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A REVIEW OF THE SWEETPOTATO WHITEFLY IN SOUTHERN CALIFORNIA

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Abstract.—The sweetpotato whitefly, *Bemisia tabaci* Gennadius, of Palaearctic origin was originally introduced into California in the late 1920s. Since that time it has been restricted to the state's southern desert valleys and has, at times, been a significant agricultural problem. In the mid-1980s, however, a new "strain" of *B. tabaci* was introduced to southern California and has wreaked great havoc in the area. This strain, from poinsettia plants, has become known as the B strain, poinsettia strain or poinsettia whitefly. This paper documents the new introduction, notes the poinsettia strain's differences from other *B. tabaci,* and assesses the possibilities for its control.

Key Words.—Insecta, Aleyrodidae, *Bemisia tabaci,* sweetpotato whitefly, California

California has been experiencing serious problems with whiteflies during the last several years. Of the approximately 1160 described species of whiteflies in the world, 54 occur in the state along with approximately a dozen undescribed native species. Of California's described species, at least 11 were introduced by man's activities, and five have been introduced in the last 15 years. Several of the introduced species have become serious pests and two are currently quite problematic: the ash whitefly, *Siphoninus phillyreae* (Haliday), and the sweetpotato whitefly, *Bemisia tabaci* (Gennadius). These species currently have extremely large populations in areas of California.

The ash whitefly, an easily recognized species, was introduced into the state in the late 1980s, and although it spread rapidly with tremendous population explosions (Sorensen et al. 1991), a successful parasite was found (Bellows et al. 1991) and effective biological control has progressed rapidly. The sweetpotato whitefly (SPW), however, has been in California since the 1920s (Russell 1975), but only in the last two decades, particularly the early 1980s, has it been a serious agricultural problem (Natwick & Zalom 1984) and a taxonomic and ecological curiosity. Currently, it is in a disastrous expansion phase in southern California, which involves the acquisition of many new hosts. This paper documents the ecological history and potential taxonomic problems with SPW in southern California.

BACKGROUND

The *Bemisia tabaci* was originally described as an *Aleyrodes* from tobacco in Greece in 1889 (Gennadius 1889). Since then, the species has been redescribed in synonymy many times (Table 1). The insect has spread to most tropical and subtropical areas of the globe, occasionally causing serious damage upon colonization. It was first recorded from India in 1905 (Misra & Lambda 1929, Reddy & Rao 1989, Immaraju 1989), and by 1919 had become a serious pest of cotton in the Punjab (now Pakistan) (Immaraju 1989). It has been reported as a serious

Table 1. Taxonomic synonyms of sweetpotato whitefly.[a]

Genus	Species	Author	Date	Type locality
Aleyrodes	*tabaci*	Gennadius	1889	Greece
Aleyrodes	*inconspicua*	Quaintance	1900	Florida
Bemisia	*emiliae*	Corbett	1926	Sri Lanka
Bemisia	*costa-limai*	Bondar	1928	Brazil
Bemisia	*signata*	Bondar	1928	Brazil
Bemisia	*bahiana*	Bondar	1928	Brazil
Bemisia	*gossypiperda*	Misra & Lambda	1929	Pakistan
Bemisia	*acyranthes*	Singh	1931	Pakistan
Bemisia	*hibisci*	Takahashi	1933	Taiwan
Bemisia	*longispina*	Priesner & Hosny	1934	Egypt
Bemisia	*gossypiperda* var. *mosaicaivectura*	Ghesquiere	1934	Zaire
Bemisia	*goldingi*	Corbett	1935	Nigeria
Bemisia	*nigeriensis*	Corbett	1935	Nigeria
Bemisia	*rhodesiaensis*	Corbett	1936	Rhodesia
Bemisia	*manihotis*	Frappa	1938	Madagascar
Bemisia	*vassyierei*	Frappa	1939	Madagascar
Bemisia	*lonicerae*	Takahashi	1957	Japan
Bemisia	*minima*	Danzig	1964	U.S.S.R.
Bemisia	*miniscula*	Danzig	1964	U.S.S.R.

