The spider mite predator *Metaseiulus* (= *Typhlodromus*) *occidentalis* (Nesbitt) effectively controls spider mites in many of California's deciduous orchards and vineyards. Two laboratory-selected predator strains, one resistant to Sevin and Guthion and another to permethrin (Ambush/Pounce) and Guthion, have been released and successfully established in apple and almond orchards (*California Agriculture,* January and November-December 1980). A predator strain resistant to Cygon (dimethoate) was successfully established in a vineyard (*California Agriculture,* May 1980).

Predators and other natural enemies often are exposed to an array of pesticides. Therefore we tested several *M. occidentalis* colonies to determine the effects of fungicides being evaluated by Dr. Mary Ann Sall and colleagues at University of California, Davis, for powdery mildew (*Uncinula necator*) control in vineyards. We discovered that selection in the vineyard has developed populations of *M. occidentalis* that are genetically resistant to sulfur, which has been used for many years to control powdery mildew. Populations collected from apple, pear, or almond orchards and from wild blackberries in Berkeley are susceptible to sulfur.

The genetic basis of the resistance to sulfur was determined so that we could more easily incorporate resistance to this fungicide into other strains resistant to insecticides such as Guthion, Sevin, and Ambush/Pounce. We also found that several colonies of the predator *M. occidentalis* exhibit tolerance or resistance to Benlate (benomyl), Bayleton, and an experimental fungicide, CGA-64251. These results indicate that resistance, cross-resistance, and natural tolerance in various colonies of this predator could allow considerable flexibility in future fungicide usage in California vineyards without detriment to these important spider mite predators.

Predator responses to sulfur

Adult female or larval predators were tested on treated leaf discs in the laboratory at 78° to 80°F under a 16-hour daylength. Females or larvae were transferred with a fine camel's-hair brush to discs that were dusted, treated with water, or dipped into solutions with one-half, one, or two times the labeled field rates of each formulated material:

Resistance to sulfur in a vineyard spider mite predator

Marjorie A. Hoy □ Kathlyn A. Standow

H. F. Knop

Colonies of a spider mite predator can survive sulfur applied to control powdery mildew.

Cosan, Super-six, That, and FMC wettable sulfur. Sulfur dust rates were estimated by comparing the amount of sulfur by weight on leaves freshly treated in a vineyard to the amount deposited by a hand duster. Mortality usually was assessed 48 hours later. Predator eggs were 0 to 24 hours old (eggs usually hatch about 96 hours after deposition at these temperatures). Predator colonies tested were isolated from vineyards (treated frequently with sulfur), pear, apple, or almond orchards (rarely treated with sulfur), and wild blackberries (presumably never treated with sulfur).

Sulfur resistance was found in the three vineyard populations (Raven, Cecil, and No. 3) and was absent or low in all other field-collected predator populations tested. Resistance to sulfur was exhibited by the larvae (table 1); there were no substantial differences in survival of the adult females over 48 hours. Larvae from vineyard populations lived to become adults on sulfur-treated surfaces, whereas those from the Jones pear orchard, the WA-O apple orchard, or the Berkeley blackberry colony had substantially lower survival rates and rarely were able to survive the molt from the larval to the protonymphal stage on leaf discs treated with one-half, one, or two times the field rates.

Thus, sulfur treatments would affect susceptible predator populations by reducing their ability to increase, although adult females would appear to be unharmed after 48 hours. All sulfur formulations tested (dusts, wettable powders, and flowable sulfurs) were similar in their effects, although resistance levels varied in the three vineyard populations tested.

Genetic basis of sulfur resistance

Insecticide-resistant strains of *M. occidentalis* released into vineyards must be resistant to sulfur as long as sulfur remains the primary fungicide used to control powdery mildew. A genetic analysis of sulfur resistance was conducted using the sulfur-resistant Raven vineyard colony (R) and the susceptible Berkeley blackberry colony (S). Reciprocal F_1, F_2, and backcross larvae were tested for their ability to survive to adulthood on leaf discs treated with Cosan. Doses tested ranged from $\frac{1}{128}$ to 64 times the field dose of 4 pounds (80 WP) Cosan per 100 gallons water.

Mortality of the S colony was high (greater than 80 percent) at ½ pound of formulated material (fig. 1A). The LC_{50} value (amount that kills one-half of the population) for the Berkeley blackberry colony was 0.16 pound active ingredient per 100 gallons. In contrast, larvae from the R colony never exhibited

TABLE 1. Comparison of Sulfur Resistance in Several Populations of *M. occidentalis* using One-half, One and Two Times the Field Dose

