A PRELIMINARY STUDY OF THE SEASONAL POPULATION TRENDS AND DAMAGE ASSOCIATED WITH THRIPS AND PLANT BUGS IN ARIZONA PISTACHIOS.

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A PRELIMINARY STUDY OF THE SEASONAL POPULATION TRENDS AND DAMAGE ASSOCIATED WITH THRIPS AND PLANT BUGS IN ARIZONA PISTACHIOS

by

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ABSTRACT

Western flower thrips, *Frankliniella occidentalis* Pergande, were sampled twice weekly from April through July, 1983, on pistachios in Arizona. The thrips entered the orchards in April, male blossoms became available, and breeding occurred. The population increased until male flowers dehisced, at which time they dispersed from the study orchards.

An insecticide treatment had no significant effect upon the thrips population or upon yield. Although the epicarps of the nuts sustained considerable superficial scarring from thrips feeding, no internal effects were found.

Stink bugs (*Chlorochroa* spp.) and leaf-footed bugs (*Leptoglossus clypealis* Heid.) were present in August and September, but the 1983 populations were very low. Their feeding produced oozing spots on the epicarp but was not correlated with any visible nutmeat damage.

Results of this research indicate that thrips are not economically significant on bearing Arizona pistachio trees. However, the impact of pistachio-feeding Hemiptera remains to be determined.

INTRODUCTION

Since the early 1970's, commercial pistachio orchards have been planted in southern Arizona. These trees first produced a harvestable crop in the fall of 1982. The Say stink bug, *Chlorochroa sayi* Stal. was found in great numbers during the late summer of 1982 in early August. A leaf-footed plant bug, *Leptoglossus clypealis* Heid. was present in smaller numbers during this time. These bugs attacked the nuts, resulting in a subsequent nut drop estimated at up to 80%. The biology-ecology of these species on pistachios has never been investigated. There was also a need to evaluate the pest status of these insects and to develop sampling methods and control strategies should they continue to cause economic losses during the late season.

Large numbers of the western flower thrips (WFT), *Frankliniella occidentalis* Pergrande, have been reported on pistachio trees during the early season in Arizona. As with the hemipterous insects, there was a need to determine the effects of these populations, if any, on pistachio nut production. There was also a need for investigating the biology-ecology of the western flower thrips on pistachio and to establish sampling methods since this information was not available under Arizona conditions.

LITERATURE REVIEW

The Pistachio

The Pistachio - General Introduction

The pistachio is a very old crop, having been in cultivation since ancient times. It is thought to have originated in central Asia where wild pistachio trees still grow. In recent times, commercial pistachios have been grown primarily in the Mediterranean-Middle Eastern regions. Iran, Turkey, Syria, Italy and Afghanistan all produce this crop for export, Iran and Turkey being the major exporters to the United States. Pistachios are also grown in Pakistan and Lebanon but in smaller quantities (Whitehouse 1957).

Although there are many species in the genus *Pistacia*, the nut of only one are regularly eaten by humans. *Pistacia vera* L., the commercial pistachio, produces fruit which are many times larger than those of other *Pistacia* species. It is also the only species in which the shell splits, exposing the nutmeat (Crane and Iwakiri 1981). Pistachio trees are alternate bearing (Woodroof 1979), dioecious, deciduous members of the family Anacardiaceae (Crane et al. 1971). Male (staminate) and female (pistillate) inflorescences consist of panicles of one to several hundred apetalous flowers. Wind is the pollinating agent (Crane and Iwakiri 1981). The trees grow to a height of 2Ø feet (Crane et al. 1971) and begin to produce limited numbers of nuts after 4-5 years although crops are light until about 1Ø years after planting. In Iran, the peak production age is 2Ø years (Whitehouse 1957).

Pistachio Growth and Development

In California, flowers are produced and the leaves begin to grow in early April, with fertilization occurring during the first two weeks of April (Crane et al. 1976, Woodroof 1979, Johnson 1969). The pistachio fruit is a drupe consisting of a seed (kernel) within a hard shell (endocarp) and a fleshy hull (mesocarp and epicarp) (Crane and Iwakiri 1982).

Crane et al (1971) termed pistachio pericarp growth cyclic and defined 3 distinct periods based upon growth of trees in Winters, CA:

<u>Period</u> <u>1.</u> April 17 (bloom) - May 19 (the beginning of endocarp lignification). This period is marked by a rapid growth of the pericarp (diameter growth = Ø.Ø381 mm/day). All endocarp growth is completed during this period.

<u>Period</u> <u>2.</u> May 19 - August 18. Growth is limited to Ø.Ø14 mm/day as only the epicarp and mesocarp are

growing. The kernal begins to expand within the shell in late June (approximately 2 months after fertilization) and reaches full size by early August when shell split occurs. Nut shell split begins around July 28 and is complete in most nuts by August 11.

Period 3. August 18 - September 8. Nut growth occurs at a rate of 0.042 mm/day. All of the parts of the nut are more or less completely developed and the overall size of the nut expands at a rate slightly faster than in period 2.

Pistachio Harvesting

Harvest usually occurs in early fall during September, and can vary as much as 4-5 weeks from year to year. The nut is mature when the hull can be separated easily from the shell (Crane 1978). This period of maturation is characterized by a change in the hull from translucent to opaque (Crane 1978, Crane and Iwakiri 1981). Harvesting before the optimal time is undesirable as it can result in underdeveloped nuts. Late harvesting can result in shells stained by the release of tannins from the hulls. Imported red pistachios are dyed prior to marketing to conceal stains on the shells. Domestic pistachios are dehulled by techniques which do not result in nutshell staining and so most U.S. grown pistachios remain undyed (Crane 1978). In California and Arizona, harvesting is accomplished by knocking the nuts off the trees with poles and collecting them on canvas sheets.

History of the Pistachio Industry in the United States

Pistachio nuts have been available on the U.S. market since 1880 but did not become popular until the 1930's when vending machines came into common use (Whitehouse 1957). By the early 1970's, Americans were consuming 87% of the world's supply, some 30 million lbs./year (Anon. 1971).

In response to the growing demand in this country, commercial pistachio groves were planted in the United States (Joley 1979). The pistachio had been identified as a potential new crop for the U.S. in 1904 but lack of an appropriate cultivar prevented large scale commercial planting until the 1950's with the development of the Kerman variety (Crane and Iwakiri 1981). Since 1958, approximately 30,000 acres have been planted in California, resulting in a harvest of 4000 tons in 1977 (Joley 1979).

Crane and Iwakiri (1981) predicted that U.S. production would exceed domestic demand by the mid 1980's, thus eliminating the need to import from the Middle East. Having domestic production meet domestic demand is of considerable advantage since, in recent years, many of the biggest exporting nations have undergone periods of great political instability, both internally and in their relations with the U.S.

The Pistachio in Arizona

Being a very xerophilous crop (Whitehouse 1957, Speigel-Roy et al 1977), the pistachio is an ideal candidate for growth in the arid conditions of southern Arizona. These plants have an unusually deep root system and can withstand great dryness in the upper soil region. They require long, hot, dry summers for proper maturation of the fruit.

In many respects, southern Arizona is comparable to the pistachio growing regions of Iran, where optimal production occurs in areas with an elevation of 4000 feet, 10-15 inches of annual precipitation and summer temperatures reaching 100 degrees F (Whitehouse 1957). Commercial pistachio growing was begun in Arizona in the 1970's. Other areas where pistachio cultivation is being attempted include Australia and Mexico (Maggs 1973).

Beside the potential for insect damage, a condition known as epicarp lesion can result in serious yield loss. Symptoms involve a darkening of the nut surface followed by shriveling and finally, nut drop. Although its cause is unknown, epicarp lesion may be due to insect damage, physiological factors or scion-rootstock incompatibility (Bolkan et al. 1984).

Insects of Pistachio

Old World Insects

Schneider (1958) reported that more than 20 species of insect have been known to damage pistachio in Syria. Most of the Old World pistachio pests fall into two orders, Coleoptera and Lepidoptera.

The coleopterous insects which attack pistachio include the pistachio bark beetle, *Hylesinus vestitus* Muls. This beetle, a member of the family Scolytidae, is regarded as the most dangerous insect pest of pistachio in the Middle East (Rizk and Abdullah 1981, Abu Yaman 1969). Bud loss and reduction of new growth are the types of damage it does (Schneider 1958, Abu Yaman 1969). Another beetle, the pistachio borer, *Capnodis cariosa* Pall., a buprestid, kills trees by destroying the roots. A third beetle, *Psuedocoeliodes rubricus* (Gyll.) is a curculionid which feeds upon and desroys male inflorescences, resulting in pollen loss (Tzanakakis 1972[1969]).

The lepidopterous pests include two gelechiids: the pistachio fruit moth, *Recurvararia pistaciicola* Danil., whose larvae feed in the nuts destroying the endocarp (Abu

Yaman and Jarjes 1972) and the pistachio bud moth, *Telphusa pistaciae* Sattler whose larvae feed upon and destroy flower buds resulting in bud losses of up to 27% (Samet 1982). A third lepidopterous insect occasionally causing damage is the pistachio silkworm, *Pachypasa otus* Drury. The larvae of this insect can cause severe defoliation (Schneider 1958).

No mention is made in the literature of thysanopterous or hemipterous insect pests of pistachio in the old world.

Pistachio Insects in the U.S.

Whitehouse (1957) stated that pistachios in the U.S. have seldom experienced serious injury from insects. As an imported crop, it exists in the U.S. without any of its native pest species. It was initially thought to be free of insect pests but more and more insects, either native or pests of other crops, are being found on this crop.

The major pest in California is the navel orangeworm (NOW), *Amyelois transitella* (Walker). This pyralid causes damage when the larvae enter developing nuts exhibiting some type of wound on the pericarp before shell split, and again after shell split when all nuts become susceptible. Tolerance to this insect is quite low as the nuts are marketed in the shells with no opportunity for nut meat inspection. Control is achieved with cultural practices such as sanitation and early harvest. Chemical control is also used. The citrus flat mite, *Brevipalpus lewisi* (McGregor), has attained pest status in a few orchards in California. Damage, which looks like a dark blistering, occurs on the stems, petioles and nuts and may result in nut drop (Bentlely 1982).

Other insects found on pistachio in California include the western flower thrips,*Frankliniella occidentalis* (Pergrande); the soft brown scale, *Coccus hesperidium*; the pistachio seed chalcid, *Megastigmus pistaciae*; the omnivorous leafroller, *Platynota stultana* (Walsingham); the peach twig borer, *Anarsia lineatella* (Zeller); the dried fruit beetle, *Carpophilus hemipterus* (L.); and various hemipterous insects such as *Euschistus* spp. and the boxelder bug, *Leptocoris trivittatus* (Bentlely 1982, Woodroof 1979, Johnson 1969, Joley 1979).