[a] See Taxonomic Assessment and Biological Control section for comments on *B. poinsettiae* Hempel, 1923.

pest of various crops in: the West Indies, Nicaragua, Venezuela, Brazil, Turkey, Israel, Egypt, Sudan, Iran, Thailand, and the Philippines. In addition, it is known from southern Europe, the Middle East, much of Africa, Madagascar, Sri Lanka, China, Malaya, Australia, New Guinea, Fiji, and Hawaii, among other locations. By 1978, SPW was known from at least 420 plant species in 18 families (Mound & Halsey 1978, Greathead 1986), but new hosts are being continually added as the current infestation in California and Arizona grows. Currently, SPW is a major economic pest of cotton, tobacco, cassava, sweetpotato and soy bean in many areas of the world.

After its introduction to the U.S., SPW was redescribed as *Bemisia inconspicua* by A. L. Quaintance (1900) from material collected on okra and sweetpotato in Florida between 1897 and 1898. Later, museum specimens were found to have been collected in Pomona, Putnam County, Florida in 1894 (Russell 1975). It has since spread across the southern part of the U.S. Prior to 1985, it was found in outdoor environments in Florida, Georgia, Texas, Arizona and California. Recently, it has been found in extremely high populations in the agricultural areas of Arizona, California, Texas and northwestern Mexico.

History in California

Specimen records at the U.S. National Museum of Natural History indicate it had been introduced into California by at least 1928 (Russell 1975), when it was collected on cotton at Calipatria, Imperial County. Subsequent records of early spread in California are shown in Table 2. Although SPW was in California in the late 1920s, it was found outdoors only in the desert valleys of Imperial,

Table 2. The earliest records of the spread of *Bemisia tabaci* within California, after its 1928 introduction (Calipatria, Imperial Co.) on cotton.

Year	County	Location	Host
1947	Riverside Co.	Coachella	sweetpotato
1950–1954	Riverside Co.	Indio	cotton
1951	Imperial Co.	Calexico	cotton
1952	Riverside Co.	Coachella	cotton
1953	Riverside Co.	Thermal	sweetpotato
1953	Riverside Co.	Mecca	sweetpotato
1954	Imperial Co.	Imperial	cotton
1954	Riverside Co.	Riverside	cotton[a]
1955	Riverside Co.	Riverside	euphorbia[a]
1961	San Bernardino Co.	Yucca Valley	*Hibiscus* sp.

[a] In greenhouse.

Riverside, San Bernardino and San Diego Counties. It was seldom, if ever, found in greenhouses in California, and then usually on plants imported recently from other states.

In the Imperial Valley of California, a curious and disastrous phenomenon occurred with SPW in the summer and fall of 1981; its populations exploded on numerous crops, including cotton, melons and lettuce. D-Vac® monitoring by University of California Agricultural Extension personnel collected over 60,000 whiteflies per 100 sweeps of the devices (Natwick & Leigh 1984). The large numbers of whiteflies were severely debilitating the infested crops, and also transmitting serious viral diseases to the crops. High incidences of squash yellow leaf curl and lettuce infectious yellows resulted in premature plow-down and total crop loss in many lettuce and melon fields in fall 1981 (Duffus & Flock 1982, Natwick & Zalom 1984).

Although 1981 was a disastrous year for the growers in the Imperial, Bard and Palo Verde Valleys of California, SPW had actually been building up populations over the preceding several years. University of California extension personnel had been making routine whitefly counts for many years (Natwick & Leigh 1984) because SPW and another species, banded-winged whitefly [*Trialeurodes abutiloneus* (Haldeman)] were found on cotton infested with cotton leaf crumple, a viral disease. Prior to 1975, D-Vac® catches for SPW were running consistently lower than 300–400 per 100 sweeps. However, in 1975 the number jumped to nearly 4300 whiteflies per 100 sweeps. Numbers dropped the next year, only to leap to an incredible 35,000 whiteflies per 100 sweeps in 1977. The populations dropped again to near zero in 1978, only to be followed by the disastrous rebound seen in 1981.

