

Virus Decline of Strawberry in California and the Role of Insect Vectors and Associated Viruses

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ABSTRACT

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Greenhouse white fly, *Trialeurodes vaporariorum* (Westwood); western flower thrips, *Frankliniella occidentalis* (Pergande); and strawberry aphid, *Chaetosiphon fragaefolii* (Cockerell), are common pests of strawberries in California and are vectors of one or more viruses. Most of the viruses transmitted by these vectors do not cause symptoms on strawberry when the infection occurs individually. However, when one of the viruses (*Beet pseudoyellows virus* or *Strawberry pallidosis-associated virus*) transmitted by *T. vaporariorum* is present along with one of the viruses transmitted by *F. occidentalis*, *C. fragaefolii*, or other

sources, it results in a virus decline of strawberry, which can cause significant crop losses. Stunted root and plant growth, purple coloration of foliage, and dieback of the plant are some of the symptoms associated with virus decline. Increases in *T. vaporariorum* infestations during the past few years significantly elevated the risk of whitefly as a crop pest and a disease vector. This article reviews virus decline of strawberry, symptoms of infection, and the current status of insect vectors in California strawberries.

INTRODUCTION

Strawberries are the fifth most valuable commodity in California with a crop value of \$2.2 billion (CDFA 2014). Strawberries are primarily grown in Watsonville, Santa Maria, and Oxnard areas in California, primarily as an annual crop. With fall and summer plantings, strawberry fields are present year-round in some areas. In recent years, some growers have started to prune plants after peak harvest to extend the life of the original planting to add a few more months of production. This second-year production is typically not recommended because of the potential for low yield compared with the first year, as well as an increased risk of pests and diseases both in the second-year crop and neighboring new plantings. High input costs for fumigation, land preparation, transplants, and planting have prompted some growers to opt for second-year production. Increased whitefly infestations and second-year cropping are thought to have contributed to the recent virus decline. This article provides an overview of virus decline of strawberry, component viruses involved, symptoms of infection, insect vectors responsible for the spread, and management practices.

VIRUS DECLINE OF STRAWBERRY

Virus decline of strawberry, also referred to as pallidosis-related decline of strawberry or pallidosis disease, is caused by a complex of viruses transmitted by whiteflies, aphids, thrips, pollen, nematodes, seeds, and some other unknown sources (Converse et al. 1987; Martin and Tzanetakis 2006; Tzanetakis et al. 2003a; Tzanetakis et al. 2003b; Tzanetakis et al. 2013; Wintermantel 2004;). Virus decline occurs only when one of the whitefly-transmitted viruses is present in the plant along with one

of the viruses transmitted by other sources (Fig. 1). Stunted plant growth, purple coloration of foliage, and dieback are general symptoms of virus decline (Fig. 2). Actual mechanism of infection and the synergistic interaction between the viruses involved is not clear, but symptoms vary depending on the types of viruses present.

Whitefly-transmitted viruses include *Beet pseudoyellows virus* and *Strawberry pallidosis-associated virus* (genus *Crinivirus*). Non-whitefly-transmitted viruses include *Strawberry necrotic shock virus* (genus *Ilavirus*), which can be transmitted by thrips, pollen, and seed; and *Tomato black ring virus*, *Tomato ringspot virus*, and *Strawberry latent ringspot virus* (genus *Nepovirus*), which are transmitted by nematodes and seeds but rarely detected in strawberries since the advent of the widespread use of soil fumigants prior to planting (Martin and Tzanetakis, 2006). Aphid-transmitted viruses like *Strawberry crinkle virus* (genus *Cytorhabdovirus*), *Strawberry mild yellow edge virus* (genus *Potexvirus*), *Strawberry mottle virus* (family Secoviridae), *Strawberry vein banding virus* (genus *Caulimovirus*) viruses, and the less common Strawberry latent C virus (genus *Nucleorhabdovirus*) (Martin and Tzanetakis 2006) are probably the most important viruses that contribute to virus decline.

