Induced immunelike resistance to spider mites in cotton

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Plants respond to 'vaccination'

Young cotton seedlings exposed to caged spider mites developed resistance to later mite feeding, lending support to the belief that resistance to a variety of insects can be induced by stressing the host plant.

Although immunization is the primary means of disease control in animals, plant biologists have made relatively little use of induced resistance to protect crops. Plant pathologists have recently found that restricted inoculations of viruses, bacteria, and fungi can induce resistance in plants against subsequent disease caused by these pathogens. For some years, commercial tomato growers in Europe have successfully used sprays of mild strains of tobacco mosaic virus to protect their crops against economically damaging strains of this virus.

Stimulated by reports of "plant conditioning" in the entomological and ecological literature, work at the University of California, Davis, has explored the possibility of inducing resistance in cotton seedlings against spider mites and other pests. Other researchers working on plants as varied as sugarbeets attacked by beet flies, English walnuts attacked by walnut aphids, and native birch trees attacked by autumnal moth caterpillars had noticed that damaged plant tissue was inferior as food for insects developing later. Coincident with these field observations were reports by chemists that plants damaged by feeding insects contained higher concentrations of "secondary metabolites," which were presumed to possess deterrent or antibiotic activity against some insect species. These results suggested that it might be possible to induce resistance against economically important pests such as spider mites on cotton, thus reducing the need to use chemical pesticides.

In an initial set of laboratory experiments, my colleague, entomologist James Carey, and I found that changes in cotton seedlings induced by prior feeding of mites reduced the population growth of spider mites. We randomly assigned cotton seedlings at the cotyledon stage to an experimental group, which was infested with 16 adult female two-spotted mites (*Tetranychus urticae*) or a control group, which received no mites (fig. 1). After five days, we removed all spider mites from plants of both treatments, allowed the plants to grow without mites for 12 to 14 days, and then challenged each one with three adult female two-spotted mites. These mites fed and reproduced for 14 days, more than enough time to complete a generation, when the experiment was stopped and mite populations were counted.

The spider mite population growth on plants damaged by previous feeding was about half the growth on undamaged control plants (fig. 2). The induced resistance was systemic; leaves not present at the time of "inoculation" showed resistance.

Vertebrate immune responses are generally quite specific; an animal synthesizes antibodies that are highly effective against only the attacking antigen. It soon became apparent that induced resistance in cotton was far less specific. Plants damaged by the strawberry mite, *Tetranychus turkestani* became resistant to the two-spotted mite, *T. urticae* (fig. 2).

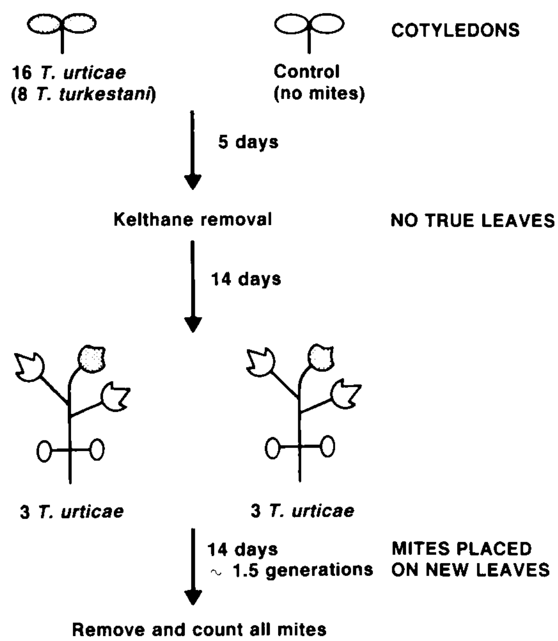

Fig. 1. Mites in experimental group fed on cotton seedlings for five days, then were removed. After 14 days, damaged and undamaged plants were again exposed to mites and mite increases compared.

Mechanically abrading cotton seedling leaves with powdered carborundum induced resistance to mite feeding just as effectively as previous mite damage did.

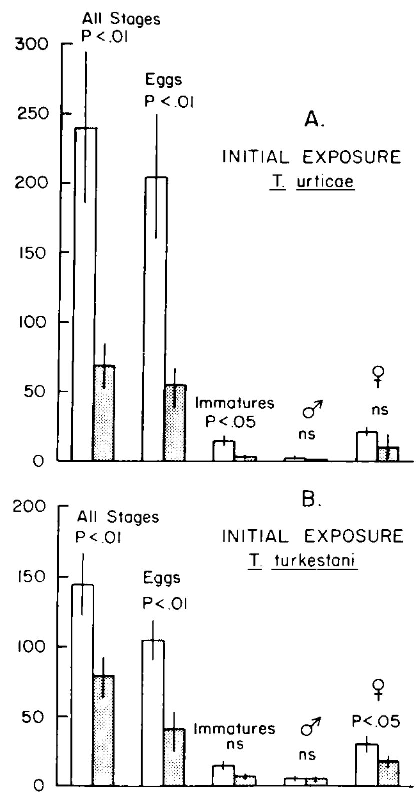

Fig. 2. Two-spotted spider mite population growth on previously damaged plants (shaded bars) was about half of that on undamaged plants (open bars). Plants were resistant whether they had first been exposed to two-spotted mite (A) or strawberry mite (B). (Lines represent standard error.)

