Verticillium Wilt of Cauliflower in California

STEVEN T. KOIKE, University of California Cooperative Extension, Salinas 93901; KRISHNA V. SUBBARAO, Department of Plant Pathology, University of California, Davis, c/o U.S. Agricultural Research Station, Salinas 93905; R. MICHAEL DAVIS, Department of Plant Pathology, University of California, Davis 95616; THOMAS R. GORDON, Department of Plant Pathology, University of California, Berkeley 94720; and JUDITH C. HUBBARD, Department of Plant Pathology, University of California, Davis, c/o U.S. Agricultural Research Station, Salinas 93905

ABSTRACT

Koike, S. T., Subbarao, K. V., Davis, R. M., Gordon, T. R., and Hubbard, J. C. 1994. Verticillium wilt of cauliflower in California. Plant Dis. 78:1116-1121.

Since 1990, commercial cauliflower in coastal California has been severely affected by a vascular wilt disease. Symptoms consist of chlorosis, defoliation, stunting, wilting, and vascular discoloration. Disease has been widespread and has caused significant damage in summer and fall crops. *Verticillium dahliae* was consistently isolated from xylem tissue in stems and roots of affected plants. Techniques tested for inoculation of cauliflower plants were dipping clipped or nonclipped roots into spore suspensions, injecting spore suspensions into cauliflower stems, and planting seedlings into soil along with an agar block colonized with microsclerotia. Only dipping roots into spore suspensions was consistently successful in causing Verticillium wilt. Pathogenicity was established by dipping roots of 30-day-old seedlings of cauliflower cv. White Rock into conidial suspensions (10^7 conidia per milliliter) for 5 min. Control plants were dipped into sterile distilled water. All plants were potted into autoclaved soil and incubated both in a growth chamber (20 ± 1/15 ± 1 C day/night regime) and in a greenhouse (23 ± 1/10 ± 1 C day/night regime). After 4 wk, inoculated plants were stunted and chlorotic and *V. dahliae* was reisolated, whereas control plants were symptomless and *V. dahliae* was not reisolated. When incubation temperature maxima in the greenhouse exceeded 30 C, inoculated plants failed to show symptoms. Soil from commercial fields was assayed for microsclerotia on NP-10 selective medium using the modified Anderson sampler. *V. dahliae* was widely distributed in the Salinas Valley, with propagule densities as high as 93 microsclerotia per gram of soil. Evaluation of cauliflower cultivars in *V. dahliae*-infested fields indicated that all were susceptible. This new disease has become a major threat to cauliflower production in coastal California.

Additional keywords: cole crops, cultural practices, disease management, resistance

Cauliflower (*Brassica oleracea* L. var. *botrytis* L.) is an important vegetable crop grown commercially in California. In coastal California (comprising Santa Cruz, San Benito, Monterey, San Luis Obispo, Santa Barbara, and Ventura counties), cauliflower is grown year-round on 15,600 ha with a gross value of over $158 million. In addition to being an important vegetable commodity, cauliflower is a significant rotation crop for the sizable lettuce crop grown in the Salinas Valley and other coastal vegetable regions.

In 1990, some cauliflower plants in the Salinas Valley that matured during the April through October harvest period exhibited chlorosis of lower leaves, defoliation, stunting, and wilting. In fields where these symptoms were evident, growers sustained yield losses because of reduced size and quality of the harvested flower heads and postharvest breakdown during storage and shipment. *Verticillium dahliae* (Kleb.) was consistently associated with these symptoms. Disease surveys identified five fields in the Salinas Valley that showed symptoms in 1990; by 1992, an additional 12 Salinas Valley fields were affected. The disease has become established in this area and threatens the cauliflower industry in coastal California. Although *V. dahliae* is widely distributed in the agricultural soils of coastal California, cauliflower had not previously been described as a host.

The objectives of this study were to identify the causal agent of the disease, to evaluate natural inoculum densities in the Salinas Valley, and to screen commercial cauliflower cultivars for resistance. A preliminary report was published (9).

MATERIALS AND METHODS

Identification of the pathogen. Symptomatic cauliflower plants were collected from major production areas in coastal California (Monterey, San Luis Obispo, Santa Barbara, and Santa Cruz counties) (Fig. 1). Stems from symptomatic plants were washed with tap water, soaked in a 10% bleach solution for 5 min, then rinsed twice with sterile distilled water. After removal of the outer stem cortex, small pieces of the underlying vascular tissue were placed in petri plates containing 2% water agar or acidified potato-dextrose agar (APDA) containing 2 ml of 25% lactic acid per liter. Plates were incubated on laboratory benches at 22 ± 1 C. Resulting *Verticillium* colonies were transferred to water agar plates, and subcultures were established from single

Accepted for publication 11 July 1994.

spores and maintained on potato-dextrose agar slants. The isolates were identified as *V. dahliae* based on published descriptions (15).

