Distribution, Cultivar Susceptibility, and Epidemiology of *Apium virus Y* on Celery in Coastal California

Steven T. Koike, University of California Cooperative Extension, Salinas 93901; Hsing-Yeh Liu and John Sears, USDA-ARS Crop Improvement and Protection Research Unit, Salinas, CA 93905; Tongyan Tian, California Department of Food and Agriculture, Sacramento 95832; Oleg Daugovish, University of California Cooperative Extension, Ventura 93003; and Surendra Dara, University of California Cooperative Extension, San Luis Obispo 93401

Abstract

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Apium virus Y (ApVY) is a potyvirus that was recently found to cause crop loss to celery (*Apium graveolens*) in California. Symptoms on leaves exhibit varying forms of chlorosis and necrosis. Depending on the cultivar, celery petioles could also exhibit extensive necrotic, sunken, elongated lesions. Severely affected plants were unmarketable. Disease incidence surveys found that a susceptible celery (cv. 414) showed 55% (2007) and 71% (2008) disease. Because it was noted that the Apiaceae weed poison hemlock (*Conium maculatum*) was present in almost all areas where ApVY affected celery, a 4-year survey collected overwintered hemlock from six coastal county regions and tested composite samples for ApVY using reverse transcription-polymerase chain reaction (RT-PCR) and ApVY-specific primers. These plants were consistently positive for ApVY. Seeds collected from these plants were also positive when tested with the same RT-PCR method. However, when ApVY-positive hemlock seeds were germinated and the resulting seedlings tested, all results were negative. The failure of ApVY to be transmitted from hemlock seeds to seedlings

was further documented by collecting newly germinated hemlock seedlings from the field and testing them with RT-PCR. All such seedlings were negative for ApVY even though large, adjacent, overwintered hemlock plants tested positive. Two crops of celery seed were produced from ApVY-positive mother plants; celery seed from these infected plants likewise tested positive for ApVY, but seedlings grown from the seed lots were negative for ApVY. Twenty-one celery and celeriac cultivars were inoculated with ApVY using viruliferous aphids, planted in a replicated field trial, and then grown to maturity. Seven cultivars remained symptomless, tested negative for ApVY, and showed signs of possible resistance. The epidemiology of disease caused by ApVY in California evidently involves poison hemlock as a common overwintering host with subsequent vectoring of the virus from hemlock to celery via aphids. ApVY was not seedborne in this weed host or in celery in our experiments. Our data suggest that growers can manage this disease by controlling poison hemlock weed populations and by planting celery cultivars that are not susceptible to ApVY.

Celery (*Apium graveolens*) is an important leafy plant in the family Apiaceae that is grown both as a fresh market and processed commodity. Fresh market celery is sold either as entire heads that are harvested as intact bundles or as prewashed, cut, and bagged value-added products such as celery sticks. Processed celery is used in a diverse range of products including soups, juices, prepared foods, spices, and other products. California is the number one celery producer in the United States, with over 10,845 ha grown in 2010, which represented approximately 93% of the country's celery (18). The value of this California crop in 2010 was \$381 million. As a cool-season biennial vegetable, celery thrives in the moderate climate of coastal California. The main coastal vegetable growing counties Santa Clara, Santa Cruz, Monterey, San Luis Obispo, Santa Barbara, and Ventura annually account for virtually all of the state's celery (3). Approximately 84% of the celery acreage in California is located in Monterey and Ventura counties (44 and 40% of the total state acreage, respectively).

Because celery is a relatively slow growing vegetable, taking 100 days or more to grow from transplant to harvest size, all celery grown in California is planted in the field as transplants. However, the transplant process creates another opportunity for plant patho-

gens to become established on celery. Transplants are typically grown under high humidity and high plant density conditions in greenhouses and are subject to two significant seedborne pathogens, *Septoria apiicola* (causal agent of Septoria late blight) and *Pseudomonas syringae* pv. *apii* (causal agent of bacterial blight) (7). Since these diseases can be carried out to the field through infected seedlings, growers regularly monitor transplants for these pathogens. Celery mosaic virus (CeMV) has caused significant damage to celery, and a celery-free period has been implemented for reducing CeMV incidence in the United States and Australia (9). Virus diseases are usually of minor concern on coastal celery in California; on occasion a few plants can be found infected with CeMV, Cucumber mosaic virus (CMV), or Tomato spotted wilt virus (TSWV) (7,20).

