Strategies for Chemical Control of Snap Bean Rust in Florida and Their Compatibility with Canadian Residue Tolerances

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ABSTRACT

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Chemical control of snap bean rust using crop phenology as a basis for spray application was equivalent to the standard practice of full-season use of ethylene bisdithiocarbamate (EBDC) fungicide (maneb or mancozeb) plus sulfur. A maneb or mancozeb plus sulfur tank mix applied weekly until flowering was followed by two or three applications of chlorothalonil. EBDC residues in the crop phenology system were less than 0.1 ppm, whereas full-season use of EBDC plus sulfur in one of the two years of testing resulted in residues five times larger than the 0.1-ppm Canadian tolerance. Spray programs using the crop phenology method or full-season use of 1.17 kg a.i./ha chlorothalonil also were found to be cost-effective means for snap bean rust control while maintaining fungicide residues within limits established by the Canadian government. Bitertanol, a currently unregistered fungicide, provided outstanding rust control when used as a routine spray or when weekly sprays were initiated after rust appearance (on-demand).

Rust, caused by *Uromyces phaseoli* (Reben) Wint., is a destructive disease of snap beans (*Phaseolus vulgaris* L.) throughout the United States (9,13). It is a particular problem in the winter vegetable production regions of south Florida (2,8,11). In Homestead, Dade County, snap bean rust usually first appears in early January and becomes progressively more severe during the spring crop from February to April. Less frequently, powdery mildew, caused by *Oidium* spp., also results in economic losses in the spring crop.

In Florida, snap beans are routinely sprayed every 5–7 days with an ethylene bisdithiocarbamate (EBDC) fungicide such as maneb or maneb plus a zinc salt. During the months when rust is particularly severe, sulfur is often tank-mixed with EBDC fungicides to provide increased rust control. Despite this intensive spray regime, currently registered fungicides often do not provide adequate control (5).

A significant proportion of the Florida winter snap bean crop is exported to Canada. In the 1983–1984 winter season, Canada received 18% of all the snap beans delivered to the 21 major consumer centers of North America (1). In fact, Toronto received more bushels of snap beans than the economically important American consumer centers of Philadelphia, Boston, and Detroit.

The Canadian government has established an EBDC tolerance level of 0.1 ppm. In contrast, the U.S. EBDC tolerance is 7–10 ppm for fresh-market snap beans. Because produce brokers rather than growers control the final destination of fresh-market snap beans, grower spray programs cannot be tailored on a field-by-field basis for eventual U.S. or Canadian consumption.

Periodically since 1981, several winter snap bean shipments from Florida were found by Canadian regulatory officials to have EBDC residues greater than 0.1 ppm. These beans were considered unacceptable, and sale in Canada was prohibited. Regular spraying with alternative fungicides, particularly the higher labeled rates of chlorothalonil, is considered economically prohibitive by Florida growers.

A possible means of reducing EBDC residues was suggested by the success of insect pest management strategies based on snap bean crop phenology (12). While snap beans typically require 10–11 wk from planting to harvest, the period from flowering to harvest lasts only 2–3 wk. Hence, insecticide sprays can be targeted to that time period when pods are being set and developed, usually with considerable savings in numbers of insecticide applications and production costs (7,12). It was hypothesized that a similar approach based on crop phenology could be used for bean rust management to reduce EBDC spray residues on pods. A less expensive EBDC and sulfur tank mix followed by one to three sprays with chlorothalonil during the pod formative stage might be adequate.

These studies were conducted to compare the crop phenology-based spray program with the routine, full-season use of EBDCs or chlorothalonil for rust control efficacy, cost-effectiveness, and EBDC residue levels on harvested beans. In addition, two ergosterol biosynthesis inhibitor fungicides were evaluated as potential chemical control alternatives.

