Characterization of Fusarium Yellows Resistance in Collard

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ABSTRACT

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The yellows disease of cole crops, caused by *Fusarium oxysporum* f. sp. *conglutinans*, can be very damaging to collard. Growers in the southeastern United States frequently produce collard in hot, summer months when conditions for yellows development are favorable, and thus, incidence of this disease is increasing. A collection of essentially all U.S. commercial cultivars of collard, various landraces of collard, and other representative cole crops was evaluated for response to artificial inoculation with *F. oxysporum* f. sp. *conglutinans* under controlled-temperature conditions. In addition, the same collection was evaluated following transplanting for response to naturally infested soil in the field during summer 1997 and 1998. In all trials, genotype had the most significant effect on percentage of diseased plants, and genotype responses ranged from resistant (0 to 20% diseased) to susceptible (61 to 100% diseased). There was a significant temperature effect on percentage of diseased plants in one growth chamber experiment with five genotypes that resulted primarily from an increase in disease incidence for the cultivar Blue Max at 30°C compared with 25°C. Temperature was not significant in a second experiment with 20 genotypes. In the field, although significant differences were observed among genotypes and between years, a significant genotype × year interaction was not detected for percentage of diseased plants, indicating a similar ranking of genotypes for resistance between years. There was a significant correlation between results from controlled-environment studies and the field. A resistant response to *F. oxysporum* f. sp. *conglutinans* was expressed in certain cultivars of collard, including Flash, Heavycrop, and Morris Heading, and also in specific landraces. This resistance was stable in relatively high temperature environments used in evaluations. Results of this research indicate that choice of cultivar is a critical factor in producing collard where conditions favor infection by *F. oxysporum* f. sp. *conglutinans*. This information will aid in development of new yellows-resistant cultivars.

Yellows of cole crops (*Brassica oleracea* L.) is caused by a specific form of the persistent soilborne fungus *Fusarium oxysporum* Schlechtend.:Fr. f. sp. *conglutinans* (Wollenweb.) W.C. Snyder & H.N. Hans. that only infects members of the Brassicaceae. Yellows is a warm-weather disease and does not develop well at temperatures below 18°C (11). Most cole crops, including cabbage (*B. oleracea*, Capitata Group), broccoli (*B. oleracea*, Italica Group), Brussels sprouts (*B. oleracea*, Gemmifera Group), cauliflower (*B. oleracea*, Botrytis Group), and collard and kale (*B. oleracea*, Acephala Group), have representative accessions reported susceptible to yellows (11).

Collard has been traditionally grown during cool season environments in fall,

winter, and spring, when yellows is not typically a problem (9). However, more growers in the southeastern United States are producing collard in hotter summer months to provide buyers with a year-round supply of this vegetable. Consequently, reports of yellows in collard are increasing. Experience with yellows in other cole crops indicates that conventional control measures, such as seed treatment, crop rotation, and fungicide applications, would be ineffective for control of yellows in collard (11). Development of resistant cultivars of collard is more likely to result in control of this potentially damaging disease.

Wisconsin Hollander, a cultivar of cabbage, was the first reported cole crop bred with yellows resistance (6). Yellows resistance in this cultivar was determined to be polygenic (1) and also was shown to break down with increasing temperatures above 20°C (12). This type of resistance was designated "Type B" resistance (15). A more important yellows-resistant cultivar of cabbage, Wisconsin Ballhead, was described and released by Walker and Blank (14). Resistance in this latter cultivar was determined to be controlled by a single dominant gene (13) and was stable at temperatures up to 26 to 28°C (16). This sec-

ond type of yellows resistance was designated "Type A" (15). Type A resistance has been used effectively in cabbage for about 70 years and is often cited as a classic example of long-lasting, monogenic, dominant host-plant resistance (4). At present, cultivars of fresh market cabbage widely grown in the United States have Type A resistance to yellows, and outbreaks of this disease in primary cabbage production areas remain uncommon.