The only post-harvest pest of pistachios in California is the Indian meal moth, *Plodia interpunctella*. The larvae of this moth can do extensive damage to stored nuts which are not under refrigeration (Joley 1979, Woodroof 1979).

Leptoglossus Biology and Ecology

General Description

The genus *Leptoglossus* (Hemiptera:Coreidae) is cosmopolitan, and is thought to have originated in the

American tropics (Heidemann 1910). All members of this genus have expanded-flattened areas on the hind tibiae (Leonard 1931), are phytophagous and possess defensive stink glands (Miller 1956). The mouthparts are of a piercing-sucking type and consist of 4 stylets enclosed within the modified labium (Koerber 1963).

In Arizona pistachio orchards, L. clypealis Heidemann is the predominant species. It can be distinguished from others by the presence of a stout spine projecting anteriorly from the vertex. (Gibson 1917, Allen 1969). It is distributed throughout the central and southwestern United States and into Mexico (Allen 1969).

The eggs of Leptoglossus, as well those of the Coreidae, are very distinctive. They are cylinders, laid on their sides in chains. Each chain contains up to 14 eggs. The eggs average 2 mm long by 1.25 mm wide by 1.0 mm high and are of a dull brown color. On the dorsal surface of each egg is a pseudoperculum through which the nymphs emerge. There are 5 nymphal instars. The first 2 instars are reddish-orange in color and gregarious in habit. Instars 3-5 become more brownish and take on more solitary habits. Wing pads are first evident in the third instar nymphs (Leonard 1931, Koerber 1963).

Host Range and Crops Damaged

Species of Leptoglossus are known to damage many crops throughout the world. L. clypealis Heid. has been cited as a pest of almonds and plums (Ebeling 1959, Heidemann 1910). L. gonagra Fabricius is a pest of citrus in Puerto Rico (Leonard 1931). L. zonatus Dallas causes economic injury in oranges when planted in the vicinity of pomegranates (Quayle 1929). L. oppositus Say damages melons and fruit trees (Lugger 1900). L. phyllopus, L. oppositus and L. zonatus have all been known to damage cotton (Morrill 1910).

L. membranaceus Fabricius is an Old World species known as a pest of cucurbits, cotton, orange, pomegranate and banana (Pagden 1928, Jadhav et al. 1979). L. phyllopus, which also occurs in the New World, is mentioned most prominently in the literature. It has been recorded as damaging oranges, cucurbits, peaches and cowpeas (Lugger 1900, Snapp 1948, Schalk and Fery 1982). It also is responsible for causing the diseases black pit and kernel spot in filberts and pecans (Ebeling 1959, Johnson 1969).

Leptoglossus spp. are probably most injurious to seeds of pines grown for seed. L. corculus is an economic pest of loblolly and shortleaf pine (DeBarr and Ebel 1974, DeBarr and Kormanik 1975). Loblolly pines, when caged with this species, abort 56% of the cones as compared with 22%

abortion in protected trees (Williams and Goyer 1980). *L. occidentalis* (Say) has also been known to cause similar injury. Ebel and Yates (1974) cite this species as an economic pest of shortleaf pine. Krugman and Koerber (1969) have found it injurious to ponderosa pine.

Seasonal and Life History

Very little information is available in the literature on the life and seasonal history of *Leptoglossus*. No studies have been undertaken on *L. clypealis* specifically.

L. occidentalis in northern California undergoes 1 generation per year. The overwintered adults become active in the spring. The females mate repeatedly and produce an average of 12 eggs per day. The eggs hatch in 10 days. This generation reaches adulthood in late August (Koerber 1963).

L. phyllopus on pecan in Georgia has 2 generations per year. The adults overwinter in grass and under leaves or bark. Females undergo a preoviposition period of 8-13 days and oviposit an average of 27.5 days. The average female lays 145.5 eggs over her lifetime. An average of 9.1 days is required for hatching of the eggs. The nymphs take an average of 44.7 days to reach adulthood (Adair 1932).

L. membranaceus Fab. is an Old World species occurring throughout Africa and Asia. It takes an average of 6.73 days for eggs of this species to hatch. Total life from egg to adult death ranges from 35 to 94 days. Generation time is generally about one month (Pagden 1928).

Control

Again, the literature here is lacking. Excellent control of *L. corculus* (Say) on seed pine has been achieved with carbofuran (DeBarr et al. 1982). Two egg parasites have been discovered on *Leptoglossus* in Georgia. *Ooenocyrtus leptoglossi* Yoshimoto, an encyrtid parasitic upon *L. corculus* (Yoshimoto 1977) and *Habronotus atriscapus* Gahan, a parasite of *L. phyllopus* (Adair 1932).

Chlorochroa Biology and Ecology

General Description

There are 2 species of stink bugs (Pentatomidae) which have been found feeding upon pistachios in Arizona. They are the Say stink bug, *Chlorochroa sayi* Stal., and the conchuela stink bug, *C. ligata* Say.

Say stink bug adults are green, sometimes with a purplish cast. The scutellum is marked with 3 white spots. The average female is 13.5 mm in length. The conchuela is dark brown with red margins (Werner et al 1979, Caffrey and Barber 1919).

C. sayi eggs are 1.1-1.2 mm in length by 0.88-0.93 mm wide and are of a cylindrical shape. They are laid in clusters of 2-4 parallel rows with an average of 26 eggs/cluster. The first instar nymphs average 1.1-1.54 mm by 0.935-1.072 mm. The second instar nymphs are 2.2-2.53 mm by 1.54-2.117 mm. Instars 3-5 range from 3.8-10.6 mm in length by 2.365-7.0 mm in width. C. ligata nymphs are comparable in size and also undergo 5 instars (Caffrey and Barber 1919).

Distribution

The Say stink bug is found throughout the western United States (Caffrey and Barber 1919) and is the most widespread pentatomid species in Arizona, having been collected in all counties except Mohave (Butler and Werner 1960).

Of the 4 pentatomids commonly found in agricultural situations in Arizona, the Say stink bug is considered the most injurious. C. ligata is relatively scarce in Arizona, being confined to the eastern portions of the state (Werner et al. 1979).

Host Range

C. sayi has a broad host range. Among the cultivated plants it feeds upon are: alfalfa, barley, beans, buckwheat, cabbage, cotton, grapes, lettuce, milo maize, oats, okra, peaches, peas, rye, squash, sugar beets, sorghum, tomato, various vegetables and wheat (Morrill 1907, Caffrey and Barber 1919, Butler and Werner 1960). The native hosts include London rocket, red-stem filaree, Russian thistle, pigweed, mallow, wild oat, lambsquarters and cacti (*Opuntia* spp.) (Caffrey and Barber 1919, Patton and Mail 1935, Butler and Werner 1960).

Damage

C. sayi is a very serious pest of all small grains in western North America. It causes stunting and non-development of grain by piercing and feeding upon the contents of the developing seeds (Caffrey and Barber 1919, Patton and Mail 1935). The genus *Chlorochroa* has a feeding preference for the starchy contents of grain seeds while they are in the milk or early dough stages. These 2 stages suffer the worst effects from stink bug feeding (Esselbaugh 1948). *C. ligata* has been cited as an economic, though occasional, pest of sorghum (Hall and Teetes 1982b).

The Say stink bug is also an economic pest of cotton (Morrill 1905, 1910). The damage is caused by young bolls being shed in response to stink bug feeding. Older bolls develop carpel damage, seed injury, stained lint, and decreased yields. Stink bug feeding can lead to boll rot (Wene and Sheets 1964). C. sayi has also been shown to cause economic losses in sugar beets grown for seed and in alfalfa (Hills and McKinney 1946, Morrill 1907).

Seasonal and Life History

Russell (1952) and Caffrey and Barber (1919) described the seasonal and life histories of the Say stink bug in Arizona and New Mexico, respectively. The adults overwinter on host plants or in leaf litter and emerge in the spring when the days begin to get warm. In Arizona, this occurs from March to April. The adults mate and lay eggs on newly emerging native plants and weeds such as Russian thistle. The females mate repeatedly and lay an average of 151 eggs over their lifetimes. The adults of this first generation migrate to cultivated crops in the summer and proceed to feed and reproduce. The second generation reaches adulthood in mid-June. Further generations are produced at a rate of 1 generation every 5-6 weeks as long as the weather allows. This continues until late September. Overwintering is initiated in October-November.

Incubation of eggs lasts an average of 9 days declining to 5-7 days in the summer. In laboratory studies, 91.88% of the eggs hatch.

The first instar lasts an average of 1.5 days(Caffrey and Barber 1919). Nymphs in the first instar are gregarious and do not feed as there is sufficient yolk in their alimentary tracts (Esselbaugh 1948).

The second instar lasts an average of 8.2 days. These nymphs are also gregarious and are the first stage to feed. The third instar lasts an average of 6.4 days, the fourth instar 8.2 days, and the fifth instar 14.9 days for a total mean nymphal development time of 42.7 days. The third to fifth instar nymphs are solitary in habit. Adult females live an average of 33 days while adult males average 23 days (Caffrey and Barber 1919).

As with all insects, temperature greatly affects time and success of development. Patton and Mail(1934) found that no eggs hatch at 17 C, 20 of 20 hatch at 22 C and 27 C and 18 of 20 hatch at 32 C. Although they stated that relative humidity was constant during the study, they failed to mention what the relative humidity was. Furthermore, as the temperature is increased, hatching time was found to decline from 14 days at 17 C to 4 days at 32 C. Therefore, the greatest reproductive potential occurs at 27 C since fecundity is highest and time of hatching is short. Caffrey and Barber (1919) found that nymphs reared at 90 F completed development an average of 5 days sooner than those reared at 70 F.

Control

A number of naturally occurring biological control agents are capable of reducing the populations of Chlorochroa. The 2 most important predators are those in the genera Orius and Collops, which feed upon the stink bug eggs (Esselbaugh 1948). Although insects in the hemipterous genera Sinea and Phymata have been known to feed upon Chlorochroa nymphs, few predators feed upon the nymphal and adult stages due to the noxious secretions from the scent glands (Caffrey and Barber 1919).