Material*	Colonies and source	Mortality after 48 hours on residues: Females at† ½	1	2‡	Larvae at† ½	1	2‡
		%	%	%	%	%	%
Cosan	Raven vineyard	15	15	15	6	6	5
(micronized sulfur)	Cecil vineyard	0	0	0	49	90	55
4 lb 80 WP/100 gal	Vineyard No. 3	20	17	12	53	81	100
	Jones pear orchard	14	20	20	97	92	100
	WA-O apple orchard	0	0	0	97	100	100
	Berkeley blackberries	0	2	0	100	100	100
FMC							
(wettable sulfur)	Raven vineyard	—	—	—	6	6	15
5 lb 92 WP/100 gal	Cecil vineyard	—	—	—	56	53	21
	Berkeley blackberries	—	—	—	88	90	100
Super-Six							
(flowable)	Raven vineyard	—	—	—	0	10	0
3 lb/150 gal	Cecil vineyard	—	—	—	0	0	0
	Berkeley blackberries	—	—	—	56	81	94
That							
(flowable)	Raven vineyard	—	—	—	13	11	44
2 pt/100 gal	Cecil vineyard	—	—	—	48	45	62
	Berkeley blackberries	—	—	—	83	88	96
Sulfur (FMC)	Raven vineyard	—	0	—	—	0	—
(dust)	Cecil vineyard	—	0	—	—	32	—
15 lb/acre	Vineyard #3	—	0	—	—	20	—
	Sevin-Guthion selected colony	—	0	—	—	38	—
	Turlock almond orchard	—	0	—	—	64	—
	WA-O apple orchard	—	0	—	—	96	—
	Berkeley blackberries	—	0	—	—	74	—

*Formulation and rate used as one time field dose.
†At each dose, 40 to 60 mites were tested; mortality adjusted by Abbotts correction for control mortality.
‡Times labeled field dose per 100 gallons water.

TABLE 2. Toxicity of Other Pesticides to *M. occidentalis* at One-half, One and Two Times the Field Dose

Material*	Colonies and source	Mortality after 48 hours on residues: Females at† ½	1	2‡	Larvae at† ½	1	2‡	Eggs at† ½	1	2‡
		%	%	%	%	%	%	%	%	%
Benlate (benomyl)	Sevin-Guthion	10	10	9	—	—	—	8	8	—
(registered)										
0.5 lb AI/100 gal	Cecil vineyard	0	0	0	—	—	—	—	—	—
	Berkeley blackberry	13	19	38	—	—	—	95	100	—
Bayleton	Sevin-Guthion	0	0	0	13	13	22	9	12	12
(not registered										
for vineyard use)	Cecil vineyard	20	12	16	9	28	26	10	14	12
1.5 oz. AI/100 gal										
CGA-64251	Sevin-Guthion	0	3	0	—	—	—	4	2	10
(not registered										
for vineyard use)	Raven vineyard	4	0	6	—	—	—	0	0	0
0.525 oz AI/100 gal	Berkeley blackberry	0	0	0	—	—	—	0	0	0
Mesurol (bird	Sevin-Guthion	99	100	—	—	—	—	100	100	—
repellent)										
(registered)	Vineyard #3	98	98	—	—	—	—	—	—	—
2 lb AI/100 gal	Berkeley blackberry	100	100	—	—	—	—	100	100	—
Kryocide	Sevin-Guthion	0	18	3	—	—	—	33	20	—
(registered)										
8 lb AI/100 gal	Vineyard #3	40	17	—	—	—	—	25	0	—
	Berkeley blackberry	2	0	57	—	—	—	43	0	—

*Formulation and rate used as one time field dose.
†At each dose, 40 to 60 mites were tested; mortality adjusted by Abbotts correction for control mortality.
‡Times labeled field dose per 100 gallons of water.

more than 22 percent mortality at any dose tested, including the extraordinary doses of 32, 64, 128, and 256 pounds formulated Cosan per 100 gallons water. Thus, resistance was extremely high in this R colony, but no accurate LC_{50} value could be estimated, because the R colony did not exhibit a linear response to sulfur. To our knowledge, an acquired resistance to sulfur never has been demonstrated in any other phytoseiid predator, or in any other biological control agent.

Both sets of F_1 progeny were quite resistant to sulfur (fig. 1A). The two types of F_1 progeny had different survival rates, as expected in a species with males that are parahaploid (adult males have only one functional set of chromosomes, which they inherit from their mothers; females have two sets). Thus, the F_1 progeny with R mothers had greater resistance than the F_1 progeny with S mothers. Their mortality was close to that exhibited by the R colony, especially in the dose range between ½ and 8 pounds. This response strongly suggests that sulfur resistance is determined by a dominant or semidominant gene. The increased mortality at the higher doses could indicate that additional, smaller (modifying) genes also contribute to the sulfur resistance. The high level of R in the reciprocal F_2 progeny (fig. 1B), and the reciprocal backcross progeny (fig. 1C) support the hypothesis that sulfur resistance is predominantly determined by a single dominant or semidominant gene in this R colony of *M. occidentalis.*

Benlate, Bayleton, and the experimental fungicide CGA-64251 were tested to determine if alternative fungicides could be used selectively in California vineyards, although Bayleton and CGA-64251 are not registered for use in vineyards. We also tested Mesurol, registered as a bird repellent, and Kryocide, used to control lepidopteran pests in vineyards.