Symptoms of these virus infections vary in different strawberry species and cultivars. General symptoms of infection in strawberries or indicator plants caused by various viruses associated with the decline are summarized in Table 1 (Converse 1981; Converse et al. 1987; Frazier 1955; Hepp and Martin 1992; Martin and Tzanetakis 2006; NBDAAF 2014; Tzanetakis and Martin 2005).

Virus decline or pallidosis disease is indigenous to North America and was described by Frazier and Stubbs in 1969 following its first detection in Australia and United States. Virus decline in California strawberries was reported in 2004 and more recently in 2013 (Dara 2013; Tzanetakis et al. 2004b). Symptoms of decline that were observed during the 2013 outbreak included stunted root and plant growth, brittle roots, and purple or red

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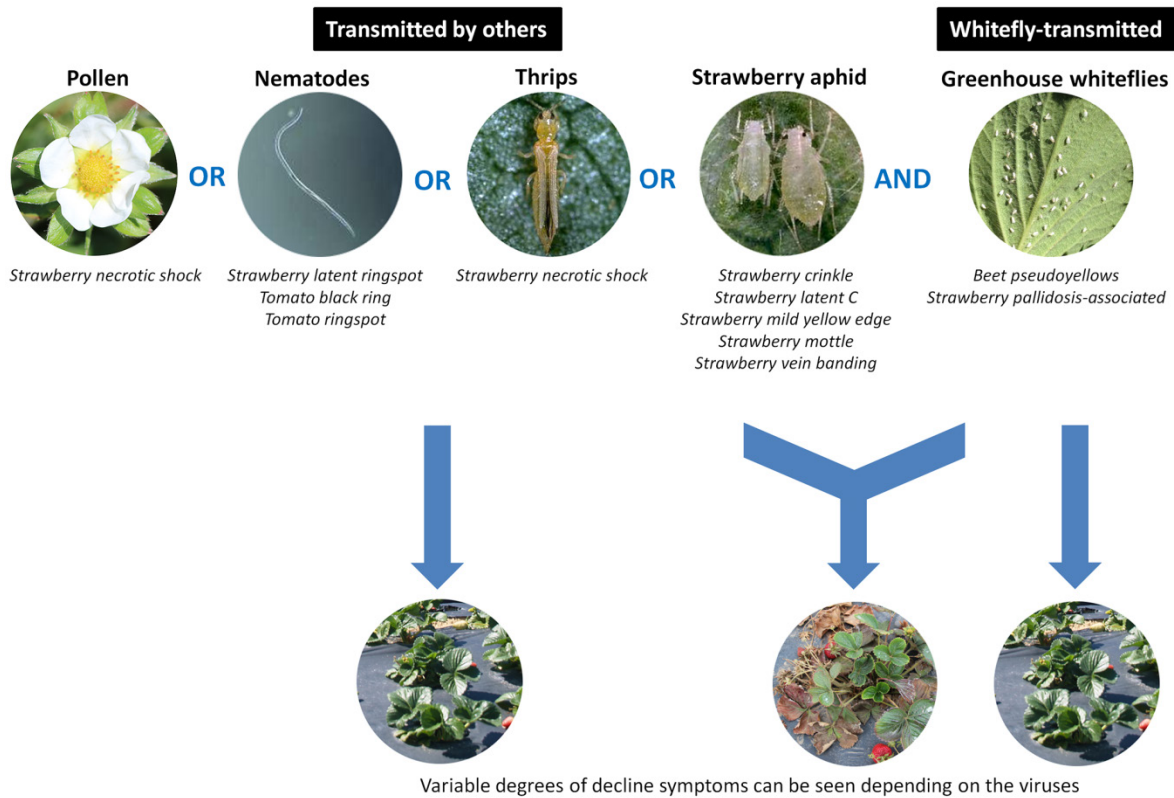