Type A and Type B resistances were both deemed effective against a primary form of *F. oxysporum* f. sp. *conglutinans*, designated as race 1. Race 1 has been identified as the primary cause of yellows in cabbage, and it can infect all known *B. oleracea* crops (4,11). Four other races of *F. oxysporum* f. sp. *conglutinans* have been reported, including: race 2, primarily found on radish (2); race 3, found on common stock (*Mathiola incanata*) in California (2); race 4, found on common stock in New York (3); and race 5, a unique form that infects cabbage with Type A resistance (10). Although race 5 is similar to race 1 in that it attacks cabbage, it is rare and has only been found in California (10). It is generally assumed that *F. oxysporum* f. sp. *conglutinans* in the southeastern United States is essentially all race 1 since cabbage that lacks Type A resistance and other susceptible *B. oleracea* crops are readily infected by yellows in this region, whereas cabbage with Type A resistance is protected against the disease.

Resistance to race 1 in cabbage may prove especially important to collard improvement. Cabbage is likely the closest relative to collard among all cole crops (5), and thus, it should be relatively easy to transfer resistance from cabbage to collard. A prerequisite for a program to develop yellows-resistant collard adapted to high temperature environments is to evaluate the relative resistance or susceptibility of existing collard germplasm and the stability of any potential resistances at high temperatures. There is little information on the relative susceptibility of cultivars of collard to yellows (7,8). Thus, the specific objective of this research was to evaluate a collection of collard for seedling response to inoculation with *F. oxysporum* f. sp. *conglutinans* race 1 under controlled-temperature conditions in growth chambers and plant response after transplanting into soils naturally infested with race 1 during hot summer growing conditions.

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MATERIALS AND METHODS

Controlled-temperature experiments.

Controlled-temperature experiments were conducted to evaluate response of collard seedlings to inoculation with *F. oxysporum* f. sp. *conglutinans* in two temperature regimes. Experiments were conducted in GC-15 plant growth chambers (Environmental Growth Chambers, Chagrin Falls, OH). Inoculation and disease evaluation involved a modification of procedures described by Williams (17).

In the first experiment, four cultivars of collard, including Top Bunch (Sakata Seed America, Inc., Morgan Hill, CA), Morris Heading and Georgia (Alf Christianson Seed Co., Mt. Vernon, WA), and Blue Max (Abbott and Cobb, Feasterville, PA), and one cabbage, Bravo (Harris Moran Seed Co., Salinas, CA), were tested. Bravo cabbage contains Type A resistance to *F. oxysporum* f. sp. *conglutinans* and served as the resistant control in this experiment. Preliminary studies indicated that Georgia and Top Bunch were highly susceptible to *F. oxysporum* f. sp. *conglutinans*, while Morris Heading and Blue Max exhibited some resistance (7). Thus, in selecting these five genotypes for this first experiment, we expected them to exhibit diverse reactions when inoculated with *F. oxysporum* f. sp. *conglutinans*. For this and all subsequent trials in the growth chamber, seed were germinated in Metromix 360 (Grace Sierra, Milpitas, CA) in seedling trays. Trays were maintained in a walk-in growth room at 22°C with a 14-h photoperiod supplying 240 $\mu\text{E}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$. After 12 days, seedlings were inoculated with *F. oxysporum* f. sp. *conglutinans*.

To prepare inoculum, one isolate of *F. oxysporum* f. sp. *conglutinans* race 1 from broccoli (supplied by C. Kurowski, Harris-Moran Seed Co., San Juan Bautista, CA) was used in all of the controlled-temperature experiments. This isolate was grown in potato dextrose broth on a platform shaker at 150 rpm for 4 days at 22°C. Spores were separated from mycelium by centrifugation for 2 min at 4,000 rpm, and a suspension of 1.0×10^7 microconidia per milliliter was prepared in sterile distilled water. Twelve-day-old seedlings were removed from the potting mix, and roots were lightly washed, blotted, and immersed in the conidial suspension for 5 min. Twenty inoculated seedlings of each genotype were then planted into $26 \times 54 \times 6$ cm trays filled with a 50:50 mix of Metromix 360 and washed quartz sand. Each genotype was placed at random into each of four trays. In addition, 20 non-inoculated seedlings of each genotype were transferred to two trays of the same potting soil:sand mix to serve as controls. The experimental design was a split-plot with temperature treatments randomized between chambers and genotypes randomized within temperature treatments. Two trays of inoculated seedlings and one control