MATERIALS AND METHODS

Field experiments. Two field experiments were conducted at the IFAS, University of Florida, Tropical Research and Education Center (TREC) in Homestead, Dade County. In the 1984 experiment, snap beans, cultivar Savor, were direct-seeded into a Rockdale series soil (pH about 7.8) on 1 March. Ten treatments were replicated four times in a randomized complete block design. Individual test plots consisted of four rows 6.1 m long on 0.91-m centers. Unless otherwise stated, treatments were applied weekly beginning 22 March. Treatments were chlorothalonil (Bravo 500), 1.17 and 2.34 kg a.i./ha; a tank mix of the EBDC mancozeb (Manzate 200), 1.34 kg a.i./ha, and sulfur (THAT), 2.24 kg a.i./ha; bitertanol (Baycor), 0.14 and 0.28 kg a.i./ha; and triadimefon (Bayleton), 0.14 and 0.28 kg a.i./ha. In addition, a bitertanol on-demand treatment was included and consisted of weekly applications at the 0.28-kg a.i./ha rate initiated after rust was discovered in plots (5 April) during routine twice-per-week field inspections. A spray schedule based on the bean crop phenology (phenology treatment) was also tested. Plants were sprayed with EBDC (mancozeb) and sulfur until flowering, then 2.34 kg a.i./ha chlorothalonil was applied weekly until the allowed days-to-harvest interval (7 days). Control plots were sprayed with water.

All treatments were applied with a tractor-mounted, hydraulic-boom sprayer at a pressure of 190 nt/cm^2, delivering 923 L/ha of spray mixture. Five nozzles with disk-core, hollow-core nozzle tips (D-4-25, Spraying Systems, Inc., Wheaton, IL) were used per row of beans. Three nozzles discharged spray over the tops of plants, and one each discharged to each side of the row canopy.

Weed control consisted of a pre-emergence application of trifluralin at

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0.84 kg a.i./ha and metolachlor at 1.29 kg a.i./ha and periodic mechanical cultivation and hand-weeding. Benomyl applications were made as recommended for white mold control (8); insects were controlled as needed based on field scouting results (7,8,12), primarily with acephate, methomyl, and endosulfan. Disease severity ratings were made three times during the season by counting rust pustules on the abaxial surfaces of five randomly selected trifoliolate leaves taken from the middle of the plant canopy of the interior rows of each plot.

The two interior rows of test plots were harvested on 1 May. Total and marketable weights of snap beans were recorded. Percentage by weight of pods with specific diseases was also determined.

The 1985 field experiment was planted at TREC on 14 February, using snap bean cultivar Sprite. Experimental design, application methods, and cultural practices were the same as in the 1984 trial. Two chlorothalonil and three bitertanol treatments were the same as in 1984. Other fungicides tested were a tank mix of maneb (Dithane M-22 Special), 1.34 kg a.i./ha plus sulfur (THAT), 2.24 kg a.i./ha; maneb (Dithane FZ), 2.69 kg a.i./ha; and sulfur (THAT), 2.24 kg a.i./ha. The phenology treatment was again included, using maneb, 1.68 kg a.i./ha plus sulfur, 2.24 kg a.i./ha up to flowering, then chlorothalonil, 2.24 kg a.i./ha, until 7 days before harvest. Weekly sprays were begun on 18 March, except the bitertanol on-demand applications, which were begun on 25 March. On 25 April, 6.1 row-meters were harvested from the interior rows of each plot, and yield data were recorded as described for the 1984 experiment.

All disease severity and yield data were analyzed by a series of preplanned single-degree-of-freedom orthogonal contrasts, as suggested by Swallow (10), using the procedures outlined by Little and Hills (4). Data for number of pustules were transferred to ($\log_{10}$ + 1) equivalents before analysis (4).

Analysis of EBDC residues on snap beans. Snap bean samples for determinations of EBDC residues were collected from the following treatments: EBDC (mancozeb or maneb) plus sulfur tank mix, phenology treatment, and the water-sprayed control. At harvest, about 1 kg of bean pods was taken from each replicate of these treatments, double-bagged, tagged, and immediately frozen. Within 3 days, the frozen samples were packed in dry ice (−78 C) and shipped via air freight from Homestead to the Bureau of Chemical Residue Laboratory of the Florida Department of Agriculture and Consumer Services in Tallahassee. Laboratory analyses were initiated within 24 hr.

The EBDC analytical procedure was essentially that of Newsome (6). The EBDC moiety was isolated by ion exchange chromatography and quantitated by gas-liquid chromatography.