FIGURE 1

Virus and vector complex of virus decline of strawberry. When one of the viruses transmitted by pollen, nematodes, thrips, or strawberry aphid are present along with one of the viruses transmitted by the greenhouse whitefly, virus decline of strawberry occurs. Some of the non-whitefly-transmitted viruses can be vectored by multiple sources.

coloration especially of older leaves (Fig. 2). When infection causes a significant reduction in the root system (Converse and Volk 1990), it can affect the development of the rest of the plant. Chlorosis of the foliage due to virus infection could also affect plant development. As the infection progresses, leaves dry out and plants may eventually die. If infected plants are pruned, newly emerged leaves may not immediately show foliar symptoms due to the seasonal fluctuations of virus titers, but the viruses are systemic and remain in the infected plants (Martin and Tzanetakis 2006). When only *Strawberry necrotic shock virus* is present, plants may appear to recover from the disease symptoms (Martin and Tzanetakis 2006).

The severity of disease symptoms from virus decline also varies depending on strawberry cultivars and the combination of partner viruses (Martin and Tzanetakis 2006). ELISA or reverse transcription PCR techniques are necessary to detect causal organisms in infected plants. It is therefore important to have the specimens examined by a qualified laboratory for accurate diagnosis using appropriate methods.

STRAWBERRY PESTS

The Western tarnished plant bug, *Lygus hesperus* Knight, also known as lygus bug, is a major pest of strawberries in all coastal California fruit-production areas (Zalom et al. 2014). Greenhouse whitefly, *Trialeurodes vaporariorum* (Westwood), is a common species of whitefly in the coastal region of California, and can reduce yields and fruit quality through direct feeding (Zalom et al. 2014). Sooty mold growing on honeydew secreted by whiteflies also affects fruit yield and quality. Greenhouse whitefly numbers increased in the Santa Maria area in recent years. When they were

not well managed on second-year strawberry fields, nearby newly planted fields experienced early and heavy infestations (Dara 2013). Additionally, *T. vaporariorum* feeds on a wide range of commercial crops, such as avocado, caneberries, grape, lettuce, pepper, tomato, and ornamentals, grown on the Central Coast, providing a continuous presence of hosts and allowing the pest to move to strawberries, which are grown in nearly 40,000 acres (CSC 2014). Western flower thrips, *Frankliniella occidentalis* (Pergande), is another common pest of strawberries and can cause Type I bronzing (reddish brown discoloration) of berries around the cap (Zalom et al. 2014). Both *T. vaporariorum* and *F. occidentalis* do not usually require targeted treatments and are kept under control by a natural enemy complex or pesticide treatments against *L. hesperus*. However, some growers have started to apply pesticides in recent years in which *T. vaporariorum* numbers were high. Multiple species of aphids occur at low numbers on strawberries and the strawberry aphid, *Chaetosiphon fragaefolii* (Cockerell), is one of them (Zalom et al. 2014). Plant pathogenic nematodes are not a problem in California strawberries due to commonly practiced soil fumigation as well as clean nursery production methods that prevent the introduction of nematodes into production fields. Therefore, most likely the nematode-transmitted viruses are not contributing to the decline. The insect vectors *T. vaporariorum*, *F. occidentalis*, and *C. fragaefolii*, which were generally minor pests, have now become a serious concern for strawberry growers because of their ability to transmit viruses.



FIGURE 2

Symptoms of virus decline of strawberry: (A and B) stunted plant and root growth in infected plants; (C) purple or reddish coloration; (D) dried foliage; (E) an infected field; and (F) reddish coloration on new growth. Some of these symptoms could be similar to those caused by some soilborne diseases.

TABLE 1
Symptoms of infection in strawberry and indicator plants by different viruses.