tray were placed in each of two growth chambers. Each of the inoculated trays served as a subsample.

For 2 days, the growth chambers were set at the same conditions (constant 25°C with only one-third of chamber lights on for a 14-h photoperiod and relative humidity at 70%) to allow full recovery from transplant shock. After 2 days, both chambers were set with maximum available lights ($600 \mu\text{E}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$) with a 14-h photoperiod, but one chamber was maintained at constant 25°C and the other was set to a 30°C day/25°C night regime. For both temperatures, relative humidity was kept constant at 70%. Throughout the experiment, a filled reservoir of water was maintained in each of the chambers, allowed to equilibrate to the temperature of each chamber, and used to water plants. Numbers of asymptomatic (healthy), symptomatic (i.e., diseased and exhibiting one-sided yellowing, wilting, or necrosis of leaf tissue), and dead seedlings were recorded every 3 days, beginning 8 days after inoculation (DAI) and up to 24 DAI. The percentage of diseased plants (i.e., disease incidence) for a given genotype was calculated using the sum of symptomatic plus dead seedlings. In this and all other trials, genotypes were given a relative resistance rating based on percentage of diseased plants, with 0 to 20% designated resistant, 21 to 40% moderately resistant, 41 to 60% moderately susceptible, and 61 to 100% susceptible. This experiment was repeated, and the two trials (treated as separate replications) were combined to analyze genotype and temperature regime effects on disease incidence.

In a second experiment, 20 genotypes were tested. These included: the five genotypes evaluated in the first experiment; the collard cultivars Flash and Heavycrop (Abbott and Cobb); the collards Champion, Vates, and Green Glaze (Alf Christianson); two experimental breeding lines of collard, S.C. Header and S.C. Glaze, maintained by M. Farnham; four landraces of collard designated N.C. landrace-1, N.C. landrace-2, S.C. landrace-1, and S.C. landrace-2 collected and maintained by M. Farnham; two cultivars of broccoli, Baccus and Packman (Seminis Vegetable Seed, Woodland, CA), and two cultivars of kale, Blue Knight and Blue Armor (Alf Christianson Seed Co.). This set of genotypes included all commercially available collard cultivars except one. The cultivars of broccoli and kale were included to determine their relative reaction to *F. oxysporum* f. sp. *conglutinans*. Bravo cabbage again served as resistant control.

Germination of seed, seedling inoculation, and setup of the second experiment were the same as that described for the first experiment, except that there was only one sample of 20 seedlings per genotype in each chamber-treatment. In addition to four trays of inoculated seedlings at each

temperature, one tray of noninoculated controls (five seedlings for each of the 20 genotypes) also was included. Data were collected in the same manner in this experiment as in the first experiment. The experiment was repeated, and the two trials (treated as separate replications) were combined to analyze genotype and temperature effects on disease incidence.

Field trials in naturally infested soil.

Two field trials, one each in 1997 and 1998, were conducted in a grower's field (Lakeland sand, pH 6.2) in Lexington County, SC, that had been abandoned for summer collard production because of a high incidence of yellows. In addition to the 20 entries tested in the second growth chamber experiment, five additional entries were included. These were: a cultivar of collard, HiCrop (Park Seed Co., Greenwood, SC); a landrace of collard designated TX landrace-1, collected and maintained by M. Farnham; and three cultivars of kale, Vates, Red Green Glaze, and Squire, obtained from E. Borchers (Hampton Roads Exp. Stn., Hampton Roads, VA). As in the controlled-temperature studies, Bravo cabbage served as the yellows-resistant control.