Inoculation techniques and effects of disease on plant growth. Two types of inocula and four inoculation techniques were tested on cauliflower cv. White Rock in two experiments each in the growth chamber and greenhouse. Cultures of *V. dahliae* (isolate 90-05) were grown by transferring pieces of agar from slants to APDA plates and incubating them at room temperature (22 ± 1 C). This isolate was chosen after a preliminary virulence evaluation of 10 *V. dahliae* isolates from cauliflower. Spore suspensions were prepared from 25-day-old cultures by adding 10 ml of sterile distilled water to each plate and scraping the cultures with a rubber spatula. With use of a hemacytometer, the inoculum concentration was adjusted to 10^7 conidia per milliliter. The second type of inoculum was 3-cm^2 agar disks containing microsclerotia.

Commercially produced 30-day-old transplants of cauliflower cv. White Rock were used for all inoculation experiments. Plant roots were washed free of potting mixture particles prior to inoculation and planting. Ten cauliflower seedlings were inoculated by each of the four methods: 1) root dip, 2) root-clip dip, 3) stem injection, and 4) placement of an agar disk with microsclerotia around the roots at planting. Prior to inoculation, roots of seedlings inoculated by the root-clip dip method were trimmed by 2.5 cm. Roots of untrimmed and trimmed seedlings were dipped in the conidial suspension for 5 min and then planted individually in autoclaved soil (sandy loam) in 12-cm^2 pots. Seedlings for stem injection were planted in pots first, and 1 μl of inoculum was injected directly into the stem 1 cm above the soil line immediately after transplanting. Inoculations were also made by planting seedlings along with an agar block colonized with microsclerotia placed next to the roots at a depth of 4 cm. Sterile water controls for each of the treatments, except the last, were established. Plants were incubated both in a growth chamber (20 ± 1/15 ± 1 C day/night regime) and in a greenhouse where the mean maximum temperature ranged from 22 to 25 C or from 27 to 35 C for experiments conducted during spring or summer, respectively. After 4 wk of incubation, all plants were gently washed free of soil, and growth parameters such as height, number of leaves, and shoot and root dry weights were collected for each plant. Surface-sterilized stem cortical segments were placed on APDA to reisolate *V. dahliae*.

The effectiveness of each method was evaluated by comparing inoculated plants with the corresponding controls. Data collected for comparison included plant height (above the soil line), number of fully expanded leaves, and total shoot and root dry weight. Foliar symptom severity and root discoloration severity were rated subjectively. Foliar symptom severity was rated on a scale of 0–4 in which 0 = normal plants and 4 = plants with ≥75% of leaves showing chlorosis. Severity of root discoloration was rated on a scale of 1–4 in which 1 = normal appearance and 4 = extensive browning of lateral roots and reduced lateral root system. Each experiment was analyzed separately because of the different number of treatments, and mean comparisons were made using Fisher's protected LSD ($P \leq 0.05$). The results from the two growth chamber experiments were consistent, so data from only one experiment are presented.

Pathogenicity tests. Koch's postulates were completed by dipping roots of 10 30-day-old seedlings of cauliflower cv. White Rock in the conidial suspension of isolate 90-05 for 5 min and planting them into autoclaved soil in 12-cm^2 pots. Control plants were dipped in sterile distilled water for 5 min and planted similarly. Inoculated and control plants were incubated both on greenhouse benches (23 ± 1/10 ± 1 C day/night temperature) and in a growth chamber (20/10 C day/night temperature).

After 4 wk, the number of plants exhibiting lower leaf chlorosis was recorded. Plants were excised and the number of plants showing vascular discoloration was recorded. Stem and root tissue of all plants was then processed as described above and placed on APDA plates. After 2 wk of incubation on laboratory benches (22 ± 1 C), the presence or absence of *V. dahliae* was recorded for all plants. Cultures from these colonies were purified, and 30-day-old plants of cauliflower cv. White Rock were again inoculated and incubated as described above. After 4 wk, the number of plants exhibiting wilt symptoms was recorded. All experiments were repeated once.

Evaluation of natural inoculum density. Soils from affected cauliflower fields in the Salinas Valley were collected when the crop was near maturity during the months of April through September and assayed for *V. dahliae*. For each field, nine collection sites were located randomly along an "X" pattern that extended throughout the entire field. At each site, a 3 × 3 m^2 area was marked, and eight 25-cm-deep soil cores were removed at random from plant rows with a 2.5-cm-diameter soil probe and bulked into a composite sample. Soils were air-dried in the laboratory (23 ± 2 C) for 6 wk, mixed thoroughly, and pulverized with a mortar and pestle. The powdered soils were sifted through a 20-mesh sieve to remove small pebbles. From each composite sample, 10 g of soil was placed in snap-cap vials and mixed with 2.5 ml of a DL-methionine solution (7.5 mg/ml) (7). Vials were capped and incubated in the dark at 30 C for 1 wk.