In the late summer (August–September) of 2007, unusual and unrecognized virus-like symptoms were observed on celery grown on various farms in Santa Clara and Monterey counties. Disease incidence was quite high, and the severe symptoms caused the celery to be unmarketable and resulted in crop loss. Symptoms on leaves were extremely variable (Fig. 1) and consisted of general chlorosis, chlorotic or necrotic line patterns, chlorotic blotches and mottling, necrotic lesions, ring spots, and distorted and twisted leaflets. Celery petioles sometimes showed extensive necrotic, sunken, elongated lesions (Fig. 2). Collectively, these symptoms appeared to be different than those caused by CeMV, CMV, or TSWV. Subsequent determination of a suspect virus pathogen, pathogenicity tests, and virus characterization confirmed that these outbreaks were caused by *Apium virus Y* (ApVY) (17,19). The purposes of this study were to document the incidence of ApVY in

Corresponding author: S. T. Koike, E-mail: stkoike@ucdavis.edu

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commercial celery fields, determine incidence of ApVY in Apiaceae weeds common in coastal California celery-growing areas, test celery cultivars for ApVY susceptibility, and investigate possible sources of primary inoculum and therefore define aspects of disease epidemiology that could lead to effective ApVY management in celery.

Materials and Methods

Disease incidence in commercial celery plantings. In 2007 and 2008, disease caused by ApVY was primarily clustered in two celery-producing areas, one in south Santa Clara County and one in south Monterey County. Disease incidence in these two regions was determined by selecting celery fields and evaluating four randomly selected sections within each field. For each section, 50

plants were examined for foliar and petiole symptoms related to ApVY infection. Mean percent disease incidence was derived from these four counts. The names of the celery cultivars were obtained when possible.

Field survey of infected Apiaceae weeds. A preliminary field survey in 2008 in Gilroy, CA indicated that celery infected with ApVY was located near noncrop areas that harbored poison hemlock (*Conium maculatum*) weeds that were also positive for the pathogen (19). We therefore conducted an extensive 4-year field survey of poison hemlock plants and other Apiaceae weeds growing in the celery production areas in the coastal counties. Each sample was collected according to weed species and consisted of 20 to 30 shoots that were randomly collected from throughout the colonized area. Each shoot was taken from the woody stem of a

Fig. 1. Leaf symptoms of celery infected by *Apium virus Y* showing a wide range of chlorosis, chlorotic line patterns and blotches, mottling, necrotic lesions, and ringspots.

Fig. 2. Petiole symptoms of celery infected by *Apium virus Y* showing extensive necrotic, sunken, elongated lesions.

single overwintered plant, was approximately 15 to 20 cm long, and had a minimum of six leaves. Shoots were collected randomly and were not selected based on the presence or absence of virus-like symptoms. Shoots were bulked into plastic bags, placed in an ice chest, and delivered to the lab for testing. The presence of ApVY in the composite samples was confirmed by reverse transcription–polymerase chain reaction (RT-PCR). Weed samples were collected from Santa Clara, Santa Cruz, Monterey, San Luis Obispo, Santa Barbara, and Ventura counties. This survey was conducted from 2008 through 2011.

Sample preparation and RT-PCR. The method used for RT-PCR sample preparation was described by Rosa et al. (14) and was slightly modified. Two hundred to 250 mg of leaf tissue was ground in 5.0 ml of a carbonate-based buffer (10) containing 1% sodium metabisulfite. Four microliters of the solution were removed and added to 50 µl of a glycine-based buffer (10), heated at 95°C for 5 min, and immediately chilled on ice. One-tube RT-PCR reactions were performed as described by Osman and Rowhani (10), using a pair of ApVY-specific primers (reverse primer 5'-TCCTCTTTGCTACTGACACTGCC-3' and forward primer 5'-TCTTGAGAACGGAACATCACCAG-3'). The annealing temperature used was 54°C.

