Trends In Temporal Distribution in 1988-1994, Host Plant Relations, and Virus-Vector Characteristics of Two Whitefly Populations In Arizona

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Abstract

The abrupt and widespread introduction and establishment of the B type whitefly B. tabaci (Genn.) (also B. argentifollii) in Arizona in approximately 1987-1990 has given rise to unprecedented losses in vegetable and fiber crops in Arizona, and elsewhere throughout the sunbelt states. This report documents the discovery and the tracking of B type whitefly over time in Arizona crop and weed species, and reports important biological characteristics of the A and B whitefly populations with respect to host range, host preferences, and virus-vector capabilities. Here, from tracking data, we provide direct evidence that the A and B whitefly populations existed simultaneously in the state for a short period of time during 1989-90, and that by 1991, the B type population had become predominant whitefly pest and whitefly vector of plant viruses in Arizona crops. Unique host ranges and host preferences represent the most important distinctions between these two populations of B. tabaci, and are largely responsible for the altered epidemiologies of several whitefly-associated virus diseases, and for new pest problems in previously unaffected crops. From these collective data, it is possible to present an historical documentation of the emerging importance of the B whitefly as a pest and virus vector in Arizona. An unusually broad host range and the ability to induce phytotoxic disorders, set the B population apart from the historically problematic, local A type B. tabaci, and provide insights into the underlying basis of its unprecedented impact on crop production in Arizona. Baseline information about whitefly biology, host range, and virus-vector capabilities is relevant to the design and implementation of management practices aimed at controlling the whitefly as a pest and virus vector in Arizona crops.

Introduction

The whitefly *Bemisia tabaci* (Genn.) species complex (Brown et al., 1995) has become a serious global insect pest and plant virus vector during the last decade (Brown, 1990; Brown, 1994; Brown and Bird, 1992; Byron et al., 1990). Until recently, members of this whitefly complex were viewed as minor and sporadic pests in most parts of the world. However, *B. tabaci* has been recognized as an important vector of plant geminiviruses in subtropical locales since the early 1900's (Mound and Halsey, 1978).

Most present-day whitefly problems in the Western Hemisphere, inclusive of the sunbelt states of the US, are associated with the recently introduced B biotype/population of *B. tabaci* (also *B. argentifollii).* Prior to the

introduction of the B type whitefly in vegetables and cotton in the US. In Arizona, the A type of *B. tabaci* was the vector of the lettuce infectious yellows closterovirus (LIYV) and the most important regional hosts of the whitefly and LIYV were beets, cucurbits, lettuce, melons, squashes, spinach, watermelon, and several overseasoning weed species. In addition, the A type whitefly colonized cotton, a crop which is unaffected by the LIY disease, but is a host of cotton leaf crumple disease (Dickson and Laird, 1954). Diseases caused by LIYV became epidemic in the southwestern US and northern Mexico for the first time in 1980-81, and thereafter epidemics were common in lettuce, melons, and other cucurbits on an annual basis until about 1990 (Brown and Nelson, 1984); (Brown and Nelson, 1986), (Duffus et al., 1986). The rapid decline in the incidence of LIY disease in Arizona after the 1990 growing season coincided widespread colonization by the B type whitefly. This whitefly was found in extremely high numbers in broccoli, cauliflower, cotton, melons, squashes, weeds, and many ornamentals not considered hosts of the indigenous A biotype. Despite a decreased importance of LIY disease in Arizona vegetable crops, both the A and B type whiteflies are effective whitefly vectors of subgroup III or whitefly-transmitted (WFT) geminiviruses known to occur in the southwestern US, including cotton leaf crumple virus (CLCV) (Brown et al., 1987; Brown and Nelson, 1984; Brown and Nelson, 1987) and squash leaf curl virus (SqLCV) (Brown and Nelson, 1984; 1986; 1989).

Although the indigenous A type population of *B. tabaci* was recognized as the predominant whitefly pest and virus vector in the southwestern US from at least from the 1950's to approximately 1990, it has not been detected in field samples from Arizona since 1990-91 when the B biotype became firmly established in the region. Thus, the widespread and successful establishment of the B type whitefly has resulted in the apparent disappearance of the A type whitefly in Arizona agroecosystems. In retrospect, the B type whitefly population was first discovered in the southwestern US in inornamental crops approximately in 1987-1988 (Brown, 1994; Brown, et al., 1995; Byrne and Miller, 1990; Costa and Brown, 1990; Costa and Brown, 1991), shortly after its accidental introduction into the US and the Caribbean Basin in about 1986 (Brown, et al., 1995; Costa et al., 1993; author, unpublished data). The primary reason that this whitefly went unnoticed for some was because there are no classical morphological characters that can be used to readily distinguish between distinct *B. tabaci* populations (Bedford et al., 1994; Rosell et al., in preparation; Russell, 1957). As a result, the B biotype was not immediately recognized as distinct from local *B. tabaci* populations when it first appeared in the Western Hemisphere. Further, it was not readily distinguished based on specific host range or host preferences or on differential virus-vector capabilities because these characteristics were similar and overlapped with those known for the A type whitefly. And, finally, whiteflies were considered subtropical insects, and were generally poorly studied at this time. As a result, the B biotype in invaded many food and fiber producing locales, worldwide, transported on infested plant materials in ornamental nursery crops and vegetable transplants (Brown, et al., 1995; Brown et al., 1995).

Subsequent studies have demonstrated the B type whitefly to be a highly polyphagous insect, and it is presently thought capable of colonizing several hundred plant species including cotton, tobacco, ornamentals, vegetables, and weeds (Byrne and Bellows, 1991; Costa and Brown, 1991; Coudriet et al., 1985). This high degree of polyphagy, combined with an ability to transmit many recently discovered geminiviruses (Bedford et al., 1994), has been of primary importance in the emergence of whitefly-transmitted geminiviruses as globally important plant pathogens (Brown, 1990; 1994; Brown and Bird, 1992).

Here are reported the results of studies whose objectives were to define: the distribution, the host ranges, and the virus-vector capabilities of two *B. tabaci* populations, with particular emphasis on how such differences impact virus disease incidence and spread Arizona cropping systems. A portion of this study involved a long-term field study designed to identify important cultivated and weed hosts of the whitefly and to monitor the distribution of whitefly transmitted plant viruses in Arizona agroecosystems. In these studies, we documented a shift in composition in whitefly populations which occurred immediately during the following introduction of the B biotype into Arizona. In addition specific crop and weeds utilized for overseasoning hosts were identified, and new trends in distribution and predominant types of WFT virus diseases in crops were documented. It is hoped that the systematic documentation of these trends will permit a greater understanding of the ephemeral status of whitefly-transmitted viruses in Arizona agroecosystems, and create a better appreciation of how differences in the biology of two distinct whitefly vector populations can affect cropping strategies and management approaches required to achieve virus disease control.

Materials and Methods

Field surveys to determine natural host ranges and relative population densities of the A and B biotypes. Leaves of common weed and cultivated plants were inspected throughout the spring, summer, and fall (March -November) for the presence of whitefly adults, and for evidence of reproduction and completion of the whitefly life cycle. Sites were visited every three to five weeks throughout the growing seasons in 1988-89 and again in 1991-93. During 1994, field-collected whitefly adults were received from various researchers conducting whitefly studies in southern Arizona. For routine surveys, plants inspected were those cultivated species and weeds growing in the field, along field edges, and along irrigation ditch banks. Fields were also casually inspected for the presence of absence of disease symptoms caused by whitefly-transmitted virus pathogens: (1) lettuce infectious yellows closterovirus (LIYV) in beets (1988 only), lettuce, melons, spinach (1988-89 only), and watermelon (2) for squash leaf curl geminivirus (SqLCV) in melons, pumpkin, squashes, and watermelons, and for (3) cotton leaf crumple geminivirus (CLCV) in cotton. In Coolidge and Maricopa, Arizona, guayule and small-scale pepper and tomato plantings were monitored when available during 1988-1993, whereas in the Yuma Valley, broccoli, cabbage, cauliflower, and safflower (1988-89 only) fields were included in the survey.

To estimate whitefly population densities, plants upon which whitefly adults were present were scored as 'feeding' hosts, whereas those that harbored 3-4th instars to the pupal stage and empty pupal cases were scored as 'reproductive hosts'. Relative adult population densities were estimated by visual inspection of several leaves per plant species at the same sampling site. Densities of less than 10 whiteflies per plant were described as very low, less than 30 as 'low', between 30-50 as 'moderate', 50-200 as 'high', and over 200 were scored as 'very high'.

Composition of field populations in southern Arizona from 1988-1994 based upon esterase electromorphs. Adult whiteflies were collected from different hosts using a hand-held aspirator, transferred to small vials placed on ice, and transported to the UA laboratory for electrophoretic analysis of non-specific esterase patterns. Esterase electromorphs were compared for different populations of adult whiteflies using a protocol, modified from (Wool et al.,, 1989) .