The vials were then opened and allowed to air-dry for 1 wk at 22–24 C. Samples were repulverized and placed onto petri plates containing Sorensen's NP-10 selective medium (17) using the modified Anderson sampler (2,13). With the Anderson sampler, 0.5 g of pulverized soil from each sample was distributed over two replicates of six petri plates. Plates were incubated in the dark at 22–24 C for 3 wk. After incubation, the surfaces of the agar media were gently washed under running tap water to dislodge and remove soil particles. Washed plates were then examined for *V. dahliae* microsclerotia clusters using a dissecting microscope with transmitted light. Counts from the two replications were combined for mean values and expressed as microsclerotia per gram of soil.

Disease incidence. Disease incidence was determined in all fields in which soil samples were collected. At each of the nine collection sites within a field, the total number of plants and the number of plants showing vascular discoloration were counted in the 3 × 3 m^2 evaluation areas. Cauliflower stems were cut transversely 5 cm above the soil line, and presence or absence of vascular discoloration was determined. Plants showing vascular discoloration were collected randomly from these sites and tested for presence of *V. dahliae* by isolation on water agar as described above. Because cauliflower is closely related to broccoli (*B. o. botrytis*), disease incidence and inoculum density data were also collected from selected broccoli fields at near crop maturity and during the same time of year as described above. All broccoli fields were in proximity to the cauliflower fields surveyed.

Cultivar evaluation. To test commercially available cultivars for Verticillium wilt resistance, four trials were estab-

Fig. 1. Coastal counties of California where Verticillium wilt of cauliflower has been observed.

lished in commercial fields in the Salinas Valley in 1991 and 1992. Cultivars were planted in a randomized complete block design with six replications. Each plot was one bed 1 m wide and 8 m long. Cultivars were direct-seeded onto raised beds using an EarthWay Precision Seeder (EarthWay Products, Inc., Bristol, IN). Selected trials also contained broccoli, cabbage (*B. o. capitata* L.), Chinese cabbage (*B. pekinensis* (Lour.) Rupr.), and bok choy (*B. chinensis* L.). Cauliflower cv. White Rock was planted in all trials as a control because it is one of the most widely planted cultivars in the Salinas Valley and is highly susceptible to Verticillium wilt. Soil samples collected from the sites prior to planting were assayed for *V. dahliae* by the methods described above. Standard agronomic practices, such as irrigation, fertilization, and weed and insect control, were followed during both seasons (1). At maturity, cultivars were evaluated for both the percentage of diseased plants and disease severity. In each replication, six plants were cut transversely at 5 cm above the soil line. The number of plants showing vascular discoloration was recorded, and disease severity was rated on a scale of 0–2 in which 0 = no vascular discoloration, 1 = <50% of vascular ring showing discoloration, and 2 = ≥50% of vascular ring showing discoloration. Analysis of variance was performed on the data using the MSTAT-C statistical package, and mean comparisons were made using Fisher's protected LSD ($P \leq 0.05$).