There are several possible causes for these population explosions, which probably result from several interrelated concurrent events. Starting in 1975, the southern California desert areas experienced unusually warm winter temperatures, with a virtual absence of days below freezing (only two years out of nine had recorded temperatures below 0° C) (Flock & Christopherson 1985). Because SPW is apparently of tropical origin, cool or cold temperatures appear to prevent normal development, while high summer temperatures and humidity probably enhance development. Comparing the warm winter temperature ranges in the Imperial

Valley with the sudden upsurges observed in SPW populations shows an intriguing, yet not exactly corresponding, correlation.

A second event in the Imperial Valley area in 1975 involved the first use there of synthetic pyrethroid insecticides for general pest control (E. T. Natwick, personal communication). Such pyrethroids have a devastating effect on the natural enemies (primarily parasitoids) of SPW. Essentially the lack of cold winter temperatures allowed SPW to maintain larger than normal populations through the winter, and a reduced natural enemy population allowed SPW an unencumbered pathway to the devastating populations that were encountered between 1975 and 1990. By 1986, researchers and growers were discovering ways to deal with the SPW problem. They observed that the SPW population was building up on cotton to such large levels that by the time the cotton was ready for the normal fall defoliation and harvest, it would be heavily covered with honeydew and sooty mold. When the cotton was defoliated, the whiteflies would move in large numbers into other crops including squash, melons, lettuce, sugar beets, tomatoes and other specialty crops, transmitting viral diseases presumably picked up from weeds and other virus infected hosts. By defoliating cotton early, it was found that SPW did not have time to develop large populations that could move onto other crops, and the cotton would be fairly free of honeydew and sooty mold (Meyerdirk et al. 1986).

By 1990, just when the SPW problem seemed to be under control in the desert southwest, a second disastrous phenomenon occurred, this time as a result of events in Florida four years earlier. SPW had maintained a foothold in Florida for many years, seldom being more than a scientific curiosity. Inexplicably in 1986, growers of greenhouse poinsettias had a devastating outbreak of SPW that appeared overly resistant to chemical control (Hamon & Salguero 1987). As the summer of 1986 wore on, these SPW jumped to numerous other greenhouse bedding plants and nursery stock; they also began infesting outdoor vegetable crops and gardens with disastrous results. By 1987, the large poinsettia nurseries of San Diego County were found to be infested, and over the next year or two SPW was found on poinsettias in many greenhouses throughout California. Shortly thereafter, in late 1990, SPW moderately infested commercial citrus groves near Phoenix, Arizona; it had never been found on this crop in economically damaging populations before (D. N. Byrne, personal communication). SPW was observed to spend the winter in fairly large numbers on this plant.

Prior to the find of SPW on citrus, researchers in Florida and Arizona were beginning to evaluate some of the characteristics and effects of the SPW "strain" (hereafter referred to as poinsettia SPW) that began attacking greenhouse poinsettias and other crops in Florida in 1986. Poinsettia SPW was found to cause virus-like symptoms in cucurbits (Yokomi et al. 1990; Costa & Brown 1990, 1991a, b) that were quickly called "squash silver leaf." These symptoms probably are related to a phytotoxin injected into the plant by poinsettia SPW, because the plants recovered from the effects when the whiteflies were removed.

In contrast, it was found that the original "strain" of SPW (hereafter referred to as cotton SPW) reared from cotton, squash and other crops in Arizona (Costa & Brown 1990, 1991) and California (Perring et al. 1991) did not produce these same symptoms in squash plants. Shortly thereafter, researchers in Arizona (Costa & Brown 1990, 1991) and California (Perring et al. 1991) investigated the isozymic variation in poinsettia versus cotton SPW "strains" using several different electrophoretic techniques. Populations of poinsettia SPW from poinsettias were found to show slight, but consistently different, esterase banding patterns from those cotton SPW populations that had existed in the southwest prior to 1986. Taxonomists, however, have not been able yet to show a morphological difference between these populations, and they are both currently considered to be *B. tabaci.*

After SPW was discovered on citrus in Arizona, it was assayed using electrophoretic techniques and found to be poinsettia SPW (D. N. Byrne, personal communication). By early spring 1991, it became evident that SPW was occurring in large numbers over the winter on cole crops, particularly broccoli, in the Yuma and Imperial Valleys; the presence of SPW on cole crops in winter had never been experienced in these areas before. These whiteflies also were determined to be poinsettia SPW (T. M. Perring, personal communication).