Using this diagnostic approach, two distinct, diagnostic patterns or electromorphs were found in Arizona populations of *B. tabaci*. One distinct esterase electromorphs were obtained for a population of *B. tabaci* maintained in a colony at the UA main campus that originated from cotton in Phoenix, AZ in 1981, and a second diagnostic pattern was obtained for a colony of whiteflies reared on poinsettia plants that had been established from nursery cuttings in 1987 (Byrne and Miller, 1990; Costa and Brown, 1991) These results indicated polymorphism between the populations examined and provided a diagnostic assay to differentiate between two whitefly populations. The two populations were tentatively designated as either the A biotype of *B. tabaci* , the local or 'indigenous' whitefly population, and the second, from the poinsettia colony was termed the B biotype. This latter whitefly is now known to be an exotic population of *B. tabaci* that was inadvertently introduced into Arizona, numerous sites in the US and Caribbean Basin, and eventually, nearly throughout the world on infested nursery plants beginning in approximately 1985-86.

Using this diagnostic electrophoresis assay, the distribution of the A and B biotypes of *B. tabaci* were monitored in Arizona cropping systems from 1988 to 1994. This assay, also permitted the tracking of the B type whitefly as it become established in the US, the Caribbean Basin, Central America, and throughout the Eastern Hemisphere and Australia during 1988-present (Brown et al., 1995; Costa et al., 1993).

Experimental host choice studies. Host choice tests were conducted in a small, isolated greenhouses on the UA campus. Whiteflies of the A and B biotype were reared in separate colonies, and were routinely verified as A or B using the diagnostic esterase assay described above. Approximately 100 pairs of whitefly adults were released from cotton plants (upon which they had been reared for at least 10 generations), and allowed to disperse in a greenhouse containing different test plants (4-6 true leaf stage). Whiteflies were permitted to move freely between and/or to settle on plants of choice. Test plants (4-6 true leaves) were: common bean "Topcrop', cotton 'DP70', broccoli 'Waltham 29', cauliflower 'Snowball', and okra 'Clemson Spineless'. Plants were arranged randomly on benches in the greenhouse and whiteflies were permitted to move freely among plants for three days, after which they were killed by fumigation using a non-systemic insecticide.

Offspring were permitted to develop on test plants for several weeks, or until adults emerged. Eggs and life stages were tabulated by recording the number of eggs and various instars on leaves of test plants. Life stages were counted at routine intervals by carefully placing plants with leaves (attached) under a dissecting microscope for observation.

Experiments were conducted during the spring and/or fall seasons in two consecutive years, and data shown are averaged values from three replicates and three experiments (standard deviations not shown).

Virus transmission studies. Whitefly-transmitted viruses and source plants used in this study were: cotton leaf crumple geminivirus in cotton (Brown and Nelson, 1987), chino del tomate geminivirus in tomato (Brown and Nelson, 1988), squash leaf curl geminivirus in squash (Brown and Nelson. 1989), and lettuce infectious yellows closterovirus (Brown and Nelson, 1986; Brown and Poulos, 1989) in lettuce or melon.

Colonies of the A and B biotypes used in virus transmission experiments were reared on pumpkin or cotton, respectively, for at least 10 generations. Adult whiteflies were allowed a 24-hr acquisition-access period (IAP) on virus-infected source plants that were inoculated approximately 3-4 weeks earlier. Twenty adult whiteflies were transferred to each virus indicator plants (3-4 leaf stage) (Table 5) and permitted a 3-day inoculation-access period (AAP). Whiteflies were killed by fumigation and plants were treated with a systemic insecticide to prevent further development of progeny on inoculated plants.

Inoculated plants were maintained in an insect-free greenhouse and observed for development of characteristic symptom development over a 3-wk period. Plants were scored either positive or negative for disease symptoms. A total of 30 plants was inoculated with each of four WFT viruses.

Results

Field Studies-1988-1989.

Host plants. Adults, developing instars, and empty pupal cases of *B.tabaci* were observed on numerous weed and cultivated hosts throughout annual survey seasons (Tables 1 and 2). In 1988, the most common cultivated hosts in southern Arizona were cotton, cucurbits, lettuce, melons, squash, and watermelon. In central Arizona, beets, spinach, and pumpkin were also heavily to moderately colonized by *B. tabaci,* whereas, in Yuma, safflower was a moderate host (Table 1). And, in this same year, field bindweed, cheeseweed, wild morninglory, and wild sunflower were important reproductive weed hosts in 1988. Plant species that were particularly poor whitefly hosts were pepper, tomato, several desert weeds predominant along ditch sides early in the season(s), ground cherry, pigweed, and sowthistle (Table 1; Brown et al., 1990).

In 1988, extensive seasonal monitoring of whiteflies was done in numerous locations in south-central Arizona. Population development from early June through early November was similar in south-central Arizona, and similar trends were observed in all fields monitored (over ten in the Coolidge area), with initial populations increasing in late July, peaking in mid-October, and declining by early November (J. Easley and J. K. Brown, unpublished data). Examples of this trend are shown for two cultivars of cotton, 'S-6 and DP 90', and for camphorweed and sunflower, two weeds that were once predominant hosts of the *B. tabaci* (the A type) in the spring and early summer in central Arizona. Seasonal development of *B. tabaci* populations is compared to that of the resident whitefly, *Trialeurodes abutilonea* (Haldeman) in two cotton fields (Figures 1a,b) and two weeds (Figures 2a,b; Brown et al., 1990).

In 1989, hosts upon which whiteflies fed and reproduced differed somewhat from those recorded in 1988, and previously. In retrospect, these seemingly subtle changes provided the first evidence toward a transition in the plant species that would support whitefly populations, and was an indication that the B biotype had begun to colonize host plants in the field for the first time in southern Arizona. Although many of the same cultivated and weed species are hosts of the B biotype, there are several additional species that comprise the host range of the B biotype. Weed hosts that differed most notably in colonization by the whitefly were goosefoot, groundcherry, pigweed, puncturevine, and sowthistle, which were among the species that supported the highest densities of whitefly populations in 1989. In contrast, population densities were somewhat lower on sunflower and camphorweed than the previous year (Brown et al., 1990).

In 1989, cotton continued to support high densities of whiteflies in central Arizona (Figure 3 a,b) and the Yuma Valley. An example of trends in population increases in cotton in Coolidge, AZ are shown for two cultivars, 'S-6' and 'DP90', and is similar to those observed in 1988 in the same region. In Central Arizona, beets, lettuce and spinach were only moderate whitefly hosts, whereas, populations developed on experimental plantings of pepper and tomato for the first time. Whiteflies densities in lettuce and melons in Central Arizona were somewhat typical to prior years, as was the situation in these crops in the Yuma area (Brown et al., 1990). However, in 1989, broccoli, cabbage,and cauliflower crops were unexpectedly colonized for the first time by *B. tabaci* in the Yuma Valley

(author, pers. observ), with populations reaching moderately high densities, a phenomenon not documented previously, except in the Eastern Hemisphere (Cock, 1986).

Whitefly populations. Esterase analysis indicated that whitefly samples from south central Arizona and Yuma were comprised of either the A or B biotypes, whereas those from nursery grown-poinsettia, and several other ornamentals from nurseries were the B biotype (Table 3; Brown, 1992). Samples collected from central Arizona and from Florida samples (site where B biotype first documented) (Brown, 1992; Costa et al., 1993) in 1989 were comprised primarily of the A biotype (70%), but the B biotype was clearly detectable in approximately 30% samples from several areas in the state, including the UA Maricopa Agricultural Center and the Yuma Valley (data not shown). By A biotype was was not detected in any of the samples evaluated, whereas the B biotype was detected in 100% of the samples analyzed (Costa et al., 1993). In 1991, the A biotype was found in cotton in a remote field in Sonoita but samples from the rest of the state contained only the B biotype. (Table 3; Brown, 1992).

Virus diseases. In 1988 and 1989, characteristic virus disease symptoms were observed for several WFT viruses previously documented in the region: LIYV disease symptoms were observed in beets, lettuce, melons, spinach, and watermelons in nearly 100% of fields examined in south central and Yuma areas, CLCV in cotton was estimated at 20-60% incidence, and SqLCV disease incidence was approximately 70% in pumpkin and summer squashes in central Arizona, and often 100% in Yuma (author, pers. observation).