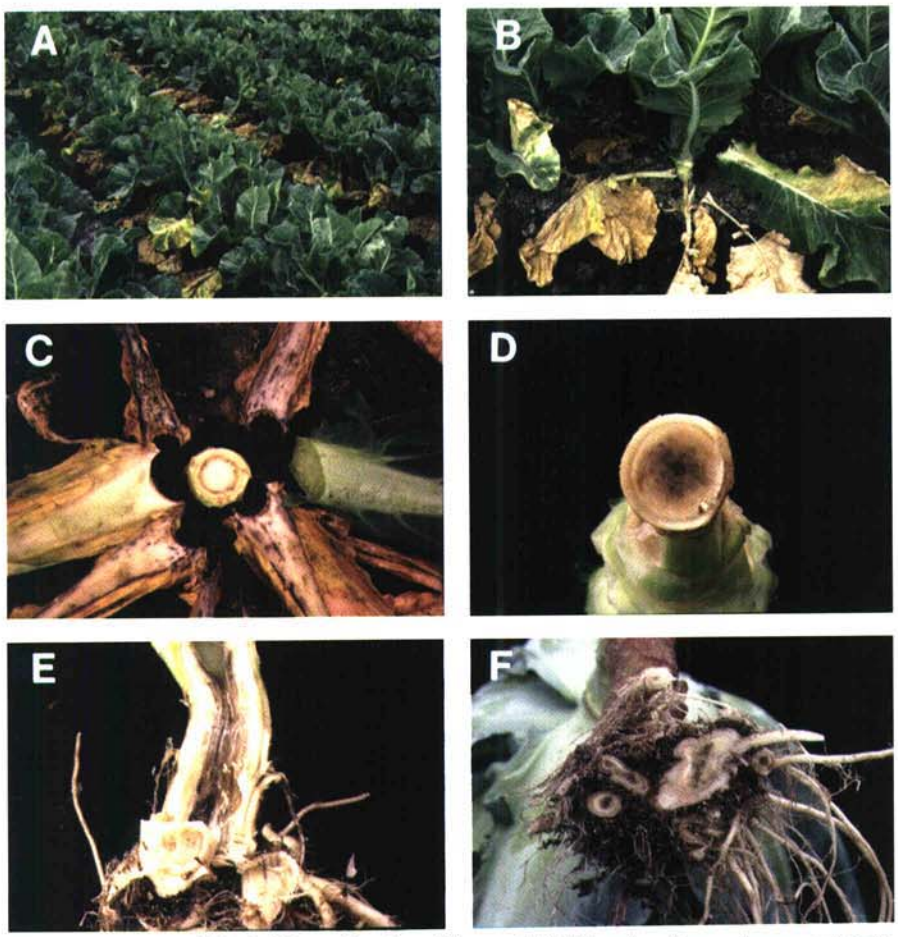

Fig. 2. Symptoms of Verticillium wilt of cauliflower: **(A)** Chlorosis of lower leaves and leaf drop of infected plants. **(B)** Close-up of infected plant showing lower leaf chlorosis and drop. **(C)** Transverse cut on stem 2 in. above soil line showing vascular discoloration, chlorosis, and abscission of lower leaves; (right) symptomless leaf. **(D)** Transverse cut on stem at soil line showing diffuse vascular discoloration. **(E)** Vertical cut on stem showing vascular discoloration. **(F)** Transverse cut on roots showing vascular discoloration.

RESULTS

Symptoms. Verticillium wilt symptoms were not observed in the field until cauliflower plants developed heads (curds) (Fig. 2). At the heading stage, external symptoms consisted of yellowing of the older, lower leaves. Chlorosis and yellowing of leaves continued up the cauliflower stem as plants matured. As disease progressed, the oldest leaves desiccated and abscised from the plant. At maturity, infected plants were generally stunted and foliage exhibited wilting during warmer daytime temperatures. Cross and longitudinal sections of stems and main roots revealed dark discoloration of the vascular tissue.

Identification of the pathogen. *V. dahliae* was consistently isolated from vascular tissues of symptomatic cauliflower plants on APDA and water agar. The pathogen was identified by the characteristic verticillate conidiophores, production of black microsclerotia, and absence of chlamydospores (15). No other pathogen was recovered from cauliflower stem tissue on APDA or water agar. The disease was confirmed in all of the cauliflower-producing counties of coastal California with the exception of Ventura County.

Inoculation techniques and effects of disease on plant growth. Results of individual experiments on inoculation techniques in the greenhouse are pre-

Table 1. Effects of inoculation technique and *Verticillium dahliae* inoculum source on the growth of cauliflower cv. White Rock in growth chamber and greenhouse experiments with a day/night temperature regime of 20 ± 1/15 ± 1 C and 22 ± 3/10 ± 1, respectively

	Plant height (cm)		Number of leaves		Dry weight (g) Shoot		Dry weight (g) Root		Symptom severity[b]		Root discoloration[c]	
Technique[a]	Growth chamber	Greenhouse	Growth chamber	Greenhouse	Growth chamber	Greenhouse	Growth chamber	Greenhouse	Growth chamber	Greenhouse	Growth chamber	Greenhouse
Root dip	12.6	12.9	10.4	13.2	0.97	1.93	0.12	0.13	3.2	3.8	3.2	3.4
Root-clip dip	12.9	12.7	11.8	11.8	0.80	2.16	0.09	0.15	3.6	3.4	3.6	2.8
Agar block	15.7	14.8	9.0	10.0	1.41	2.75	0.14	0.18	0.6	1.8	0.6	1.6
Plant injection	15.0	14.8	9.0	9.8	1.15	2.79	0.13	0.17	2.2	1.6	2.2	1.8
Sterile water root dip	15.8	17.1	8.2	9.2	1.64	3.04	0.21	0.28	0.2	0.0	0.2	1.0
LSD ($P \leq 0.05$)	1.4	1.5	2.1	2.1	0.36	0.27	0.05	0.05	1.0	1.0	1.0	0.7

[a] Values are the means of 10 plants. Differences between the uninoculated, intact root, root-clip, and sterile water injection checks were not significant.
[b] Foliar symptom severity rated on a scale of 0–4 in which 0 = normal plants and 4 = plants with ≥75% of leaves showing chlorosis.
[c] Extent of root symptoms rated on a scale of 1–4 in which 1 = normal appearance and 4 = extensive browning and reduced root laterals.

sented separately because of the different incubation temperatures. Of the four inoculation techniques tested, root dip and root-clip dip methods resulted in significantly more severe symptoms than did either direct injection or agar blocks containing microsclerotia. Root dip and root-clip dip inoculations significantly reduced plant height and dry weights of shoots and roots and significantly increased the number of leaves, symptom severity, and root discoloration compared with sterile water controls in all experiments except that in the greenhouse during summer (temperature maxima, 27–35 C) (Table 1, Fig. 3). The results of the experiment conducted in the greenhouse under high temperature conditions are shown in Table 2. There were no significant differences in any of the variables measured either among the inoculation techniques or between their corresponding uninoculated checks.

