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Response of *Brassica oleracea* L. to *Bemisia tabaci* (Gennadius)

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Abstract. **The relative resistance of 18 cultivars of *Brassica oleracea* L. to attack by the sweetpotato whitefly [Bemisia *tabaci* (Gennadius)] was studied in screen cage (spring), field (autumn), and laboratory tests. The B. *oleracea* entries consisted of six types, including 16 green and two red cultivars. Cabbage (Capitata Group) and broccoli (Boytrytis Group) were less infested than other crops in a screen cage test, with kale, collard (Acephala Group), and brussels sprouts (Germmiter Group) experiencing relatively high and kohlrabi (Gongtlodes Group) intermediate infestations. Relative ranking of crops was similar in an autumn field study, with the exception of brussels sprouts, which had an intermediate level of infestation. Differences in numbers of whiteflies among cultivars within crops were negligible or inconsistent, except that red cultivars of brussels sprouts ('Rubine') and cabbage ('Red Acre') were much less infested than green cultivars. In a laboratory test, differences of whitefly oviposition and nymphal survival and development were small, indicating that nonpreference factors, rather than antibiosis, are the best explanations for differences in the numbers of whiteflies among the *B. oleracea* cultivars that were tested,**

The sweetpotato whitefly has recently expanded its host range and increasingly has damaged *Brassica oleracea.* In California, damage has been particularly severe in broccoli and cauliflower (Perring et al., 1991), and in southern Texas, it has been severe in cabbage (Committee on Agriculture, U.S. House of Representatives, 1992). These whitefly attacks have caused economic hardship not only because of direct injury to the crop but also because of the monetary loss from decreased marketing opportunities. In addition, whitefly infestations of vegetable brassicas can lead to an increase of whitefly populations on warm-weather crops such as cotton *(Gossypium hirsutum* L.) and cucurbits by providing a refuge for breeding and development during the winter months (Committee on Agriculture, U.S. House of Representatives, 1992).

Brassica oleracea is a polymorphic species that provides a variety of vegetables for human consumption. The various crops of this species represent diverse botanical varieties that produce distinct harvestable plant parts and exhibit unique morphologies. Differences in anthocyanin intensity in the foliage and the presence or lack of waxy bloom on the leaf surface can result in different color and appearance characteristics that have been found to affect levels of insect infestation (Eigenbrode and Shelton, 1990; Radcliffe and Chapman, 1966).

Our objective was to investigate the effect of various crops, cultivars, and color forms of *B. oleracea* on levels of whitefly infestations on plants grown in screen cage and field experiments. In the laboratory, we tested whether the differences observed in the screen-cage and field tests were due to nonpreference factors, antibiosis, or both.

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Materials and Methods

Six groups of *B. oleracea* were tested in this study: kale and collard, cabbage, broccoli, kohlrabi, and brussels sprouts. Each crop was represented by three cultivars.

Screen cage test. For the screen cage test, plants were seeded in a greenhouse on 1 Mar. 1992 into a commercial peat mixture. On 1 Apr., seedlings were transplanted into a 40 x 20 × 3.4-m, outdoor screen cage. The plot area consisted of single rows on raised beds 1 m apart with 0.7-m spacing between plants in a row. This area was fumigated with methyl bromide and fertilized at the rate of 1135 kg 10N–10P_2O_5–10K_2O/ha before planting. Plots were sidedressed with NH_4NO_3 as recommended (Cook and Ezell, 1983). The design was a randomized complete block with four replicates per treatment. Crops were randomized within each block and cultivars were nested within respective crops. Each replicate consisted of three plants per cultivar. On 15 Apr., ≈10,000 whitefly adults were released into the screen cage. From 17 Apr. to 16 June, adult whiteflies per plant were counted weekly (except the first three weeks of May). Height. diameter, and number of leaves of each plant were also recorded. Counts of whitefly nymphs were taken from one randomly selected leaf from the lower third of each plant on 19 May and 10 June. On 2 June, a color reading was made on the upper surface of a randomly selected leaf from the upper third of each plant with a chromameter (model CR-200; Minolta, Ramsey, N.J.). Data in this and other experiments were subjected to analyses of variance and means were separated using a general linear models procedure together with the least significant difference test at $P \leq 0.05$.