Virus	Symptoms of infection
<i>Strawberry crinkle virus</i>	Chlorotic spots of varying sizes on distorted and crinkled leaves, distortion of petioles, reduction in leaf and fruit size, and reduction in yields in cultivated strawberries.
<i>Strawberry latent ringspot virus</i>	No symptoms on leaf, fruit, or plant in cultivated strawberries when infected only by this virus.
<i>Strawberry mild yellow edge virus</i>	No symptoms in some and dwarfing, epinasty of leaves with chlorotic flecks which become necrotic leading to interveinal necrosis, and small fruit in other cultivated strawberries.
<i>Strawberry mottle virus</i>	In cultivated strawberries, no symptoms when infected only by this virus. Some strains of virus reduce plant vigor and yield.
<i>Strawberry necrotic shock virus</i>	In the indicator strawberry, <i>Fragaria vesca</i> , severe necrosis of first few leaves only.
<i>Strawberry pallidosis-associated virus</i>	In the indicator strawberry, <i>F. virginiana</i> , small chlorotic leaves and short runners.
<i>Strawberry vein banding virus</i>	Symptomless in most cultivated strawberries and chlorotic banding or streaks of veins, necrosis of veins and interveinal area, and leaf curling in <i>F. vesca</i> and <i>F. virginiana</i> .
<i>Tomato black ring virus</i>	Symptoms range from none to yellow blotching in <i>F. vesca</i> , and yellow blotching, ring spots, and crinkling of leaves, stunted plants, and plant death in cultivated strawberries.
<i>Tomato ringspot virus</i>	Reduced plant growth and yield in some cultivated strawberries. Mild mosaic and reddish coloration of petioles and leaves in <i>F. vesca</i> and severe necrosis in <i>F. virginiana</i> .

VIRUS AND VECTOR INTERACTIONS

Virus and insect vector interactions have evolved in a manner to improve the acquisition of virus by the vectors and its eventual spread to healthy plants (Mauck and Bosque-Pérez 2012; Moreno-Delafuente et al. 2013). In some cases, a mutualistic relationship exists between viruses and vectors whereby increased fecundity, longevity, or shorter generation time is observed for vectors feeding on virus-infected hosts (Feres et al. 1989; Jiu et al. 2007; Maris et al. 2004). Viruses inhibit the production of plant defense chemicals and favor herbivore feeding and population build up for increased viral transmission (Abe et al. 2012; Luan et al. 2012; Zhang et al. 2012). In other cases, viruses alter the plant's attractiveness to vectors as well as the feeding and settling behavior of vectors for a quick or a prolonged acquisition of the virus followed by a rapid dispersion thereafter (Maris et al. 2004; Medina-Ortega et al. 2009; Werner et al. 2009). Arrestant behavior, which improves the viral acquisition by the vector, was noticed in female silverleaf whitefly, *Bemisia tabaci*, feeding on eggplant infected with *Tomato yellow leaf curl virus* (Moreno-Delafuente et al. 2013). Male *F. occidentalis* infected with *Tomato spotted wilt virus* probed the plant tissues more than non-viruliferous males, thus enhancing the viral transmission frequency (Stafford et al. 2011). Once vectors become viruliferous, dispersal to and feeding on healthy plants is important for viral transmission. Such behavior has been seen in bird cherry-oat aphid, *Rhopalosiphum padi* (L.), following infection with *Barley yellow dwarf virus* (Ingwell et al. 2012). Aphids preferred healthy wheat plants once the aphids became viruliferous. Although the virus-vector interactions associated with virus decline of strawberry are not thoroughly described, an understanding of some of the general interactions of the same or similar vector species with other plant hosts could be useful for a general understanding of strawberry virus decline. This information on virus acquisition and vector behavior could be useful for developing appropriate strategies for vector management.