By July 1991, it was obvious that a major and catastrophic change had taken place in the SPW situation in the Imperial and Palo Verde Valleys (Weddle & Carson 1991, Perring et al. 1991). Observers in the field made many startling discoveries. Some cotton was covered completely by adult whiteflies before the plants could produce more than three or four leaves. The first leaves of squash plants were being devastated before the plants could send out three or four inches of runners. Many fields were disced under. The cotton that did mature was hopelessly sticky with honeydew before the bolls could open. Fields of alfalfa were so sticky they could not be baled. In late August, table grape vineyards on the north shore of the Salton Sea in Riverside County were found heavily infested and sticky with SPW. The same was found on new growth of grapefruit plantings and on many weed species in the immediate vicinity. Some of this infestation apparently originated from clouds of SPW that have been observed flying across the Salton Sea from breeding grounds in the Imperial Valley. These whiteflies are generally considered to be the poinsettia SPW.

After just one season, cotton SPW is now believed to be practically nonexistent in California (T. M. Perring, personal communication), due either to interbreeding, competition between the two strains, the extreme cold temperatures of December 1990, or possibly all of these reasons. Cross breeding experiments that are now being conducted in Arizona and California may shed light on this phenomenon. However, work that had been done on the two strains prior to this summer has also produced some other interesting differences between the two SPW strains. Poinsettia SPW is more cold tolerant. The time required to complete a generation has been found to be slightly shorter in poinsettia SPW, or identical in the two strains (usually 16–23 days), but poinsettia SPW is considered to be five times as prolific (T. M. Perring, personal communication). Poinsettia SPW has been found to extract five times as much nutrient material from plants and, therefore, produces five times as much honeydew as cotton SPW. Although cotton SPW is thought to be a better virus disease vector, at least with lettuce infectious yellows (J. E. Duffus, personal communication), poinsettia SPW has produced such large populations that plants die before virus symptoms appear (F. Laemmlin, personal communication), so its effectiveness in virus transmission is unknown. Furthermore, poinsettia SPW severely attacks more crops, including some not previously utilized by cotton SPW.

By the first week in October 1991, SPW had been found in moderate numbers in dooryard vegetable gardens in the city of San Bernardino. This is the first important record for any SPW outdoors in California outside of the desert valleys. One week later, SPW was found on established, outdoor poinsettia bushes in Riverside, Riverside County. The owners of these bushes said that the whiteflies had been a problem since the previous year. By December, SPW had been found in three southern San Joaquin Valley counties in field situations not associated with nurseries.

Taxonomic Assessments and Biological Control

As was done with ash whitefly, the first step that should be taken to find an effective biological control for SPW is to identify the native home of the insect, so that natural enemies can be found. In the case of SPW, however, this creates an immediate dilemma. Up until recently, the native home of SPW was thought to be either the Orient or Africa/the Middle East (Mound 1963, Lopez-Avila 1986, Anonymous 1987). Other *Bemisia* are prevalent in southern Russia and are also known from mainland Asia, southeast Asia along the Pacific rim, Africa, and one species each from South America and the western United States (Mound & Halsey 1978). Certainly, the area to the north and west of Pakistan shows the greatest diversity in parasitoids of *Bemisia* (Mound & Halsey 1978, N. Mills 1992), reputedly an indication of a genus epicenter.

SPW was probably moved around the world at a very early date, but was not described until 1889. Because SPW has probably been reintroduced into many countries numerous times, it becomes extremely difficult to trace the origin of the whitefly. Because poinsettia and cotton SPW cannot presently be separated morphologically, we cannot effectively access pre-1986 museum specimens to ascertain where poinsettia SPW occurred prior to 1986. Lacking adequate surveys using electrophoretic analysis to separate the strains, we so far have very limited knowledge of where poinsettia SPW presently occurs in the world. We know only that it has been transported over most of the U.S. and the Caribbean on poinsettia and other nursery crops (J. K. Brown, personal communication). It has also been transported to Canadian greenhouses (Broadbent et al. 1989), from where it escaped to the field but probably could not survive the Canadian winters.