Field test. In a separate field test, conducted during late Summer and Autumn 1992, all of the *B. oleracea* groups and cultivars used in the spring study (with the exception of 'Rio Verde' cabbage substituting for 'Golden Acre') were included. In this test, we relied on naturally occurring populations of whiteflies to infest the plants. Plants were seeded in the greenhouse on 29 July and transplanted to the field on 3 Sept. The plot area was not fumigated, but plots were fertilized as previously described for the screen cage study. Weekly measurements of whitefly populations and plant traits were also taken as described for the screen cage study conducted in spring and were recorded for each plant beginning 8 Sept. and ending 28 Oct. In both outdoor tests, the cumulative insect days (Johnson et al., 1992; Ruppel, 1983) per plant were calculated from the weekly adult counts. This statistic combined the number of insects present and the time they persist, and it provides a better measure of their overall impact than weekly density records. The design and number of experimental units were as previously described for the spring, screen cage study.

Laboratory test. Cultivars used in the screen cage and field experiments were tested for their effects on oviposition and whitefly nymph survival and development in a no-choice laboratory test. When greenhouse-grown plants had five true leaves, they were transplanted to 800-cm^3 clay pots and moved to a controlled-environment room held at a constant 25+ 2C, photoperiod of 12h light: 12 h dark, and alight intensity of 120 $\mu mol \bullet m^{-2} \bullet s^{-1}$. The design was a split-plot with crops as main plots and cultivars as subplots. Each of the five replications included one plant per cultivar. Five whitefly females were placed in a clip-on sandwich cage 1.7 cm in diameter (Lewis, 1973) on the youngest leaf on which a cage would fit. After 24 h, the cage and females were removed and the eggs counted. The eggs began to hatch after 1 week, at which time the total number of first-stage nymphs was determined. When adults began to eclose, the number of empty pupal cases was counted daily until eclosion ceased. Nymphal mortality on a plant was calculated from the number of newly hatched nymphs minus the number of empty pupal cases.

Results and Discussion

In the screen cage study, the number of released whitefly adults gradually declined

(Table 1), and by early May, only immatures were present on the plants. Adults from this generation began to emerge in late May, and the whitefly population increased for the duration of the experiment as the temperature increased. In contrast, the numbers of naturally occurring adult whiteflies were relatively constant in the field experiment (Table 2).

In the screen cage experiment, adult whitefly counts were highest on kale, brussels sprouts, and collard; counts were usually lower on broccoli, kohlrabi, and cabbage (Table 1). This difference was particularly evident in comparisons of cumulative insect days for the six crops (Table 1). Additionally, fewer whitefly nymphs were found on cabbage and broccoli by 16 June than on the other four crops (Table 3). In the autumn field experiment, kale and collard again had more whitefly adults and higher cumulative insect days than other crops, although broccoli and cabbage harbored the lowest populations (Table 2). Contrary to observations in the screen cage experiment where brussels sprouts had high whitefly populations (Table 1), the number of whiteflies were intermediate on autumn-grown brussels sprouts (Table 2).

Table 1. Mean number of adult whiteflies per plant on *Brassica oleracea* crops and cultivars grown in screen cage experiment (spring).