Some of the aphid-transmitted viruses such as *Strawberry mottle virus* that contribute to virus decline are generally retained for a few days in *C. fragaefolii* once they are acquired by the vector (Mellow and Frazier 1970). Some of these viruses remain latent for 10 to 20 days in the aphid body before transmission which can last for up to two weeks. However, *Strawberry mild yellow edge* will persist in aphid for the life of aphid once it is acquired. *Trialeurodes vaporariorum* can acquire *Beet pseudoyellows virus* within one hour of feeding on an infected host and can transmit the virus for 6 days although transmission decreases with time (Duffus 1965). If *T. vaporariorum* acquires a virus as a nymph, the adult may have to feed again on an infected host to be able to transmit the virus. Both *Beet pseudoyellows virus* and *Strawberry pallidosis-associated virus* are transmitted only by *T. vaporariorum* (Tzanetakis et al. 2006). *Strawberry pallidosis-associated virus* has a narrow host range and infects only strawberries and related species.

CURRENT ISSUE

The appearance of virus decline of strawberries along with increased *T. vaporariorum* numbers in California strawberries in 2013 was consistent with the observations of Tzanetakis et al. (2006). Diagnostics of infected plants in the Santa Maria area in 2013 revealed non-whitefly-transmitted *Strawberry mild yellow edge virus*, *Strawberry mottle virus*, and *Strawberry necrotic shock virus* along with whitefly-transmitted *Strawberry pallidosis-associated virus* and *Beet pseudoyellows virus* (W. Wintermantel, personal communication). Among the whitefly-

transmitted viruses, *Strawberry pallidosis-associated virus* was predominant. When non-whitefly-transmitted viruses are present in fruit production fields at low levels, they are generally not a concern and vectors are also managed with treatments targeted towards other major pests. But when *T. vaporariorum* numbers increase and contribute to the transmission of other viruses, the incidence of virus decline of strawberry can also increase.

DISEASE AND VECTOR MANAGEMENT

Titers of the disease causing viruses in the plant might change based on various factors, but viruses generally remain systemic in the plant (Martin and Tzanetakis 2006; Tzanetakis et al. 2004a). Some growers in the Santa Maria area adopted pruning in an effort to eliminate infection; however, symptoms appeared on new growth in a few days or weeks as viruses were still present in the plant. There are no curative treatments for viruses once the plants are transplanted to the field. Obtaining virus-free transplants for fruit production fields and effectively managing insect vectors are critical in controlling virus decline of strawberry. The following are some recommendations to address the strawberry pallidosis issue.

- (i) Meristem culturing is adopted by strawberry nurseries in an effort to produce disease-free mother plants. Additional screening for viruses might be necessary during transplant production so that virus infections will be detected before transplants go to the fruit production fields. Healthy nursery stock eliminates one pathway for the introduction of partner viruses to fruit production fields.
- (ii) Avoiding new plantings in the vicinity of infected fields or removing infected fields before new planting will help minimize the risk of virus transmission.
- (iii) Effective weed management can prevent the movement of vectors or viruses from weed hosts to strawberry fields.
- (iv) When disease is frequent or widespread in an area, maintaining a regional virus-free period by aggressive whitefly management and/or at least a month without strawberries can reduce the risk of viruliferous whiteflies moving to new fields. Although *T. vaporariorum* can infest other hosts, strawberries are the primary hosts having a vast production area.
- (v) Avoiding second-year strawberries and having a strawberry-free period is important to minimizing virus transmission to new plantings.
- (vi) Regularly monitoring fields and administering effective treatments following IPM guidelines can keep vector populations under control.
- (vii) If necessary, managing vector populations on crops other than strawberries should also be considered.
- (viii) Collaboration and communication among growers, researchers, and other groups to stay informed about pest and disease status and timely treatments are always critical for the success of any management strategy.

With an effective outreach program on the virus decline of strawberry caused by viruses, virus vectors, and their management, the grower community will be better positioned to manage the virus related decline. A YouTube video (www.youtube.com/watch?v=m1YRRE_PY8s) made by University of California Cooperative Extension provides a general overview of virus decline of strawberry, its vectors, and management options. Additional research to improve the understanding of the mechanism of disease transmission by vectors, disease symptoms in various strawberry varieties, and disease and vector management would be useful.

