Evaluation of Copper Fungicides and Rates of Metallic Copper for Control of Melanose on Grapefruit in Florida

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ABSTRACT

Timmer, L. W., and Zitko, S. E. 1996. Evaluation of copper fungicides and rates of metallic copper for control of melanose on grapefruit in Florida. Plant Dis. 80:166-169.

Several copper fungicides were evaluated over a 3-year period for control of melanose, caused by *Diaporthe citri* on Duncan grapefruit in Florida. In most cases, two rates of each product were evaluated using a single application per season. The amount of metallic copper applied per hectare explained 37 to 60% of the variability in the melanose severity rating and 34 to 62% of the variability in the percentage of the fruit marketable as fresh from 1992 to 1994. Certain copper products were significantly more effective than others when applied at the same rates of metallic copper. Recommendations will continue to be based primarily on the amount of metallic copper per hectare, but adjustments should be made for the relative efficacy of certain products.

Additional keyword: *Phomopsis citri*

Copper fungicides are the mainstay for control of foliar fungal diseases of citrus in Florida. These materials are highly effective for control of melanose, caused by *Diaporthe citri* F. A. Wolf (anamorph *Phomopsis citri* Fawc.), and greasy spot, caused by *Mycosphaerella citri* Whiteside, and are also used in control programs for citrus scab caused by *Elsinoe fawcetti* Bitancourt & Jenk. and Alternaria brown spot caused by *Alternaria alternata* (Fr.:Fr.) Keissl. pathotype *citri* Solel. Copper fungicides were used extensively in the early years, but use diminished somewhat with the introduction of benomyl and captafol. Usage has increased again recently with the banning of captafol and the development of resistance to benomyl in many citrus pathogens (6). Copper products, benomyl, ferbam, and citrus spray oil are the only fungicides currently registered on citrus for foliar pathogens (6).

Grapefruit (*Citrus paradisi* Macfady) are susceptible to melanose from the time of petal fall, usually late March or early April, until the fruit reaches about 7 cm in diameter, usually late June to early July (8, 10,14). In Florida, infection usually occurs in May and June when rainfall is most frequent (14).

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Florida Agricultural Experiment Station Journal Series No. R-04638.

Accepted for publication 7 November 1995.

Publication no. D-1995-1211-05R

Although copper fungicides are highly effective for control of melanose and other citrus diseases, there are many problems associated with their use. Extensive use for many years has resulted in accumulation of copper in citrus soils with some old groves containing up to 370 kg/ha of metallic copper (1). These levels are highly toxic to citrus roots and interfere with uptake of iron and other nutrients in acid soils. Liming of soils to pH 6.5 ameliorates the phytotoxic effects of copper (1, 2). In addition, copper sprays can darken already existing blemishes such as windscar, melanose, or insect damage thus further reducing marketability of the fruit (3). These phytotoxic effects occur most commonly when copper is applied in complex tank mixes with other pesticides or nutritional materials, in combination with acidic products, or at high temperatures.

Until recently, one to two applications of copper fungicide at 9 kg/ha of metallic copper were recommended for melanose (5). For all uses, annual rates of application often exceeded 30 to 40 kg/ha. Recommendations were made on the basis of metallic copper on the assumption that the efficacy of different products was solely the result of their copper content. Individual comparisons of copper products to date largely support that assumption (9,11,12, 15,16), but a wide range of materials have not been evaluated concurrently. Only occasionally have two products with the same content of metallic copper differed in the level of disease control (8). Indeed, in some tests, there was no significant response to rate of application (9,11), which suggests that rates of application could have been reduced without jeopardizing control. Liquid copper formulations often contain a lower percentage of metallic copper but some of these have not been highly effective or have been phytotoxic (9,12).

It would be highly desirable to decrease the rates of copper fungicides to reduce soil accumulation and phytotoxic effects without affecting disease control. Many new formulations and products have appeared on the market with claims of being more effective than other materials per unit of metallic copper. The current study was conducted to compare the effectiveness of different copper fungicides and evaluate the hypothesis that melanose control is dependent solely on the metallic copper content of these products.