Eggs of Chlorochroa are parasitized by the genus Trissulcus (Caffrey and Barber 1919, Jubb and Watson 1971a, 1971b) The tachinid genera Gymnosoma and Cylindromya parasitize the later life stages and emerge from adult stink bugs (Werner et al 1979, Caffrey and Barber 1919, Eger and Ables 1981). Patton and Mail (1935) consider Gymnosoma unimportant in the control of Chlorochroa as they do not interfere with the feeding or other activities of their hosts. Werner et al (1979) assert that tachinid parasites are effective in the reduction in numbers of overwintering females but have little effect thereafter. They feel that egg-parasitic wasps offer better control as they are constant throughout the season. Jubb and Watson (1971b) found 51% parasitism of *C. sayi* eggs with *Trissolcus utahensis* Ashmead. Maximum parasitization was found to occur at temperatures from 25 C to 30 C in Arizona.

Cultural methods can offer excellent control of *Chlorochroa* species. Destruction of weeds and native plants is effective as it removes overwintering and first generation sites. Plowdown of crop stubble also works through the elimination of overwintering quarters (Caffrey and Barber 1919, Patton and Mail 1935).

Since infestations of *C. sayi* are worse in cotton planted next to alfalfa and sugar beets, control in cotton involves exercising care to get proper distance between these crops (Wene and Sheets). Strip cutting alfalfa reduces the numbers of stink bugs flying to other, more sensitive crops (Morrill 1907).

Western Flower Thrips Biology and Ecology

General Description

The western flower thrips, *Frankliniella occidentalis* Pergande, is a member of the family Thripidae in the order Thysanoptera. Watts (1936) offered the following general description of the life stages: The egg is kidney-shaped and of a creamy white color. It is 0.25 mm in length by 0.1 mm in diameter. There are 2 larval instars. The newly hatched larva is colorless, later becoming yellow after feeding; the prepupa is characterized by short wing pads and freely articulating antennae. The prepupa is formed after the mature larva drops from the plant and finds protection in the soil. The pupa has long wing pads and the antennae are fastened to the upper surface of the head. Both the prepupal and pupal stages are inactive, although a thrips in either stage will move sluggishly when disturbed. The adults are of a deep yellow color. The female is 1.0 mm long and the male is slightly smaller, averaging 0.7 mm.

Mature females deposit eggs into plant tissues by means of a saw-like ovipositor. The females of this species can reproduce parthenogenetically as well as sexually (Martin 1978 , Bryan and Smith 1956 , Lublinkhof and Foster 1977). The males are haploid and the females diploid. Thus, if the egg is fertilized, a female will be produced. If it is unfertilized, a male will result (Bryan and Smith 1956, Watts 1936).

Mouthparts and Feeding

The mouthparts of Thysanoptera have been described by Borden (1915) and Peterson (1915). They are of a rasping/sucking type. There is a cone on the ventral surface of the head capsule. Within this cone are enclosed the mouthparts. The paired maxillae are long and slender. The right mandible is rudimentary and acts as a linkage between the pharynx and the front of the cone.

The maxillae and the left mandible are the piercing organs. The mandible is larger and is used to break larger plant cells while the maxillae break the finer cells. In feeding, the head is moved forward and backward, allowing the mouthparts to break the cell walls of the host plant. This is the rasping portion of the feeding process. The insect then lowers its head and draws up the cell contents through the pharynx. This is the sucking portion of feeding. The insect continues the rasping and sucking in a linear fashion over the plant surface (Borden 1915).

Distribution

The western flower thrips is broadly distributed throughout North America. It has been recorded from Mexico City north to British Columbia and east to Connecticut (Bryan and Smith 1956). It is the most common and widespread species of thrips in California and Arizona (Bryan and Smith 1956, Bibby 1958).

Host Range

In California, this thrips has been found on 139 plant species in 45 families (Bryan and Smith 1956). In Arizona, it has been recorded on the following economic crops: alfalfa, Brussels sprouts, cauliflower, cotton, grapes, lettuce, melons, onions, peas, potatoes, and sugar beets. It has also been found on the following weeds and native plants: mallow, sunflower, London rocket, globe mallow, Johnsongrass, yucca, mesquite, palo verde, cottonwood and a wide variety of native annuals (Bibby 1958).

Damage

Thrips cause economic damage in two ways, by vectoring plant diseases (Bailey 1935) and by direct damage through feeding or oviposition. The feeding results in "silvering" of the surfaces of fruits (Bailey 1933) and bronzing and blasting developing safflower buds (Carlson 1964).

Frankliniella species have been of economic importance in a wide variety of crops in the U.S. Among these are tree fruits (Bailey 1933), onions (Hale and Shorey 1965, Harding 1961), alfalfa (Martin 1978), grapes (Yokoyama 1977), and pistachios, although the economic damage discovered inpistachios has been limited to the foliage of young, non-bearing trees (Bentlely 1982).

Damage in grapes occurs by oviposition, which results in a characterisitic scar called a halo on the surface of the grape. It has long been suspected that thrips feeding causes scarring on the surface of grapes but this has yet to be shown (Yokoyama 1977).

Seasonal and Life History

Frankliniella californica (Moulton) overwinters in California as an adult with more females than males surviving due to better cold-tolerance (Bailey 1933). Another species, *F. tritici*, the flower thrips, overwinters in various stages in South Carolina, with slow development occurring over the winter. Throughout this period, adults and nymphs are found on the host plants. No evidence exists that members of this species undergo any sort of hibernation state (Watts 1936).

In the spring, as temperatures increase, western flower thrips begin to reproduce, with population fluctuations occurring throughout the spring (February - April). The population peaks in California in late spring/summer (late April - early August) and begins to decline in August. This decline is due, in large part, to the disappearance of suitable host plants. The decline continues through the overwintering period. Rainfall is probably the greatest factor in differences between thrips populations from year to year. More rainfall results in more plant growth, which in turn allows for greater thrips populations (Bryan and Smith 1956). In California grapes, the peak population of thrips occurs from late May-early June. This period coincides with the grape bloom period. Although hemimetabolous overall, the Thysanoptera are considered by many to be intermediate between the hemimetabolous and holometabolous orders as they have internal development of wings (early stages) and undergo a quiescent period prior to adulthood. This inactive period is functionally and behaviorally similar to the pupal stage of holometabolous insects. For this reason, the active immature stages are frequently called larvae and the inactive stages called prepupae and pupae instead of nymphs (Borror et al. 1981) Mature larvae drop to the ground and inhabit cracks in the soil for the pupation period. Newly emerged adults then fly to host plants (Bailey 1933).

Bryan and Smith (1956) found that average adult female western flower thrips produce a daily mean of 0.66-1.63 progeny and lived 40.0 days, while Martin (1978) found that the mean progeny per female per lifetime is 21.0 and the average adult longevity is 57.2 days.

Developmental time, egg to adult, lasts from 8.4 to 44.2 days, depending upon temperature (Bryan and Smith 1956, Lublinkhof and Foster 1977). As temperature is increased, development occurs more rapidly. Lublinkhof and Foster (1977) found fecundity greater at 20 C than at either 15 C or 30 C. This indicates that there is an upper, as well as a lower limit for optimal population increase. In addition, they found a longer preovipostional period at lower temperatures (10.4 days at 15 C) than at higher temperatures (2.4 days at 20 C and 30 C). The number of generations per year also depends upon temperature. Life cycles at 20 C and 30 C are short, while fecundity is greatest at 20 C. Thus, 20 C provides ideal conditions for thrips population buildup. Harding (1961) found that a mean daily temperature of 15 C or more favors the heaviest infestations.

Some researchers have discovered that thrips tend to fly in large aggregations when certain climatic conditions are met. Lewis (1964) states that most species of thrips undergo a mass flight when the temperatures are between 19 and 21 C. Harding (1961) found an inhibition of flight below 11 C.

Control

Chemical controls have long been used where western flower thrips are of economic importance. Hale and Shorey

(1965) achieved good control on onions with dimethoate and phorate.

The western flower thrips has a number of predacious and parasitic species which may be of use in biological control. Minute pirate bugs (Orius spp.), the convergent ladybeetle (Hippodamia convergens Guerin) and lacewing larvae (Chrysopa spp.) have been known to feed upon the western flower thrips (Watts 1936). Stoltz and Stern (1978) showed that Orius populations increase, through increased fecundity and survival, with increases in thrips populations. Orius tristicolor (White) is found throughout Arizona while O. insidiosus (Say) is limited to Graham and Cochise counties. In addition to being good thrips predators, Orius is resistant to most insecticides (Werner et al. 1979). Wilson and Cooley (1972) mentioned 2 parasites, an unidentified chalcidoid and a nematode [Howardula aptini(Sharga)], but made no comment as to their potential for biological control of the western flower thrips.

Cultural control has also been shown to be of practical value in the reduction of western flower thrips populations.Stoltz and McNeil (1982) discovered that great numbers of the thrips fly from hay fields to neighboring bean fields after the hay has been cut. Strip-cutting of the hay resulted in the movement of almost no thrips from hay to beans.

Finally, host plant resistance may offer some potential for thrips control. 20% of the cassava clones stored at the cassava germ plasm bank at the Centro Internacional de Agricultura Tropical showed a complete absence of thrips feeding damage (unidentified *Frankliniella* sp.). It was determined that these clones had very pubescent leaves, which was the source of the resistance (Van Schoonhoven 1974).

MATERIALS AND METHODS

Location and Description of Research Orchards

Two orchards were used during this research. Most of the studies were conducted at the Jim Cook orchard near Bonita, (Graham county) AZ. This site was selected for the majority of the studies because it is much more homogeneous than the Bowie orchard. The Bonita orchard consists of 40 acres of 10-year old trees. The male to female ratio is 1:14. The trees were watered approximately twice monthly by sprinkler system.

The 800 - acre Henry Mollner orchard, 1.5 mi. south of Bowie, (Graham county) AZ., was used primarily to corroborate findings from Bonita. This orchard is drip irrigated and the trees planted at a sex ratio of 1 male to 14 females. The trees range in age from 1 to 10 years. This study was concentrated in the oldest, bearing trees.

To distinguish between sprayed areas and control areas, the control trees were marked with pink plastic ribbon. A ground rig was used to spray the orchard and the control trees were not sprayed. There were 8 control areas, each consisting of 3 rows by 4 trees until just prior to spraying for stink bugs, when the control area was expanded to 3 rows by 6 trees. The orchard was divided into 4 quadrants of approximately equal size and each quadrant had 2 control areas within it, 10 trees apart.