Recently, however, evidence is emerging that indicates *B. tabaci* may be of New World origin. For example, it seems to do best on hosts that are of New World origin (unpublished data), such as sweetpotato, poinsettia, tomato, common bean, squash, peppers, and tobacco. Further, in Puerto Rico (Bird 1957), a strain of *B. tabaci* was identified that feed solely on *Jatropha gossypifolia* L., a plant of New World origin, despite numerous trials on other hosts; a feeding pattern that seems highly unlikely if *B. tabaci* were of Old World origin. A New World origin hypothesis for *B. tabaci* would have important ramifications for searching for natural enemies, switching the search emphasis to the Neotropics.

New studies of genetic variance may also suggest a New World origin for *B. tabaci*. Wool et al. (1991) examined isozymes of *B. tabaci* populations in Israel and found genetic uniformity, with no geographical races existing there. However, in examining *B. tabaci* from Columbia, they found differing esterase patterns among populations from various Columbian regions. In fact, the esterase pattern found in samples from the Valle, near Cali, were "very similar to the Israeli pattern" (Wool et al. 1991: 228). Similar circumstances exist in other homopterans, suggesting that centers of origin for a species probably have higher genetic variability than do invaded areas. For example, among now cosmopolitan aphids, such as *Myzus persicae* (Sulzer) and *Macrosiphum euphorbiae* (Thomas), electrophoretic surveys of variance in North America indicate that the former, with zero variability in the Nearctic, probably had a limited introduction to that continent, whereas the latter, with a higher heterozygosity level, is probably a Nearctic endemic (May & Holbrook 1978).

This limited "founder effect" variance appears contrary to implied increasing genetic variance in other invasive whiteflies, such as *Siphoninus phillyreae* recently in California, where Sorensen et al. (1991) proposed a mutation-driven expansion of feeding-range, caused by explosive invasive populations in the absence of population controls. (A situation also similar to poinsettia SPW there.) Clearly, electrophoretic surveys of *S. phillyreae* in California should be (or *should have been*) conducted to monitor its heterozygosity during the geographical expansion. If limited genetic variability were maintained for *S. phillyreae* during its California explosion, then theories of expansions in the range of host-feeding during invasions might require modification (J. T. Sorensen, personal communication).

SPW, like several other whiteflies and scale insects, tends to be morphologically variable depending on both its host and on its location on the plant (Mound 1963). In SPW, the last stage nymph ("pupa") usually has a smooth dorsal surface if the host leaf is smooth. Alternatively, if the underside of the host leaf is covered with stiff hairs or spines, the pupa usually possesses very long (usually two to eight) dorsal setae arising on the head, thorax and abdominal areas. The pupa also tends to develop other unique characteristics on given hosts, as has been demonstrated by cross-rearing various populations on different hosts. Before interhost morphological variability was realized, numerous *Bemisia* synonyms were described as distinct species, but are now considered to be *B. tabaci* (Russell 1957) (Table 1).

Partly because of host induced morphological variation, conventional taxonomists have not been able to find characters in any of the life stages of SPW that would indicate that more than one species is present. Current diagnostic methods require either live insects to test for the ability to induce squash silver leaf symptoms, or adults that have been adequately preserved for electrophoretic analysis.

What poinsettia SPW actually represents remains in question. Because no differentiating morphological traits have been found it must currently be considered to be the same species as cotton SPW, *B. tabaci.* Yet its explosive population growth and host acquisitions in the presence of cotton SPW suggest that it probably represents something more than a simple biotype, perhaps a sibling species. (Interestingly, type material of *Bemisia poinsettiae* Hempel, 1923, described from Brazil on *Poinsettia* [obtained by E. Delfosse], shows no conventionally used morphological characters that can be used to separate it from *B. tabaci,* with which it thus may be synonymous.) Although there are a few taxonomic tools that are still available to use (e.g., morphometric multivariate analyses), it may take a while before they can be adequately developed on this problem. However, even if we can satisfactorily determine the relationships between the two SPW "strains," we will still require satisfactory control measures. Cotton SPW caused as much as $100 million in agricultural losses in southeastern California in 1981 (Duffus & Flock 1982). With recent developments, losses in 1991 may go well beyond that mark, because now crops are being attacked that were not infested previously.

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