MATERIALS AND METHODS

Copper fungicides were evaluated each year from 1992 to 1994 in a grove of mature Duncan grapefruit trees planted on 7.5 by 7.5 m spacing near Bowling Green, Florida. Each treatment was replicated five times on three-tree plots arranged in a randomized complete block design. Guard trees were located between plots within rows and one guard row was located between treatment rows. Copper products tested varied somewhat from year to year and treatments were randomized in each year. All applications were made with a commercial airblast sprayer using 2,400 liters/ha. Growers may make one to several applications of copper depending on the disease history of the grove and weather conditions during the season. Only a single application of each product was made in each year to provide a severe test of performance of each material. Applications were made when fruit reached about 2 to 3 cm in diameter on 21 April 1992, 11 May 1993, and 12 May 1994.

Rates selected for each product were usually the minimum dosage recommended by the manufacturer and twice that rate. Across all products, the rates of metallic copper ranged from 1.75 to 9.2 kg/ha. These products were tested: Copper-Count-N (copper ammonium complex, 94 g/liter metallic Cu; Mineral Research & Development Corp., Charlotte, NC); Champ Formula II F (copper hydroxide, 363 g/liter metallic Cu), and Champ Formula II DF (copper hydroxide, 37.5% metallic Cu; Agtrol Chemical Products, Houston, TX); KOP Hydroxide 50 (copper hydroxide, 50% metallic Cu; Drexel Chemical Co., Memphis, TN); ChemNut 50DF (copper oxychloride, 50% metallic Cu) and Blue Shield 50 DF (copper hydroxide, 50% metallic Cu) (Cuproquim Corp., Houston, TX); Cuproxat (basic copper sulfate, 192 g/liter metallic Cu; Agrolinz, Inc., Memphis, TN); Kocide DF (copper hydroxide, 40% metallic copper) and GX-306062E (copper hydroxide, 35% metallic Cu) (Griffin Corp., Valdosta, GA).

At fruit maturity in October to November of each year, melanose severity was rated on 100 fruit per tree, on the following scale: 0 = no melanose; 1 = mild melanose, suitable for fresh market; 2 = moderate speck melanose, suitable only for processing; 3 = severe speck melanose; 4 = moderate tear-stain or mudcake melanose; and 5 = severe tear-stain or mudcake melanose. An average severity rating was calculated for each tree as well as the percentage of fruit marketable as fresh for those in categories 0 and 1.

All data were subjected to analysis of variance and means separated using the Waller-Duncan *k*-ratio *t* test, $P \leq 0.05$. All data sets were tested for homogeneity of variances (7) and all except the 1994 data on the percentage of marketable fruit met the criteria. The 1994 data were transformed to arcsin square root values prior to analysis. Regression analysis and curve fitting were conducted using SigmaPlot for Windows (Jandel Scientific Software, Transforms & Curve Fitting, San Rafael, CA) to determine the relationship of the amount of metallic copper applied to the melanose severity rating and to the percentage of fruit marketable as fresh. The coefficients of determination presented represent adjusted values.

RESULTS

Melanose severity varied among seasons. In 1992, melanose was severe but developed late in the season. Very little disease occurred from the time of application until the end of May and only 12.5 mm of rainfall was recorded during that time. Some melanose developed following 38 mm of rain the first week of June and severe melanose occurred following 240 mm of rain the third week of June. Some additional melanose occurred following 113 mm of rain the first week of July, although fruit was becoming resistant by that time. In 1993, melanose was mild with most of the infection occurring in late May and early June (65 mm of rain) and late June (68 mm of rain). In 1994, melanose was severe with infection periods occurring in mid-May (39 mm of rain), early June (106 mm of rain), mid-June (103 mm of rain), and early July (67 mm of rain). Minimum wetting periods required for infection are about 12 h at 25°C and 18 to 24 h at 15 to 25°C (12) and disease severity increases greatly with longer moist periods.

In every year, all of the products tested significantly reduced melanose severity and increased the percentage of marketable fruit (Table 1). Even though only a single application was made and infection periods often occurred long after the application, disease severity was reduced even with the lowest rates of copper. Evaluation of severity ratings gave slightly better separation of treatments but the percentage of marketable fruit allowed better assessment of the economic impact of treatments. Melanose was as severe in 1992 as in 1994, but the level of control attained was much better in 1994 since infection periods occurred closer to the application date.