Seed of all genotypes were planted during the second week of May in 150-cell trays filled with Metromix 360. Prior to transplanting, the field was disked and fertilizer with 4-24-16 N-P-K was broadcast at 336 kg/ha. Seedlings were transplanted to the field on 19 June 1997 and 15 June 1998. Plants that died from transplant shock were replaced within a week of transplanting. Stand counts were taken 2 weeks following transplanting to adjust the stands for loss of plants. We assumed any plants lost within the first 2 weeks died from causes other than yellows. In both years, plants were side-dressed three times with fertilizer with 22-0-22 N-P-K at 170 kg/ha and once with fertilizer with 33.5-0-0 N-P-K at 112 kg/ha. Insects were managed with applications of *Bacillus thuringiensis* at the high recommended rates. Plots were irrigated with 13 to 18 mm of water applied three to four times weekly as needed. Both experiments used a completely randomized design, since we had no basis for blocking the field with regard to gradients that might influence distribution of *F. oxysporum* f. sp. *conglutinans*. Instead, we assumed that the fungus was randomly distributed throughout the field. There were five replications of each entry with 30 plants per plot. Spacing between rows was 1.02 m, and spacing between plants within a row was 0.3 m.

Symptoms of yellows were evaluated visually 5, 7, and 10 weeks after transplanting by recording the number of plants without symptoms, with typical symptoms of one-sided leaf yellowing or distortion of leaves, or that were dead. The number of symptomatic plus dead plants was divided by the number of living plants recorded 2

weeks post-transplanting to calculate percentage of diseased plants per plot. Plots were maintained several weeks after the week 10 observations, but incidence of yellows did not increase during this time. Thus, percentage of diseased plants at 10 weeks after transplanting was deemed the critical measure for evaluating relative resistance or susceptibility of all genotypes. The data sets from 1997 and 1998 were combined and analyzed together to determine genotype, year, and genotype $\times$ year effects on disease.

Statistical analysis. All analyses of variance were performed with PROC GLM of SAS (SAS Institute, Cary, NC; release 6.12). All data sets were tested for equality of variance and normality before analysis, but transformations were not necessary. Means of disease incidence for 20 genotypes tested in both the second growth chamber experiment and the field trials were compared, and Pearson correlation coefficients were calculated to determine if growth chamber and field results were correlated.

RESULTS

In the first and all subsequent controlled-temperature trials, symptoms of yellows were first observed 5 DAI and the percentage of diseased plants among inoculated genotypes plateaued by 21 DAI (Fig. 1). Therefore, readings at 21 DAI were treated as peak disease incidence. There was no evidence of any disease symptoms in noninoculated controls in the first and all subsequent growth chamber trials. In addition, percentages of diseased plants were not significantly different between the two subsamples per entry within a temperature treatment (growth chamber).

Statistical analysis of the first growth chamber experiment indicated that tem-

perature, genotype, and temperature $\times$ genotype interaction effects were significant ($P \leq 0.05$) for percentage of diseased plants at 21 DAI (Table 1). At both temperatures, the resistant control, Bravo cabbage, was relatively free of disease. Conversely, Top Bunch and Georgia collard genotypes were susceptible to *F. oxysporum* f. sp. *conglutinans* at both temperatures, exhibiting very high percentage of diseased plants at 21 DAI. Morris Heading was significantly more susceptible than the resistant cabbage at both temperatures, but exhibited a relatively resistant response compared with Top Bunch and Georgia. The significant temperature and genotype $\times$ temperature effects for percentage of diseased plants at 21 DAI are largely explained by a nearly fourfold increase in percentage of diseased plants for Blue Max at 30°C than at 25°C (Table 1). At 25°C, Blue Max was not significantly different from resistant Bravo, but it was moderately susceptible at 30°C.