Plant changes caused by spider mites have important effects on even more distantly related organisms. I have found that beet armyworm caterpillars, *Spodoptera exigua*, had a lower probability of survival to pupation on cotton plants previously exposed to spider mites than on control plants with no previous exposure (table 1). Dr. William Schnathorst, from the Department of Plant Pathology at UC Davis, told me he had observed over the years that cotton seedlings he had accidentally allowed to become infested with mites were very poor hosts for *Verticillium* fungi. Indeed, when he, Rodney Adamchak (graduate student in entomology), and I repeated this experiment under carefully controlled conditions, we found that mite-damaged plants were less likely to develop symptoms of Verticillium wilt than were undamaged controls. Clearly, changes in cotton seedlings caused by spider mite feeding affect a diverse array of organisms that utilize the plant in very different ways.

TABLE 1. Fate of beet armyworm larvae after host plant exposure to mites

Plant treatment	Survival of larvae		
	Pupation	Death	Total
Exposed to mites	25	111	136
Unexposed control	43	93	136
Total	68	204	272

It seemed reasonable to suspect that the induced response might involve something unique to plant-feeding mites. Spider mites inject saliva into the host plant during feeding, and this saliva is thought to produce physiological and hormonal changes in the plant. Other workers have shown that spider mite feeding causes major changes in cotton seedlings. Therefore, I wondered if there was something special about spider mites or if, instead, plants were responding to damage in general, of which mites represented one of many possible sources.

To answer these questions, I divided cotton seedlings into three experimental treatments: one-third of the plants damaged in five days of feeding by eight strawberry mites, one-third damaged mechanically without mites by abrasion of the cotyledons with powdered carborundum, and one-third undamaged, as controls. As in previous experiments, plants were allowed to grow to the three-leaf stage and were then challenged with three adult female two-spotted mites.

Mechanical abrasion induced resistance against two-spotted mites as effectively as previous mite damage did. Resistance apparently can be induced by a variety of stresses to the host plant and does not require a stimulus specific to spider mites. Obviously, growers will not be able to expose their cotton seedlings to mite feeding for five days and remove the mites at the end of this period, as was done in the laboratory. If resistance can be induced by a variety of cultural techniques, however, induced resistance may become a practical management tool.

In all of these experiments, the spider mites were caged on specific plants of various treatments, so they had no opportunity to respond to the quality of the cotton seedlings by moving. In a new set of experiments, Susan Harrison (graduate student in ecology) and I offered adult female two-spotted mites a choice between a cotton seedling that had received previous damage and one that had received no damage. The mites quickly responded, choosing undamaged plants in preference to previously damaged seedlings. Adult females are able to perceive and respond to changes triggered by very low levels of feeding damage to the cotyledons; however, immature spider mites do not show this response.

Additional variations on the basic theme provided new clues about the mechanism of induced resistance. In one test, mites fed for five days on the first set of true leaves rather than the cotyledons. This procedure was as effective at inducing resistance as damaging the cotyledons had been. I also tried waiting 60 days