Generally, liquid or flowable formulations were less effective than the dry formulations (Table 1). However, liquid and flowable products cannot be applied at high rates of metallic copper due to the phytotoxicity problems. The higher rate of each product usually, but not always, gave better control than the lower rate. Rate effects were more evident in 1992 and 1994, when melanose was more severe, than in 1993. Differences between low and high rates were more frequently observed with the most effective products (e.g., Kocide, ChemNut) than with less effective materials (e.g., Blue Shield, Copper-Count-N) (Table 1).

Regression analyses indicated that the metallic copper content of the products accounted for a substantial amount of the variability in melanose severity (37 to 60%) and in the percentage of marketable fruit (34 to 62%) (Fig. 1). Each additional kg/ha of metallic copper increased the percentage of marketable fruit by 4.25 and 6.43 percentage points in 1992 and 1994, respectively. Thus, increasing rates had substantial benefit in those 2 years. However, each additional kilogram increased marketable fruit by only 1.56 percentage points in 1993, when melanose was mild.

Though much of the variability was accounted for by metallic copper content of the treatments, there were significant differences among products applied at the same rate of metallic copper (Table 1). For example, at low rates of copper (1.75 to 1.82 kg/ha), Cuproxat (L) was more effective than Champ Formula II F (L) and Copper-Count-N (L) (1992, 1993). Interestingly, Champ Formula II DF (L) was more effective than the comparable flowable formulation (Champ Formula II F [L]) in 1994. At medium levels of copper (2.7 to 3.63 kg/ha), Kocide DF (M) and ChemNut DF (M) were more effective than Champ Formula II F (M) or Copper-Count-N (M) in 1992. At high rates (4.8 to

Table 1. Effect of applications of copper fungicides on melanose severity and the percentage of fruit acceptable for the fresh market

Fungicide	Rate/ha	Metallic Cu/ha (kg)	Severity rating (1 to 5)			Marketable fresh (%)[x]		
			1992	1993	1994	1992	1993	1994
Unsprayed control	. . .	. . .	2.23 a[y]	1.64 a	2.35 a	28.9 f	52.4 f	10.4 f
Champ Formula II F (L)[z]	9.5 liters	1.75	2.00 b	1.04 b	1.68 b	36.9 e	75.0 e	43.5 e
Champ Formula II F (M)	18.9 liters	3.50	1.81 cd	0.61 cdef	1.48 bc	43.7 cd	87.7 abc	55.6 de
Champ Formula II DF (L)	4.5 kg	1.70	. . .	. . .	1.39 cd	. . .	. . .	60.2 cde
Champ Formula II DF (M)	9.1 kg	3.41	. . .	. . .	1.39 cd	. . .	. . .	57.1 de
Copper-Count-N (L)	14.2 liters	1.82	1.87 bc	. . .	. . .	39.9 de	. . .	. . .
Copper-Count-N (M)	28.4 liters	3.63	1.92 bc	. . .	. . .	36.9 c	. . .	. . .
Cuproxat F (L)	9.5 liters	1.82	1.69 de	0.71 cde	. . .	46.6 bc	83.4 bcd	. . .
Cuproxat F (M)	18.9 liters	3.63	1.64 de	0.59 ef	. . .	48.5 bc	87.4 abc	. . .
Blue Shield DF (M)	6.8 kg	3.4	. . .	0.64 cdef	1.31 cd	. . .	87.0 abc	63.0 cde
Blue Shield DF (H)	13.6 kg	6.8	1.64 de	0.61 def	1.35 cd	48.5 bc	86.8 abc	66.2 bcd
Drexel KOP Hydroxide WP (M)	6.8 kg	3.4	. . .	0.86 bcd	1.27 cde	. . .	80.0 cde	70.8 bcd
Drexel KOP Hydroxide WP (H)	13.6 kg	6.8	. . .	0.56 ef	0.99 f	. . .	87.6 abc	84.4 ab
GX-306062 E (M)	10.2 kg	3.6	. . .	. . .	1.12 def	. . .	. . .	74.9 abcd
GX-306062 E (H)	13.6 kg	4.8	. . .	. . .	1.03 ef	. . .	. . .	83.3 ab
Kocide DF (M)	6.8 kg	2.7	1.51 ef	0.56 ef	1.51 bc	51.8 b	88.2 ab	54.1 ef
Kocide DF (H)	13.6 kg	5.4	1.37 fg	0.49 ef	1.03 ef	60.2 a	89.2 ab	81.9 abc
Kocide DF (XH)	22.7 kg	9.1	. . .	0.39 f	0.86 f	. . .	92.9 a	90.8 a
ChemNut 50 DF (M)	6.8 kg	3.4	1.54 ef	0.88 bc	1.44 bc	52.5 b	78.3 de	54.7 ef
ChemNut 50 DF (H)	13.6 kg	6.8	1.21 g	0.64 cdef	0.85 f	63.5 a	85.8 abc	90.8 a