Thrips Population Sampling

Twice weekly, from April 28- August 9, 1983, the following sampling design was used for sampling western flower thrips in Bonita: in each of the 8 control areas, the center 2 female trees were used. Each tree was approached from the west and the nut cluster nearest eye-level selected. A clip-board with an 8.5 by 11 inch sheet of yellow paper was placed under this cluster. With a pencil, the cluster was tapped once, briskly. The number of thrips falling onto the sheet of paper was noted. This procedure was performed on each tree for each of the 4 compass points and for both nut clusters and leaves. In addition, ninth and tenth samples were taken on the west side of each tree, 1-2 feet higher than the first two. A male tree within each control area was sampled using the same method. For the male tree, blossoms and leaves were the sampling units. This gave a total daily control sample size of 80 female leaves and nut clusters as well as 40 male blossoms and leaves.

Four female and four male trees were randomly selected from the treated areas in each of the 4 quadrants. Each tree was sampled in the same method as the control trees. This gave a daily treated sample size of 80 female leaves, nut clusters, male leaves and male blossoms.

<u>Survey for Thrips Feeding (Epicarp Scarring)</u>

The purpose of this study was to determine the incidence of western flower thrips feeding - scarring on pistachio nuts and to determine the proportion of nuts with no, light or heavy thrips scarring in control and treated nuts.

Within the 40 acre Bonita orchard, 10 control areas of 3 rows by 4 trees were established. The rest of the orchard was chemically treated 3 times for thrips (on May 3, 6 and 26, 1983). One tree was selected from 5 of the 10 control areas as was one tree from the treated area near (approximately 3 trees away from) each of the 5 control areas. The selected tree was approached from the west and the nut cluster nearest to eye-level examined. The nuts in this cluster were counted and placed into 3 categories: no damage = free of all signs of thrips feeding scars; light damage = thrips feeding scars present in some degree, but not so severe as to cause an indentation or other disruption of the epicarp surface; heavy damage = thrips feeding has resulted in scars so extensive as to have caused notable indentation (creasing or puckering) on the epicarp surface. This procedure was repeated for the three other compass points and was done on 5 control and 5 treated trees per sample day. This was done on 8 days (May 24, 27 and 31, June 3, 7, 10, 14 and 17, 1983) for a total sample size of 160 nut clusters. For analysis, the total number of nuts in each of the three damage categories was calculated.

Stink Bug and Leaf-Footed Bug Population Survey

Monitoring of stink bug and leaf-footed bug populations occurred from August 12 to September 18, 1983, in the Bonita and Bowie orchards. The following sampling regime was followed twice weekly during this period: One tree was randomly selected from each of the 8 control areas. One treated tree was selected near (approximately 5 trees away from) the sampled control tree. For every tree sampled, a branch was selected at each of the 4 compass points. A standard beating sheet (25.5" across, muslin with wood-strip supports) was placed under the selected branch and the branch beaten with a 36" stick. The number, species and life stage of stink bugs and leaf-footed bugs falling onto the sheet were recorded. This gave a daily sample size of 32 control and 32 treated branches.

Survey for Hemiptera-Related Feeding Damage

The purpose of this study was to determine the incidence of external damage, caused by feeding of plant bugs in control and treated areas, on pistachio nuts.

Within the 40-acre Bonita, orchard, 10 control areas of 3 rows X 6 trees were established. The rest of the orchard was twice sprayed for hemipterous insects, on August 9 and 13, 1983. One tree was selected from 6 of the 10 control areas, as was one tree from the treated area near (~3 trees away from) each of the 6 control areas. The selected tree was approached from the west and the nut cluster nearest eye-level examined. The number of nuts in this cluster with stink bug feeding evidence (puncture mark with exudate) was recorded, as was the number of nuts in the cluster without damage, this procedure was repeated for the three remaining compass points. Six control trees and 6 treated trees were sampled each day. This entire procedure was performed on August 12, 19 and 31, 1983. For analysis, the total number of nuts damaged and the total number undamaged, of 72 nut clusters total (3 days) was calculated for both treated and untreated samples.

Pistachio Nut Dissections

Dissection of pistachio nuts was conducted to 1.) determine the percent of undeveloped nuts in the control and treated areas, 2.) determine the incidence of damage corresponding to stink bug and leaf-footed bug feeding, and 3.) correlate external damage with internal damage to indicate whether or not these hemipterous insects can penetrate the shell in feeding.

On each of three dates (August 12, 19 and September 11, 1983), at least 100 nuts were randomly collected from the treated and 100 from the control areas of the Bonita, orchard. One hundred nuts/sample day/control or treated area were dissected. The number of undeveloped nuts/100 was recorded and an additional number of nuts dissected to bring the total number of developed nuts to 100. Presence/absence of hemipteran feeding damage was recorded, nut by nut, in the following manner:

A. Presence/absence of feeding damage on the epicarp (external portion of nut). The presence of a small puncture surrounded by a drop of exudate was considered evidence of hemipteran feeding activity.

B. Presence/absence of feeding damage on the internal surface of the endocarp (shell). The presence of a discolored area on the shell was considered positive indication of hemipteran feeding.

C. Presence/absence of feeding damage on the nutmeat. Evidence of hemipteran feeding on the nutmeat involved a dark discoloration on the surface and/or a necrotic area resulting in a cavity on the nutmeat surface.

It was further noted whether or not epicarp damage, if any, corresponded with damage to the shell and nutmeat.

Pistachio Harvest Analysis

In early October, 1983, while harvest was in progress, 100 nuts from the sprayed areas and 300 from the untreated areas were randomly collected throughout the Bonita orchard. The southeast quarter of the orchard was not sampled, as it had already been harvested at this point. The collected nuts were frozen to prevent the growth of *Aspergillus* and thawed/dried at room temperature for 1/2 hour to ready them for analysis.

A Mettler analytical balance was used to weigh the nuts. Each nut was weighed in its shell. The nut was then cracked and the meat alone was weighed. Both weights were recorded to 1 mg. After cracking for the weight analysis, a single shell from each nut was measured, length and width, and the results recorded to 0.5 mm.

Statistical Methods

The thrips population sampling data were analyzed on a day by day basis. The data collected from May 10-June 3, 1983, (a total of 7 sampling days) were analyzed using a non-paired t-test (LeClerg et al 1962): $t = \frac{\bar{x}_1 - \bar{x}_2}{s} \sqrt{\frac{n}{2}}$.

Calculated t-values were compared with the t-value from tables at 1 df, t.Ø5.

The thrips scarring survey, the plant bug damage survey and the nut dissections were all analyzed with chitests ($X^2 = S\frac{(o-e)^2}{o-e}$, Le Clerg et al, 1962). Chi square values were calculated for each category of thrips "damage" (none, light or heavy), control and treated. The stink bug damage survey data were similarly grouped into three categories and X^2 analysis performed in the same manner. For analysis of the nut dissections, numbers of nuts fitting into 6 categories (epicarp damaged or undamaged, shell damaged or undamaged internally and meat damaged or undamaged) were totalled for the control and treated groups. Chi square was calculated for each of these 6 categories and compared to table values of X^2 at 1 d.f. and .Ø5% confidence level. In addition, numbers of undeveloped nuts, control and treated, from the nut dissections were totalled and the X^2 values calculated.

The harvest analysis (weights, lengths and widths) was performed using a t-test for unequal sample size: t= $\frac{\bar{x}_1-\bar{x}_2}{s}\sqrt{\frac{n_1 n_2}{n_1-n_2}}$ (LeClerg et al. 1962). The t-values for control and treated groups were calculated and compared to the t-value from tables at 1 d.f. and t .Ø5.

No analysis was performed for the stink bug/leaf-footed bug population survey as the 1983 populations of these insects were quite low. The results of the survey showed similarly low numbers and thus, do not lend themselves to any meaningful statistical analysis.

RESULTS AND DISCUSSION

Results of Thrips Population Survey

Western flower thrips (WFT) entered the orchard in mid-April of 1983, as soon as the male blossoms opened. Thrips in general have been demonstrated to prefer feeding on pollen over other plant tissues (DeBarr and Kormanik 1975).

Mean numbers of thrips per day per sampling unit over the 1983 season appear in figures 1-4. Figure 1 shows the trends of WFT on male blossoms. Numbers of thrips per male blossom started high, these thrips undoubtedly having come from other cultivated plants growing in the area. The population reached its peak on May 5 and proceeded to decline thereafter until all male blossoms had dried and fallen off the trees (by about May 27). Whether this decline is due to the May 6 insecticide treatment or to normal seasonal attrition remains unclear since an identical treatment on May 3 seems to have had no effect at all upon the population. Although the life stages of the thrips were not differentiated in sampling, many nymphs were observed on male blossoms during this peak period. Since immature thrips cannot fly or otherwise disperse any great distance, it must be assumed that

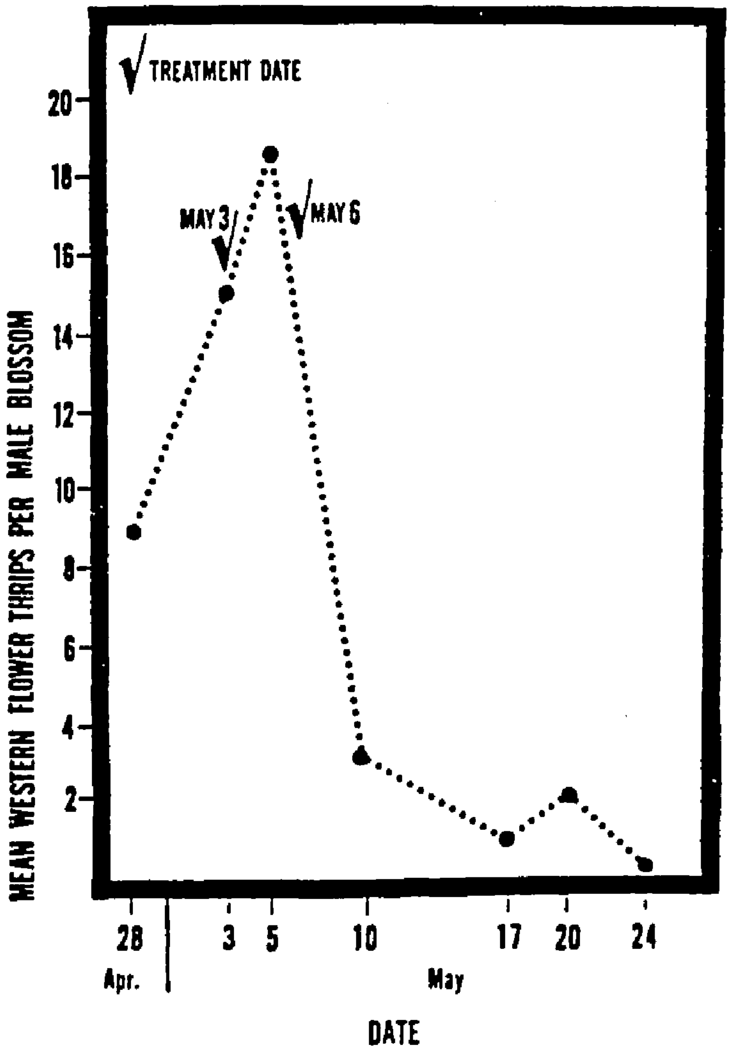

Fig. 1. Abundance of Western Flower Thrips on Male Pistachio Blossoms During the 1983 Season.