There were no significant differences between the two root dip inoculation methods (Table 1). Reductions in plant height and dry weight of shoots and roots ranged from 20 to 26%, 29 to 51%, and 43 to 57%, respectively. Severe symptom development was always associated with increased number of leaves on plants.

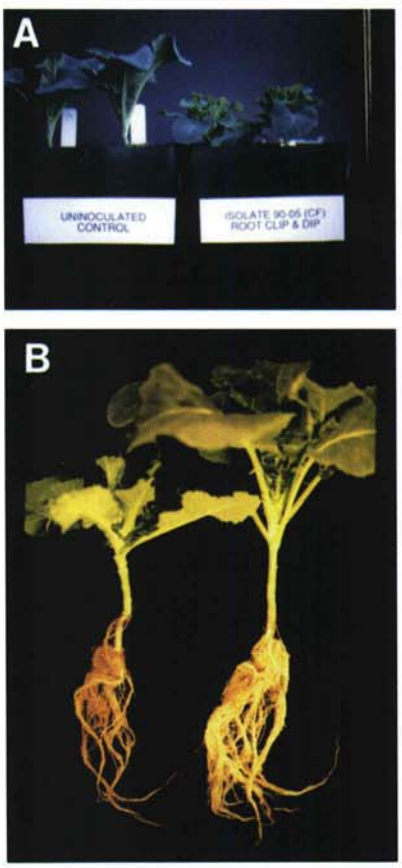

Fig. 3. Verticillium wilt symptoms on inoculated cauliflower plants: **(A)** Inoculated plant (right) with stunting and increased number of leaves compared with uninoculated plant (left). **(B)** Inoculated plant (left) with discoloration of roots compared with uninoculated plant (right).

Differences between uninoculated intact root and root-clip checks were also not significantly different (*data not shown*). The number of fully expanded leaves produced by plants inoculated by either direct injection or agar blocks containing microsclerotia and the sterile water controls was not significantly different (Table 1).

Pathogenicity tests. After 4 wk, all inoculated plants exhibited stunting, chlorosis, and defoliation of lower leaves. Diseased plants also produced smaller and more numerous leaves than uninoculated plants. All inoculated plants showed vascular discoloration. Only *V. dahliae* was isolated on APDA from stem tissue of inoculated plants. Control plants were symptomless, and *V. dahliae* was not recovered from plated stem tissue. Cauliflower plants inoculated with *V. dahliae* reisolated from infected plants showed symptoms identical to those of the initial inoculation.

Evaluation of natural inoculum density and disease incidence. In the 10 cauliflower fields surveyed, soil inoculum density varied from 2.2 to 92.9 microsclerotia per gram of soil (Table 3). As few as five microsclerotia per gram of soil were associated with 98% wilt of cauliflower. The pathogen was isolated consistently from symptomatic plants collected in the 3×3 m^2 areas that were surveyed for disease incidence. Occasional colonies of *V. tricorpus* I. Isacc were observed in the NP-10 plates and were distinguished from *V. dahliae* by the larger size of microsclerotia, spatial arrangement of microsclerotia, and yellow pigment surrounding the colony (4,12,13). The six broccoli fields surveyed showed no symptoms of Verticillium wilt even though the propagules in soil ranged

Table 2. Effects of inoculation technique and *Verticillium dahliae* inoculum source on the growth of cauliflower cv. White Rock in a greenhouse experiment conducted during the summer with mean maximum temperatures ranging from 27 to 35 C

Technique[a]	Plant height (cm)	Number of leaves	Dry weight (g)		Symptom severity[b]	Root discoloration[c]
			Shoot	Root		
Root dip	17.2	10.8	4.93	0.31	1.4	2.2
Root-clip dip	17.5	11.2	5.15	0.43	1.0	1.8
Agar block	16.7	9.8	4.06	0.47	0.8	1.2
Plant injection	16.6	11.2	4.71	0.54	0.0	1.2
Sterile water root dip	17.1	9.4	4.69	0.52	2.2	1.4
Sterile water root-clip dip	17.0	9.4	5.29	0.44	0.8	1.4
Sterile water injection	16.1	8.8	4.58	0.37	0.6	1.4
LSD ($P \leq 0.05$)	1.6	1.3	0.59	0.22	1.2	0.9

[a] Values are the means of 10 plants.
[b] Foliar symptom severity rated on a scale of 0–4 in which 0 = normal plants and 4 = plants with ≥75% of leaves showing chlorosis.
[c] Extent of root symptoms rated on a scale of 1–4 in which 1 = normal appearance and 4 = extensive browning and reduced root laterals.