[x] Data for marketable fresh fruit for 1994 were transformed to arcsine square root values prior to analysis.
[y] Mean separation in columns by Waller-Duncan *k*-ratio *t* test, $P \leq 0.05$.
[z] Treatment designation based on metallic copper content: L = low, M = medium, H = high, XH = extra high.

6.8 kg/ha), several products were more effective than Blue Shield (H) in 1994. Products are most easily compared in Figure 1. Those products above the slope line for marketable fruit or below the slope line for severity are more effective than average per unit of metallic copper.

DISCUSSION

The amount of metallic copper applied to the fruit surface appears to be the primary determinant of the level of melanose control obtained. Within the range of rates of metallic copper evaluated in these experiments, the response was linear. However, exponential curves also gave a significant fit for the data but had similar or lower R^2 values (data not shown). Thus, in reality, increasing rates would provide diminishing returns per unit of metallic copper and if higher rates had been used, control would not have been greatly improved.

Copper fungicides are preventive and act only to inhibit conidial germination (13). They do not redistribute over the fruit surface and thus coverage is lost with time due to fruit growth and to weathering. Increased rates of copper or more effective materials probably do not compensate as much for fruit growth as for weathering.

Some products provided better control per unit of metallic copper than certain other materials, but differences were not significant in all years. Liquid and flowable formulations were not highly effective. In most cases, they provided no better control than dry products per unit of metallic copper and are much more expensive to manufacture. Current retail prices range as high as $15.60 per kg of metallic copper for some of the liquid products to as low as $8.60 per kg for some of the less expensive dry materials.

With Florida grapefruit, the losses incurred from reduced packout of fresh market fruit are substantial. Assuming a yield of 50 tons/ha and using the average price of fresh market, white grapefruit from 1990 to 1994 of $215 per ton ($8.61/box) and a processing price of $67 per ton ($2.68/box) (4) and adding the penalty of $25 per ton charged by packinghouses for eliminations, we calculated an average cost of $866 per hectare for each 10% reduction in packout. Actual values would be somewhat less because the figures do not consider melanose-affected fruit that could have been also downgraded for size, deformities, or other blemishes. Values for red grapefruit would be slightly higher, because prices for processed red grapefruit are lower. From the above figures, the value of each additional kilogram of copper per hectare was $368, $135, and $557 in 1992, 1993, and 1994, respectively. The differences between products at the same rate of metallic copper were significant, but quite difficult to quantitate precisely. However, where significant differences existed, there was usually a difference of 5 to 15 percentage points between the two products in the percentage of marketable fruit. Thus, using the above values, choice of a superior copper fungicide at the same rate of metallic copper could mean from $400 to $1,300 per hectare in increased returns to growers.

Growers must consider several factors in choosing copper fungicides. The cost of a product per unit of metallic copper is a primary consideration. The most economical means to achieve the highest degree of melanose control may be for growers to apply the least expensive products even though higher rates of those products may be needed. However, growers concerned about copper accumulation in soil may wish to use the most effective materials at somewhat lower rates even though total cost may be higher. Liquid and flowable formulations are more convenient to use than dry products, although, given the high cost of these materials, the convenience alone may not compensate for the expense.