RESULTS

In both the 1984 and 1985 trials, all fungicides reduced rust levels below those in the water-sprayed controls (Tables 1 and 2). The phenology treatment as well as the weekly chlorothalonil applications provided rust control in both seasons equivalent to the standard practice (8) of weekly sprays with the tank mix of EBDC (mancozeb or maneb) plus sulfur (Tables 3 and 4).

The ergosterol biosynthesis inhibitor fungicides bitertanol and triadimefon were substantially superior to other treatments for control of bean rust. In both years, pustule numbers in plots sprayed with these fungicides were at or near zero (Tables 1 and 2). The reductions in disease severity with bitertanol and triadimefon were highly significant based on *F*-test values for the appropriate preplanned contrasts (Tables 3 and 4). Triadimefon, however, resulted in phytotoxicity, manifested as marked

Table 1. Control of rust and yields of snap bean in experimental plots at Homestead, FL, in 1984

Treatments	Rates (kg a.i./ha)	Number of rust pustules[a] 9 April	16 April	23 April	Yield (kg/ha) 1 May[b] Marketable	Total
Control (water)	–	35	320	3,585	3,633	3,721
Chlorothalonil	1.17	20	180	180	4,148	4,232
	2.34	7	49	157	3,435	3,496
Phenology treatment[c]	...[c]	8	54	193	3,296	3,341
Mancozeb + sulfur	1.34 + 2.24	10	59	213	2,758	2,843
Bitertanol	0.14	0	0	0	3,050	3,088
	0.28	0	0	0	3,140	3,196
Bitertanol on-demand	0.28	21	0	0	3,924	3,992
Triadimefon	0.14	6	0	1	2,399	2,488
	0.28	2	12	0	1,839	1,869

[a] Values are numbers of pustules on abaxial surfaces of five midcanopy trifoliolate leaves and are the means of four replicates.

[b] Values are means of four replicates based on harvest of 12.2-row-meter samples.

[c] Treatment based on snap bean crop phenology. Mancozeb (13.4 kg a.i./ha) + sulfur (2.24 kg a.i./ha) sprayed weekly until flowering (16 April 1984) followed by chlorothalonil (2.34 kg a.i./ha) for the remainder of the crop.

Table 2. Control of rust and yields of snap beans in experimental plots at Homestead, FL, in 1985

Treatments	Rates (kg a.i./ha)	Number of rust pustules[a] 18 April	23 April	Yield (kg/ha) 25 April[b] Marketable	Total
Control (water)	–	264	684	4,949	5,033
Chlorothalonil	1.17	88	197	5,227	5,267
	2.34	67	64	4,675	4,710
Maneb + sulfur	1.34 + 2.24	92	226	5,021	5,069
Maneb	2.69	46	96	5,604	5,708
Sulfur	2.24	21	60	5,245	5,340
Phenology treatment[c]	...[c]	74	128	4,577	4,667
Bitertanol	0.14	0	0	4,528	4,686
	0.28	2	0	5,224	5,389
Bitertanol on-demand	0.28	8	4	5,339	5,399

[a] Values are numbers of pustules on abaxial surfaces of five midcanopy trifoliolate leaves and are the means of four replicates.

[b] Values are means of four replicates based on harvest of 6.1-row-meter samples.

[c] Treatment based on snap bean crop phenology. Mancozeb (13.4 kg a.i./ha) + sulfur (2.24 kg a.i./ha) sprayed weekly until flowering (7 April 1985) followed by chlorothalonil (2.34 kg a.i./ha) for the remainder of the crop.

reductions in yields, especially at the higher rate (Table 1). Hence, triadimefon was not included in the 1985 experiment. Phytotoxic responses were not observed for any other fungicide tested in this study.

Statistically significant differences were not found between rates of triadimefon or bitertanol (Tables 3 and 4). Statistical differences between rates of chlorothalonil were not found, except on 23 April 1985, when disease control was enhanced by the higher chlorothalonil rate (Table 4).

In the 1985 field experiment, sulfur provided control equivalent to maneb (Table 4). Surprisingly, the use of maneb or sulfur alone was more effective than the commonly used tank mix of the two fungicides (Table 4).

