used as general guidelines only. Actual toxicities in specific orchards may be different.

In addition to testing the pesticides listed in Leaflet 21343, we tested several that were not listed, including some that are not currently registered for use in almonds or are not registered in California at this time. We included those to determine which are most promising for future incorporation into an integrated mite management program for almonds.

Results

Pesticides in table 1 are from Leaflet 21343. Table 2 lists pesticides that are not registered or are not recommended in the leaflet.

Acaricides that were low in toxicity to *Metaseiulus occidentalis* included Plictran, Vendex, Omite, Apollo, and Savey. The Plictran, Vendex, and Omite application rates used are important, because the higher recommended rates were toxic to this predator. The integrated mite management program has thus encouraged the use of low rates of these materials to preserve both the predator and the prey. Abamectin, Dibeta, and Kelthane were toxic to the predator. Abamectin and Dibeta, which are currently unregistered, might be used in a selective manner if rates were very low, but such use would have to be determined by field trials.

Insecticides that were generally low in toxicity to the predator included Guthion, Diazinon, Parathion, Imidan, *Bacillus thuringiensis,* and Thiodan. Sevin had low toxicity to the COS strain, but was toxic to native populations. At higher rates, Guthion and Malathion showed moderate toxicity to native strains of the predator. Lorsban, Dibrom, and Dibeta were moderately toxic to all colonies tested. Supracide, Pounce, Danitol, Pydrin, Ambush, and Zolone appeared to be highly toxic to the predator.

Among the fungicides, Captan, Maneb, Ziram, Funginex, and Rovral appeared to have low toxicity to the western predatory mite. Benlate and sulfur had low toxicity to the COS stain, but were generally toxic to the native populations from almond orchards.

Our laboratory assays suggest that growers and pest control advisors wishing to preserve *M. occidentalis* populations can choose among several options in controlling diseases, insects, and spider mites.

Marjorie A. Hoy is Professor, and Janet Conley is Staff Research Associate I, Department of Entomological Sciences, University of California, Berkeley.
This research was supported by UC/IPM, Almond Board of California, and W-84 Regional Research Project. The authors thank William Barnett, Frank Zalom, Lonnie Hendricks, Walter Bentley, Robert Curtis, Mary Louise Flint, and Michael Stimmann for their assistance.

Tiny *Anagrus epos* wasp is an effective biological control of grape leafhopper but not of variegated grape leafhopper.

Biological control of variegated grape leafhopper

Charles H. Pickett □ Lloyd T. Wilson □ Daniel Gonzalez
Donald L. Flaherty

Within the past few years, variegated grape leafhopper has invaded the San Joaquin Valley, where it is now a serious pest of grapes. This leafhopper, *Erythroneura variabilis,* has been a pest of grapes in southern California since the 1930s, but wasn't reported in the San Joaquin Valley until 1980. Populations reach high densities on grapes in late summer, causing fruit spotting of table grapes and complete defoliation of vines. A reduction in yield and fruit quality is anticipated for vineyards repeatedly defoliated late in the season.

Grape leafhopper, *Erythroneura elegantula*, a close relative of variegated grape leafhopper, is native to the San Joaquin Valley. Grape leafhopper is frequently kept below damaging levels by natural control, in which the parasitic wasp *Anagrus epos* (Hymenoptera: Mymaridae) plays an important part. Although this parasite attacks the egg stage of several closely related species of leafhoppers, it displays a strong preference for grape leafhopper over variegated grape leafhopper. Studies indicate parasitism of grape leafhopper often exceeds 90 percent on Thompson Seedless grapes, while parasitism of variegated grape leafhopper is typically less than 20 percent. High densities of variegated grape leafhopper in late summer probably result from the low rates of parasitism by the wasp and the lack of other effective natural enemies.

Variegated grape leafhopper was probably introduced near the Fresno area and is now found from Kern County in the south to just north of Modesto in Stanislaus County. Studies show that this species is rapidly displacing grape leafhopper in many areas. Adult leafhoppers have been found inside automobiles next to vineyards and could easily be carried long distances. Variegated grape leafhopper is likely soon to reach the remaining grape-growing regions where grape leafhopper is currently established, including the wine-producing valleys of northern California.

The importation and establishment of new parasites of variegated grape leafhopper could greatly reduce the need for applying insecticides against this pest and would alleviate problems associated with resistance and secondary pests. We have

Two look-alike imported biotypes of a parasitic wasp are being tested against the variegated grape leafhopper in the San Joaquin Valley.

therefore conducted a field evaluation of variegated grape leafhopper parasites collected in the western United States outside central California (near Grand Junction, Colorado, and Coachella, California) and in northern Mexico (near Caborca, Sonora). The foreign exploration for new variegated grape leafhopper parasites was limited to areas where variegated grape leafhoppers were abundant on and around commercially grown grapes.