Table 3. Location, crop, Verticillium wilt incidence, and microsclerotia per gram (ms/g) of soil for different fields in the Salinas Valley during 1991–1993

Location	Crop	Percent discoloration[a]	Mean ms/g soil ± SE[b]
Harris Y	Cauliflower	4.7	10.0 ± 0.31
Harris S	Cauliflower	94.2	12.7 ± 2.82
Hw 68	Cauliflower	6.9	3.0 ± 0.47
Foster	Cauliflower	96.8	7.1 ± 0.31
Abbot	Cauliflower	98.4	5.6 ± 0.63
Toro	Cauliflower	10.6	2.2 ± 0.31
R1	Cauliflower	94.0	92.9 ± 8.70
R12	Cauliflower	95.0	87.7 ± 1.20
R17	Cauliflower	100.0	35.9 ± 0.35
Hitchcock	Cauliflower	37.6	7.7 ± 0.16
Hunter 6	Broccoli	0.0	32.0 ± 0.00
Hunter L	Broccoli	0.0	80.3 ± 3.92
Nashua	Broccoli	0.0	29.3 ± 2.51
Pan Hill	Broccoli	0.6	3.7 ± 0.16
Mer Bluff	Broccoli	2.5	3.1 ± 0.31
Pan Front	Broccoli	8.6	3.4 ± 0.88

[a] Percentage of plants that, when cut transversely 5 cm above the soil line, showed vascular discoloration. In each field, plants in nine plots of 3×3 m^2 were evaluated. Broccoli cultivars never exhibited leaf yellowing or leaf drop symptoms nor was *Verticillium dahliae* isolated from plants showing occasional vascular discoloration. The total area evaluated was 1.5 ha.
[b] Soil samples were collected from the same nine evaluation plots in each field. Eight 25-cm cores were taken per plot and bulked into a composite sample. Samples were dried and tested for *V. dahliae*.

from 3.1 to 80.3 microsclerotia per gram of soil (Table 3). Occasional vascular darkening of broccoli stems was observed, but neither *V. dahliae* nor any other pathogen was recovered from this tissue.

Cultivar evaluation. All commercially available cauliflower cultivars included in the experiments were susceptible to *V. dahliae* (Table 4). Individual cultivar reactions are published elsewhere (8). Cultivar variability in susceptibility to *V. dahliae* was minimal in three of the locations (Table 4). Chinese cabbage, cabbage, and bok choy were also highly susceptible to the pathogen, and *V. dahliae* was reisolated from tissues of these plants. Broccoli exhibited occasional blackening of the vascular system, but no leaf chlorosis, defoliation, wilting, or stunting was observed and the pathogen was not recovered from broccoli vascular tissue.

DISCUSSION

This is the first report of Verticillium wilt of cauliflower. In the United States, the disease is presently restricted to cauliflower-growing regions of coastal California. Verticillium wilt has apparently occurred recently in the Netherlands, Germany, and Japan (various seed companies, *personal communications*). Prior to becoming a serious problem on cauliflower, the disease occurred occasionally on the crop in coastal California, and *V. dahliae* had been isolated from infected plants. Verticillium wilt did not cause widespread losses on cauliflower in coastal California until 1990, but the disease is presently widely distributed in the coastal region and has become a significant threat to cauliflower production.

In inoculation experiments, symptom development and growth reductions were most severe in the growth chamber and under moderate greenhouse temperatures. Higher incubation temperatures in the greenhouse did not result in either significant growth reduction or symptom development. This apparent lack of symptom expression and growth reduction may have been caused by increased plant growth and unsuitable conditions for host infection by the pathogen. Under favorable conditions, cauliflower plants infected by *V. dahliae* were chlorotic and severely stunted and produced a greater number of leaves of smaller size.

Verticillium wilt symptoms on cauliflower in the field are seldom seen prior to the heading stage. It is unclear if this is because infection is lacking until that stage or because the physiological stress induced by flowering elicits the onset of symptoms on previously infected plants. The symptoms are most severe on the summer crop, which matures during late April through October. The winter cauliflower crop, which matures during November through early April, does not exhibit Verticillium wilt symptoms even when grown in fields known to be infested with *V. dahliae*. Thus, the physiological stress induced by both the onset of flowering and the higher temperatures during summer may accentuate the severity of the disease. Temperatures during summer in coastal California are in the range of 20–27 C and seldom exceed 27 C. During the second greenhouse experiment, temperatures were in the range of 27–35, although ambient temperature maxima were ≤27 C. Under these conditions, inoculated plants were symptomless. Thus, temperatures above 27 C appear to be nonconducive for cauliflower infection by *V. dahliae*.

At present, growers avoid the disease by growing alternate crops in problem fields during summer or by planting winter cauliflower crops in these fields. All commercially available cultivars are susceptible to Verticillium wilt. Efforts to identify sources of Verticillium wilt resistance in cauliflower are urgently needed. The root dip or root-clip dip techniques used in this study to determine the pathogenicity of *V. dahliae* on cauliflower can be useful in the identification of sources of resistance and evaluation of isolate virulence.