Bayleton and CGA-64251 were not toxic to any *M. occidentalis* colonies tested (table 2). Thus, these materials, if registered for use in vineyards, could be used without substantially disrupting this predator's effectiveness.

Benlate was not toxic to adult females of any *M. occidentalis* colony tested, but it did permanently sterilize the females and they deposited few eggs. The Sevin-Guthion-resistant colony was apparently cross-resistant to Benlate, and females deposited eggs at a nearly normal rate. Immatures of the Sevin-Guthion strain developed to adulthood on Benlate-treated leaf discs, whereas no larvae of the Berkeley blackberry colony survived. Thus, Benlate could be used with less disruption of predator populations if the Sevin-Guthion predator strain were established in vineyards. However, the Sevin-Guthion colony showed no cross-resistance to Mesurol, although both Sevin and Mesurol are carbamates. Kryocide was not toxic to any colonies of *M. occidentalis* tested and thus could be useful as a selective insecticide in integrated pest management (IPM) programs.

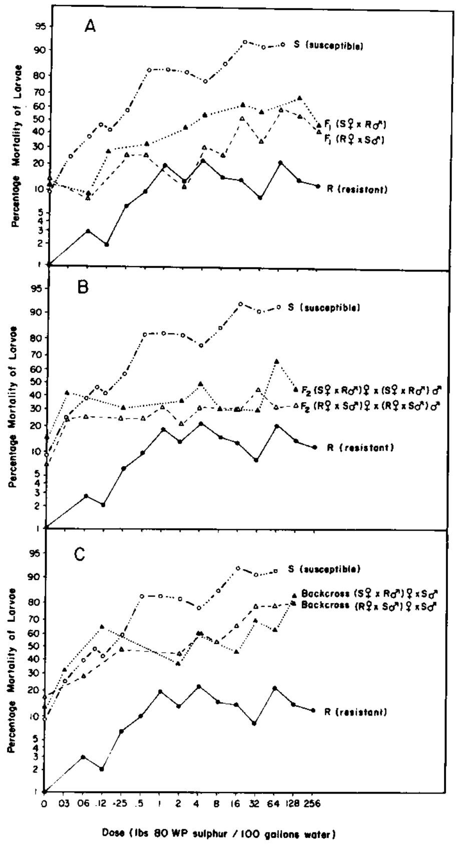

Fig. 1. Concentration response curves on logit paper of larvae of sulfur-susceptible (S) and resistant (R) *M. occidentalis* and their reciprocal: (A) F_1 progeny; (B) F_2 progeny; and (C) backcross progeny.

The responses of *M. occidentalis* to genetic selection for pesticide resistance are impressive. Different populations of this predator have responded to selection in the field, becoming resistant to organophosphorus insecticides, such as Cygon, Guthion, and diazinon, and to sulfur. In addition, laboratory selection has been successful using two different groups of insecticides: a carbamate (Sevin) and a pyrethroid (permethrin or Ambush/Pounce). This wide array of resistance is unique in a biological control agent and offers promise for increasing the effectiveness of this predator in IPM programs in California's deciduous orchards and vineyards.

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Until 1977 DBCP (1,2-dibromo-3-chloropropane) was widely used as an effective, economical nematicide on many crops including established vineyards. The chemical was especially suited for treatment of grapes, because it was easy to apply as a liquid formulation by chisel applicators or as an emulsifiable formulation in irrigation water; low in phytotoxicity; active as a fumigant, able to spread through the soil profile; highly nematicidal; persistent for long periods in the soil.

Unfortunately the chemical was found to have carcinogenic/mutagenic properties hazardous to public health, and its use has been suspended. Since no other chemical has even approached the capability of DBCP, the grape industry has been left without a replacement or alternative.

Although no nematicides are registered for use on growing vines, a number of nonfumigant materials have been used experimentally by University of California researchers for several years. In 1976 aldicarb (Temik) was applied to Cardinal vines near Lodi, California. Improvements in growth and yields were encouraging, and the trial was continued in 1977 with retreatment of half the vines in each replicate. Phenamiphos (Nemacur) was added to the test program, and several new plots also were established. In 1978 carbofuran (Furadan), ethoprop (Mocap), and Nemamort also were included.

These nonfumigant materials are carbamates or organophosphates, which act systemically to varying degrees. They are generally formulated as granular preparations containing 10 to 15 percent of the active ingredients; some are available also as emulsifiable or water-soluble formulations. The chemicals are low in phytotoxicity and can be applied to established, living plants. However, because of their low volatility, they move through the soil slowly or not at all. To reach nematodes, the chemicals must be mechanically mixed into the soil or carried through the soil profile dissolved in irrigation water.

These nematicides kill target nematodes in the soil by contact action and, in some cases, by systemic action when nematodes feed on root tissues near the point of toxicant absorption.

Carbamates and organophosphates kill insects by inhibiting activity of acetylcholinesterase and cholinesterase, which are involved in synapsis. The inhibition results in abnormal transmissions of impulses through the nervous system. Evidence of cholinesterase-