In the second experiment in growth chambers, analysis of variance indicated that only the genotype effect was significant, whereas temperature and genotype $\times$ temperature effects were not significant (Table 2). Bravo, Morris Heading, Blue Max, Top Bunch, and Georgia exhibited similar levels of disease to the first experiment. Among the additional genotypes of collard, Flash, Heavycrop, Champion, and N.C. landrace-1 and -2 were similar to Bravo in disease response at both temperatures. Other genotypes of collard, including Vates, S.C. landrace-2, and Green Glaze, were moderately resistant or moderately susceptible, exhibiting consistently more disease than Bravo but less than the susceptible Top Bunch or Georgia. Both cultivars of broccoli were more susceptible

than the resistant control, but Baccus had a significantly lower percentage of diseased plants than Packman. Both cultivars of kale were susceptible, exhibiting 85% or greater diseased plants.

Statistical analysis of 1997 and 1998 field trials showed highly significant differences between years and among genotypes for percentage of diseased plants 10 weeks after transplanting (Table 3) but no year $\times$ genotype interaction. In general, yellows was more severe in 1997 than in 1998. The resistant cabbage Bravo had 6.1 and 2.2% diseased plants in 1997 and 1998, respectively. The most susceptible entry in both field trials was Blue Armor kale, with 76.9 and 69.8% diseased plants, respectively, in 1997 and 1998. Among genotypes of collard, Flash, Heavycrop, Morris Heading, Top Bunch, N.C. landrace-1 and -2, HiCrop, Blue Max, Champion, and S.C. landrace-2 were not significantly different from Bravo in both years. Most of these genotypes always had a

Table 1. Mean percentage of diseased plants at 21 days after inoculation with *Fusarium oxysporum* f. sp. *conglutinans* race 1 for cv. Bravo cabbage and four collard cultivars grown in 25°C day/25°C night or 30°C day/25°C night regimes in a growth chamber

Cultivar	Diseased (%)	
	25/25°C	30/25°C
Bravo	2.5	5.3
Top Bunch	95.0	97.4
Morris Heading	16.2	25.1
Georgia	80.8	97.9
Blue Max	12.5	44.1
LSD _{0.05} ^z	11.7	11.4

^z Fisher's protected least significant difference, $P = 0.05$. Each LSD_{0.05} was computed from separate analysis of variance by temperature.

Fig. 1. Mean percent diseased or dead plants for four collard cultivars and cabbage cv. Bravo following inoculation with *Fusarium oxysporum* f. sp. *conglutinans* in growth chambers with either a constant 25°C temperature regime or a day/night regime of 30°C/25°C.

higher mean percentage of diseased plants than Bravo, but these differences were not statistically significant ($P \leq 0.05$). The relatively resistant response for Top Bunch in the field was very different than the susceptible response for this entry in the growth chamber seedling tests. S.C. Header and Vates were significantly more susceptible than Bravo in 1998 but not in 1997. Conversely, S.C. landrace-1 was more susceptible than the resistant control in 1997 but not in 1998. The remaining collard entries had significantly greater percentage of diseased plants than Bravo in both years. As in the growth chamber, Georgia was susceptible to yellows in the field. For broccoli, Baccus was not significantly different from the resistant control in either year, whereas Packman was significantly more diseased than the resistant control in 1997 but not in 1998. In general, cultivars of kale were susceptible to *F. oxysporum* f. sp. *conglutinans* and exhibited a high percentage of diseased plants (38.0 to 76.9) in both years.

Means for percentage of diseased plants for the 20 different genotypes tested in both the growth chamber and the field were significantly correlated between the two types of disease evaluation trials ($P < 0.001$). Correlation coefficients between genotype means for percent diseased plants at 25°C, 30°C, or the combined mean of 25 and 30°C in growth chambers and the genotype means derived by averaging results of both field trials were 0.729, 0.709, and 0.730, respectively. When Top Bunch, which exhibited drastically different responses in seedling tests versus field tests, was removed from the analysis, the correlation coefficients increased to 0.870, 0.856, and 0.879, respectively.