V. dahliae infects other *Brassica* spp., including bok choy, Chinese cabbage, broccoli raab (*B. o. italica* Plenck), Brussels sprouts (*B. o. gemmifera* DC.), cabbage, mustard (*B. juncea* (L.) Czernj. & Coss.), rapeseed (*B. napus* L. var. *napus*), rutabaga (*B. n. napobrassica* (L.) Rchb.), turnip (*B. rapa* L.), and a *B. campestris* weed (3,5,6,10,11,14,16,18). Isaac (6) inoculated cauliflower and broccoli plants with *V. dahliae* from Brussels sprouts, but the inoculations were unsuccessful. He concluded that broccoli and cauliflower were resistant to *V. dahliae* from Brussels sprouts. In the Salinas Valley, bok choy, Chinese cabbage, broccoli raab, and cabbage are grown extensively in addition to cauliflower and broccoli. Other *V. dahliae*-susceptible crops, such as grape, pepper, potato, raspberry, strawberry, tomato, and many ornamental plants, are also widely grown. Despite the regular rotation of cauliflower with the above vegetable crops, Verticillium wilt had not affected cauliflower severely until 1990. It is possible that *V. dahliae* affected a wide variety of crops grown in the Salinas Valley before 1990 but became adapted to cauliflower only recently. Further investigations into this possibility should address why the disease has become a sudden, widespread problem in the Salinas Valley.

In recent years, a shift from the variable, open-pollinated cultivars to the more desirable uniform, hybrid cauliflower cultivars has occurred. Although it is arguable that this change may have contributed to the severity of the problem, cultivar evaluations in this study that included both open-pollinated and hybrid types did not support this hypothesis.

Farming practices that require the movement of farm equipment between fields may have contributed to the rapid spread of the disease in the Salinas Valley. Many of the cultural practices, such as transplanting, weeding, tying

Table 4. Evaluation of cauliflower and other cole crop cultivars for Verticillium wilt resistance at four locations in 1991 and 1992

Year Location[a]	Crop	Number of cultivars	Incidence[b] (%)	Severity[c]
1991				
Salinas (R1)	Cauliflower	20	97–100	1.4–2.0
	Chinese cabbage	1	100	2.0
	Bok choy	1	100	2.0
	Broccoli	2	0	1.1–1.5
Salinas (Pan 6)	Cauliflower	15	14–100	0.1–1.5
	Cabbage	1	100	1.5
	Broccoli	2	0	0.0–1.0
1992				
Salinas (R17)	Cauliflower	19	75–100	1.3–2.0
	Broccoli	2	0	1.0–1.7
Gonzales (Hwy)	Caulifower	19	81–100	0.9–2.0
	Broccoli	2	0	1.4–1.6

[a] Preplanting mean microsclerotia per gram of soil ± standard error of means for the corresponding experimental locations were 92.9 ± 8.7, 42.4 ± 2.3, 30.7 ± 1.0, and 5.9 ± 1.6, respectively.

[b] Ratio of the number of plants exhibiting vascular discoloration at maturity to the total plants evaluated expressed as percentages and shown in ranges.

[c] Plants were evaluated at maturity for degree of vascular discoloration. Rating scale of 0–2 designates relative amount of vascular discoloration in stems cut transversely 5 cm above soil line: 0 = no discoloration, 1 = <50% of stem exhibiting discoloration, 2 = ≥50% of stem exhibiting discoloration. Six plants were evaluated for each of six replications. Values are the average of 36 plants and are shown in ranges. Broccoli cultivars never exhibited leaf yellowing or leaf drop symptoms nor was *Verticillium dahliae* isolated from plants showing occasional vascular discoloration. We recorded the severity of vascular discoloration despite it not being caused by Verticillium wilt. Thus, even though wilt incidence on broccoli was 0, the severity of vascular discoloration was more than 0 in some instances.

plants (placing rubber bands around cauliflower leaves to prevent yellowing of the heads), and harvesting, require the use of large numbers of labor crews that move within and between fields. The physical movement of labor crews may also have contributed to the rapid dissemination of the pathogen. In addition, the possible seedborne nature of the fungus and its contribution to the rapid spread of the disease should not be discounted. Seed companies frequently exchange germ plasm and breeding material between sister companies in different countries. The reported occurrence of Verticillium wilt on cauliflower in several countries almost at the same time supports the possibility of the seedborne nature of the pathogen and needs to be investigated further.

