THE BIOLOGY OF THE CITRUS RUST MITE AND ITS EFFECTS ON FRUIT QUALITY

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Plant feeding mites play an important part in the production of marketable Florida citrus. In most citrus-growing areas, 12 species of mites are known to feed on the stems, leaves, and/or fruit of the tree. These species are classified within four families: the Tetranychidae, or spider mites; the Tenuipalpidae, or false spider mites; the Tarsonemidae, or broad mites; and the Eriophyidae, or rust, bud, and gall mites.

Within the Eriophyidae, three species are known to inhabit Florida citrus. They are the citrus bud mite, Aceria sheldoni, the pink citrus rust mite, Aculus pelekassi, and the citrus rust mite, Phyllocoptruta oleivora (Table 1). The citrus bud mite is found in isolated coastal areas of Florida where they feed on the bud and cause subsequent deformation of fruit and leaves. The pink citrus rust mite is rarely found in commercial citrus. It often causes leaf curl from extensive feeding on new flush in nurseries. The citrus rust mite infests stems, leaves, and fruit of all citrus varieties. From a worldwide standpoint, it is one of the more serious citrus pests because it can reproduce rapidly and lower the quality of fruit via injury from cellular feeding. Its biology and the effect of feeding injury on fruit quality will be the focus of my presentation today.

Table 1. General characters separating the Eriophyid species on Florida citrus

Character	Citrus rust mite	Pink citrus rust mite	Citrus bud mite
Size	1/200 inch long	1/200 inch long	< 1/200 inch long
Color	Lemon yellow to brown	Whitish, light yellow light pink to red	Light yellow
Shape	Wedge-like soft body	Wedge-like soft body	Cylindrical soft body
Habitat	Fruit, leaves, stems of all citrus	Leaves, fruit, stems, prefer nursery citrus, new flush	Buds
Injury	Fruit and leaf russet	Fruit and leaf russet, leaf deformation	Fruit and leaf deformation

Geographical Distribution.--The citrus rust mite occurs in nearly every citrus-growing area in the world. It is native to southeast China and is reported from Asia, the Mediterranean, Africa, South America, Central America, Australia, and the USA. It appears to be most serious in citrus-growing areas where humid climatic conditions occur. In Florida, it is found in all citrus-growing areas of the state.

Life History.--The citrus rust mite has four developmental stages within its life cycle (Fig. 1). They are the egg, two nymphal stages, and the adult. Egg deposition begins within a day or two after the female reaches maturity and continues throughout her life, about 14 to 20 days. The eggs are laid, both singly and in groups, on the surface of leaves, fruit, and small twigs. The preferred egg laying site appears to be depressions on the fruit surface. The egg is spherical with a smooth regular surface and ranges in color from transparent to pale translucent yellow. They are about one-fourth the size of the adult mite and are attached to the leaf by an adhesive substance. The female lays one to two eggs a day or as many as 20 to 30 eggs during her lifetime. Eggs hatch in about 3 days at 80.6°F (Table 2). The newly hatched semitransparent nymphs, which resembles the adult, starts feeding almost immediately. Only after some time does it commence wandering. Gradually, its color turns pale yellow. The first nymphal I stage, which is approximately 0.08 mm long, molts, i.e., sheds its cuticle after about 1.4 days at 80.6°F (Table 2). The second nymphal II stage is lemon yellow in color with a body length of about 0.10 to 0.12 mm. They also resemble the adult superficially and their feeding characteristics are like the nymphal I stage. The nymphal II requires 1.5 days at 80.6°F before it molts into an adult (Table 2). The adult citrus rust mite has an elongated, wedge-shaped body about three times as long (1/200 of an inch - 0.12 mm) as wide (Table 1). Their color varies from light yellow to straw color. They have two pair of short, anterior legs and a pair of lobes on the posterior end which assist in movement and clinging to plant surfaces. The adult males have an average life span of 6 days at 80.6°F. Females in the summer will live an average of 14 days and in the winter 29 days (Table 2). The preoviposition period for the adult female is 1.8 days at 80.6°F (i.e., the period required for egg development). The female will lay eggs for 14 days. The length of the life cycle from egg to adult at 80.6°F is 6 days (Table 2).