Crop and	Mean adult whiteflies/plant							Cumulative insect
cultivar	17 Apr.	24 Apr.	29 Apr.	26 May	2 June	9 June	16 June	days
Broccoli	9.3 CB[z]	2.8 D	1.0 B	11.1 C	17.9 C	15.3 C	12.3 B	541 B
Atlantic	8.9 a[y]	3.3 a	2.0 a	14.3 a	17.5 ab	13.7 a	17.1 a	621 a
Calabrese	12.0 a	3.0 a	0.8 a	15.7 a	27.9 a	21.6 a	11.9 a	746 a
Green Goliath	6.8 a	2.1 a	0.3 a	3.1 b	8.3 b	10.5 a	7.9 a	255 a
Brussels sprouts	6.7 A	10.4 A	1.5 AB	36.1 A	60.9 A	64.8 A	108 A	2052 A
Catskill	24.4 a	16.7 a	2.0 a	58.8 a	91.6 a	99.3 a	150 a	3139 a
Jade	22.2 a	10.4 b	2.2 a	40.8 a	83.2 a	82.9 a	143 a	2575 a
Rubine	3.4 b	4.0 c	0.3 b	8.5 b	8.7 b	12.1 b	30.2 b	441 a
Cabbage	7.3 C	3.7 CD	1.5 AB	9.3 C	10.4 C	10.0 C	10.1 B	418 B
Charleston Wakefield	10.6 a	5.7 a	1.9 a	13.4 a	16.3 a	14.1 a	21.7 a	634 a
Golden Acre	7.9 ab	4.7 ab	2.3 a	12.4 a	12.4 a	14.3 a	7.3 b	531 a
Red Acre	3.4 b	0.7 b	0.3 b	2.0 b	2.4 b	1.6 b	1.3 b	89 b
Collard	3.3 AB	6.4 CB	2.5 A	26.5 B	62.5 A	65.5 A	112 A	1893 A
Green Glaze	11.3 a	4.2 a	2.3 a	15.9 a	43.1 a	38.2 b	70.1 b	1205 a
Morris Heading	15.7 a	7.8 a	2.7 a	29.0 a	88.25 a	98.9 a	152 a	2514 a
Vates	13.1 a	7.2 a	2.5 a	34.5 a	56.2 a	59.5 ab	113 ab	1959 a
Kale	2.5 AB	6.9 B	1.6 AB	27.3 AB	40.4 B	41.3 B	132 A	1634 A
Dwarf Blue Curled Vates	7.4 b	3.0 b	1.1 a	16.9 a	27.4 b	34.3 b	95.3 a	1133 a
Red Russian	14.7 a	8.1 a	1.9 a	36.1 a	57.7 a	67.5 a	176.2 a	2275 a
Vates	15.5 a	9.0 a	1.7 a	28.8 a	36.0 b	22.0 b	123.2 a	1494 a
Kohlrabi	9.5 CB	5.7 CB	1.6 AB	15.6 C	22.8 C	16.9 C	34.6 B	773 B
Kolibri	9.9 a	6.3 a	2.2 a	22.7 a	17.7 a	10.2 a	26.5 a	806 a
Purple Vienna	11.4 a	4.7 a	1.5 a	15.2 a	19.4 a	16.4 a	39.9 a	757 a
White Vienna	7.1 a	6.0 a	1.0 a	8.8 a	31.3 a	24.2 a	37.4 a	756 a

[z]Mean separation in columns for crops by LSD test at $P \leq 0.05$,
[y]Mean separation of individual cultivar within each crop by LSD test at $P \leq 0.05$.

Table 2. Mean number of adult whiteflies per plant on *Brassica oleracea* crops and cultivars grown in field experiment (autumn).