Although WFT virus-like symptoms were not observed in cole crops, a new stem streaking disorder was observed for the first time (Brown et al., 1991). In 1987-88, squash silverleaf (SSL) disorder (Yokomi et al., 1990) was documented for the first time in Arizona in experimentally infested squash (Costa and Brown, 1990; 1991) and by 1989, the SSL disorder was observed in squash fields and in home gardens throughout southern Arizona (Costa et al., 1993; author, pers. observation). As such, the SSL disorder was discovered to be a biological indicator for the B biotype when a B type esterase pattern was consistently correlated with a whitefly population's ability to induce silverleaf in squash (Costa and Brown, 1991)

At about the same time, several other similarly unique disorders in tomato (Bharanthan et al., 1992; Schuster et al., 1990) and lettuce (Costa et al., 1993) were also shown to be caused by direct feeding of the B biotype whitefly.

Field Studies-1991-1994.

Host plants. By 1991 and continuing through the end of the study period in 1994, cultivated hosts of the whitefly included traditional species such as cotton, cucurbits, lettuce as in the past. Those recognized as 'new' hosts were broccoli, cabbage, and cauliflower, pepper, soybean, and tomato. Weeds documented as important 'new' hosts were prickly lettuce, pigweed, punturevine, sowthistle, and groundcherry. Weeds that were important in 1988-89, and that remained so after 1991, are bindweed, cheeseweed, and morninglory. By 1991-94, however, sunflower was no longer an important spring/early summer host or source of the whitefly in Arizona (Table 2) (Brown et al., 1990).

Whitefly populations. Diagnostic esterase assays of all populations examined during 1991-94 indicate that all samples were the B type whitefly (Costa and Brown, 1991; Costa et al., 1993; Brown et al., 1995). The A type was not detected in any sample collected in fields or greenhouses in Arizona after 1990 (Author, unpublished).

Virus Diseases. Visual inspection of fields for characteristic disease symptoms of WFT viruses indicated that from 1991-1994, CLCV continued to infect cotton in Central Arizona and Yuma Valley with an incidence of approximately 10-50%. SqLCV disease symptoms were observed routinely in melons and watermelons (30-90%) in the Yuma Valley, in Central Arizona, as far south as Tucson. SqLCV infection was also observed in squash and pumpkin plantings in Coolidge, Maricopa, Phoenix, and Tucson, although these crops were no longer grown as widely in the state due to increasing whitefly pressures and damage caused by both SqLCV and the SSL disorder. Since approximately 1991, LIYV disease symptoms have not been observed in lettuce, melons, watermelons, or other hosts as it was prior to approximately 1981-89/90. This has led to the suggestion that the B type is a poor vector of LIYV and hence, the LIYV inoculum levels have decreased or diminished to undetectable levels (Brown et al., 1990).

In 1993-94, several young lettuce fields in the Yuma area exhibited foliar yellowing that was somewhat reminiscent of LIYV, however, no WFT virus, including LIYV, was detected in experimental greenhouse transmission experiments (author, unpublished data). The foliar yellowing symptom observed in certain lettuce cultivars is now

believed to be the caused by infestations of the B type, and mimics the disorder of lettuce recently described in Hawaii, following the establishment of the B type (Costa et al., 1993).

Experimental Host Choice Tests. In host choice tests, the A and B performed differently on the suite of plant species offered in the experiments described here. Compared to the A type, the B type had a more diverse host range and produced to higher densities on most (Table 4). For example, although bean and cotton appear to be hosts of both biotypes, the B type can also readily colonize broccoli and cauliflower, and reproduced to some degree on okra. In contrast, the A biotype could not utilize the latter three plants as reproductive hosts, though clearly, the A type was able to fed on these plant species at least long enough to deposit eggs. The utility of certain plant species to serve as a host for either feeding and reproduction of whitefly populations, exclusively for feeding but not for reproduction, likely provides important clues about the success of the B type in Arizona agroecosystems. In addition, this information has clear application toward developing an understanding the epidemiology of WFT virus diseases, and to the dynamics of whitefly populations and yield-reducing phytotoxic disorders.

Experimental Virus Transmission. The experimental evidence provided here, indicates that the B type is not an effective vector of LIYV, and/or that, in nature, the natural source of LIYV is not a host of the B type. In contrast, the B biotype can readily transmit CLCV, CdTV, and SqLCV. Although not statistically significant, the B type appears from these data to be as effective if not more so, in transmitting the three geminiviruses tested here (Table 5). Several additional studies now corroborate the efficacy of the B type as a vector of many WFT geminiviruses, including those that infect bean, cotton, cucumber, melon, passionvine, pepper, squash, tomato, and watermelon (Bedford et al., 1994; Brown 1994; Brown and Bird, 1992).

Discussion

The data presented here indicate that since approximately 1990-91, the B type has become the predominant *B. tabaci* population in Arizona, and that the initial introduction into the southwestern US occurred in approximately 1988-89. Based on these data and that from additional studies (Costa et al., 1993), the B type appears to have become rapidly established in the US as the predominant whitefly population, and the A type that was present in Arizona until at least 1990, has either disappeared, or remains in obscure sites that have yet to be identified. In retrospect a series of B type introductions occurred throughout the world, primarily through the commercial exchange of whitefly-infested ornamental plants, beginning in approximately 1985-86 (Brown et al., 1995; Costa et al., 1993). The outcome is that the B type is now present in either greenhouses and/or field crops on all continents inhabited by humans. The distribution of numerous, apparently genetically distinct, populations of *B. tabaci* (recognized initially as races or biotypes), and the impact of correspondingly variable phenotypes in agroecosystems recently affected by whitefly populations within this proposed *B. tabaci* species complex, is not yet entirely clear (Bellows et al.,, 1994; Bethke et al., 1991; Brown et al., 1995; Perring et al., 1993).

The host range data of the B type presented here are also corroborated by several recent studies that have demonstrated important differences in the host ranges of the A and B whitefly populations (Bethke, et al., 1991; Byrne, and Miller, 1990; Costa and Brown, 1991; Perring et al., 1993). These differences have been born out terms of the dramatic changes experienced in agroecosystems in Arizona, and by the need to establish new management approaches for whitefly-related pest and disease problems. For example, under high population pressures, direct feeding alone by the B type can result in high levels of damage through reduction of plant vigor, and subsequent contamination of fruits, leaves, and fiber by honeydew (the sugary waste product of the whitefly). Under lower pressures, phytotoxic disorders (squash silverleaf, uneven ripening of tomato, stem streaking of cole crops) are induced by the feeding pressures imposed by as few as three to five nymphs in a variety of plant species (Costa et al., 1993).

The collective consequences of this broader host range and higher population densities have facilitated an increased mobilization of WFT viruses in both crop and weed hosts. Further, these characteristics, and the importance of the B biotype as a vector of geminiviruses have created new local virus reservoirs in plants that are hosts of the B biotype, but which were not colonized by the A biotype. Thus, altered virus disease epidemiologies and B biotype-associated phytotoxic disorders are both the direct result of the introduction of the B type into the region.

The minimum threshold level of the adult viruliferous whitefly vector that result in virus transmission is theoretically one, indicating a strong correlation between the global increase in virus disease incidence and the associated difficulties encountered in controlling whitefly populations. The rapidly increasing importance and distribution of the *B. tabaci* species complex, and of the recognition of plant viruses transmitted by members of this

whitefly-transmitted viruses as emerging plant pathogens requires new information about the biology and genetics of the whitefly, and concerning virus-vector interactions. It is clear that this information will be needed to combat the serious constraints now imposed by the *B. tabaci* complex on the production of vegetable and fiber crops in the desert southwest.

Literature Cited

Bedford, I. D., P. J. Markham, J. K. Brown and R. C. Rosell. 1994. Geminivirus transmission and biological characterization of whitefly *Bemisia tabaci* biotypes from different geographic regions. *Ann. appl. Biol.* **125**: 311-325.

Bellows, T. S., Jr., T. M. Perring, R. J. Gill and D. H. Headrick. 1994. Description of a species of *Bemisia* (Homoptera: Aleyrodidae) infesting North American agriculture. *Ann. Entomol. Soc. Am.*, **87**: 195-206.

Bethke, J. A., T. D. Paine and G. Nuessly. 1991. Comparative biology, morphometrics, and development of two populations of *Bemisia tabaci* (Homoptera: Aleyrodidae) on cotton and poinsettia. *Ann. Entomol. Soc. Am.* **84**: 407-411.

Bharanthan, N., K. R. Narayanan and R. T. McMillan Jr. 1992. Characteristics of sweetpotato whitefly-mediated silverleaf syndrome and associated double-stranded RNA in squash. *Phytopathology* **82**: 136-141.

Brown, J. K. 1990. An update on the whitefly-transmitted geminiviruses in the Americas and the Caribbean basin. *FAO Bulletin* **39**: 5-23.

Brown, J. K., J. R. Easley, B. T. Poulos, and M. R. Nelson. 1990. Assessment of virus disease incidence and whitefly populations in an isolated agroecosystem in Central Arizona. Pages 84-89 in: Vegetable Report. College of Agriculture Series P70. Coop. Ext. Serv., Agric. Exp. Stn., University of Arizona, Tucson, AZ.