Role of celery seed in virus transmission. Experiments were conducted to determine if ApVY could be transmitted in celery seed and result in infected transplants and subsequently diseased plants in the field. Four times during June through August of 2008, we collected commercially grown celery plants that were naturally infected with ApVY, resulting in a total of 22 plants from south Santa Clara County and 12 plants from south Monterey County. The celery was dug from commercial fields, replanted into 19-liter nursery pots, and maintained in the shadehouse facility at UC Cooperative Extension, Salinas. All plants were tested by RT-PCR to confirm that these specimens were infected with ApVY.

Plants were grown throughout the summer and fall and allowed to bolt, flower, and produce seed. In November 2008, seed was harvested separately from each plant and dried for 1 week prior to testing. For each seed lot, total RNA was extracted from approximately 10 to 15 seeds using the RNeasy Mini Kit (Qiagen Inc., Valencia, CA) according to the manufacturer's instructions and tested for ApVY using RT-PCR as described previously. In addition, 10 seeds from each positive seed lot were placed in germination trays and grown in a greenhouse to the two-leaf stage. These celery seedlings were then tested for ApVY using the same method. This experiment was repeated in the same way in 2009 with four collections of naturally infected celery plants, resulting in

a total of 12 plants from south Santa Clara County and 14 plants from south Monterey County. This second set of seed and germinated seedlings was tested for ApVY by RT-PCR as described above.

Role of hemlock seed in virus transmission. Because poison hemlock was found to be widely infected in coastal California, experiments were conducted to determine if ApVY could be transmitted in poison hemlock seed and result in infected seedlings and subsequently diseased hemlock plants near celery fields. Hemlock seeds were collected in 2008 from south Santa Clara and south Monterey counties where ApVY was prevalent on celery. Approximately 10 to 15 hemlock seeds per collection were tested for ApVY by the RT-PCR method. In addition, 100 seeds from each positive seed lot were placed in germination trays and grown in a greenhouse to the four-true-leaf stage. These hemlock seedlings were then tested for ApVY using the same RT-PCR method. Seeds were tested three times, and the seedling grow out test was conducted twice.

To further examine the role of poison hemlock seeds and seedlings in the epidemiology of ApVY in California, collections of hemlock seedlings were made in March 2010 and February 2011. In these surveys, 10 replicated sets (10 to 15 plants each) of hemlock seedlings having no more than four true leaves were collected from two celery-producing areas (southern regions of Santa Clara and Monterey counties) where ApVY was most severe. The small stature of four-leaf hemlock plants ensured that these were current year seedlings that had germinated in the spring and had not overwintered from the previous season. For comparison, green shoots were collected from the woody stems of poison hemlock plants that were adjacent to the germinated seedlings and that were 0.6 or more meters tall. The size and woody nature of these plants ensured that these were overwintered plants that survived from the previous season. The presence of ApVY was confirmed in these seedling and established hemlock samples by using RT-PCR as described previously.

Evaluating celery and celeriac cultivars for susceptibility to ApVY. To evaluate celery cultivars for possible resistance to ApVY, a field trial was planted in 9 July 2009. Transplants of 19 celery and 2 celeriac (*Apium graveolens rapaceum*) cultivars were grown at a commercial transplant facility. During production, plants were not treated with any insecticides. In a separate greenhouse, green peach aphids (*Myzus persicae*) were placed onto *Nicotiana benthamiana* plants that had been inoculated with ApVY. The resulting viruliferous aphids were immediately introduced to the transplants (10 to 15 aphids per plant) when the celery cultivars were 40 days old. After the transmission access period, the plants were sprayed with an insecticide to eliminate the aphids. Ten days after inoculation, transplants were planted into the field plots with two plant rows per bed; the crop was then grown according to standard commercial practices. The experimental design was a randomized complete block with four replications. Plot sizes were 1 bed (1 m wide and 2.5 m long). On 16 October 2009, 10 plants in each of the four replications were examined for evidence of ApVY symptoms, and disease percentages were calculated. For each of the evaluated plots, symptoms were categorized as follows: no symptoms; slight chlorosis and spotting; moderate chlorosis and spotting with slight leaf distortion; severe chlorosis and spotting with significant leaf distortion. Representative leaves were collected and tested using RT-PCR to check for presence of the virus and to ensure accuracy of the evaluation.