Most parasites collected from these different regions were identical in appearance to *A. epos.* Results from this

Single leaf cages on Thompson Seedless grapes, above left, test the preference of native and imported biotypes of the parasitic wasp for grape and variegated grape leafhoppers. Large nylon or polyester organdy field cages enclosing an entire vine, below, were set up to test the rate of parasitism on variegated grape leafhopper eggs. Branch cage at upper right is designed to test the ability of imported wasps to parasitize an alternate host and to overwinter in central California.

study indicate, however, that these populations possess distinct behavioral and biological differences. We therefore refer here to parasites that physically look like the same species but are collected from different locations as "biotypes." Additional studies will be required to determine whether each biotype is in fact a distinct species.

Field evaluation

Our goal in the field-cage evaluation of imported parasites is to determine which parasite biotype or species is most likely to permanently reduce variegated grape leafhopper populations. Because we are dealing primarily with parasites that look identical, the evaluation techniques serve to (1) help rank or predict the success of each biotype and (2) determine biological characteristics that separate and identify biotypes. The second objective is important because it will make it possible to determine how accurately the initial screening studies predicted the success of released parasites. Having a means of identifying released biotypes helps in determining if one or more of them were responsible for reducing variegated grape leafhopper populations. The biological characteristics currently being used to distinguish biotypes in these studies, however, may change with time as a result of hybridization with the native biotype.

During the 1986 grape-growing season, we conducted three field tests, each measuring different biological characteristics. The first two measured rates of parasitism and host preference of two collected parasites identified as biotypes of *A. epos*, one from Coachella and the other from Grand Junction. The same biological characteristics were measured for the native biotype of *A. epos* , collected at the University of California Kearney Agricultural Center in Parlier. The "Kearney" biotype served as a standard or reference point against which to compare the candidate parasites.

The first test estimated the preference of each biotype for each leafhopper host. We quantified the preference of a parasite biotype for a leafhopper species, that is, determined a preference coefficient, by comparing the relative frequencies of parasitized leafhoppers to the relative frequencies of available leafhoppers. Preference, therefore, reflects any deviation from the expected parasitization based on the availability of hosts. For example, if a parasite were caged on a leaf having 20 variegated grape leafhopper eggs and 20 grape leafhopper eggs, and 15 variegated grape leafhopper and 5 grape leafhopper are parasitized, the relative preference shown by this biotype for the grape leafhopper would be about 0.33 or 33 percent of the preference for variegated grape leafhopper.

The preference study took place at the Kearney Agricultural Center using single leaf cages on Thompson Seedless grape vines. Spherical, 8-inch-diameter cages were constructed of a synthetic material. Approximately equal numbers of adult grape and variegated grape leafhoppers were placed in each of three cages, one cage per biotype, and replicated, depending on biotype, four to eight times. After 11 to 14 days, leafhopper adults were removed and parasites added to each respective leaf cage. Leafhopper eggs were exposed to parasites for 24 hours, incubated an additional 6 to 8 days, then examined for the percentage of parasitism.

The range of possible preference coefficients is 0.0 to a maximum value of 1.0. A value of 1.0 was assigned to the host species most frequently attacked, relative to other available hosts. Field studies show conclusively that the native or Kearney biotype of *A. epos* has a much greater relative preference for grape leafhopper than for variegated grape leafhopper (table 1). This preference may result from the way leafhoppers lay eggs in leaves. Grape leafhopper eggs produce a blister-like protrusion on the leaf surface, while the surface above variegated grape leafhopper eggs is smooth. Preference coefficients also show that the biotype from Colorado preferred variegated grape leafhopper more than grape leafhopper, suggesting that both physical and chemical cues may initiate parasitization by *A. epos.*

Most important, however, is the preference of each biotype for the two leafhopper species relative to that shown by the Kearney biotype. On the basis of the preference coefficients listed in table 1, the biotypes from Coachella and Colorado would respectively choose, provided eggs of both leafhopper species, 3.4 and 7.7 times more variegated grape leafhoppers than the Kearney biotype would choose. These results suggest that the Coachella and Colorado biotypes are more likely than the Kearney biotype to parasitize variegated grape leafhopper. They also demonstrate that the different biotypes possess a distinct, quantifiable behavioral response to their host.

The second biological characteristic tested was the rate of parasitism on variegated grape leafhopper eggs. A promising parasite should be capable of achieving higher levels of parasitism than the native biotype of *A. epos*. Using the same three biotypes of *A. epos*, we placed each in separate field cages previously inoculated in early summer with 300 immature and adult variegated grape leafhoppers and 50 immature grape leafhoppers, approximating the respective species ratio in early-season field populations. The cages, constructed of nylon or polyester organdy, enclosed an entire vine and measured 5 feet wide by 8 feet long by 6 feet tall.

The field cages were set up at three locations, representing the major climatic regions of central California where Thompson Seedless grapes are grown: a commercial vineyard near Woodlake (Tulare County), the Kearney Agricultural Center (Fresno County), and the UC West Side Field Station near Five Points (Fresno County). Depending on location and biotype, 41 to 199 adult female parasites were released into cages from June through early September and monitored for parasitism from July through October. Ten leaves were removed from each cage every two weeks and examined for parasitized eggs. Results from these field cage studies will indicate whether parasites can survive and provide similar levels of parasitism during the summer in areas represented by the study site locations.