Brown, J. K. 1994. Current status of *Bemisia tabaci* as a pest and virus vector in world agroecosystems. *FAO Plant Prot. Bull.* **42**: 3-32.

Brown, J. K. and J. Bird. 1992. Whitefly-transmitted geminiviruses and associated disorders in the Americas and the Caribbean Basin. *Plant Dis.* **76**(3): 220-225.

Brown, J. K., S. Coats, I. D. Bedford, P. G. Markham, J. Bird and D. R. Frohlich. 1995. Characterization and distribution of esterase electromorphs in the whitefly, *Bemisia tabaci* (Genn.) (Homoptera: Aleyrodidae). *Biochem. Genet.* **33**: 205-214.

Brown, J. K., H. S. Costa and F. Laemmlen. 1991. First incidence of whitefly-associated squash silverleaf (SSL) of *Cucurbita*, and of white streaking (WSt) disorder of cole crops in Arizona and California. *Plant Dis.* **76**: 426.

Brown, J. K., D. R. Frohlich and R. Rosell. 1995. The sweetpotato/silverleaf whiteflies: Biotypes of *Bemisia tabaci* (Genn.), or a species complex? *Ann. Rev. Entomology* **40**: 511-534.

Brown, J. K., J. D. Mihail and M. R. Nelson. 1987. The effects of cotton leaf crumple virus on cotton inoculated at different growth stages. *Plant Dis.* **71**: 699-703.

Brown, J. K. and M. R. Nelson. 1984. Geminate particles associated with cotton leaf crumple disease in Arizona. *Phytopathology* **74**(8): 987-990.

Brown, J. K. 1992. Biotypes of the sweetpotato whitefly:a current prospective. Beltwide Cotton Conference, National Cotton Council of America. Memphis, TN. Pages 665-670 in *Proc.* 1992.

Brown, J. K. and M. R. Nelson. 1984. Two whitefly-transmitted viruses of melons in the Southwest. *Phytopathology* **74**: 1136.

Brown, J. K. and M. R. Nelson. 1986. Whitefly-borne viruses of melons and lettuce in Arizona. *Phytopathology* **76**: 236-239.

Brown, J. K. and M. R. Nelson. 1987. Host range and vector relationships of cotton leaf crumple virus. *Plant Dis.* **71**: 522-524.

Brown, J. K. and M. R. Nelson. 1988. Transmission, host range, and virus-vector relationships of chino del tomate virus, a whitefly-transmitted geminivirus from Sinaloa, Mexico. *Plant Dis.* **72**(10): 866-869.

Brown, J. K. and M. R. Nelson. 1989. Characterisation of watermelon curly mottle virus, a geminivirus distinct from squash leaf curl virus. *Ann. appl. Biol.* **115**: 243-252.

Brown, J. K. and B. T. Poulos. 1989. Detection of lettuce infectious yellows virus (LIYV) in greenhouse and field inoculated plants using an indirect enzyme-linked immunosorbent assay. *J. Rio Grande Valley Hort. Soc.* **42**: 13-18.

Byrne, D. N. and T. S. Bellows. 1991. Whitefly biology. *Annu. Rev. Entomol.* **36**: 431-457.

Byrne, D. N., T. S. Bellows and M. P. Parella. 1990. Whiteflies in agricultural systems. *Whiteflies: their bioeconomics, pest status, and management* Ed. D. Gerling. Hants, Intercept Ltd., United Kingdom. 227-261.

Byrne, D. N. and W. B. Miller. 1990. Carbohydrate and amino acid composition of phloem sap and honeydew produced by *Bemisia tabaci*. *J. Insect Physiol.* **36**: 433-439.

Cock, M. J. W. 1986. *Bemisia tabaci-a literature survey on the cotton whitefly with an annotated bibliography.* Ascot, UK, FAO/CAB.

Costa, H. S. and J. K. Brown. 1990. Variability in biological characteristics, isozyme patterns and virus transmission among populations of *Bemisia tabaci* (Genn.) in Arizona. *Phytopathology* **80**: 888.

Costa, H. S. and J. K. Brown. 1991. Variation in biological characteristics and in esterase patterns among populations of *Bemisia tabaci* (Genn.) and the association of one population with silverleaf symptom development. *Ent. exp. appl.* **61**: 211-219.

Costa, H. S., J. K. Brown and D. N. Byrne. 1989. Host selection and offspring survival for *Bemisia tabaci* (Genn.) under greenhouse conditions. *Ent. Soc. Meeting, June, 1989* :

Costa, H. S., J. K. Brown, S. Sivasupramaniam and J. Bird. 1993. Regional distribution, insecticide resistance, and reciprocal crosses between the A and B biotypes of *Bemisia tabaci*. *Insect Sci. and Applic.* **14**: 255-266.

Costa, H. S., D. E. Ullman, M. W. Johnson and B. E. Tabashnik. 1993. Association between *Bemisa tabaci* density and reduced growth, yellowing, and stem blanching of lettuce and kai choy. *Plant Dis* **77**: 969-972.

Costa, H. S., D. E. Ullman, M. W. Johnson and B. E. Tabashnik. 1993. Squash silver leaf symptoms induced by immature, but not adult, *Bemisia tabaci*. *Phytopathology* **83**: 763-766.

Coudriet, D. L., N. Prabhaker, A. N. Kishaba and D. E. Meyerdirk. 1985. Variation in developmental rate on different hosts and overwintering of the sweetpotato whitefly, *Bemisia tabaci* (Homoptera: Aleyrodidae). *Environ. Ent.* **14**: 516-519.

Duffus, J. E., R. C. Larsen and H. Y. Liu. 1986. Lettuce infectious yellows virus-a new type of whitefly-transmitted virus. *Phytopathology* **76**: 97-100.

Mound, L. A. and S. H. Halsey. 1978. *Whitefly of the World.* New York, Wiley.

Perring, T. M., A. D. Cooper, R. J. Rodriguez, C. Farrar and T. S. Bellows. 1993. Identification of a whitefly species by genomic and behavioral studies. *Science* **259**: 74-77.

Russell, L. M. 1957. Synonyms of *Bemisia tabaci* (Gennadius) (Homoptera: Aleyrodidae). Bull.of Brooklyn Entomol. Soc. 52: 22-123.

Schuster, D. J., T. F. Mueller, J. B. Kring and J. F. Price. 1990. Relationship of the sweetpotato whitefly to a new tomato fruit disorder in Florida. *Hortscience* **25**(12): 1618-1620.

Wool, D., D. Gerling, B. L. Nolt, L. M. Constantino, A. C. Bellotti and F. J. Morales. 1989. The use of electrophoresis for identification of adult whiteflies (Homoptera, Aleyrodidae) in Israel and Columbia. *J. Appl. Ent.* **107**: 344-350.

Yokomi, R. K., K. A. Hoelmer and L. S. Osborne. 1990. Relationship between the sweetpotato whitefly and the squash silverleaf disorder. *Phytopathology* **80**: 895-900.

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Table 1. Hosts of the A biotype of *B. tabaci* in south-central Arizona cropping systems (Coolidge, Maricopa, and Yuma areas) during surveys conducted 1988-89.

HOST PLANT	COMPLETE LIFE CYCLE[1] 1988 and 1989		POPULATION DENSITITES 1988 and 1989	
Weed Hosts				
Annual morning glory	X	X	very high	moderate
Brittlebush	-	-	very low	-
Camphorweed	X	-	moderate	very low
Cheeseweed	X	X	very high	very high
Coulter globemallow	-	-	low	very low
Emory globemallow	-	-	low	very low
Field bindweed	X	X	very high	high
Ground cherry*(MAC)[2]	-	X	very low	moderate
Prickly lettuce	X	X	moderate	moderate
Sowthistle	X	X	low	high
Spurge*	-	X	-	low
Sunflower	X	X	very high	low
Tumble pig weed*	-	X	-	low
Cultivated Hosts				
Beets	X	n/a	high	n/a
Broccoli	-	X	-	high
Cabbage	-	X	-	high
Cauliflower	-	X	-	high
Cotton	X	X	very high	very high
Lettuce	X	X	moderate	low
Melons (*Cucumis*)	X	X	very high	very high
Safflower	X	-	moderate	-
Spinach	X	X	moderate	low
Summer squash	X	X	very high	very high
Tomato*[3] (MAC)	-	X	very low	high
Pepper* (MAC)	-	X	very low	high
Pumpkin (MAC)	X	X	very high	very high
Watermelon (*Citrullus*	X	X	very high	very high

[1]X= empty pupal cases observed; - = no empty pupal cases observed
[2]Maricopa Agricultural Center, UA, Maricopa AZ
[3]*Not recorded previously as a host of the A biotype of *B. tabaci* in the US

Table 2. Hosts of the B biotype of *B. tabaci* in south-central Arizona cropping systems (Coolidge, Maricopa, and Yuma areas) during surveys conducted 1991-1993.