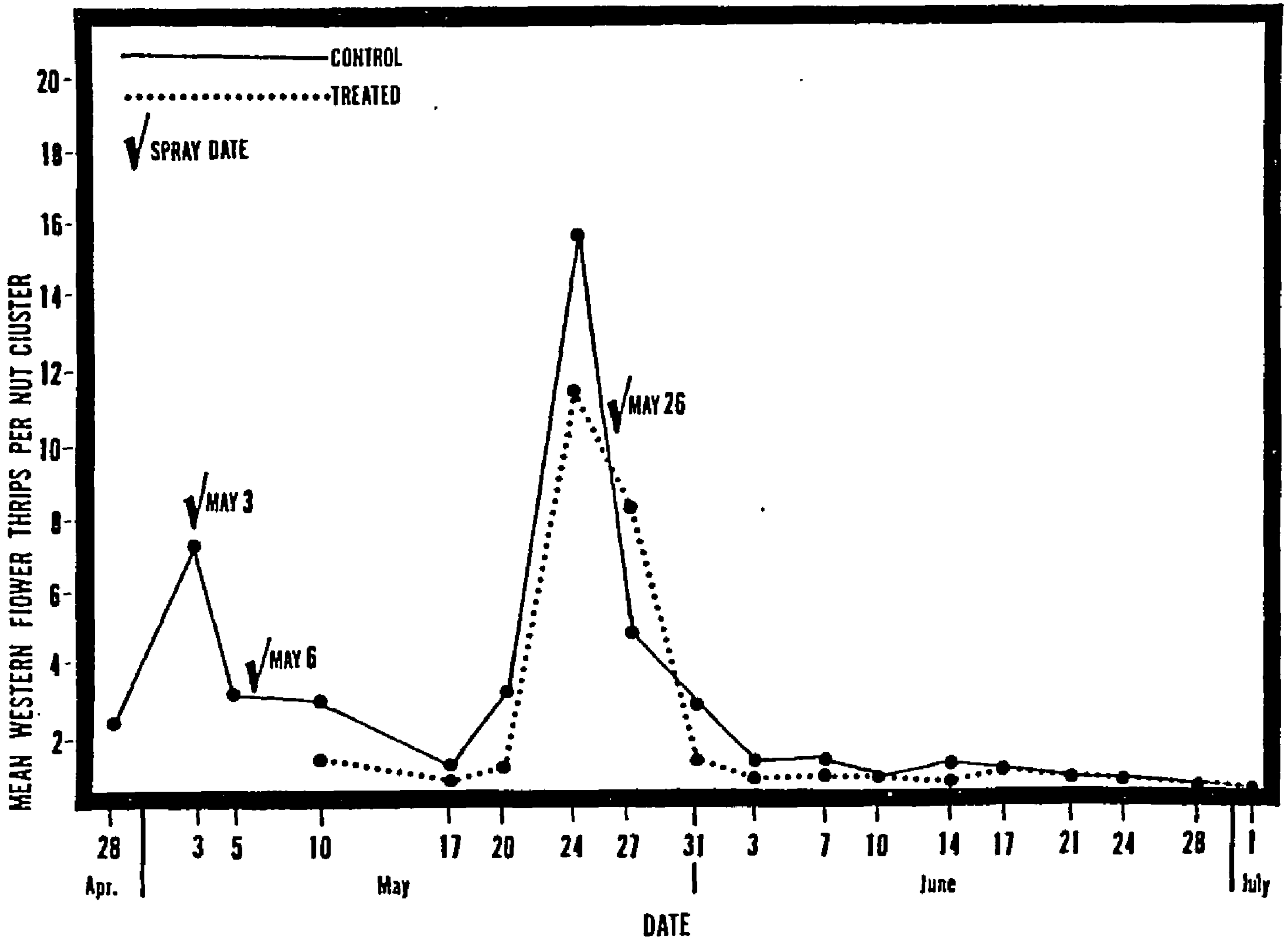

Fig. 2. Abundance of Western Flower Thrips on Nut Clusters of Pistachio During the 1983 Season.

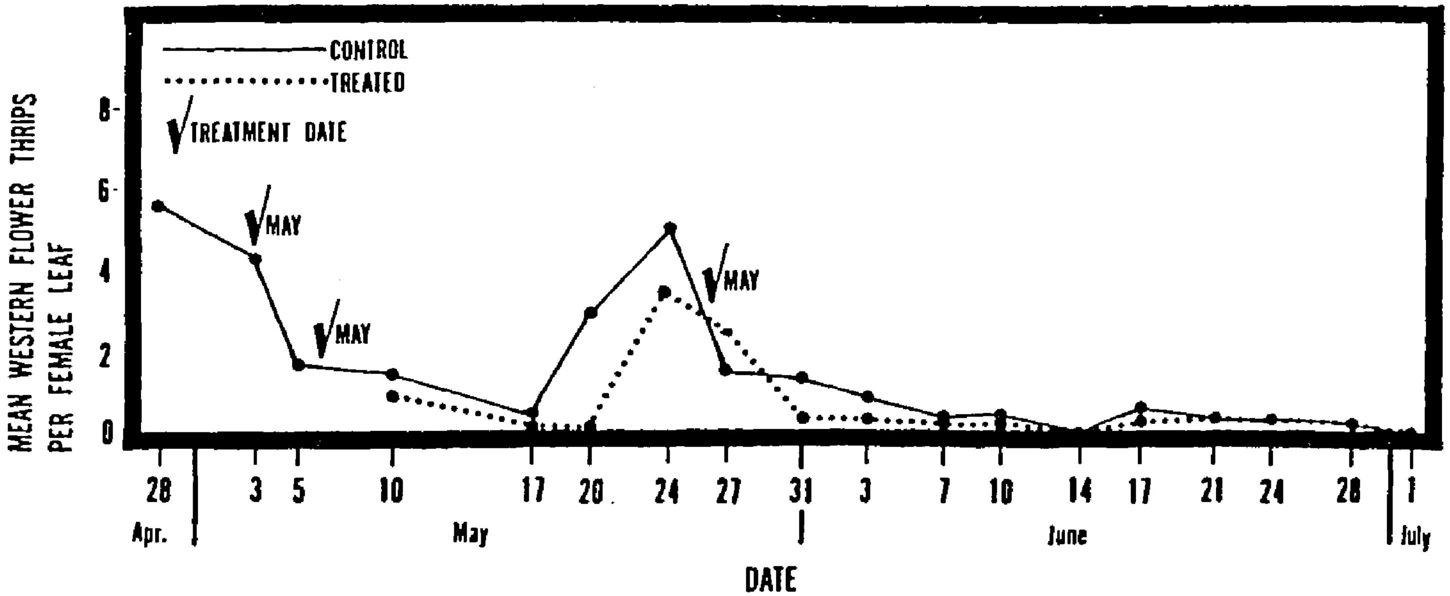

Fig. 3. Abundance of Western Flower Thrips on Female Pistachio Leaves During the 1983 Season.

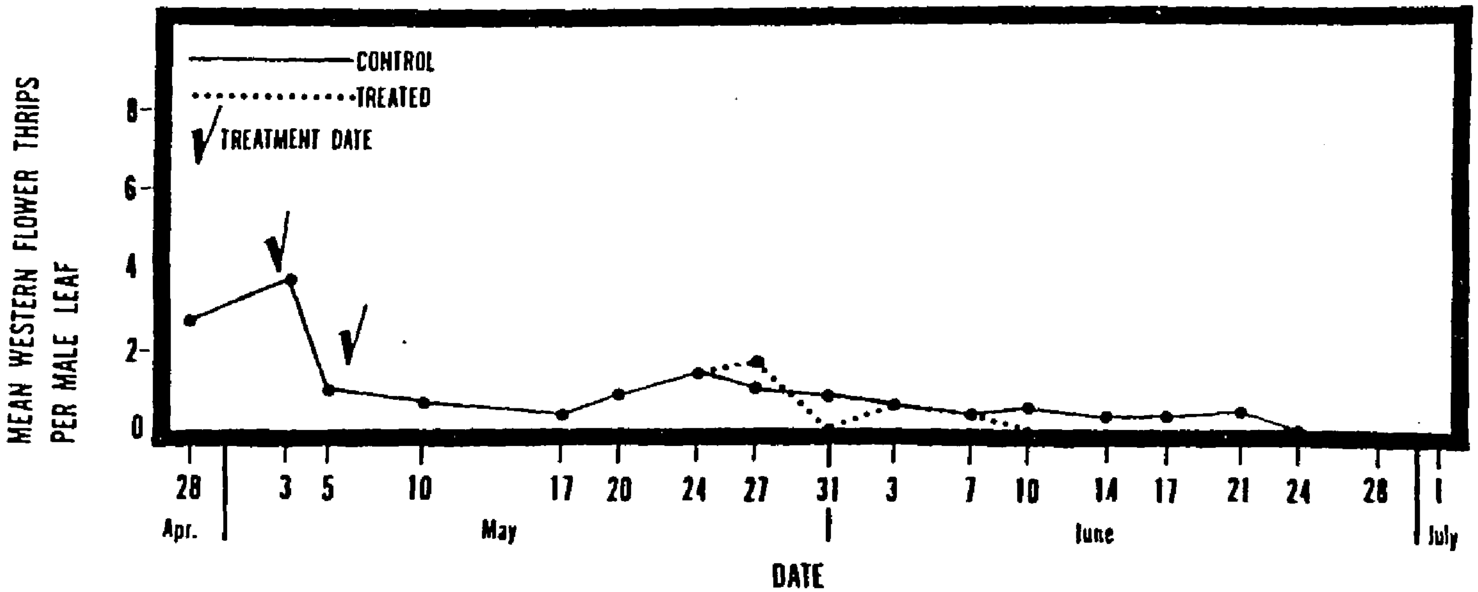

Fig. 4. Abundance of Western Flower Thrips on Male Pistachio Leaves During the 1983 Season.

reproduction of thrips is taking place in the male blossoms at this time. Nymphs were never found with any regularity at any other time or on any other of the 3 sampling units (male leaf, female leaf, nut cluster). It would appear that the WFT uses the male blossoms as a breeding substrate. Given the time needed for nymphal development of thrips in relation to the relatively short period of time the male blossoms are available, it appears that only one generation of thrips can be produced on this host per year.