Disease control when bitertanol was used on-demand compared favorably with use of this fungicide throughout the entire season. In 1984, pustule numbers in bitertanol on-demand plots were initially higher than in plots sprayed weekly with either rate of bitertanol but were reduced to similar low numbers after two sprays (Table 3). In 1985, numbers of pustules were equivalent with plots sprayed on-demand and weekly with bitertanol on all observation dates (Table 4).

Single-degree-of-freedom comparisons failed to detect many significant differences in marketable yield, total yield, and percentage of pods with specific diseases. Highest yields were recorded for the 1.17-kg a.i./ha chlorothalonil treatment in 1984 and for maneb applied alone in 1985, but differences from other treatments were not statistically significant. Marketable yields in the 1984 triadimefon-treated plots were significantly lower than in the bitertanol-treated plots, even though disease control was comparable. In 1985, the 2.7% Rhizoctonia pod rot damage in bitertanol-treated plots was significantly higher than the 0.58% level observed in chlorothalonil-treated plots (single-degree-of-freedom contrast *F*-test = 8.01, significant at $P = 0.01$). These fairly low levels of Rhizoctonia pod rot, however, did not result in corresponding significant differences in marketable yield between these two treatments.

EBDC residues on snap beans. In 1984, EBDC residues of 0.62 and 0.55 ppm were found on pods harvested 3 and 7 days, respectively, after the last application of the mancozeb plus sulfur tank mix. EBDC residues were not detected on beans from the phenology treatment plots and were therefore within the 0.1-ppm Canadian tolerance level.

In the 1985 experiment, differences in EBDC residues between the maneb plus sulfur tank mix full-season and the phenology treatment were not found.

Table 3. Preplanned single-degree-of-freedom orthogonal contrasts, orthogonal contrast sum of squares (CSS), and *F*-test values (*F*) for snap bean rust severity in experimental plots at Homestead, FL in 1984

	Statistics for transformed ($\log_{10} + 1$) number of rust pustules[a]					
	9 April		16 April		23 April	
Preplanned contrasts	**CSS**	***F***	**CSS**	***F***	**CSS**	***F***
Control vs. treatment	1.59	6.92*[b]	8.87	39.5*	24.80	91.79**
Sterol inhibitors vs. other fungicides	2.17	9.44**	17.93	79.88**	28.96	107.20**
Chlorothalonil vs. mancozeb + sulfur, phenology treatment[c]	0.01	0.08	0.45	2.00	0.03	0.12
Mancozeb + sulfur vs. phenology treatment	0.02	0.12	0.71	3.18	0.14	0.50
Rates of chlorothalonil	0.41	1.79	0.18	0.78	0.22	0.80
Bitertanol vs. triadimefon	0.02	0.11	0.29	1.30	0.24	0.88
Bitertanol on-demand vs. bitertanol weekly	2.93	12.73**	0.00	0.00	0.015	0.05
Rates of bitertanol	0.00	0.00	0.00	0.00	0.00	0.00
Rates of triadimefon	0.03	0.13	0.24	1.10	0.0038	0.014

[a] Based on number of pustules on abaxial surfaces of five midcanopy trifoliolate leaves and are the means of four replicates.

[b] * = Significant difference(s) at $P = 0.05$ and ** = significant differences at $P = 0.01$.

[c] Treatment based on snap bean crop phenology. Mancozeb (13.4 kg a.i./ha) + sulfur (2.24 kg a.i./ha) sprayed weekly until flowering (16 April 1984) followed by chlorothalonil (2.34 kg a.i./ha) for the remainder of the crop.

Table 4. Preplanned single-degree-of-freedom orthogonal contrasts, orthogonal contrast sum of squares (CSS), and *F*-test values (*F*) for snap bean rust severity in experimental plots at Homestead, FL, in 1985

	Statistics for transformed ($\log_{10} + 1$) number of rust pustules[a]			
	18 April		23 April	
Preplanned contrasts	**CSS**	***F***	**CSS**	***F***
Control vs. treated	4.99	40.22**[b]	7.17	16.26**
Maneb, sulfur, maneb + sulfur, phenology treatment[c] vs. other fungicides	4.64	37.41**	11.41	258.73**
Maneb, sulfur, maneb + sulfur, vs. phenology treatment	0.16	1.25	0.03	0.71
Maneb, sulfur vs. maneb + sulfur	0.31	2.50	0.59	13.4**
Maneb vs. sulfur	0.15	1.19	0.07	1.51
Bitertanol vs. chlorothalonil	11.21	92.10**	16.56	373.31**
Bitertanol on-demand vs. bitertanol weekly	0.38	3.02	0.14	3.23
Rates of bitertanol	0.17	1.40	0.00	0.00
Rates of chlorothalonil	0.08	0.61	0.44	10.02**

[a] Based on number of pustules on abaxial surfaces of five midcanopy trifoliolate leaves and are the means of four replicates.