HOST PLANT	COMPLETE LIFE CYCLE[1]	POPULATION DENSITIES
Weed Hosts		
Prickly lettuce	X	high
Spurge*[2]	X	moderate
Tumble pigweed*	X	low
Annual morninglory	X	moderate
Field bindweed	X	high
Arrow weed*	X	moderate
Prostrate pigweed*	X	high
Lambsquarters	-	very low
Goosefoot	-	moderate
Puncturevine	X	high
Sowthistle	X	high
Cheeseweed	X	high
Groundcherry*	X	very high
Purslane	-	low
Nutsedge	-	very low
Cultivated Hosts		
Broccoli*	X	very high
Cabbage*	X	very high
Carrots	X	moderate
Cauliflower*	X	very high
Cotton	X	very high
Cucumber	X	very high
Lettuce	X	low-moderate
Melons (*Cucumis*)	X	very high
Pepper*	X	moderate
Soybean	X	high
Squash (*Cucurbita*)	X	very high
Tomato*	X	high
Watermelon (*Citrullus*	X	very high

1 X= empty pupal cases observed; - = no empty pupal cases observed

2*Not recorded previously as a host of the A biotype of *B. tabaci* in the US

Table 3. General Esterase Electromorph Profiles of Whitefly Populations in Arizona 1988-1991

Year	Location	Host Plant	Marker
1988	Tucson	cotton	A
		poinsettia	B
		pumpkin	A
	S. Florida	nightshade	B
1989	Casa Grande, AZ	cotton	A
		tomato	A
		zucchini	B
	Tucson, AZ	cotton	A
		poinsettia	B
		pumpkin	A
	Florida	nightshade	B
		tomato	B
		Sida sp.	B
1990	Casa Grande, AZ	cotton	B
		cucumber	B
	Yuma, AZ	broccoli	B[2]
	El Centro, CA	rappini	B[2]
	Florida	tomato	B
1991	Casa Grande, AZ	buffalo gourd	B
		cotton	B
		pepper	B
	Phoenix, AZ	citrus	B
		cotton	B
		muskmelon	B
	Sonoita, AZ	cotton	A
	Yuma, AZ	alfalfa	B
		cotton	B
		lettuce	B
		muskmelon	B
		nightshade	B
		okra	B
		peanut	B

Table 4. Number of eggs and different developmental stages of A and B biotype whiteflies in host choice tests conducted under greenhouse conditions. Data are the average number of each stage or instar for three test plant species per experiment, and a total of three experiments conducted over a 2 yr period of time. Approximately 100 pairs of adult whiteflies were permitted free access to test plants (4-6 leaf stage) for three days following release from cotton plants upon the which colonies were reared for at least 10 generations. (Standard deviations are not shown).

'A' Biotype EGGS/INSTAR	Eggs	1st Instar	2nd Instar	2nd Instar	3rd Instar	#Pupae/ Adults
DAYS AFTER INITIAL OVIPOSITION	4	7	7	19-20	19-20	19-4
TEST PLANT						
Common bean	641	489	459	418	360	342
Broccoli	25	15	14	3	0	0
Cauliflower	37	24	3	0	0	0
Cotton	515	488	447	431	402	429
Okra	56	44	32	26	21	16

'B' Biotype EGGS/INSTAR	#Eggs	1^{st} Instar	2^{nd} Instar	2^{nd} Instar	3^{rd} Instar	#Pupae/ Adults
DAYS AFTER INITIAL OVIPOSITION	4	7	7	19-20	19-20	19-24
TEST PLANT						
Common bean	558	544	310	297	233	217
Broccoli	524	461	397	382	359	347
Cauliflower	476	447	423	415	408	393
Cotton	578	558	591	483	479	469
Okra	360	224	198	187	165	149

Table 5. Virus transmission by adult A and B populations of *B. tabaci* to select virus host species, following acquisition access to LIYV, or to one of three WFT geminivirus (CLCV, CdTV, or SqLCV)-infected source plants. Following a 24-hr acquisition access period on the respective virus source plants, twenty adult whiteflies were transferred to virus indicator hosts for a 48-hr inoculation access period (IAP). Data are for three experiments with 10 replicates (plants) each. The A biotype colony was reared on 'Big Max' pumpkin, and the B biotype colony was reared on cotton 'Delta Pine 70'.

Plant Virus/ Virus	Virus Source	Test Host Inoculated	Transmission Frequency (%) #Infected/#Inoculated			
Acronym			A biotype		B biotype	
Cotton leaf crumple geminivirus	cotton	cotton	25/30	83%	28/30	93%
(CLCV)	cotton	*Malva parviflora*	28/30	93%	29/30	96%
Chino del tomate gemnivirus	tomato	tomato	19/30	63%	24/30	80%
CdTV)	tomato	bean	23/30	76%	26/30	86%
	tomato	*Malva parviflora*	22/30	73%	27/30	90%
Squash leaf curl geminivirus	squash	squash	28/30	93%	30/30	100%
(SqLCV)	squash	bean	27/30	90%	29/30	96%
Lettuce infectious yellows closterovirus	lettuce	lettuce	22/30	73%	2/30	6%
(LIYV)	melon	melon	25/30	83%	1/30	3%

Figure Legends

Figure 1. Example of typical whitefly (*Bemisia tabaci* and *Trialeurodes abutilonea*) population densities in (a) cotton (S -6) monitored from June 8 - November 2, 1988, and (b) cotton (Delta Pine 90) in the Signal Peak area of Arizona monitored from June 8 - October 24, 1988. These collections were likely the A type of whitefly.

Figure 2. Example of typical whitefly (*Bemisia tabaci* and *Trialeurodes abutilonea*) population densities in (a) sunflower from June 8- August 31, 1988, and (b) camphorweed from June 8 - December 5, 1988 in the Signal Peak area of Arizona. These collections were likely the A type of whitefly.

Figure 3. Example of typical whitefly (*Bemisia tabaci* and *Trialeurodes abutilonea*) population densities in (a) cotton (S-6) from August 17 - December 5, 1989, and (b) cotton (Delta Pine 90) from August 17 - November 13, 1989 at Sudance Farms, Coolidge, AZ. These collections were likely the A type of whitefly.

Table 1. Hosts of the A biotype of *B. tabaci* in south-central Arizona cropping systems (Coolidge, Maricopa, and Yuma areas) during surveys conducted 1988-89.

HOST PLANT	COMPLETE LIFE CYCLE[1] 1988 and 1989		POPULATION DENSITIES 1988 and 1989	
Weed Hosts				
Annual morning glory	X	X	very high	moderate
Brittlebush	-	-	very low	-
Camphorweed	X	-	moderate	very low
Cheeseweed	X	X	very high	very high
Coulter globemallow	-	-	low	very low
Emory globemallow	-	-	low	very low
Field bindweed	X	X	very high	high
Ground cherry*(MAC)[2]	-	X	very low	moderate
Prickly lettuce	X	X	moderate	moderate
Sowthistle	X	X	low	high
Spurge*	-	X	-	low
Sunflower	X	X	very high	low
Tumble pigweed*	-	X	-	low
Cultivated Hosts				
Beets	X	n/a	high	n/a
Broccoli	-	X	-	high
Cabbage	-	X	-	high
Cauliflower	-	X	-	high
Cotton	X	X	very high	very high
Lettuce	X	X	moderate	low
Melons (*Cucumis*)	X	X	very high	very high
Safflower	X	-	moderate	-
Spinach	X	X	moderate	low
Summer squash	X	X	very high	very high
Tomato*[3] (MAC)	-	X	very low	high
Pepper* (MAC)	-	X	very low	high
Pumpkin (MAC)	X	X	very high	very high
Watermelon (*Citrullus*)	X	X	very high	very high

[1] X= empty pupal cases observed; - = no empty pupal cases observed
[2] Maricopa Agricultural Center, UA, Maricopa AZ
[3] *Not recorded previously as a host of the A biotype of *B. tabaci* in the US

Table 2. Hosts of the B biotype of *B. tabaci* in south-central Arizona cropping systems (Coolidge, Maricopa, and Yuma areas) during surveys conducted 1991-1993.