Fig. 2 presents the population data of WFT on nut clusters during the 1983 season. Although a small peak occurred May 3, the greatest abundance was on May 24. Thrips on female and male leaves (fig. 3 and 4) showed 2 peaks. The first peak was at the beginning of the season, April 28-May 3. A second peak was noted on May 24. This second peak was slightly smaller for the female leaf sample and considerably lower than for the male leaf samples. In all cases, populations had fallen to almost zero by June 3 and continued to be slight until July 1, when no thrips were found.

As the population on the male blossoms was declining (May 10-24), the populations on the other substrates increased and then fell for the year. This would suggest that the thrips move from the male blossoms to the other parts of the trees as the male blossoms senesce and fall.

Table 1. Mean Number of Western Flower Thrips per Pistachio Nut Cluster on Treated and Untreated Trees.

date	treated	untreated	t
May 10	1.20	2.50	2.28
17	0.58	0.86	1.78
20	1.06	0.85	0.64
24	10.50	12.20	0.45
27	4.60	7.00	1.60
31	0.70	1.60	4.06 *
June 3	0.50	0.60	0.35

* Significant with t-test at .05% level of probability.

In June, the thrips either die off or emigrate from the pistachio orchards and do not reappear until the next spring.

Table 1 presents the results of a comparison between the untreated control trees and treated trees. Although Fig. 1 shows a noticeable difference between control and treated on most days, only May 31 had a significant difference between the two populations. They were well on their decline by this time. It should be further noted that the samples taken immediately after the last 2 sprays showed no significant differences between control and treated. Either the treatments have had no effect or the trees in the untreated check were contaminated with the insecticide during application. Since the spray was conducted with a ground rig and control trees bordering the treated trees were not sampled, this latter explanation seems unlikely.

A chemical treatment was initiated on May 3, before the control areas had been established; the entire orchard was treated. The effect this treatment later had upon the control remains unknown. It may have had an effect upon the first treated and untreated differentiated sample (May 10), in which no significant difference was found. It is doubtful, however, that this early exposure and its residues had effect upon the May 27 sample which, a day after the final spray, showed no difference between control and treated trees.

The precision/accuracy of any thrips sampling method is subject to scrutiny. Moffitt (1964) used white and yellow sticky boards to trap WFT in pear orchards. The efficiency ranged from 91.1% of the population captured with white traps to 8.9% caught on the yellow boards. The sticky trap method can get costly and messy and can lose efficiency as the trap fills with dust, plant parts and other insects.

Another popular method for sampling thrips has been to take some unit of plant into the lab for inspection. LePelley (1942) sampled thrips on coffee by picking leaves and placing them into alcohol for later counting. Evans (1933) placed plant portions into a cylinder apparatus with a repellent (turpentine) at one end and an attractant (light) at the other. Thrips collected at the light were then counted.

For this study, a practical, in-field method of sampling was desired. Since thrips are positively thigmotactic (Watts 1936), a means of dislodging them is essential to an efficient sampling method. Evans (1933), Southwood (1966) and Ota (1968) all used or recommended chemical fumes (either turpentine or ethyl acetate-methyl isobutyl ketone) as a method of dislodging thrips for counting. The problem with chemical dislodging is that

Table 2. Relative Variability 1/ and Mean Number of Western Flower Thrips on Pistachios, from Samples, Bonita, AZ., 1983.

	sample unit							
	female leaf		nut cluster		male leaf		male blossom	
date	RV	$\bar{X}$	RV	$\bar{X}$	RV	$\bar{X}$	RV	$\bar{X}$
Apr. 28	6	5.8	10	2.7	10	2.5	11	9.2
May 3	7	4.6	7	7.5	8	3.7	8	15.6
5	10	1.7	9	3.2	10	1.4	13	18.8
10	14	0.8	12	1.3	20	0.6	29	3.5
17	22	0.3	11	1.1	22	0.3	11	1.4
24	10	3.3	8	10.3	11	1.4		
27	13	1.5	8	4.7	11	0.8		
31	30	0.1	14	0.7				
June 3	30	0.1	14	0.5				

1/ Relative Variability (RV) $= \frac{s}{\sqrt{n}} \Big/ \bar{X}\ (100)$, and is expressed as a percentage.

these chemicals cause general dispersal, including flight. Thus, many will not fall onto a counting board.

It became clear that a physical dislodging method would be most practical without unduly sacrificing accuracy. Strickland (1961) stated that beating can be a reliable comparative method when care is exercised in its execution. Powell and Landis (1965) used a very similar method to the one used in this study to sample thrips on potato foliage. They dislodged the thrips by striking the foliage with the hand and collecting them on a clipboard covered with a gridded cotton sheet. Ota (1968) found an efficiency of 28-90% with the shake and count method as compared to 93.8-94.3% for liquid extraction. As previously mentioned, the time necessary for liquid extraction negated its use here. The major disadvantage of the beating method remains the decrease in accuracy in windy conditions (Powell and Landis 1965).

Table 2 presents the relative variability values for 8 sampling dates during the peak of the 1983 WFT population. These values ranged from 6 to 30% for thrips sampled on the female leaf, 7 to 14% for samples from the nut clusters, 8 to 22% for the male leaf samples and 11 to 29% for the samples from the male blossoms. In general, the R.V. values stayed low (approximately 10%) as long as the mean was relatively high (>2.0). The R.V. values increased as the mean number of thrips declined. The only exception to this generality was the male blossom sample on May 10, which had an R.V. of 29% with a mean of 3.5. The variability here can be accounted for in the development of the pistachio. During this time many male blossoms were dry and had very few thrips while others were still green and had many thrips.

The seasonal R.V. average ranged from 10.0 to 14.4% for the 4 sampling substrates. This indicates a fairly high level of precision. Southwood (1966) indicated that an R.V. of 25% or lower is acceptable for drawing sufficiently accurate conclusions about damage assessment and pest control decisions. This sampling method meets the criteria of speed and reliabilty.

Results of Thrips Scarring Survey

The results of the survey for thrips feeding scars on the surface of pistachio nuts in Bonita are shown in table 3. Tables 4-7 present the same data statistically analyzed using a chi square test for significance. It can be seen that the greatest proportion of nuts was categorized as "lightly damaged" by thrips. This amounted to 67% of the nuts in the control population and 69% of the nuts from the treated trees. Statistically (Table 5), there is no difference between the control and treated in

Table 3. Results of Thrips Scarring Survey, Bonita, AZ., 1983.

a.	total nuts undamaged	total nuts with light damage	total nuts with heavy damage	total nuts examined
control	145	1136	438	1719
treated	230	1140	272	1642

b.	X nuts per cluster undamaged	X nuts per cluster with light damage	X nuts per cluster with heavy damage	X nuts per cluster
control	0.9	7.1	2.7	10.7
treated	1.4	7.1	1.7	10.3

c.	% of nuts undamaged	% of nuts lightly damaged	% of nuts heavily damaged
control	8	67	25
treated	14	69	17

Table 4. Chi Square of Nuts Not Damaged by Thrips, Control and Treated, Bonita, AZ., 1983.

class	observed (O)	expected (E)	O-E	$(O-E)^2$	$(O-E)^2/E$
control no damage	145	187.5	42.5	18Ø6.3	32.9
treated no damage	23Ø	187.5	42.5	18Ø6.3	32.9
total	375	375			X^2=65.8*

X^2 at 1 d.f. and P of .Ø5 = 3.84.
* Significant at Ø.Ø5 level.

Table 5. Chi Square of Nuts Damaged by Thrips, Control and Treated, Bonita, AZ., 1983.

class	observed (O)	expected (E)	O-E	$(O-E)^2$	$(O-E)^2/E$
control light damage	1136	1138	2.Ø	4.Ø	Ø.ØØ4
treated light damage	114Ø	1138	2.Ø	4.Ø	Ø.ØØ4
total	2276	2276			X^2=Ø.ØØØ8

X^2 at 1 d.f. and P .Ø5 = 3.84.

Table 6. Chi Square of Heavily Damaged Nuts from the Thrips Scarring Survey, Control and Treated, Bonita,AZ., 1983.

class	observed (O)	expected (E)	O-E	$(O-E)^2$	$(O-E)^2/E$
control heavy damage	438	355	83.0	6889	19.4
treated heavy damage	272	355	83.0	6889	19.4
total	710	710			X^2=38.8*

X^2 at 1 d.f. and P .05 = 3.84.
* Significant at 0.05 level.

Table 7. Chi Square of All Categories of Nut Damage Combined (Total Nuts), Control and Treated, Bonita, AZ., 1983.

class	observed (O)	expected (E)	O-E	$(O-E)^2$	$(O-E)^2/E$
control total	1719	1680.5	38.5	1482.3	0.9
treated total	1642	1680.5	38.5	1482.3	0.9
total	3361	3361			X^2=1.8

X^2 at 1 d.f. and P .05 = 3.84.

terms of numbers or percentage of lightly damaged nuts. Both control and treated trees had an average of 7.1 nuts per cluster lightly damaged by thrips.

Fourteen percent of the nuts on the treated trees had no thrips scarring at all, an average of 1.4 nuts per cluster. Eight percent, or an average of Ø.8 nuts per cluster of the nuts left untreated experienced no thrips scarring. A chi square test (Table 4) revealed a significant difference in the numbers of nuts undamaged from treated trees compared to untreated trees.

Similarly, there was also a statistically significant difference (Table 6) between the numbers of nuts heavily damaged in control nuts versus treated nuts, there being more heavily damaged nuts in the untreated sample. On the average, 25% of the nuts from untreated trees exhibited heavy thrips damage, compared to 17% for nuts from treated trees. This amounted to averages of heavily damaged nuts per cluster of 2.7 for untreated and 1.7 fortreated.

An average cluster of pistachios from the treated areas had 1.4 nuts undamaged, 7.1 lightly damaged and 1.7 in the heavily damaged category for a total of 1Ø.3 nuts per cluster. The average untreated cluster had Ø.9 nuts undamaged, 7.1 with light thrips damage and 2.7 heavily scarred for a total of 1Ø.7 nuts per cluster. There was no statistically significant difference (Table 7) between the total nuts per cluster, control and treated.

Overall, it can be stated that the treatment successfully reduced the numbers of nuts heavily damaged by thrips but did not affect the the number of nuts produced, at least upon a per-cluster basis. Production per tree was not examined.