Crop and	Mean adult whiteflies/plant								Cumulative insect
cultivar	8 Sept.	15 Sept.	22 Sept.	29 Sept.	7 Oct.	15 Oct.	21 Oct.	28 Oct.	days
Broccoli	5.3 B[z]	4.6 B	10.6 CB	7.6 CD	3.0 C	9.2 B	6.3 D	9.7 C	331 D
Atlantic	5.1 ab[y]	5.3 a	7.7 a	6.2 a	3.0 a	7.8 a	8.1 a	6.9 a	313 a
Calabrese	3.2 b	3.0 a	11.9 a	5.0 b	2.3 a	11.1 a	5.6 a	9.5 a	378 a
Green Goliath	7.7 a	5.6 a	12.3 a	12.4 a	3.1 a	8.6 a	4.7 a	12.7 a	326 a
Brussels sprouts	5.6 B	5.5 B	7.0 C	9.3 CD	3.8 CB	10.2 B	13.7 CB	14.4 C	374 D
Catskill	5.7 b	4.4 b	9.3 a	13.9 a	3.3 ab	15.3 a	21.5 a	17.0 a	541 a
Jade	10.0 a	11.7 a	9.4 a	13.4 a	7.0 a	12.3 a	14.9 a	17.3 a	502 a
Rubine	0.7 c	0.3 b	1.6 a	2.1 b	0.8 b	1.9 b	3.0 b	8.5 a	78 b
Cabbage	5.5 B	2.6 B	6.0 C	6.7 D	3.3 CB	7.8 B	10.1 CD	8.8 C	291 D
Charleston Wakefield	5.3 ab	2.8 a	1.6 ab	9.1 a	4.7 a	12.7 a	15.1 a	12.3 a	393 a
Rio Verde	9.9 a	4.2 a	7.4 a	8.1 a	4.2 a	9.4 a	13.2 a	5.1 b	174 a
Red Acre	0.3 b	0.7 b	0.5 b	1.4 b	1.3 a	1.2 b	1.5 b	9.1 a	72 b
Collard	8.3 A	5.3 B	12.7 B	16.1 B	5.7 B	18.7 A	16.4 AB	26.8 B	641 B
Green Glaze	8.4 a	4.3 a	3.3 b	12.7 b	4.1 a	15.8 b	11.3 b	21.3 b	467 b
Morris Heading	6.0 a	3.3 a	8.1 b	9.7 b	6.9 a	10.7 b	15.3 ab	13.1 b	461 b
Vates	10.6 a	8.6 a	26.7 a	27.6 a	5.8 a	29.4 a	22.6 a	45.9 a	995 a
Kale	10.7A	11.0 A	12.7 A	26.0 A	11.0 A	21.8 A	19.1 A	34.0 A	845 A
Dwarf Blue Curled Vates	14.9 a	14.2 a	27.3 a	36.8 a	18.9 a	32.8 a	27.6 a	35.2 a	1058 a
Red Russian	8.4 b	7.4 a	25.1 a	21.2 a	6.2 b	15.8 b	9.7 b	28.2 a	687 a
Vates	8.6 b	11.3 a	13.8 a	20.4 a	8.8 b	18.7 b	21.5 a	38.7 a	790 a
Kohlrabi	5.9 B	3.6 B	9.6 CB	12.5 CB	4.2 CB	12.6 B	13.3 CB	31.5 AB	502 C
Kolibri	8.4 a	2.1 a	7.0 a	10.7 a	3.4 a	8.7 a	9.8 a	25.1 a	404 a
Purple Vienna	5.2 ab	2.6 a	8.4 a	11.5 a	4.8 a	15.9 a	9.1 a	33.3 a	468 a
White Vienna	4.3 b	6.1 a	13.7 a	14.9 a	4.5 a	13.2 a	20.7 a	36.3 a	634 a

[z]Mean separation in columns for crops by LSD test at $P \leq 0.05$.
[y]Mean separation of individual cultivars within each crop by LSD test at $P \leq 0.05$.

Variation exhibited by cultivars within crops depended on the crop group (Tables 1 and 2). No differences in cumulative insect days ($P \leq 0.05$) were found among broccoli, kohlrabi, or kale cultivars in either test, although adult counts on some dates were significant. The three collard cultivars consisted of 'Vates' and 'Morris Heading', cultivars with normal waxy bloom on foliage, and 'Green Glaze', a cultivar with leaves exhibiting a "glossy" appearance because of less waxy bloom.

Low amount of waxy bloom has been linked with resistance to diamondback moth, imported cabbage worm, and cabbage whitefly (Stoner, 1992; Thompson, 1963). Although not usually statistically significant, 'Green Glaze' had fewer whiteflies than the other two cultivars on all dates in the screen cage and on some dates in the field test (Tables 1 and 2). Significantly fewer whitefly nymphs were found on 'Green Glaze' (21.8 per leaf) compared to 'Vates' (83.3) and 'Morris Heading' (85.5) in the 10 June count.

The greatest differences in whitefly counts occurred among the brussels sprout cultivars. 'Catskill' and 'Jade' suffered the heaviest cumulative insect days over all cultivars in the screen cage experiment. In contrast, 'Rubine', a red cultivar, had the third lowest cumulative population (Table 1). Whiteflies were not as numerous on brussels sprouts in the autumn field test; even so, 'Rubine' had significantly fewer whiteflies than 'Catskill' or 'Jade' (Table 2).

Consistent and significantly different whitefly populations also occurred among cabbage cultivars. Similar to our brussels sprouts observations, the red 'Red Acre' cabbage was the cabbage least preferred by whiteflies as well as the least preferred of all cultivars in both outdoor tests (Tables 1 and 2). Fewer nymphs per leaf also were present on 'Red Acre' than on any other cultivar (Table 2).