DISCUSSION

Symptoms of yellows were readily observed in seedling evaluations within growth chambers where 12-day-old seedlings were artificially inoculated with *F. oxysporum* f. sp. *conglutinans* and in field trials where 4- to 5-week-old plants were set into naturally infested soil. Overall, percentages of diseased plants were higher in seedlings in the growth chambers than they were in the field. This may have been caused by all seedlings contacting the pathogen in the artificially inoculated trials, whereas some transplants probably escaped infection in the field, because the fungus likely was not distributed evenly or in sufficiently high inoculum densities to affect all plants uniformly. Alternatively, the relatively older plants used in the field studies may have been less susceptible compared with the seedlings inoculated in the growth chamber.

Across all trials, the resistant control Bravo exhibited the fewest diseased plants of all genotypes. Some individual plants of Bravo, known to contain type A resistance, exhibited symptoms of yellows, but this

was relatively rare. Walker and Smith (16) also observed some symptoms in a few individuals of cabbage from homozygous lines expressing type A resistance, and such individuals were more frequent at temperatures above 28°C. Interestingly, we observed no significant difference between Bravo in the 25°C/25°C and 30°C/25°C regimes in growth chambers, and susceptible individuals of Bravo also were infre-

quent in the field trials in Lexington, where soil temperatures typically exceed 30°C during summer. Although there has been some conflicting discussion about whether or not type A resistance may break down at 28°C or higher (4,11,16,17), it appeared very stable at temperatures of 30°C and above that occurred in our trials. It is also possible that rare susceptible individuals in Bravo could represent susceptible inbreds

Table 2. Mean percentage of diseased plants 21 days after inoculation with *Fusarium oxysporum* f. sp. *conglutinans* for 20 genotypes of *Brassica oleracea* grown in 25°C day/25°C night or 30°C day/25°C night regimes in a growth chamber

Crop	Genotype	Diseased (%)	
		25/25°C	30/25°C
Cabbage	Bravo	0.0	5.0
	Flash	0.0	15.0
Collard	Heavycrop	2.5	0.0
	Champion	5.0	20.0
	Morris Heading	7.5	15.0
	Blue Max	7.5	35.0
	N.C. landrace-1	12.5	20.0
	S.C. landrace-1	12.5	40.0
	N.C. landrace-2	20.0	15.0
	S.C. Header	21.5	35.0
	Vates	30.0	52.5
	S.C. landrace-2	40.0	22.5
	Green Glaze	40.0	50.0
	S.C. Glaze	52.5	65.0
	Georgia	72.5	75.0
	Top Bunch	92.5	100.0
Broccoli	Baccus	32.5	45.0
	Packman	87.5	82.5
Kale	Blue Knight	85.0	100.0
	Blue Armor	97.5	95.0
	LSD _{0.05} ^z	24.4	27.9

^z Fisher's protected least significant difference, $P = 0.05$. Each LSD_{0.05} was computed from separate analysis of variance by temperature.

Table 3. Mean percentage of diseased plants 10 weeks after transplanting 25 genotypes of *Brassica oleracea* to a field naturally infested with *Fusarium oxysporum* f. sp. *conglutinans*

Crop	Genotype	Diseased (%) ^y	
		1997	1998
Cabbage	Bravo	6.1	2.2
	Flash	3.5	14.5
Collard	Heavycrop	7.3	3.8
	Morris Heading	10.0	8.3
	Top Bunch	14.8	6.2
	N.C. landrace-1	15.4	3.6
	Hi Crop	16.0	3.0
	N.C. landrace-2	16.4	5.7
	S.C. Header	19.6	24.6
	Blue Max	20.9	5.7
	Champion	20.9	7.8
	S.C. landrace-2	24.3	17.3
	Vates	25.9	18.8
	S.C. landrace-1	26.2	8.1
	Green Glaze	29.4	28.1
	S.C. Glaze	37.7	32.4
Broccoli	Georgia	69.9	55.9
	TX landrace-1	71.1	66.4
	Baccus	20.4	2.7
	Packman	37.0	16.9
Kale	Blue Knight	46.8	38.0
	Red Gleen Glaze	69.5	38.8
	Vates	70.5	48.1
	Squire	74.1	58.5
	Blue Armor	76.9	69.8
	LSD _{0.05} ^z	20.1	16.4