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LITERATURE CITED

- Abe, H., Tomitaka, Y., Shimoda, T., Seo, S., Sakurai, T., Kugimiya, S., Tsuda, S., and Kobayashi, M. 2012. Antagonistic plant defense system regulated by phytohormones assists interactions among vector insect, thrips and a tospovirus. *Plant Cell Physiol.* 53:204-212.
- California Department of Food and Agriculture (CDFA). 2013. California agricultural statistics 2013 crop year. CDFA, Sacramento, CA.
- Converse, R. H. 1981. Infection of cultivated strawberries by Tomato ringspot virus. *Phytopathology* 71:1149-1152.
- Converse, R. H., Martin, R. R., and Spiegel S. 1987. Strawberry mild yellow-edge. Pages 25-29 in: *Virus Diseases of Small Fruits*. R. H. Converse, ed. Agric. Handb. No. 631. USDA, Washington, DC.
- Converse, R. H., and Volk, E. 1990. Some effects of pallidosis disease on strawberry growth under greenhouse conditions. *Plant Dis.* 74:814-816.
- California Strawberry Commission (CSC). 2014. 2014 acreage survey. CSC, Watsonville, CA. http://www.calstrawberry.com/fileData/docs/2014AcreageSurvey_Update.pdf
- Dara, S. 2013. Pallidosis disease in strawberries. *West. Fruit Grow.* 133:44-45.
- Duffus, J. E. 1965. Beet pseudo-yellows virus, transmitted by the greenhouse whitefly (*Trialeurodes vaporariorum*). *Phytopathology* 55:450-453.
- Fereres, A., Lister, R. M., Araya, J. E., and Foster, J. E. 1989. Development and reproduction of the English grain aphid (Homoptera: Aphididae) on wheat cultivars infected with *Barley yellow dwarf virus*. *Environ. Entomol.* 18:388-393.
- Frazier, N. W. 1955. Strawberry vein banding virus. *Phytopathology* 45:307-312.
- Frazier, N. W., and Stubbs, L. L. 1969. Pallidosis-A new virus disease of strawberry. *Plant Dis. Rep.* 53:524-526.
- Hepp, R. F., and Martin, R. R. 1992. Occurrence of strawberry mild yellow-edge associated virus in wild *Fragaria chiloensis* in South America. *Acta Hortic.* 308:57-59.
- Ingwell, L. L., Eigenbrode, S. D., and Bosque-Pérez, N. A. 2012. Plant viruses alter insect behavior to enhance their spread. *Sci. Rep.* 2:578. <http://www.nature.com/srep/2012/120815/srep00578/pdf/srep00578.pdf>
- Jiu, M., Zhou, X. P., Tong, L., Xu, J., Yang, X., Wan, F.-H., and Liu, S.-S. 2007. Vector-virus mutualism accelerates population increase of an invasive whitefly. *PLoS ONE* 2(1):e182. doi:10.1371/journal.pone.0000182.
- Luan, J.-B., Yao, D.-M., Zhang, T., Walling, L., Yang, M., Wang, Y.-J., and Liu, S.-S. 2012. Suppression of terpenoid synthesis in plants by a virus promotes its mutualism with vectors. *Ecol. Lett.* 16:390-398.
- Maris, P. C., Joosten, N. N., Goldbach, R. W., and Peters, D. 2004. Tomato spotted wilt virus infection improves host suitability for its vector *Frankliniella occidentalis*. *Phytopathology* 94:706-711.
- Martin, R. R., and Tzanetakis, I. E. 2006. Characterization and recent advances in detection of strawberry viruses. *Plant Dis.* 90:384-396.
- Mauck, K., and Bosque-Pérez, N. A. 2012. Transmission mechanisms shape pathogen effects on host-vector interactions: Evidence from plant viruses. *Funct. Ecol.* 26:1162-1175.