Another factor that may have influenced the rapid spread of Verticillium wilt on cauliflower is the limited crop rotation practiced in the vegetable-growing areas of coastal California. Lettuce (*Lactuca sativa* L.) is the predominant crop and is rotated most often with cauliflower, broccoli, celery (*Apium graveolens* L.), or spinach (*Spinacia oleracea* L.). However, in many fields it is common to rotate cauliflower with lettuce every year, which has the potential to rapidly increase soil inoculum density in those fields. In our study, as few as five microsclerotia per gram of soil were associated with wilt in nearly 100% of the cauliflower plants. Therefore, the choice of a rotation crop with lettuce should be made with extreme caution. It is interesting to note that broccoli, a close genetic relative of cauliflower, was unaffected by the disease even when grown in *V. dahliae*-infested fields with as high as 80 microsclerotia per gram of soil. We have also been unable to isolate the pathogen from broccoli plants. The possibility that some factor in broccoli prevents *V. dahliae* infection needs to be investigated further.

ACKNOWLEDGMENTS

We thank J. Aragon, S. Bassi, S. Dacuyan, J. E. DeVay, T. G. Gonzales, E. D. Oakes, J. Manassero, M. Mulanax, R. Miller, E. J. Paplomatas, L. H. Sorensen, B. Taylor, J. Taylor, M. Vidauri, J. Wakeman, and the cauliflower industry of coastal California. We also thank Golden Fields Greenhouses for providing cauliflower transplants.

LITERATURE CITED

1. Anonymous. 1992. Integrated pest management for cole crops and lettuce. University of California Statewide Integrated Pest Management Project Publ. 3307.
2. Butterfield, E. J., and DeVay, J. E. 1977. Reassessment of soil assays for *Verticillium dahliae*. Phytopathology 67:1073-1078.
3. Ciccarese, F., Frisullo, S., and Cirulli, M. 1987. Severe outbreaks of Verticillium wilt on *Cichorium intybus* and *Brassica rapa* and pathogenic variations among isolates of *Verticillium dahliae*. Plant Dis. 71:1144-1145.
4. Davis, J. R., and McDole, R. E. 1979. Influence of cropping sequences on soil-borne populations of *Verticillium dahliae* and *Rhizoctonia solani*. Pages 399-405 in: Soil-Borne Plant Pathogens. B. Schippers and W. Gams, eds. Academic Press, New York.
5. Engelhard, A. W. 1957. Host index of *Verticillium albo-atrum* Reinke & Berth. (including *Verticillium dahliae* Kleb.). Plant Dis. Rep. Suppl. 244:21-49.
6. Isaac, I. 1957. Verticillium wilt of Brussels sprout. Ann. Appl. Biol. 45:276-283.
7. Kapulnik, E., Quick, J., and DeVay, J. E. 1985. Germination of propagules of *Verticillium dahliae* in soil treated with methionine and other substances affecting ethylene production. (Abstr.) Phytopathology 75:1348.
8. Koike, S. T., and Subbarao, K. V. 1994. Evaluation of cauliflower cultivars for resistance to Verticillium wilt, 1993. Biol. Cult. Tests Control Plant Dis. 9:25.
9. Koike, S. T., Subbarao, K. V., Davis, R. M., and Gordon, T. R. 1993. Verticillium wilt of cauliflower in California. (Abstr.) Phytopathology 83:1345.
10. Krikun, J., and Bernier, C. C. 1987. Infection of several crop species by two isolates of *Verticillium dahliae*. Can. J. Plant Pathol. 9:241-245.
11. Niederleitner, S., Linkernagel, V., and Bartscherer, H.-Ch. 1991. Investigations of *Verticillium dahliae* pathogenesis in *Impatiens balsamina* and *Brassica napus*. J. Plant Dis. Prot. 98(5):484-489.
12. Paplomatas, E. J. 1991. Biocontrol of Rhizoctonia damping-off of cotton seedlings by *Verticillium tricorpus*. Ph.D. dissertation. University of California, Davis.
13. Paplomatas, E. J., Bassett, D. M., Broome, J. C., and DeVay, J. E. 1992. Incidence of Verticillium wilt and yield losses of cotton cultivars (*Gossypium hirsutum*) based on soil inoculum density of *Verticillium dahliae*. Phytopathology 82:1417-1420.
14. Rogerson, C. T. 1957. Verticillium wilt in Kansas. Plant Dis. Rep. 41:1053-1054.
15. Smith, H. C. 1965. The morphology of *Verticillium albo-atrum, V. dahliae*, and *V. tricorpus*. N.Z. J. Agric. Res. 8:450-478.
16. Snyder, W. C., Hansen, H. N., and Wilhelm, S. 1950. New hosts of *Verticillium albo-atrum*. Plant Dis. Rep. 34:26-27.
17. Sorensen, L. H., Schneider, A. T., and Davis, J. R. 1991. Influence of sodium polygalacturonate sources and improved recovery of *Verticillium* species from soil. (Abstr.) Phytopathology 81:1347.
18. Vargas-Machuca, R., Martin, C., and Galindez, W. 1987. Recovery of *Verticillium dahliae* from weed plants in farmers' fields in Peru. Plant Dis. 71:756-758.