Whitefly populations were higher on brussels sprouts relative to the other crops in the screen-cage test (Table 1) than in the autumn field test (Table 3). A comparison between the smaller brussels sprout plants and the other cole crops in the autumn study may account for the reduction in whitefly infestation. However, the respective environments of the spring and autumn trials possibly conditioned plants so that the relative resistance of crops was altered. There is considerable evidence that environmental conditions (e.g., temperature) can affect plant resistance to insect attack (Tingey and Singh, 1980). Although our two outdoor tests were conducted in different seasons, the temperature and moisture conditions to which plants were subjected were similar. Average spring and autumn temperatures for the durations of the tests were 22 and 20C, respectively. In addition, soil moisture conditions were maintained at an optimum in both seasons by supplementing rainfall with irrigation. The photoperiod was the environmental condition that varied the most between tests, and this difference cannot be ruled out as a possible factor altering relative resistances.

With the exception of observations of the relative resistance of brussels sprouts in the autumn field study, results of the spring and autumn studies were similar, with high whitefly infestations occurring on collard and kale and low ones on broccoli and cabbage. Also, whitefly populations were low on red cultivars in both outdoor tests.

There was little difference in oviposition by whiteflies isolated by clip cages on leaves of *B. oleracea* crops and cultivars grown in a controlled environment (Table 4). This result indicates that once female whiteflies were brought into contact with foliage, there were no chemical or physical factors present to deter egg laying under our experimental conditions. Survival of nymphs was high among all cultivars, although some significant differences occurred among crops (Table 4). The length of nymphal development differed only slightly among crops. The two red cultivars Red Acre cabbage and Rubine brussels sprouts, found to have such low densities of whiteflies in the previous two tests, differed little from other cultivars in oviposition, survival, or development. Optimally, whitefly antibiosis tests such as these would also be conducted under field conditions. However, considering the difficulty of eliminating contamination by naturally occurring whiteflies and their natural enemies in the greenhouse or field, we chose to use controlled conditions. At the same time, we are aware that the production of chemicals repellent or toxic to whiteflies may occur to a greater degree in one environment than in another. The lack of evidence for antibiosis in the laboratory is not entirely surprising, because examples of resistance involving whiteflies and most cases of cole crop resistance to insect pests involve antixenosis rather than antibiosis (Gerling, 1990; Maxwell and Jennings, 1980).

Unlike the laboratory test, in which whitefly adults were confined to specific plants, whiteflies in the screen cage and field tests were free to select plants on which to alight and become established. In these situations, nonpreference mechanisms such as visual cues and plant odors affect whitefly choices. Of these, vision is of primary importance in whiteflies and is used for discrimination of shapes, sizes, and colors (Vaishampayan et al., 1975a, 1975b; van Lenteren and Noldus, 1990). In outdoor tests, the largest differences in whitefly counts among cultivars appeared to be a response to color.

Color reading of the selected cultivars with the chromameter provided an objective measure of color values on the Hunter L, a, and b scale (Hunter and Harold, 1987). The tristimulus values considered, a and b, match the color stimulus considered. The red leaf cultivars Rubine brussels sprouts and Red Acre cabbage had significantly lower b values (closer to blue) and higher a values (closer to red) than two of their normal-colored counterparts, and they had consistently lower whitefly counts (Table 5). Whiteflies are attracted to yellow or yellow-green in laboratory and field tests (Berlinger, 1980; Husain and Trehan, 1940; Mound, 1962). Mound (1962) found that whiteflies were attracted by blue and ultraviolet light. However, Mound theorized that this was shortwave, light-induced, migratory behavior and would direct whitefly flight

Table 3. Number of whitefly nymphs on *Brassica* crops during screen cage experiment.

	Total nymphs/leaf[z]	
Crop	20 May	16 June
Broccoli	14.2 ab	23.2 c
Brussels sprouts	23.5 a	89.7 a
Cabbage	6.9 b	16.7 c
Collard	20.9 a	63.6 ab
Kale	26.5 a	75.5 ab
Kohlrabi	23.7 a	58.5 b

[z]Mean separation within columns by LSD at $P \leq 0.05$.