Results

Disease incidence in commercial celery plantings. In 2007, nine celery fields, three in Santa Clara County and six in Monterey County, were evaluated for symptoms associated with ApVY. Disease incidence ranged from 0 to 55% (Table 1). In 2008, in the five celery fields evaluated (three in Santa Clara County and two in Monterey County), disease incidence ranged from 5 to 71% (Table 1). In both years, cv. 414 had the highest disease incidence and consistently showed chlorosis and necrosis on leaves and necrotic

Table 1. Incidence of *Apium virus Y* (ApVY) in celery fields in 2007 and 2008

Year County	Cultivar	% Symptomatic plants ^a
2007		
Santa Clara 1	414	55.0
Santa Clara 2	341	23.8
Santa Clara 3	414	52.0
Monterey South 1	Conquistador	10.9
Monterey South 2	Conquistador	0.0
Monterey South 3	Conquistador	0.0
Monterey South 4	Sonora	0.0
Monterey Salinas	(Unknown)	0.3
Monterey Castroville	(Unknown)	0.6
2008		
Santa Clara 1	414	5.0
Santa Clara 2	414	17.0
Santa Clara 3	414	22.0
Monterey Salinas 1	Sonora	18.0
Monterey Salinas 2	414	71.0

^a Disease incidence was determined by randomly selecting four sections per field. For each section, 50 plants were examined for symptoms related to ApVY infection. Mean percent disease was derived from these four counts.

lesions on petioles. Cultivars 341, Conquistador, and Sonora likewise showed foliar symptoms but in some cases did not show the petiole necrosis symptom.

Field survey of infected Apiaceae weeds. Apiaceae weeds were collected over a 4-year period from a six coastal county region in California (Fig. 3). Poison hemlock was the Apiaceae weed that was most commonly encountered in these celery-producing areas and therefore was the species primarily collected and tested (Table 2). For the 4-year survey, 60.6% (114 of 188 total) of the composite poison hemlock samples tested positive for ApVY using the RT-PCR method with ApVY-specific primers. In Santa Clara County, 82% (55 of the 67 sets) of the composite hemlock samples were positive. In other areas, 60% (43 of 72 sets) of the samples from Monterey County, 70% (7 of 10 sets) from Ventura County, 33% (2 of 6 sets) from Santa Barbara County, 14% (3 of 21 sets) from San Luis Obispo County, and 33% (4 of 12 sets) from Santa Cruz County were positive for ApVY. The Apiaceae weed sweet anise (*Foeniculum vulgare*) from Monterey and Ventura counties was negative (0 of 10 sets) for ApVY. All other weeds including hoary cress (*Cardaria draba*), little mallow (*Malva parvifolia*), and perennial pepperweed (*Lepidium latifolium*) from Santa Clara County also were negative.

Role of celery seed in virus transmission. All celery plants collected from Santa Clara and Monterey counties in both 2008 and 2009 exhibited typical symptoms associated with ApVY and had extensive chlorosis, necrosis, leaf mottling, leaf distortion, and elongated, necrotic petiole lesions. All plants tested positive using RT-PCR and ApVY-specific primers. Most plants successfully produced abundant seed that was harvested and dried. For the 2008 set of seed plants (18 and 9 plants from Santa Clara and Monterey counties, respectively), assayed seed lots from different plants were 56% (15 of 27) positive for ApVY. However, when seeds from each of the ApVY-positive lots were grown and resulting seedlings tested for ApVY, all tests were negative. For the 2009 set of seed plants (12 and 14 plants from Santa Clara and Monterey counties, respectively), the seed lots were 54% (14 of 26) positive for ApVY, but all seedlings tested negative for the virus.

Fig. 3. Percentage of composite poison hemlock samples positive for *Apium virus Y* in the coastal celery producing counties of California: SCrz = Santa Cruz, SCI = Santa Clara, Mont = Monterey, SLO = San Luis Obispo, SB = Santa Barbara, Ven = Ventura.

Role of hemlock seed in virus transmission. For the two sets of poison hemlock seed collected from plants growing in celery production areas, 58% (28 of 48) of the tested seeds were positive for ApVY. However, when 100 hemlock seeds from each of the sets were grown and the resulting seedlings tested, all results were negative for ApVY. Hemlock seedlings showed no symptoms associated with virus infections. Results were similar for the three seed assays and the two grow out experiments.