Table 1. Preference coefficients and average seasonal percentage parasitism by imported and native biotypes of *Anagrus epos*

	Biotype of *A. epos*		
Item	UC Kearney Agric. Ctr.	Coachella CA	Grand Junction CO
	Preference coefficients		
Variegated grape leafhopper	0.145	0.490	1.000
Grape leafhopper	1.000	1.000	0.235
	Parasitism of variegated grape leafhopper eggs		
	%	%	%
UC West Side Field Station	0	18	9
UC Kearney Agric. Ctr.	17	28	1
Woodlake, CA	8	22	1

The Coachella biotype, of all three parasites tested, most consistently parasitized the highest percentage of variegated grape leafhopper eggs at all three locations (table 1). Parasitism reached 55 percent on variegated grape leafhopper and averaged 18, 28, and 22 percent over the summer at the three locations. Although these values do not represent exceptionally high levels of parasitism, they are several times greater than those measured for the Kearney biotype. Caged leafhoppers in our study were first exposed to each biotype much later in the season than would occur in a typical commercial vineyard under natural conditions. The number of parasite generations thus was probably half the usual nine or ten per growing season reported for the local biotype of *A. epos*. Under natural conditions outside a cage, parasitization by the Coachella biotype could conceivably reach much higher levels than recorded in this study and several times greater than those by the Kearney biotype.

The Colorado biotype, surprisingly, parasitized a very low percentage of variegated grape leafhopper, similar to that by the Kearney biotype. Observations in the laboratory and an independent field cage study suggest this biotype is capable of reaching much higher levels of parasitism if it is initially exposed to a relatively high host density. These results suggest that the Colorado biotype, like the Kearney biotype, may have a relatively poor ability to search for variegated grape leafhopper eggs. These results also provide another biological index with which to compare and identify biotypes of the parasitic wasp.

We are currently testing *A. epos* and a new species of Trichogrammatidae near the genus *Ittys*, both from Caborca, Mexico, and the two biotypes of *A. epos* collected from Coachella and Grand Junction for their ability to overwinter in central California. All of these parasites attack only the egg stage of its host. Because variegated grape leafhopper overwinters as an adult, the parasites need alternate leafhopper hosts that maintain an egg stage during winter.

The overwintering studies are being conducted at the UC West Side Field Station in a French prune tree refuge for *Anagrus* parasites. One of perhaps several alternate leafhopper hosts in the refuge is the rose leafhopper, *Edwardsiana rosae*. Following two applications of an insecticide to remove native parasites, rose leafhopper nymphs were added during July and August to five cages, each of which enclosed a 3-foot length of branch. Parasites were added in late August and early September to all but one cage, which served as a control.

Data recorded from caged leaves in September and October 1986 suggest that all imported and tested parasites are capable of parasitizing and completing development on the rose leafhopper. Parasitized eggs were found on leaves collected from cages housing the Colorado and Caborca biotypes of the parasitic wasp, while exit holes produced by adult parasites of all four biotypes and the new species were found on leafhopper eggs from the cages. Leaves from the control cage contained no eggs that were parasitized or had exit holes. This finding indicates that the insecticide application was successful in reducing contamination of our imported parasites with the native biotype. Further sampling will be done to determine whether the parasites can survive overwintering temperatures in central California.

Conclusions

The field cage evaluation techniques used in this study provided quantitative information for ranking the effectiveness of the imported parasite biotypes and species as well as for identifying biotypes. One of these techniques quantified parasite preferences for hosts and is, to our knowledge, a new approach for ranking insect-feeding biological control agents. Both the Coachella and Colorado biotypes of the parasitic wasp *Anagrus epos* showed a greater preference for variegated grape leafhopper eggs than did the native Kearney biotype. The Coachella biotype in separate field studies also parasitized a greater percentage of variegated grape leafhopper than did the Kearney biotype.

Results to date indicate that considerable potential exists for establishment of one or more new *Anagrus* biotypes that have a greater ability than the native biotype to regulate variegated grape leafhopper populations. We are continuing our evaluations of these and other imported parasites.

Charles H. Pickett is Postdoctoral Researcher, and Lloyd T. Wilson is Associate Professor, Department of Entomology, University of California; Daniel Gonzalez is Entomologist, Division of Biological Control, UC Riverside; and Donald L. Flaherty is Farm Advisor, Cooperative Extension, Tulare County. *The authors thank Teri Bates and Pat Henier for their assistance in data collection, William Settle for the photo of* A. epos, *John Sorenson for identifying leafhoppers, and Bill Peacock for the use of his vineyard. Funding for this research program was provided by the California Raisin Advisory Board, the California Table Grape Commission, and the Wine Growers of California.*