The thrips produced very shallow feeding scars which, in dissection, were never observed to be deeper than one half of the thickness of the hull. The likelihood of this type of feeding leading to internal injury seems quite small. The epicarp is a protective structure and is shed or removed prior to marketing. Therefore, the hull can withstand any amount of thrips scarring since it is not marketed with the nut and scarring seems to have no effect upon yield. Indeed, some nuts in the Bowie orchard were observed to have 100% of the epicarp covered with feeding scars but perfectly normal nut meats and shells. Bentlely (1982) considers WFT damaging only to leaves of non-bearing trees in California. Based on these data, it appears that WFT does not cause appreciable damage to pistachios in Arizona and that their control is unwarranted.

Since thrips are predominantly pollen feeders, it may well be that they are beneficial in pistachios as well as on other crops as pollinators (Patton and Mail 1935, Yokoyama 1977).

Results of Stink Bug and Leaf-Footed Bug Population Survey

In the Bonita orchard, 80 beating-sheet samples were taken on each of 9 dates. On each of the first two sample dates (Aug. 12 and Aug. 19),only 2 C. sayi adults were found. No bugs of any kind were found on the remaining 7 dates (Aug. 25, Aug. 29, Sept. 1, Sept. 5, Sept. 8, Sept. 15 and Sept. 18).

In the Bowie orchard, approximately 60 samples were taken on each of 5 dates. On August 16, a single colony of 25 second instar C. ligata nymphs was found. On August 28, a total of 8 second instar L. clypealis and 8 second instar plus one adult C. ligata were found. On September 5, a single colony of 10 second instar L. clypealis nymphs was found. On September 5, 2 late instar L. clypealis and one adult were found along with 1 C. ligata adult. On September 18, no bugs were found.

Therefore, of the 1020 samples taken during August and September in Bowie and Bonita, a total of 4 C. sayi, 35 C. ligata and 21L. clypealis were found or mean per sample of 0.004, 0.03 and 0.02 respectively. Populations of all 3 species were extremely low in 1983. Although sampling error tends to be larger when the populations are quite small, the results of the stink bug sampling in 1983 probably accurately reflected the population since very few of these insects were sighted by other means. A more intensive sampling method would have given more accurate results but would not have been warranted since so few insects would probably not pose any threat to the crop.

The 1982 season was characterized by large numbers of all 3 species of bugs, while in the 1983 season, very few were present. Which season is anomalous and which represents the norm remains to be seen. In the future, pistachio growers should become vigilant from the beginning of August through harvest for the presence of these insects. Further study, in a Hemiptera-heavy year, is surely needed to establish to what extent these insects cause economic loss, how they cause it and how they can be controlled.

The stink bug/leaf-footed bug sampling design has been included in this work for future use in pistachio orchards, especially in the event of future outbreaks. Beating-sheet sampling is probably the most practical and useful method in this situation.

Although useful only as a relative method of sampling (Southwood 1966), beating is preferable to sweeping. Say stink bugs are sensitive to light, shadow and plant movement, and move to the center of the plant in response to these stimuli where sweep nets cannot collect them (Wene and Sheets 1964). This eluding response to movement and shadow also makes sight-sampling difficult. Beating-sheets offer the greatest possibility for quick and reliable sampling of hemipterous insects in pistachios.

Results of Survey for Hemiptera-Related Feeding Damage

Table 8 presents the total number of nuts examined in 1983 and how they were classified with respect to hemipteran damage. Tables 9 and 10 show these data statistically using a chi square test for significance.

There was a significant difference between the number of nuts left undamaged in the control areas as compared with the number in the treated area. Control of stink bugs significantly reduced the number of feeding punctures in the treated nuts. Whether chemical treatment is warranted or not depends upon whether or not the stink bug "damage" on the epicarp relates to any internal damage. As mentioned with the thrips damage survey, the epicarp is discarded and any damage restricted to the epicarp alone can be tolerated. The shell, which is fully hardened by the time the stink bugs appear, should prevent the deep insertion of the sucking mouthparts. However, DeBarr and Kormanik (1975) reported that it is the tendency of *L. corculus* to feed deeply within the internal portions of pine seeds.

Table 8. Number of Nuts with and without Stink Bug Damage on the Epicarp, Control and Treated, Bonita, AZ., 1983.

	nuts from control trees	nuts from treated trees
No. without stink bug damage on epicarp	431	502
No. with stink bug damage on epicarp	274	271

Table 9. Chi Square for Nuts Free of Stink Bug Damage to epicarp,Control and Treated, Bonita, AZ., 1983.

class	observed (O)	expected (E)	O-E	$(O-E)^2$	$(O-E)^2/E$
control no damage	431	466.5	35.5	1260.3	2.7
treated no damage	502	466.5	35.5	1260.3	2.7
total	933	933			$X^2=5.4$*

X^2 at 1 d.f. and P .05 = 3.84.
* Significant at 0.05 level.

Table 10. Chi Square for Stink Bug Damaged Nuts (epicarp), Control and Treated, Bonita, AZ., 1983.

class	observed (O)	expected (E)	O-E	$(O-E)^2$	$(O-E)^2/E$
control damaged	274	272.5	1.5	2.3	0.0008
treated damaged	271	272.5	1.5	2.3	0.0008
total	545	545			$X^2=0.0016$

X^2 at 1 d.f. and P .05 = 3.84.

The time of year of feeding as related to plant development has been shown to greatly affect damage caused to many plants. *C. ligata* on sorghum panicles causes the greatest losses in the hard dough stage (Hall and Teetes 1982b). Puncture during the water stage of pecan causes black pit disease, which results in total destruction of internal tissues and nut drop. Later puncturing causes kernal spot in which discoloration on the nut meat occurs and the nuts do not drop (Adair 1932). With pine seeds, damage is much greater before the seed coat forms (DeBarr and Ebel 1974, Krugman and Koerber 1969). Early feeding by *Leptoglossus* in California pistachios has been shown to result in epicarp lesion followed by nut drop. Later feeding (after shell lignification) results in mottling of the epicarp but the nuts are retained. In Arizona, *Leptoglossus* (as well as stink bug spp.) have not been found on pistachios until well after lignification. Therefore, it can be assumed that exclusion of *Leptoglossus* during the early (and most susceptible) part of the season in Arizona would greatly minimize the chances of damage.

Table 10 data show no statistically significant difference in damaged nuts between the control and treated samples. The only difference occurs in the number of undamaged nuts.

One of the most difficult problems encountered in assessing stink bug damage on pistachios is that direct evidence of feeding in many plants is often very hard to see (Adair 1932). The presence of a spot on the epicarp with a drop of exudate was considered positive evidence of hemipteran feeding. Girault (1906) found that a drop of exudate formed on the surface of grapes after feeding by _L. phyllopus_. He postulated that this exudate prevents the re-introduction of the stylet at the same site. Conclusive evidence that the exudate spot on the pistachio nuts is a by-product of stink bug or leaf-footed bug is lacking.

A possible solution to the dilemma of proving stink bug feeding lies in the work of Hall and Teetes (1982a) and Bowling (1980) who used an acid fuchsin dye solution to stain the stylet sheath left by hemipterous insects after the retraction of the stylet. They worked with sorghum and soybeans, respectively. Casual experimentation with stink bugs showed that this dyeing technique works quite well on pistachios. Further research on stink bugs on pistachios should probably include this technique, which can be used to indicate the presence and frequency of feeding. The total damage done by these insects will be very dependent upon how many different feeding punctures each is capable of producing in its lifetime.

Duration of feeding may also play an important factor in the damage caused. Koerber (1963) has established that individual feedings can last for several hours. DeBarr and Kormanik (1975) found that 60% of pine cones abort in response to 24 hours of *Leptoglossus* feeding but percent abortion rose to 100% when feeding was allowed to proceed for 4 days. Another factor contributing to the severity of the injury is the number of punctures per nut. Leonard (1931) found that drop of oranges occurred only in the presence of a great number of *Leptoglossus* punctures per fruit.

Although native plants in areas adjoining the research orchards were repeatedly examined for these insects, none was ever found. *L. phyllopus* has been known to overwinter on silverleaf nightshade (Hall and Teetes 1981) and *C. ligata* is thought to breed on mesquite (Morrill 1905). Both of these plants are available in the immediate area of the orchards and should be watched carefully in future studies, as should sorghum, cotton and other economic crops known to be alternate hosts.

Results of Pistachio Nut Dissections

Pistachio nuts were dissected to determine whether the assumed stink bug damage on the epicarp corresponded with any internal damage. If so, it would be good evidence that stink bugs are able to penetrate the nut shell and cause damage to the shell and meat. To determine the frequency of internal injury and its relationship to external evidences of feeding, the presence or absence of discoloration on the internal surface of the shell and the surface of the nut meat was noted. If the shell or nut meat damage corresponded to external damage, it was also noted. In only 2 nuts out of a total of 983 examined did what appeared to be external evidence of stink bug feeding equate with damage to the shell and meat. This amounted to 0.002% of all the nuts examined. Needless to say, this minuscule frequency supports the argument that stink bugs and leaf-footed bugs are generally unable to puncture the shell of pistachios at the time these insects are present in Arizona.

Tables 11-16 show the results of the dissections for the Bonita control and treated nut samples. The results in each category are expressed as a percent of all the nuts examined. It can be seen that damage in the form of discoloration on the shell (2.3-3.0%) and discoloration and/or necrosis of the nutmeat (10.3-12.3%) was present in the samples. As mentioned, only in 2 individual nuts was the external and internal damage in the same place, which was the criterion for relating external and internal damage. The presence of internal damage not corresponding to

Table 11. Chi Square of Epicarp Undamaged (Percent), Treated and Control, Bonita, AZ., 1983.

class	observed (O)	expected (E)	O-E	$(O-E)^2$	$(O-E)^2/E$
control epicarp undamaged	6.7	9.5	2.8	7.84	0.83
treated epicarp undamaged	12.3	9.5	2.8	7.84	0.83
total	19.0	19.0			X^2=1.66

X^2 at 1 d.f. and P .05 = 3.84.

Table 12. Chi Square of Epicarp Damaged (Percent), Treated and Control, Bonita, AZ., 1983.

class	observed (O)	expected (E)	O-E	$(O-E)^2$	$(O-E)^2/E$
control epicarp damaged	93.3	90.5	2.8	7.84	0.09
treated epicarp damaged	87.7	90.5	2.8	7.84	0.09
total	181.0	181.0			X^2=0.12

X^2 at 1 d.f. and P .05 = 3.84.