Table 4. Oviposition, survival, and development of immature whiteflies on Brassica crops and cultivars.

Crop and cultivar	Length eggs/ female	Nymphal survival (%)	Nymphal development (days)
Broccoli	10.8 A[z]	82 B	14.2 AB
Atlantic	9.5 ay	86.1 a	14.3 a
Calabrese	12.0 a	78.5 a	14.2 a
Green Goliath	10.9 a	81.3 a	14.0 a
Brussels sprouts	11.4 A	89.6 A	14.4 A
Catskill	12.7 a	83.6 a	14.8 a
Jade	11.6 a	89.7 a	14.2 a
Rubine	10.0 a	95.5 a	14.3 a
Cabbage	11.3 A	87.9 AB	14.2 AB
Charleston Wakefield	11.4 a	92.0 a	14.2 ab
Rio Verde	10.8 a	82.3 a	14.6 b
Red Acre	11.7 a	89.4 a	13.6 a
Collard11.5 A	88.5 AB	13.8 CB	
Green Glaze	10.6 a	92.0 a	13.8 ab
Morris Heading	11.6 a	83.4 a	13.4 a
Vates	12.4 a	90.1 a	14.2 b
Kale	10.7 A	89.7 A	13.2 D
Dwarf Blue Curly Vates	11.7 a	90.3 a	13.0 a
Red Russian	10.3 a	87.8 a	13.2 a
Vates	10.0 a	91.0 a	13.3 a
Kohlrabi	11.3 A	93.9 A	13.6 C

[z]Mean separation in columns for crops followed by LSD test at $P \leq 0.05$.
[y]Mean separation of individual cultivars within each crop by LSD test at $P \leq 0.05$.

Table 5. Differences in number of whitefly adults, and a and b color values (2 June 1992).

Crop and cultivar	No. adults[y]	Mean tristimulus values[z] a	b
Brussels sprouts			
Catskill	91.6	–11.4	12.8
Rubine	8.1	–6.7	5.8
Cabbage			
Golden Acre	12.4	–10.1	10.6
Red Acre	2.4	–5.7	2.8

[z]Paired comparisons between Catskill and Rubine, and Golden Acre and Red Acre for mean adults and a and b tristimulus values significantly different at $P \leq 0.05$.

[y]Mean number of whitefly adults.

toward the sky rather than foliage; therefore, it would not be involved in host finding. Burrows et al. (1983) studied visual attraction in the potato aphid and found that attractiveness could be expressed as a yellow : blue wavelength distimulus ratio, with higher ratios being more attractive. Whether a similar color preference with whiteflies exists at different wavelengths is not known. However, foliage that reflects peak wavelengths in the red or blue-green clearly is not attractive to the flies.

The visual response to shape and size of plants also may influence insect attraction. Elsey (unpublished) found that the number of whiteflies landing on collard plants during 24 h was correlated with plant size. An aphid pest of carrots *(Dancus carota* L.) was found to settle in numbers proportional to the area of foliage available to them (Dunn, 1969). In our work, the use of regression analysis to detect an association between the number of whitefly adults with plant dimensions was ambiguous. The most efficient linear regression model [by *R'* selection method (Freund and Lettell, 1991)] included the variables plant diameter and leaf count. This model usually resulted in a significant regression, but the percentage of this variation explained by the model varied from negligible to 40%.

Apart from antixenosis factors, gross structural differences among the crops may have contributed to differences in whitefly counts. For example, fewer whiteflies were found on cabbage than the other crops. This may be due in part to the head formation in cabbage that renders the favored upper portion of the plant (Butler et al., 1986) unfit or unavailable for feeding and oviposition.

Due to the significant damage that whiteflies can inflict on cole crops, further study of plant characters, such as red or glossy foliage, is warranted to evaluate the potential of using such characters to minimize whitefly infestations. Altieri and Schmidt (1987) showed that mixed plantings of different broccoli cultivars experienced lower cabbage aphid infestation than uniform cultivar plantings. Although the resistance associated with red foliage described in this study may not be transferable to green-colored cultivars, it is possible that mixed plantings of red and green ctdtivars might provide a management strategy for reducing whitefly infestations.

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