HOST PLANT	COMPLETE LIFE CYCLE[1]	POPULATION DENSITIES
Weed Hosts		
Prickly lettuce	X	high
Spurge*[2]	X	moderate
Tumble pigweed*	X	low
Annual morninglory	X	moderate
Field bindweed	X	high
Arrow weed*	X	moderate
Prostrate pigweed*	X	high
Lambsquarters	-	very low
Goosefoot	-	moderate
Puncturevine	X	high
Sowthistle	X	high
Cheeseweed	X	high
Groundcherry*	X	very high
Purslane	-	low
Nutsedge	-	very low
Cultivated Hosts		
Brocolli*	X	very high
Cabbage*	X	very high
Carrots	X	moderate
Cauliflower*	X	very high
Cotton	X	very high
Cucumber	X	very high
Lettuce	X	low-moderate
Melons (*Cucumis*)	X	very high
Pepper*	X	moderate
Soybean*	X	high
Squash (*Cucurbita*)	X	very high
Tomato*	X	high
Watermelon (*Citrullus*)	X	very high

1 X= empty pupal cases observed; - = no empty pupal cases observed

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Broccoli	25	15	14	3	0	0
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'B' Biotype EGGS/INSTAR	#Eggs	1st Instar	2nd Instar	2nd Instar	3rd Instar	#Pupae/ Adults
DAYS AFTER INITIAL OVIPOSITION	4	7	7	19-20	19-20	19-24
TEST PLANT						
Common bean	558	544	310	297	233	217
Broccoli	524	461	397	382	359	347
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	cotton	*Malva parviflora*	28/30	93%	29/30	96%
Chino del tomate geminivirus (CdTV)	tomato	tomato	19/30	63%	24/30	80%
	tomato	bean	23/30	76%	26/30	86%
	tomato	*Malva parviflora*	22/30	73%	27/30	90%
Squash leaf curl geminivirus (SqLCV)	squash	squash	28/30	93%	30/30	100%
	squash	bean	27/30	90%	29/30	96%
Lettuce infectious yellows closterovirus (LIYV)	lettuce	lettuce	22/30	73%	2/30	6%
	melon	melon	25/30	83%	1/30	3%

Figure Legends

Figure 1. Example of typical whitefly (*Bemisia tabaci* and *Trialeurodes abutilonea*) population densities in (a) cotton (S -6) monitored from June 8 - November 2, 1988, and (b) cotton (Delta Pine 90) in the Signal Peak area of Arizona monitored from June 8 - October 24, 1988. These collections were likely the A type of whitefly.

Figure 2. Example of typical whitefly (*Bemisia tabaci* and *Trialeurodes abutilonea*) population densities in (a) sunflower from June 8- August 31, 1988, and (b) camphorweed from June 8 - December 5, 1988 in the Signal Peak area of Arizona. These collections were likely the A type of whitefly.

Figure 3. Example of typical whitefly (*Bemisia tabaci* and *Trialeurodes abutilonea*) population densities in (a) cotton (S-6) from August 17 - December 5, 1989, and (b) cotton (Delta Pine 90) from August 17 - November 13, 1989 at Sudance Farms, Coolidge, AZ. These collections were likely the A type of whitefly.