Table 13. Chi Square of Nuts With Shell undamaged Internally (Percent) ,Control and Treated, Bonita,AZ., 1983.

class	observed (O)	expected (E)	O-E	$(O-E)^2$	$(O-E)^2/E$
control shell undamaged inside	97.0	97.4	0.4	0.16	0.0002
treated shell undamaged inside	97.7	97.4	0.4	0.16	0.0002
total	194.7	194.7			X^2=0.0004

X^2 at 1 d.f. and P .05 = 3.84.

Table 14. Chi Square of Nuts with Shell Damaged Internally, (Percent), Control and Treated, Bonita, AZ., 1983.

class	observed (O)	expected (E)	O-E	$(O-E)^2$	$(O-E)^2/E$
control shell damaged inside	3.0	2.7	0.4	0.16	0.06
treated shell damaged inside	2.3	2.7	0.4	0.16	0.06
total	5.3	5.4			X^2=0.12

X^2 at 1 d.f. and P .05 = 3.84.

Table 15. Chi Square of Nut Meats Undamaged, Control and Treated (Percent), Bonita, AZ., 1983.

class	observed (O)	expected (E)	O-E	$(O-E)^2$	$(O-E)^2/E$
control meat undamaged	89.7	88.7	1.0	1.0	0.001
treated meat undamaged	87.7	88.7	1.0	1.0	0.001
total	177.4	177.4			X^2=0.002

X^2 at 1 d.f. and P .05 = 3.84.

Table 16. Chi Square of Nut Meats Damaged (Percent), Control and Treated, Bonita, AZ., 1983.

class	observed (O)	expected (E)	O-E	$(O-E)^2$	$(O-E)^2/E$
control meat damaged	10.3	11.3	1.0	1.0	0.09
treated meat damaged	12.3	11.3	1.0	1.0	0.09
total	22.6	22.6			X^2=0.18

X^2 at 1 d.f and P .05 = 3.84.

external damage could be due to other causes such as plant pathogens. That stink bugs feed deeply but leave no external evidence of feeding also remains a possibility.

Percent of nuts damaged externally and undamaged externally is shown in tables 11 and 12. For both damaged and undamaged nuts, there was no statistically significant difference between the control and treated plots. There were also no differenced between the control and treated nuts in terms of percent of shells damaged or undamaged (tables 13-16). This would indicate that the use of the insecticide at this low population density of Hemiptera made no difference in the quality of nuts.

Tables 17-19 relate to the numbers of undeveloped nuts encountered in the dissections. Data in table 17 indicate that 53 undeveloped nuts were encountered out of the 300 nuts for the control sample, and that 47 were found among the 300 treated nuts. In table 18, these numbers have been tested for chi square with no significant difference found between the 2 populations. Table 18 shows these numbers converted to percentages. Eighteen percent of the Bonita control nuts were undeveloped as were 16% of the Bonita treated nuts. Note that 36% of the Bowie nuts, which were all untreated, were undeveloped.

A "disease" known as black pit of pecan is associated with L. occidentalis and has symptoms very

Table 17. Number of Nuts Undeveloped from Samples Taken on Three Dates, Control and Treated, Bonita, AZ., 1983.

date	No. nuts undeveloped per 100 control nuts	No. nuts undeveloped per 100 treated nuts
Aug. 12	16	17
Aug. 19	28	17
Sept. 11	9	13
total	53	47

Table 18. Chi Square of the Number of Nuts Undeveloped from Control and Treated Samples, Bonita, AZ., 1983.

class	observed (O)	expected (E)	O-E	$(O-E)^2$	$(O-E)^2/E$
control	53	50	3	9	0.18
untreated	47	50	3	9	0.18
total	100	100			$X^2=0.36$

X^2 at 1 d.f. and P .05 = 3.84.

Table 19. Percent of Nuts Not Developed, Bowie and and Bonita, AZ., 1983.

	Bowie	Bonita Control	Bonita Treated
N	250	300	433
%	36	18	16

similar to the damage found in pistachios. These symptoms include the browning of internal tissues and the subsequent drop of the nut. The stink bug, Euschistus euschistoides Voll., and mechanical piercing of the nuts can also cause black pit (Adair 1932). Johnson (1969) mentions hickory and filbert as other nuts in whick black pit occurs.

Bolkanet al. (1984) conducted a study to determine the epicarp lesion vector abilities of L. clypealis on pistachios in California. They found that L. clypealis does cause epicarp lesion when feeding during early season before the shells have lignified. Sixty to seventy percent of the nuts developed the disease when exposed in June but none developed the disease when exposed in July. The critical difference between these 2 exposures is that shell hardening is completed by the end of June.

Crane and Iwakiri (1982) conducted a study in California to determine the effects of mechanical puncturing. They found 100% drop when the nuts were punctured early, and a considerable reduction in drop after lignification. Two hemipterous insects were implicated as potental vectors of epicarp lesion in this study. They are Lygus pratensis L. and Euschistus conspersus Uhler, both of which feed upon pistachio nuts in Winters, California.

The stage of nut development when hemipterous insects feed on pistachios is therefore critical. In

Arizona, these insects have never been seen in pistachios before early August, which is after lignification has taken place. The damage encountered on the nutmeats may be due to post-lignification feeding by L. clypealis, as mentioned by Bolkan et al. (1984). If these insects are responsible for this internal injury, it remains to be explained how they cause it without leaving any external evidence. Again, the use of the stylet-sheath dying technique could be useful here to show precisely where feeding has occurred.

Results of Pistachio Harvest Analysis

The results of the nut dimension measurements of the pistachios from the Bonita orchard are summarized in Table 20. The mean in-shell weight was 1.9866 g. for untreated nuts and 1.9906 g. for treated nuts. The mean weight of the nutmeat was 1.1334 g. for the untreated nuts and 1.1314 g. for the treated. Both treated and untreated had an average percent nut meat to total nut weight of 57%. The average length of an untreated nut was 2.16 cm. compared to 2.18 cm. for the average treated nut. The average width was 1.46 cm. for untreated and 1.48 cm. for the treated nuts. T-tests were performed on these 4 dimensions and the resultant t-values shown at the bottom of table 20. In no case did a calculated t-value exceed the t-value from tables at 1 degree of freedom and a confidence level of

Table 20. Dimensions of Nuts Collected from the Bonita, AZ. Treated and Untreated Areas and Their t-Values.

a. control

	weight in shell (g.)	weight of meat only (g.)	% meat weight to in-shell weight	length (cm.)	width (cm.)
X	1.9866	1.1334	57%	2.16	1.46
s	0.2454	0.1720		0.15	0.10

b. treated

	weight in shell (g.)	weight of meat only (g.)	% meat weight to in-shell weight	length (cm.)	width (cm.)
X	1.9906	1.1314	57%	2.18	1.48
s	0.2670	0.1744		0.13	0.11

c. calculated t-values

weight in shell	weight of meat only	length	width
0.1351	0.1000	1.2371	1.6495

Ø.Ø5%. These data indicate that there is no significant difference in size between the average control nut and the average treated nut. As noted earlier, there was no difference between the the number of nuts per cluster. Unless there was a difference in the number of clusters per tree, which was not tested, the yield should have been the same for both the treated and the untreated populations.

The lack of difference in yield should be due to one of 2 things: either the presence of the thrips (and the few stink bugs and leaf-footed bugs later in the season) had no impact upon yield, or the insecticide treatment used was ineffective. On only one day of thrips sampling (Table 2Ø) was there a significant difference between the control and treated populations.

Adult thrips are very mobile and may have dispersed throughout the orchard from the control areas or from outside areas after spraying. Therefore, the treatment may have had an impact upon the immediate thrips population but, due to their dispersal, no long term impact. Longevity of the pesticide residue should be taken into account in future studies. Additionally, future studies should deal only with the nymphal population, since the nymphs cannot move from tree to tree and would therefore more accurately reflect the effects of chemical treatment upon the resident population.

The insecticidal effect of this chemical application to the farmer is nonexistent since, regardless of the cause, no difference can be discerned between its use and non-use and since all indications are that western flower thrips do not cause economic losses to pistachios.

CONCLUSIONS

Data from this study indicate that western flower thrips do not economically damage pistachio nuts in Arizona. Their feeding has been shown to cause scarring on the surface of the epicarp but not to affect the nutmeats nor the yeild. The the restriction of the scars to the epicarp is linked to the size of the thrips. Their feeding is shallow, owing to the small size of the mouthparts, which cannot penetrate through the epicarp.

Early in the season, when the nuts are unfertilized and quite small, the thrips may be able to penetrate into the deeper portions. This seems to be the only way in which they might be able to cause internal injury. This possibility was not tested in this investigation. Comparison of the yield and quality of treated versus untreated populations for this injury was not possible since the insecticide treatment was commenced May 3, after fertilization had been determined to be complete (April 28). Determination of the effects of pre-fertilization nut feeding by WFT is a possibility for future study.

The western flower thrips has a preference for pollen and immigrates into pistachio orchards from nearby native plants and apples or other cultivated host plants as soon as male blossoms are available. This occurs in early April. During the 1983 season, the male blossoms had far more WFT than the leaves or the nut clusters. It is strongly suggested from these observations that WFT uses the staminate flowers as a breeding substrate in which one generation per year is produced. After the male blossoms desiccate and dehisce, the population of thrips gradually decreases to a time (approximately July 1 in 1983) when they are no longer present in the pistachio orchards.

By contrast, the hemipterous insects of pistachio in Arizona are late-season in habit, having appeared in early August and lasting through September in 1982 and 1983. It is fortunate that these insects, with their deep-piercing mouthparts, are not present in the orchards until after shell lignification has been completed. The impact and economic status of the stink bugs and leaf-footed bugs in Arizona pistachios cannot be adequately assessed here due to the very low populations encountered in the study year. Although the data are inconclusive owing to difficulty of determining the definite presence and location of feeding sites, preliminary indications are that these insects cannot pierce the hard shell and that feeding is restricted to the fleshy epicarp. The protective shield of the shell and epicarp is lowered somewhat when the shell splits and a portion of the nut meat is exposed to insect exploitation.

There is some potential for damage at this time under Hemiptera-heavy conditions.

All of the insects in this study have one thing in common, they are general feeders. The literature cites many native plants and crops which act as host plants and are available in the Bonita and Bowie areas. Since the pistachio is an introduced crop, without co-evolved insect pests, general feeders are the only possibility for insect caused damage in the United States. Indications are that these insects more or less move about from one crop to another as conditions vary. For example, the availability of pistachio pollen in April elicits transitory population of thrips, which emigrate from other hosts in the area.

This study introduced rapid, practical, and reasonably precise techniques for the sampling of these insects in pistachios. Future studies should utilize these sampling designs, either in original or modified form, to assess population levels. In addition, the economic impact of hemipterous insects needs to be determined on Arizona pistachios.

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