[b] ** = Significant difference(s) at $P = 0.01$.

[c] Treatment based on snap bean crop phenology. Mancozeb (13.4 kg a.i./ha) + sulfur (2.24 kg a.i./ha) sprayed weekly until flowering (7 April 1985) followed by chlorothalonil (2.34 kg a.i/ha) for the remainder of the crop.

DISCUSSION

When field-grown snap beans were sprayed based on crop phenology (phenology treatment), EBDC residues were within the Canadian tolerance of 0.1 ppm. In addition, rust control based on crop phenology was comparable to the standard commercial practice of full-season weekly sprays of an EBDC plus sulfur tank mix. In 1984, full-season mancozeb plus sulfur sprays resulted in EBDC residues five times that allowed by Canadian law. Extending the preharvest interval from 4 to 7 days did not alleviate the residue problem.

EBDC was not detected on beans from either the phenology treatment or the full-season maneb plus sulfur plots in 1985. Rain, application of overhead irrigation, and variations in collection and shipment procedures all may influence the amounts of EBDC detected during analytical procedures. Even though the standard grower practice has been to spray up to 4 days before harvest with an EBDC fungicide, most Florida snap bean shipments tested in Canada in recent years have had less than 0.1 ppm of EBDC. This illustrates the sporadic incidence of objectionable EBDC residues.

The phenology treatment is a viable economic choice for Florida snap bean growers at this time. Fungicide costs per hectare per season for the phenology treatment and full-season maneb plus sulfur are $105 and $63, respectively. Although the phenology treatment represents a 67% cost increase, we feel the investment is justified to maintain the $6.5 million (1) Florida export trade to Canada.

Weekly sprays with the 1.17-kg a.i./ha rate of chlorothalonil also provided comparable control and cost only $94/ha/season. In some instances, control with the 2.34-kg a.i./ha chlorothalonil rate may be superior to the lower rate (Table 4). The cost of the higher rate ($188/ha/season), however, makes this a less attractive alternative.

Few statistically significant differences in yields were associated with the levels of rust control observed, as has been reported by others (5). Kingsolver et al (3) found that the earlier in the season wheat stem rust epidemics were initiated the greater the yield losses observed. In our trials, snap bean rust first appeared just before flowering. If epidemics had begun earlier, substantial yield losses may have occurred. Even when rust onset is late in crop development, termination of fungicide sprays at flowering is not recommended. Although direct disease damage to pods was very low in our tests, sporadic but potentially devastating pod damage from *Alternaria alternata* (Fr.) Keissler and some races of *U. phaseoli* can occur in southern Florida (8).

The two ergosterol biosynthesis inhibitor fungicides were very effective for rust control. In 1984, however, triadimefon was associated with a phytotoxic response manifested as a marked reduction in yield. No such yield loss was associated with bitertanol applications in either year. Currently, bitertanol is not registered for use on snap beans in the United States. When registration is finalized, the weekly spray with the lower rate is expected to be economically competitive with the phenology treatment and 1.17 kg a.i./ha chlorothalonil. When bitertanol was used on-demand (i.e., when weekly sprays were initiated after the first occurrence of rust), the degree of rust control at the end of the crop was comparable to that for weekly, full-season bitertanol sprays. In 1984 and 1985, two sprays and one spray, respectively, were saved in bitertanol on-demand plots. In an experiment planted in December 1983 (*unpublished*), five sprays were eliminated in the bitertanol on-demand plots. The savings in number of sprays when bitertanol was used on-demand may be related to the high intensity scouting of small plots. Whether growers can take advantage of the bitertanol on-demand strategy will depend on the economics of scouting to detect low levels of rust in commercial production fields.

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