Whitefly Populations

Signal Peak Mt Area
Cotton S-6

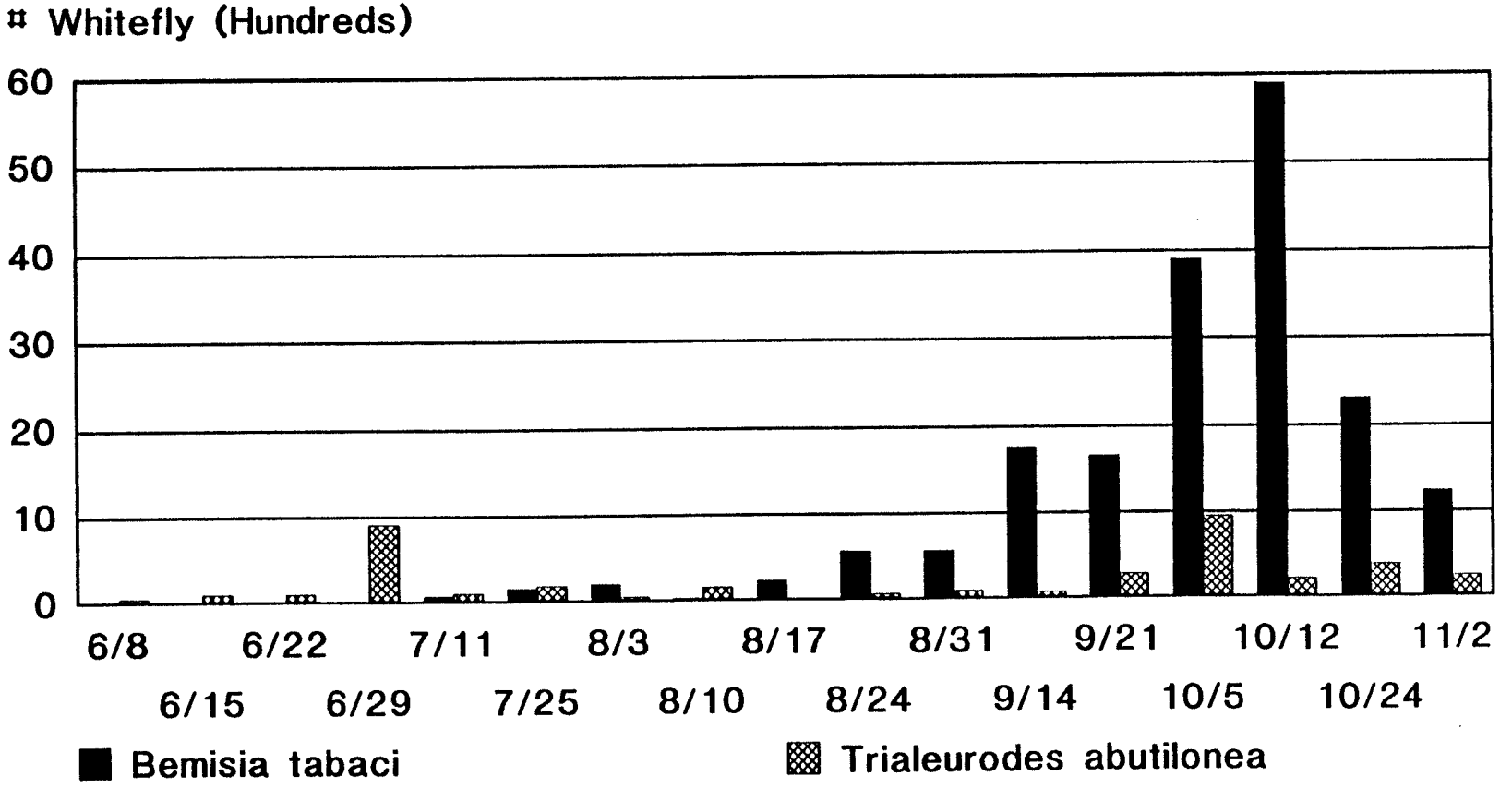

Fig 1a

Whitefly Populations

Signal Peak Mt Area
Cotton DP 90

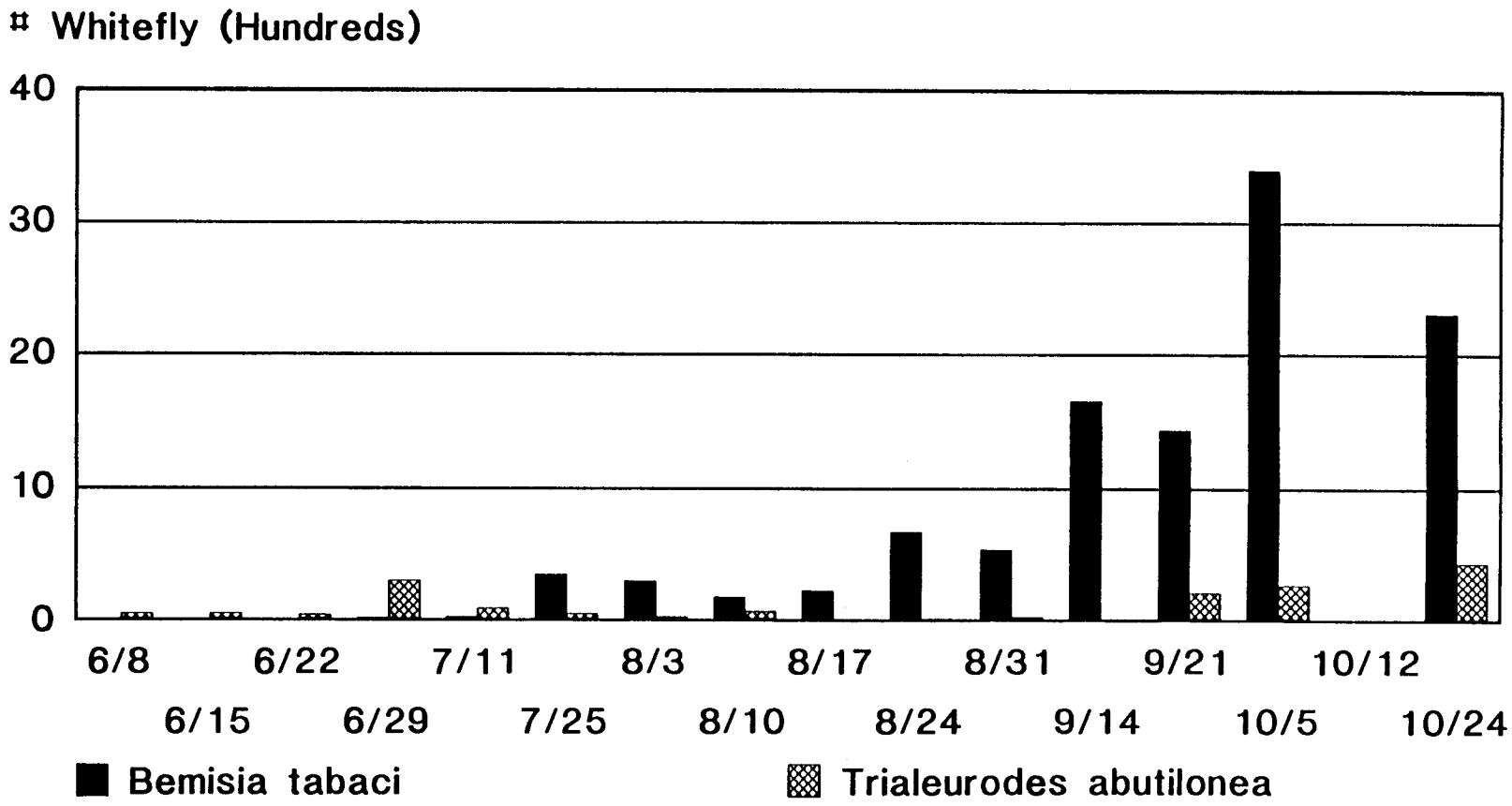

Fig 11b

Whitefly Populations

Signal Peak Mt Area
Sunflower

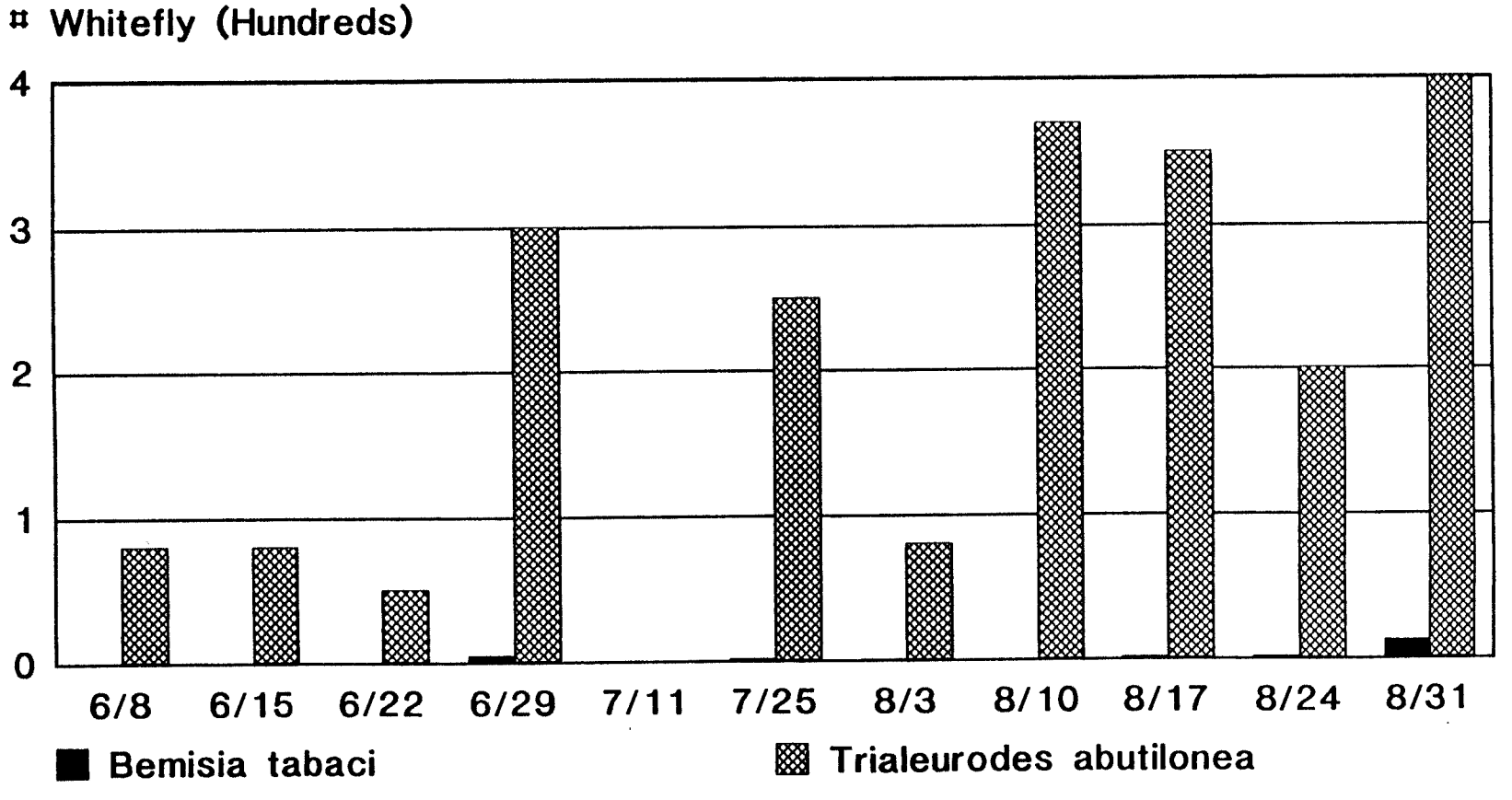

Fig 2a

Whitefly Populations