Poison hemlock seedlings that germinated naturally in the field and were collected at the four-leaf stage tested negative for ApVY. In contrast, over-wintered, woody hemlock plants growing adjacent to the seedlings tested positive for ApVY. The results were the same for both the 2010 and 2011 hemlock surveys.

Evaluating celery cultivars for susceptibility to ApVY. Thirteen of the celery and one of the celeriac cultivars showed ApVY symptoms in the field trial (Table 3). The extent of infection in these susceptible cultivars ranged from 3 to 65% (Table 3). The yellow celery varieties (Golden Pascal and Golden Self Blanching) were very susceptible and developed extensive and severe mottling and yellowing. The remaining susceptible cultivars showed varying degrees of symptoms but were mostly slight in severity (Table 3). The necrotic petiole symptom was not observed in any of these susceptible cultivars.

Six of the 19 celery cultivars (Conquistador, Mission, Sonora, Tall Utah 52-75, Safir, and 341) and one of the two celeriac cultivars (Diamant) remained symptomless. To further confirm that these cultivars were not infected with ApVY, foliage of five plants from each cultivar was collected and tested with RT-PCR. These RT-PCR tests were all negative for ApVY.

Discussion

In California, *Apium virus Y* is the most recent virus pathogen to be found infecting commercial celery and joins *Cucumber mosaic virus* (CMV) and *Celery mosaic virus* (CeMV) as a trio of virus pathogens that can cause economic damage to this crop. ApVY

Table 2. Field survey for *Apium virus Y* (ApVY) in Apiaceae and other weeds

County, collection date	Weed ^b	Composite samples ^a	
		Total	ApVY-positive
Santa Clara, June 2008	P. hemlock	8	4
	Hoary cress*	4	0
	Little mallow*	4	0
Santa Clara, June 2008	P. hemlock	38	33
Santa Clara, July 2008	P. hemlock	6	5
Monterey, July 2008	P. hemlock	14	5
Monterey, August 2008	P. hemlock	5	2
Santa Clara, August 2008	Pepperweed*	4	0
Ventura, June 2010	P. hemlock	6	4
	Sweet anise	6	0
Ventura, July 2010	P. hemlock	4	3
Monterey, July 2010	Sweet anise	4	0
	P. hemlock	38	26
Santa Clara, July 2010	P. hemlock	6	5
Santa Cruz, July 2010	P. hemlock	12	4
Monterey, August 2010	P. hemlock	15	10
Santa Clara, January 2011	P. hemlock	9	8
Santa Barbara, June 2011	P. hemlock	4	0
San Luis Obispo, June 2011	P. hemlock	21	3
Santa Barbara, August 2011	P. hemlock	2	2
Total P. hemlock samples		188	114 ^c

^a Each composite sample consisted of 20 to 30 randomly collected shoots from the weedy area. Each shoot was taken from the woody stem of a single overwintered plant. Shoots were tested as a composite sample by using reverse transcription-polymerase chain reaction with a pair of ApVY-specific primers.

^b P. hemlock = poison hemlock, *Conium maculatum*; hoary cress = *Cardaria draba*; little mallow = *Malva parvifolia*; pepperweed = *Lepidium latifolium*; sweet anise = *Foeniculum vulgare*. * = non-Apiaceae weed.

^c 60.6% disease.

belongs to the genus *Potyvirus*, has flexuous and filamentous particles, and is transmitted by aphids in a nonpersistent manner. First documented on California celery in 2007, ApVY also infects commercially grown cilantro (*Coriandrum sativum*) and parsley (*Petroselinum crispum*) in the state (17). Elsewhere, natural occurrences of ApVY have been reported exclusively on Apiaceae plants and include the following: celery and poison hemlock in Washington State (5); the cutflower bishop's weed (*Ammi majus*) in Florida (1); sea celery (*Apium prostratum*), parsley, and poison hemlock in Australia (9); celery in New Zealand (16). ApVY is also apparently established on celery and parsley in Germany and other parts of Europe (H. J. Vetten, *personal communication*). In our earlier work, we found that the experimental host range includes eight other species in the Apiaceae (19). With the exception of *Nicotiana benthamiana* (Solanaceae) and three chenopodium species (*Chenopodium capitatum*, *C. quinoa*, *Beta macrocarpa*), ApVY would not infect inoculated plants in the Asteraceae, Brassicaceae, Chenopodiaceae, Cucurbitaceae, Malvaceae, or Solanaceae (19).