^y Mean of five replications of 30 plants each.

^z Fisher's protected least significant difference, $P = 0.05$.

that occur within the hybrid. Generally, the self-incompatibility system used to make cabbage hybrids is not 100% effective, allowing for a low frequency of selfing that results in the presence of inbred seed among hybrid seed.

The relatively high percentages of diseased plants for genotypes of kale in both growth chamber and field trials indicate a general susceptibility of this cole crop to yellows. The response of kale in the field confirmed that *F. oxysporum* f. sp. *conglutinans* was generally present and well distributed throughout the field site, which was recognized by the cooperating grower as "heavily" infested. The susceptible response of kale in these trials compared with the resistant cabbage control provides a good differential with which to judge the relative resistance or susceptibility of collard, the primary focus of our research.

This study provides the first definitive evidence that significant resistance to yellows is expressed in certain commercial cultivars of collard, e.g., Flash and Heavycrop, as well as in some relatively uncharacterized collard germplasm, e.g., N.C. landrace-1. In contrast, other cultivars of collard, e.g., Georgia, or germplasm (TX landrace-1) are susceptible. Although increasing day temperature from 25 to 30°C in growth chamber studies increased disease incidence for some entries, in most cases the increases were not significant and the relative rank of entries did not change at the higher temperature. A notable exception is Blue Max, which appeared relatively resistant at 25°C/25°C but moderately susceptible at 30°C/25°C. It seems highly likely that Blue Max might contain a different resistance than type A expressed in Bravo, since the cabbage control was little impacted by temperature.

Overall, results of growth chamber seedling evaluations were correlated with field evaluations. Top Bunch was the only outlier for this trend, exhibiting 90 to 100% diseased plants in the growth chamber studies but responses not significantly different from resistant Bravo in the field. This extreme difference for Top Bunch indicates that the growth chamber and field tests assessed different attributes of infection by *Fusarium* and will not give the

same result for all possible genotypes of collard and other *B. oleracea* crops. We chose to use transplants in our field studies, as transplanting is the common practice to establish collard when environmental conditions are too harsh for direct seeding.

Results of this study show that choice of cultivar is probably the most critical factor in producing collard where *F. oxysporum* f. sp. *conglutinans* may be present in the soil and high temperatures may favor the disease. By growing resistant cultivars such as Flash, Heavycrop, or Morris Heading, producers will minimize the risk of yellows. Results also suggest that development of new yellows-resistant collard cultivars could be accomplished using two different strategies. One approach would involve moving the type A resistance in cabbage to a collard background. Since Farnham (5) showed that cabbage and collard are closely related, this approach should prove feasible. Another approach would be to develop a new cultivar of collard using the resistance already present in certain cultivars such as Flash. This latter alternative may have the advantage of exploiting possible new genes for resistance not already used in cabbage.

New cultivars of cabbage in the United States are all screened for resistance to yellows. Most determinations of resistance are based on some form of seedling test similar to the one we conducted in a controlled-temperature environment. Since results of our growth chamber and field evaluations were highly correlated, we suggest that programs aimed at developing new collard cultivars with yellows resistance should also utilize a seedling test such as the one we described. Using this approach, a differential response to *F. oxysporum* f. sp. *conglutinans* should be readily observed, and individuals of collard determined to be resistant could be advanced and used as parents in breeding for resistance to yellows or ultimately used as resistant, commercial cultivars.

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