27.5
Yolo Wonder B		
Sprayed	1.9*	19.7*
Unsprayed	3.6	11.2

[a] Genotypes are arranged from least susceptible to most susceptible to bacterial spot, based on previous years' observations.

[b] Sprayed plants received a weekly application of cupric hydroxide (Kocide 101, 3.6 g/L) + mancozeb (Dithane M-45, 1.8 g/L).

[c] Based on a scale of 0 to 5, where 0 = no disease, 1 = isolated lesions but no defoliation, and 5 = numerous large and rapidly expanding lesions and severe defoliation. Readings were made at midseason (19 August).

[d] Based on eight hand harvests from 12 August to 6 October.

[e] An asterisk indicates that the spray treatment is significantly different from the unsprayed treatment in case of each genotype according to the *t* test ($P = 0.05$).

At Athens, the Cu hydroxide + mancozeb treatment resulted in significant increases in fall armyworm damage, which caused yield decreases on all genotypes (Table 2). Plants treated with the chemical mixture had numerous holes from insect feeding, whereas water-treated (check) or streptomycin-treated plants had few. Worm counts on C44-14-19 plants averaged 11.4, 1.4, and 1.1 per plant for the Cu hydroxide + mancozeb, streptomycin, and water treatments, respectively. When six chemical treatments were applied at Athens and Blairsville in 1988, the highest aphid populations and fall armyworm damage occurred on plants treated with Cu hydroxide + mancozeb, followed by Cu hydroxide alone, and with chlorothalonil + Cu oxychloride + maneb (Bravo CM) (Table 4). Aphid populations and fall armyworm damage on plants treated with mancozeb, chlorothalonil, and streptomycin were similar to those receiving only water.

Table 2. Effect of treatment on disease severity, insects, and yield of three pepper genotypes differing in resistance to bacterial spot at two locations in 1988

Genotype[a] Treatment[b]	Location in Georgia: Blairsville Disease[c] rating	Blairsville Aphid[d] population	Blairsville Yield[e] (kg/plot)	Athens Disease[c] rating	Athens Worm[f] damage	Athens Yield[e] (kg/plot)
C44-14-19						
Cupric hydroxide + mancozeb	0.16	3.20	68.9	0.04	3.42	54.9
Streptomycin	0.15	0.20	68.3	0.05	0.22	75.4
Water	0.50	0.15	64.7	0.20	0.28	77.6
LSD ($P = 0.05$)	0.32	0.55	6.5	0.10	0.60	8.6
C44-NV22						
Cupric hydroxide + mancozeb	0.80	3.40	63.4	0.15	3.80	46.9
Streptomycin	0.70	0.26	63.7	0.15	0.24	68.7
Water	2.10	0.30	52.5	0.45	0.28	77.2
LSD ($P = 0.05$)	0.70	0.65	7.8	0.20	0.64	9.1
Yolo Wonder B						
Cupric hydroxide + mancozeb	1.3	3.50	55.6	0.15	3.45	61.5
Streptomycin	1.6	0.18	60.4	0.25	0.28	81.5
Water	3.2	0.26	25.6	0.84	0.38	72.6
LSD ($P = 0.05$)	0.6	0.74	5.0	0.33	0.45	9.3

[a] Genotypes are arranged from least susceptible to most susceptible based on earlier tests.
[b] Sprayed plants received a weekly application of Cu hydroxide (Kocide 101, 3.6 g/L) + mancozeb (Dithane M-45, 1.8 g/L), or streptomycin (Agri-mycin 17, 1.2 g/L).
[c] Based on a scale of 0 to 5, where 0 = no disease, 1 = isolated lesions with no defoliation, and 5 = numerous large and rapidly expanding lesions with severe defoliation.
[d] Based on a scale of 0 to 5, where 0 = no aphids, 1 = few scattered colonies, and 5 = numerous colonies.
[e] Based on eight hand harvests from 3 August to 28 September at Blairsville and 2 August to 10 October at Athens.
[f] Based on a scale of 0 to 5, where 0 = no damage, 1 = few feeding sites, and 5 = numerous feeding sites, with 50% or more of foliage area destroyed.

Table 3. Bacterial spot severity, aphid populations, and yield of three pepper genotypes sprayed with water or a cupric hydroxide and mancozeb combination at Blairsville, Georgia, in 1989

Genotype[a] Treatment[b]	Disease severity[c]	Aphid populations[d]	Yield[e] (mean kg/plot)
C44-14-19			
Chemical	0.2*[f]	3.6*	30.0
Water	0.7	T	26.0
C44-NV22			
Chemical	0.6*	4.1*	29.0
Water	1.2	T	27.0
Yolo Wonder B			
Chemical	1.1*	3.8*	25.4*
Water	3.2	T	13.9

[a] Arranged from least susceptible to most susceptible.
[b] Water or cupric hydroxide (Kocide 101, 3.6 g/L) + mancozeb (Dithane M-45, 1.8 g/L) were applied to runoff at 7-day intervals.
[c] Based on a scale of 0 to 5, where 0 = no disease, 1 = isolated lesions but no defoliation, and 5 = numerous large and rapidly expanding lesions with severe defoliation. Ratings were made at midseason.
[d] Based on a scale of 0 to 5, where 0 = no aphids, T = a few scattered aphids not in organized colonies, 1 = few colonies, and 5 = numerous colonies. Ratings shown were made midseason to late season (6 September).
[e] Based on hand harvests made between 17 August and 10 October.
[f] Asterisk indicates values were significantly different from water treatment based on t test ($P = 0.05$).