- Medina-Ortega, K. J., Bosque-Pérez, N. A., Ngumbi, E., Jiménez, E. S., and Eigenbrode, S. D. 2009. *Rhopalosiphum padi* (Hemiptera: Aphididae) responses to volatile cues from *Barley yellow dwarf virus*-infected wheat. *Environ. Entomol.* 38:836-845.
- Mellow, F., and Frazier, N. 1970. Strawberry mottle. Pages 4-8 in: *Viruses and Diseases of Small Fruits and Grapevines*. No. 290. Div. of Agric. Sci., Univ. of Calif., Davis.
- Moreno-Delafuente, A., Garzo, E., Moreno, A., and Fereres, A. 2013. A plant virus manipulates the behavior of its whitefly vector to enhance its transmission efficiency and spread. *PLoS ONE* 8(4): e61543. doi:10.1371/journal.pone.0061543.
- New Brunswick Dept. of Agric., Aquaculture and Fisheries (NBDAAF). 2014. Strawberry viruses and strawberry aphids. NBDAAF, Frederickton, NB, Canada.
- Stafford, C. A., Walker, G. P., and Ullman, D. E. 2011. Infection with a plant virus modifies vector feeding behavior. *Proc. Natl. Acad. Sci. U. S. A.* 108:9350-9355. <http://www.pnas.org/content/108/23/9350.full.pdf+html>
- Tzanetakis, I. E., Halgren, A. B., Wintermantel, W. M., Keller, K. E., and Martin, R. R. 2003a. Two criniviruses are associated with the strawberry pallidosis disease. *Acta Hortic.* 656:21-26.
- Tzanetakis, I. E., Wintermantel, W. M., and Martin R. R. 2003b. First report of Beet pseudo yellows virus in strawberry: A second crinivirus able to cause pallidosis disease. *Plant Dis.* 87:1398.
- Tzanetakis, I. E., Halgren, A. B., Keller, K. E., Hokanson, S. C., Maas, J. L., McCarthy, P. L., and Martin, R. R. 2004a. Identification and detection of a virus associated with strawberry pallidosis disease. *Plant Dis.* 88:383-390.
- Tzanetakis, I. E., Bolda, M., and Martin, R. R. 2004b. Identification of viruses in declining strawberries along the west coast of North America. (Abstr.) *Phytopathology* 94:S104.
- Tzanetakis, I. E., and Martin, R. R. 2005. First report of strawberry as a natural host of *Apple mosaic virus*. *Plant Dis.* 89:431.
- Tzanetakis, I. E., Martin, R. R., and Wintermantel, M. 2013. Epidemiology of criniviruses: An emerging problem in world agriculture. *Front. Microbiol.* 4:1-15.
- Werner, B. J., Mowry, T. M., Bosque-Pérez, N. A., Ding, H., and Eigenbrode, S. D. 2009. Changes in green peach aphid responses to potato leafroll virus-induced volatiles emitted during disease progression. *Environ. Entomol.* 38:1429-1438.
- Wintermantel, W. M. 2004. Emergence of greenhouse whitefly (*Trialeurodes vaporariorum*) transmitted criniviruses as threats to vegetable and fruit production in North America. *APSnet Features*. doi:10.1094/APSnetFeature-2004-0604
- Zalom, F. G., Bolda, M. P., Dara, S. K., and Joseph, S. 2014. UC IPM Pest Management Guidelines: Strawberry. UCANR Publ. 3468. Statewide Integr. Pest Manage. Prog., Univ. of Calif., Oakland.
- Zhang, T., Luan, J.-B., Qi, J.-F., Huang, C.-J., Li, M., Zhou, X.-P., and Liu, S.-S. 2012. Begomovirus-whitefly mutualism is achieved through repression of plant defenses by a virus pathogenicity factor. *Mol. Ecol.* 21:1294-1304.