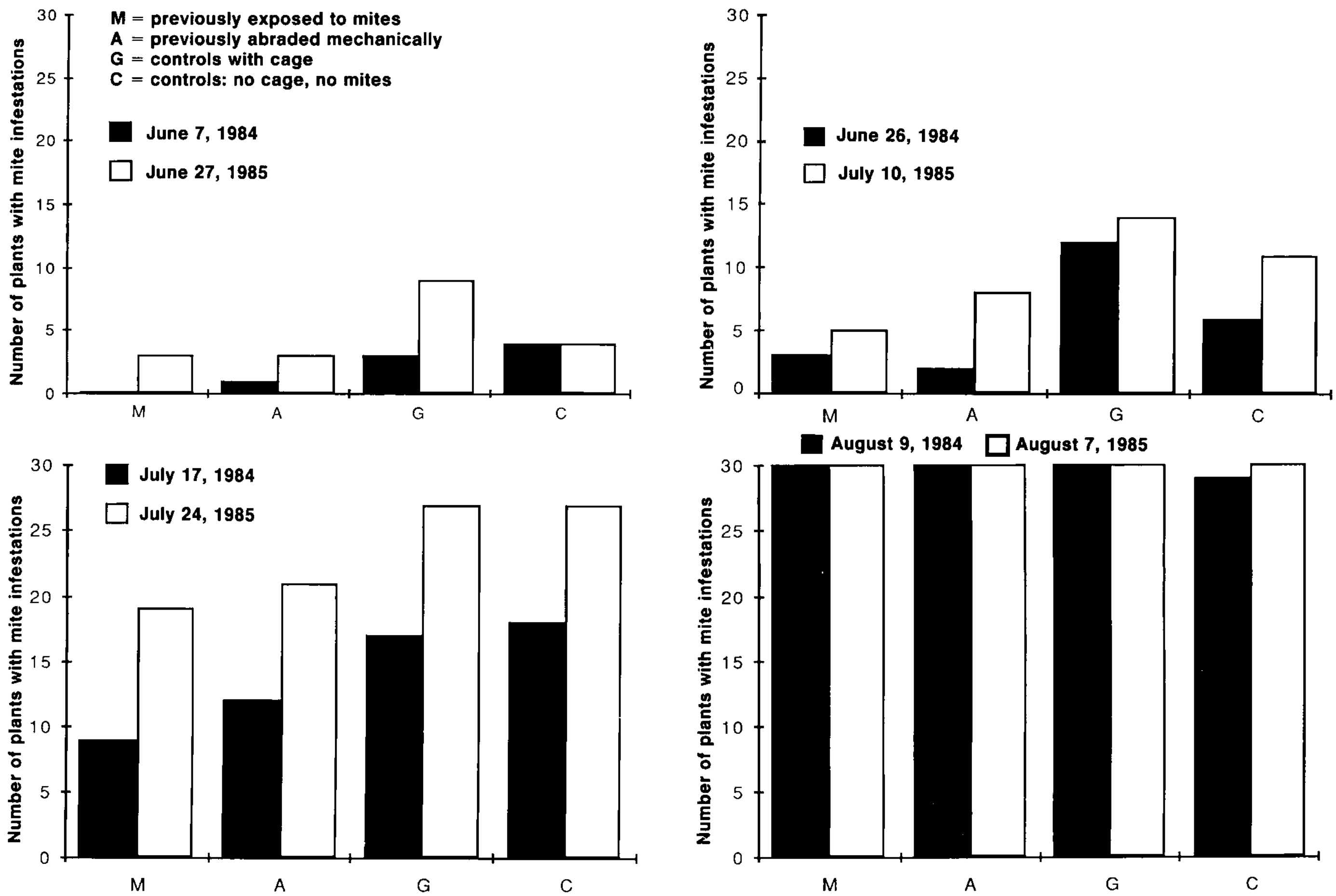

Fig. 3. In tests to determine if resistance to spider mites could be induced under field conditions, mite densities began to increase in June of both years, with greater increases on control seedlings than on those previously exposed to mites or abraded. The trend persisted until late July or early August. Differences did not disappear until later in the season.

after seedlings were damaged before challenging them. Induced resistance persisted for at least that length of time.

For induced resistance to become a practical pest management tool, the laboratory demonstration of induced resistance must be repeatable in the field. During the summers of 1984 and 1985, I repeated the experiments at the UC Westside Field Station near Five Points. In each year, 30 plants at the cotyledon stage were randomly assigned to one of four treatments: (1) plants exposed briefly to 10 caged spider mites, (2) plants mechanically abraded with carborundum, (3) a cage control group consisting of a clip cage but no mites, and (4) a control with neither cage nor mites. After 10 days, all plants were treated with Kelthane (dicofol) to remove all mites, and the subsequent population buildup of spider mites was monitored throughout the season.

Spider mite densities were too low to assess until June of both years. When populations did increase, most were Pacific spider mite, *Tetranychus pacificus*. During the first weeks of mite infestation, control seedlings were more likely to have populations than plants that had previously been exposed to mites or abraded (fig. 3). This trend persisted as spider mite infestations increased in both years. Once populations of mites were growing rapidly (late July in 1984, early August in 1985), the differences found early in the season disappeared. These results show that resistance against spider mites can be induced under field conditions.

Another potential barrier to the use of induced resistance as a management tool is the level of damage necessary. A grower will not want to damage plants to reduce spider mite populations, if damage also reduces yield. Fortunately, in the laboratory experiments, plants damaged by mites at the cotyledon stage were every bit as tall and had as much leaf area as controls. Similarly, in the field experiments, inducing resistance had no measurable effect on growth or yield by harvest time.

This work identifies a new source of resistance to spider mites, namely induced resistance. We have known for some time that mechanical wounding and application of plant growth regulators or herbicides can induce changes in plants that affect performance of plant-feeding insects and mites. Such resistance may be induced by a variety of factors that stress or wound the plant. Cultural manipulations of the host plant that have little environmental effect may enable us to control economically important pests and at the same time reduce our use of chemical pesticides.

Another potential technique involves using induced resistance similarly to a vaccine. Often a plant will be able to support high densities of one species without reductions in yield but will be seriously damaged by much lower densities of a second species. In such cases, it may be possible to inoculate the plant with the species that does not cause economic damage and to induce resistance against the more damaging species.

Results of these tests with cotton and spider mites clearly indicate that attacked plants undergo changes that reduce their quality as food for subsequent insects and mites. It remains a challenge to entomologists to learn to manage induced plant resistance so that it becomes a useful pest control tool.

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