The University of Florida recommendations will continue to be made primarily on the basis of metallic copper (6) because differences in efficacy between products are relatively small, difficult to characterize with precision, and would require an extensive testing program. Where relative efficacy is known, adjustments in the rates can be made according to the product applied. Multiple applications of low rates of copper fungicides are currently being evaluated in an attempt to maximize control and minimize copper accumulation.

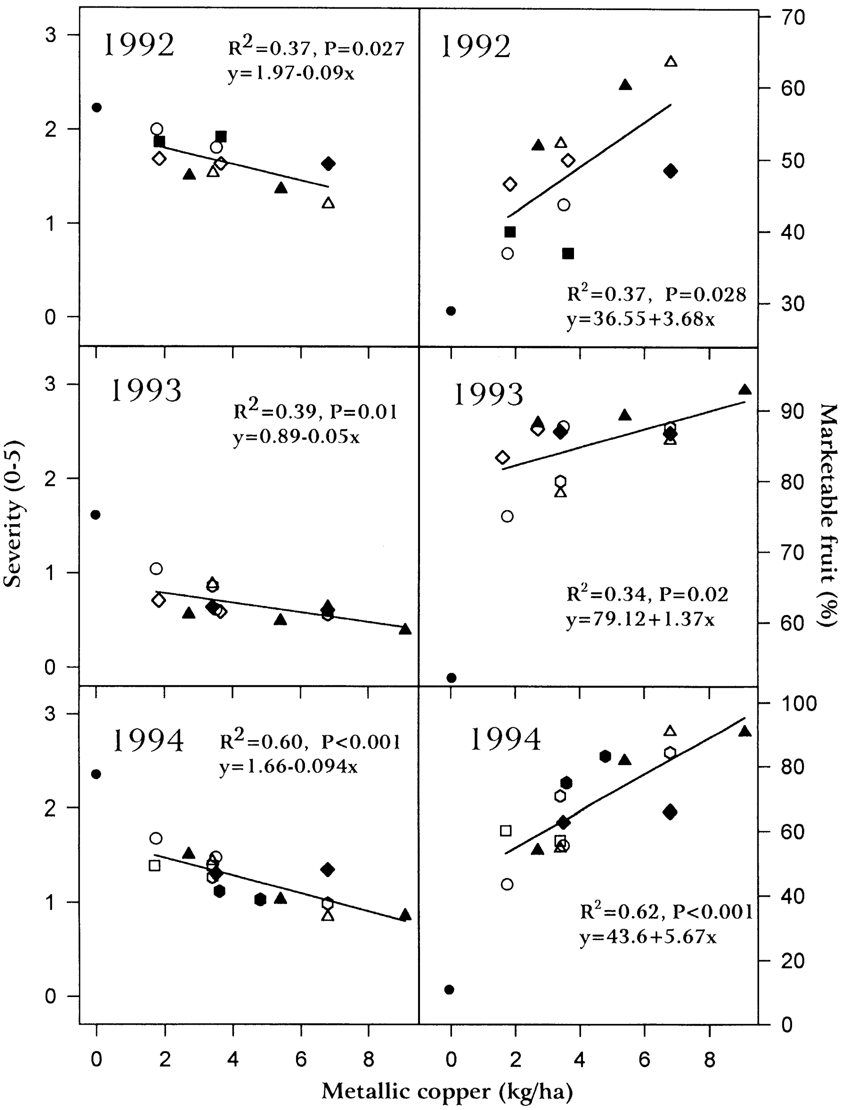

Fig. 1. Relationship of melanose control as indicated by disease severity and the percentage of marketable fruit to the metallic content of various copper products. Champ Formula II F (○); Champ Formula II DF (□), Copper-Count-N (■), Cuproxat (◇), Blue Shield DF (◆), Drexel KOP Hydroxide (⬡), GX-306062E (⬢), Kocide DF (▲), ChemNut 50 DF (△); Control (●). The unsprayed control (●) was not included in the regression analysis.

ACKNOWLEDGMENTS

The authors thank Becky L. King for technical assistance.

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