DISCUSSION

Bacterial spot caused serious yield reductions of pepper grown under conditions conducive to disease development. Although yield reduction is generally considered to be a major problem associated with this disease on pepper, until this study, limited experimental evidence (9) was available to indicate the magnitude of the loss. However, Pohronezny and Volin (22) found that early inoculation (three- to four-true-leaf stage) of tomato with *X. c. vesicatoria* caused as much as 76% defoliation and total and marketable yield reductions of 29 and 52%, respectively. On pepper, fruit lesions often contribute to quality losses (2,29), but these occurred rarely in our tests. Fruit lesions are very uncommon on peppers grown in northeastern Georgia, even on highly susceptible cultivars that are severely defoliated by the disease. The reason for the low incidence of fruit lesions in this area is not known. It is assumed that most of the yield reduction in our tests was caused by reduced fruit numbers and size that resulted from moderate to severe defoliation, although mechanisms other than defoliation have been suggested (22). The potential for the disease to cause significant yield reductions as shown in the present work, and yield and quality reductions as occur in other areas, emphasizes the need for effective control measures.

Historically, streptomycin and fixed copper compounds, the latter often in combination with maneb or mancozeb, have been the principal chemicals used for control of bacterial spot on both pepper (3,16,29) and tomato (3,4,8,14,15, 27) in the southeastern United States. However, the usefulness of streptomycin for control of the disease has diminished because of the rapid and widespread development of resistant strains of the pathogen (23,28). Copper-tolerant strains also have occurred in widespread areas (1,7,16,23), but these can be managed by using maneb or mancozeb in combination with fixed coppers. The combination increases effectiveness of the copper against both sensitive and resistant strains (4,15,16). Also, Jones et al (15) noted that strains of *X. c. vesicatoria* classified as resistant in the laboratory showed some degree of sensitivity to copper on tomato plants in the field.

The present studies show that Cu hydroxide + mancozeb can provide moderate to good bacterial spot control and significant yield increases on susceptible pepper cultivars when a season-long spray program is followed and weather conditions are not excessively conducive to disease development. In Georgia,

Table 4. Influence of various chemical treatments on insect populations or damage on C44-14-19 pepper plants at Blairsville (aphids) and Athens (fall armyworms), Georgia, in 1988

Treatment[a]	Aphid population[b]	Fall armyworm damage[c]
Mancozeb (Manzate 200)	0.1	0.2
Cupric hydroxide (Kocide 101)	1.9	2.0
Cupric hydroxide + mancozeb	2.8	2.9
Chlorothalonil (Bravo 720)	<0.1	0.2
Chlorothalonil + copper oxychloride + maneb (Bravo CM)	1.4	2.3
Streptomycin (Agri-mycin 17)	<0.1	0.1
Water (check)	<0.1	0.1
LSD ($P = 0.05$)	0.8	0.7

[a]Applications made to runoff at weekly intervals with a back-mounted, motorized mist blower. Rates were 1.8 g of Manzate 200, 3.6 g of Kocide 101, 2.4 ml of Bravo 720, 4.8 g of Bravo CM, and 1.2 g of Agri-mycin 17 per liter.
[b]Based on a scale of 0 to 5, where 0 = no aphids, 1 = a few isolated colonies, and 5 = numerous colonies.
[c]Based on a scale of 0 to 5, where 0 = no damage, 1 = few isolated feeding sites, and 5 = numerous feeding sites, with 50% or more of foliage area destroyed.

growers often experience failure in controlling the disease because they wait until the disease becomes well established before initiating a spray program. Several workers (4,27,29) have noted the difficulty of controlling bacterial spot during weather conditions highly conducive to disease development. Favorable conditions include frequent rains, blowing rain, extended periods of fog or dew, and warm weather. During the three years of our tests, conditions at Blairsville were moderately favorable for disease development; no long periods of extremely favorable conditions occurred.

Only one copper compound was tested extensively in our work. However, results of other studies (14,27,29) indicate that other copper compounds also could be used successfully. Also, maneb probably could be substituted for mancozeb, since both compounds enhance the effectiveness of copper compounds (4,16). Maneb was recently relabeled for use on peppers after a period of suspension of all ethylenebisdithiocarbamate fungicides for use on most vegetable crops.

The season-long use of Cu hydroxide + mancozeb resulted in significant increases in populations of aphids and fall armyworms when no attempt was made to control them chemically. Apparently the copper component was the major contributor to the stimulation observed, although a combination of mancozeb and copper seemed to be slightly more stimulatory than copper alone. No attempt was made to determine the mechanism for this stimulatory effect, but inhibition of entomogenous fungi is suspected. The importance of these fungi in inhibiting insects is known (24), and some fungicides are known to inhibit them (11,13). Stimulation of several types of insects by fungicides, including coppers, has been reported (13,20,21).

The relatively high yields and low disease levels on some of the C44 genotypes, even without bactericidal sprays, stress the need for an intensive effort to develop horticulturally acceptable bell pepper cultivars with resistance to bacterial spot. Several sources of resistance have been identified (10,25,26), but development of stable resistant cultivars is complicated by the presence of multiple races of the bacterial spot pathogen (5,6,9,23). Several workers (19,23) have stressed the need for development of pepper cultivars with multiple genes for resistance to bacterial spot.

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