Problems caused by ApVY exerted significant economic impacts on certain celery cultivars in parts of California in the first 2 years of the disease outbreak, with up to 55% (2007) and 71% (2008) of surveyed plants exhibiting symptoms. In both years of the field survey, cv. 414 showed a high degree of susceptibility to ApVY, which was consistent with the cultivar field trial.

Our data suggest that poison hemlock is an important factor in the epidemiology of ApVY and commercial Apiaceae crops in California. ApVY-infected hemlock was found in all of the six major coastal celery-producing counties, and during the 4-year survey 60.6% of the hemlock samples were positive. The small collection of sweet anise weeds tested negative for the pathogen and no other Apiaceae weeds were found in these collection areas. All non-Apiaceae weeds also tested negative for ApVY.

The initial outbreaks of ApVY on celery in California in 2007 prompted farmers to be concerned that diseased transplants were the source of the problem. If transplants were indeed infected, such a situation would point to the possibility that ApVY was seedborne and was transmitted via seed to the greenhouse-grown transplants. However, our multi-year production of celery seed from infected mother plants demonstrated that while celery seed tested positive for the virus, seedlings developing from the infected seed did not carry the virus. Our data suggest that celery seed tissues originating from the mother plant can be infested with ApVY but that this does not result in transmission to the celery seed embryo. Therefore, celery seed does not appear to be a source of primary inoculum for ApVY.

Similar repeated experiments with poison hemlock seeds collected from ApVY-infected plants resulted in similar findings. Most tested hemlock seeds were positive for ApVY. However, hemlock seedlings grown from these seed collections failed to develop any virus-like symptoms and tested negative for ApVY. This case is strengthened further by testing the early season (February and March), recently germinated seedlings that grew at the base of large, overwintered hemlock plants that had not yet been infested with aphid vectors. All tested hemlock seedlings were negative for ApVY, while the surviving, adjacent mother plants were positive. Poison hemlock seed therefore does not appear to be a source of primary inoculum for ApVY.

In our seed treatment experiments, we soaked poison hemlock seeds from ApVY-positive seed lots with 1% trisodium phosphate for 45 min, followed by 0.5% sodium hypochlorite (bleach diluted to 10%) for 30 min, and finally rinsed in several changes of sterile distilled water. After RT-PCR tests conducted on these seeds, we still had faint positive bands (data not shown). It is possible that the seed treatments were not completely effective in removing virus from the surfaces of the seeds. However, in all cases seedlings grown from these seeds still tested negative for ApVY.

The epidemiological dynamics can be constructed for ApVY, poison hemlock, and susceptible Apiaceae crops such as celery in California. Hemlock seeds do not have structures or a dispersal mechanism that allows for far dispersal from the parent plant; therefore, seeds usually fall adjacent and close to the parent plant (4,11). Once germinated and established, such close proximity affords the opportunity for aphids on overwintered plants to easily move from the overwintered infected plants to new seedlings, resulting in infection of the seedlings. Those seedlings that grow sufficiently to overwinter will add to the hemlock population that carries over ApVY from season to season. In California, the poison hemlock weed population functions in this manner for other diseases such as powdery mildew caused by *Erysiphe heraclei* (8).

Of the 21 celery and celeriac cultivars, seven showed signs of being resistant to ApVY, and no ApVY was detected in these plants. A number of other cultivars tested positive for ApVY but showed very slight, minor symptoms. This perhaps indicates that other cultivars possess some level of tolerance to ApVY. Overall, therefore, it appears that the celery industry has available genetic material to enable it to reduce economic losses from ApVY. This was reflected in commercial situations; in several fields in 2007 and 2008, the cultivars 341 and 414 were planted side-by-side. In all cases, cv. 414 suffered from significant foliar symptoms as well as damaging petiole necrosis, while the adjacent cv. 341 showed

Table 3. Susceptibility of celery and celeriac cultivars to *Apium virus Y* (ApVY)