Signal Peak Mt Area
Camphorweed

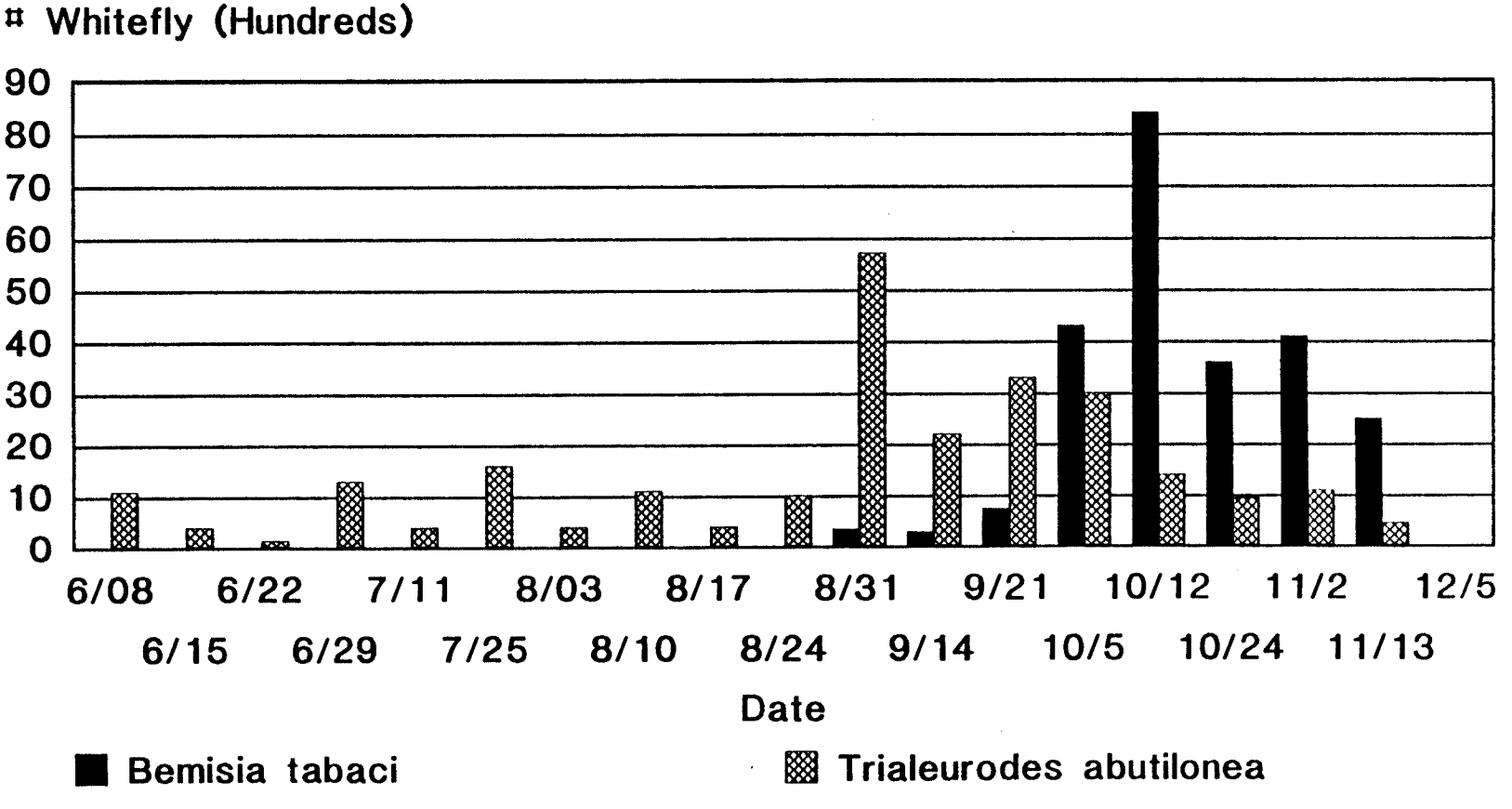

Fig 2b

Whitefly Populations

Sudance Farms
Coolidge, AZ
Field E-8 Cotton S-6

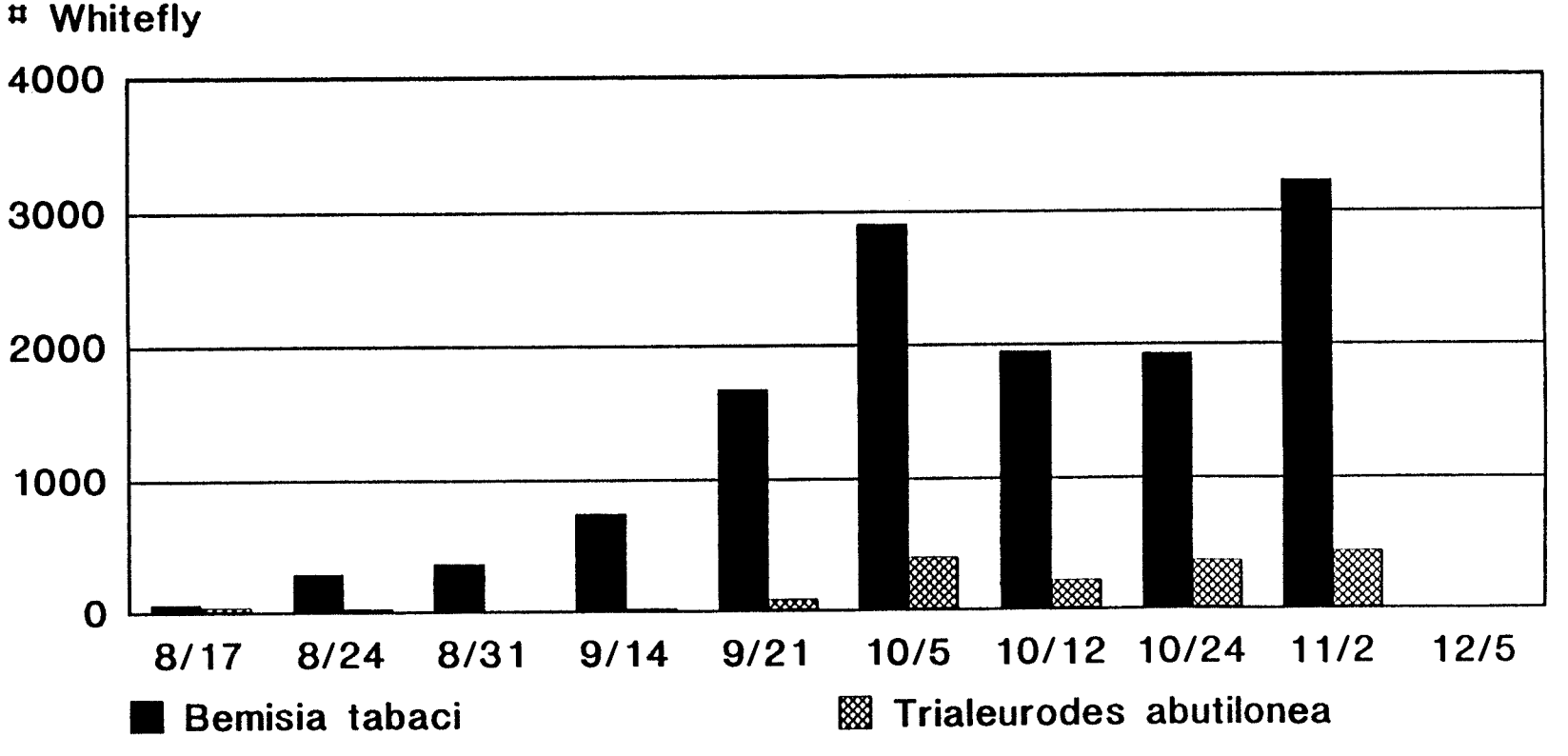

Fig 2a

Whitefly Populations

Sudance Farms
Coolidge, AZ
Field E-7 (NE) Cotton DP 90

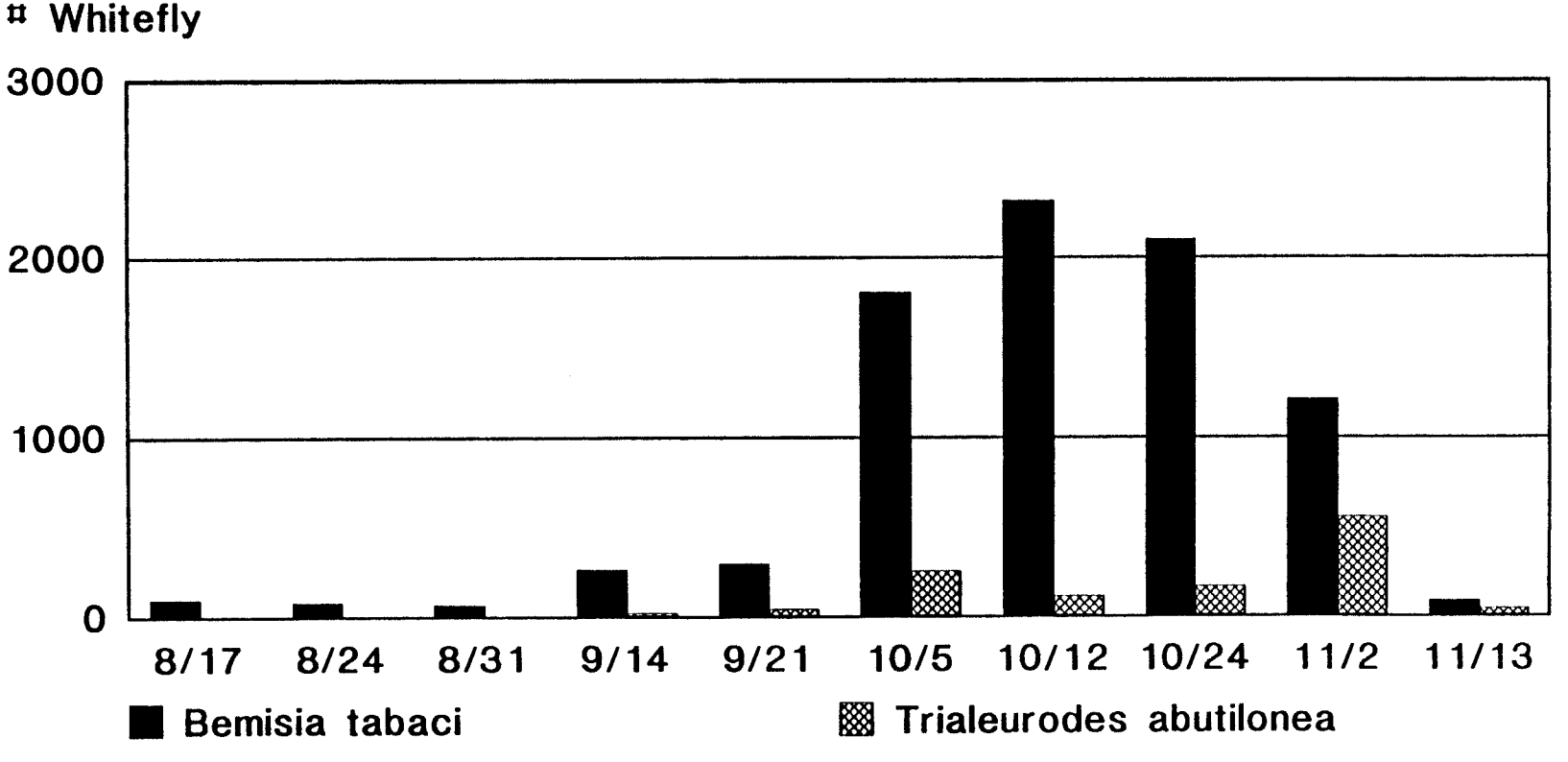

Fig 36