Cultivar	Percent infected with ApVY ^a	Symptoms
Challenger	20	Slight chlorosis and spotting
Command	3	Slight chlorosis and spotting
Conquistador	0	No symptoms
Matador	13	Slight chlorosis and spotting
Mission	0	No symptoms
Sonora	0	No symptoms
Stix	10	Slight chlorosis and spotting
Tall Utah 52-70R Improved	10	Slight chlorosis and spotting
Tall Utah 52-75	0	No symptoms
Afina	20	Slight chlorosis and spotting
Safir	0	No symptoms
Diamant (celeriac)	0	No symptoms
Tango	60	Moderate chlorosis, spotting, leaf distortion
Ventura	5	Slight chlorosis and spotting
Promise	8	Slight chlorosis and spotting
Golden Pascal	48	Severe chlorosis, spotting, leaf distortion
Golden Self Blanching	65	Severe chlorosis, spotting, leaf distortion
Ponderosa	48	Slight chlorosis and spotting
341	0	No symptoms
414	43	Moderate chlorosis, spotting, leaf distortion
Bianco de Veneto (celeriac)	10	Moderate chlorosis, spotting, leaf distortion

^a Percent infection was calculated as the number of plants showing symptoms of ApVY out of a total of 40 evaluated plants.

only a few plants with slight chlorosis but no petiole necrosis. Future research would be warranted to define genetic factors behind possible sources of resistance or tolerance of celery to ApVY.

Both the 2007 and 2008 commercial field surveys and the cultivar field trial showed that cv. 414 was very susceptible to ApVY. When ApVY was present in these commercial plantings of cv. 414, significant crop loss occurred in both 2007 and 2008. However, some differences were seen with other cultivars. Three cultivars (341, Conquistador, and Sonora) showed high levels of resistance to ApVY in the cultivar trial and in most of the surveyed commercial plantings. However, all three of these cultivars were found to have moderate disease incidence at one commercial site each. Such differences could be attributed to several possible factors. Differential efficiency of ApVY transmission by different species of aphid vectors could result in the differences seen in disease incidence. In this present study, the green peach aphid was used for inoculating celery cultivars; however, in the field other aphid species would likely be involved as well. Additional studies could investigate the aphid species that can colonize both poison hemlock and celery. The roles of environmental conditions and physiological status of the celery in disease development remain unknown. Further research could determine how environmental or physiological factors influence disease susceptibility or symptom expression.

For the field trial it is interesting to note that for all of the 14 cultivars that tested positive, disease symptoms were restricted to the foliage; the distinctive, necrotic petiole symptom was absent from all plants. We cannot exactly account for the absence of this petiole symptom in the trial because in commercial plantings, for example, cv. 414 consistently showed such necrosis. This occurrence perhaps indicates that environmental, plant physiology, virus strain, insect vector, or other factors may govern the development of this symptom. The fact that ApVY causes a diverse range of foliar symptoms is itself interesting, although not unique for celery, as Pemberton and Frost (12) and others report that CMV in celery also results in considerable variation in symptoms.

The occurrence, detection, identification, and characterization of ApVY from California celery illustrate the utility of current molecular tools and techniques in differentiating the potyviruses that infect the Apiaceae. For years, researchers have noted the occurrence of various potyvirus pathogens from celery, parsley, hemlock, and other Apiaceae plants but found slight differences in host ranges and other biological indicators (12,15). The symptoms caused by ApVY can vary greatly. Therefore, molecular methods will continue to be essential in discriminating between previously described and new potyviruses in the Apiaceae, such as in the recent discovery of *Angelica virus Y* (AnVY) from two *Angelica* spp. in Alaska (13).

The California development of ApVY in celery and the epidemiology involving poison hemlock and aphid vectors provides another case study of disease management that calls for an integrated pest management approach. Similar to *Lettuce mosaic virus* in lettuce (6,7), CeMV in celery (12), and CMV in lettuce and celery (2), California growers will need to manage and eliminate overwintering weed reservoirs that harbor ApVY, control aphids through insecticide programs and other integrated methods, and plant celery cultivars that have some resistance or tolerance to ApVY. In Santa Clara County, site of the most severe ApVY outbreaks from 2007 and 2008, growers have aggressively implemented herbicide spray programs to eliminate the hemlock patches and have stopped planting the susceptible cv. 414 celery. Circumstantially, such an IPM strategy has perhaps made a difference and

ApVY has been difficult to find on those ranches in the past two seasons.

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