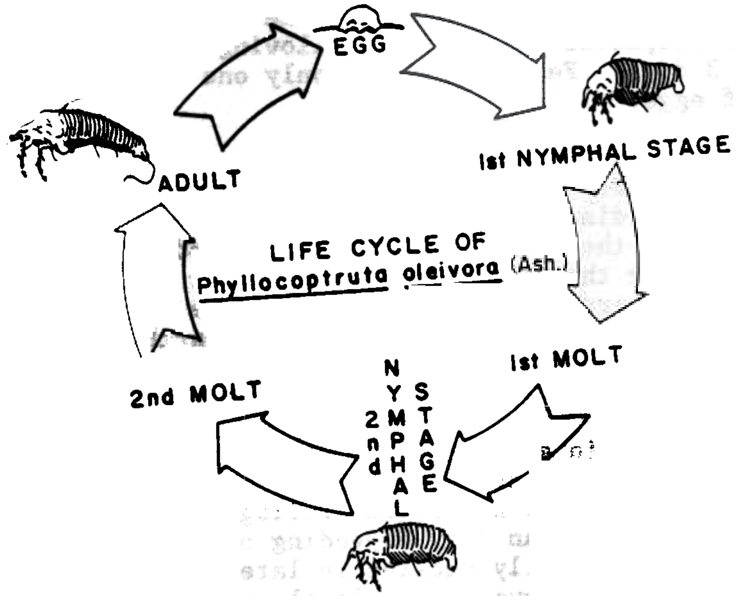

Fig. 1. The typical life cycle of the citrus rust mite.

The citrus rust mite has an interesting type of sex determination. They are parthenogenetic organisms (i.e. fertilized eggs produce females and unfertilized eggs produce males). In some areas of the world, males are absent. A female will carry no more than two eggs in its abdomen at one time. Rust mites do not mate; rather, the male produces a stalk-like spermatophore that is attached to the leaf or fruit substrate (Fig. 2). A sperm capsule attached to the spermatophore is randomly collected by the female as she moves across the surface of the plant. Males produce from 16 to 30 spermatophores per day and following deposition on the plant, they remain viable for 3 days. Females require only one spermatophore to fertilize her full complement of eggs.

Table 2. Length of life stages for citrus rust mite.

Developmental stage	Days[a]
Egg	3.2
Nymph I	1.4
Nymph II	1.4
Egg - Adult	6.0
Adult longevity	
Male	6
Female	
Summer	14
Winter	29
Preoviposition	1.8
Oviposition	14

[a] Development time determined at 80.6°F except for overwintering female adult.

Morphology of the Feeding Mechanism.--The needle-like mouthparts of the citrus rust mite, called chelicerae, are of a piercing, sucking type approximately 7 µm in length and 1 to 2 µm in diameter (Fig. 3). Their length restricts feeding to the epidermal cell layer of the plant. Both immature and adult mites obtain plant nutrients by penetrating the cell surface with their mouthparts and extracting cell contents. The mite appears to probe randomly at the fruit surface usually showing no preference for feeding sites. The time spent searching for a feeding site is generally short, averaging 11 seconds. Likewise, the time spent feeding or the insertion time is also relatively short, averaging 26 seconds.

Seasonal Ecology Within a Grove.--The citrus rust mite is present the year around on all citrus varieties and plant parts. Mite populations usually begin to increase in late-April to early-May on new foliage, reaching a peak in mid-June to mid-July. However, the peak can vary depending on weather and bloom. Citrus rust mite population densities usually decline in late August, but increase again in late October or early November; however, fall levels rarely approach those occurring earlier in the summer (Fig. 4). If the dry season of the spring extends into May, rust mites generally remain low but increase rapidly after the rainy season begins. In years when May and June are wet, peak populations may occur earlier. Citrus rust mite population dynamics and rate of increase have been correlated with high

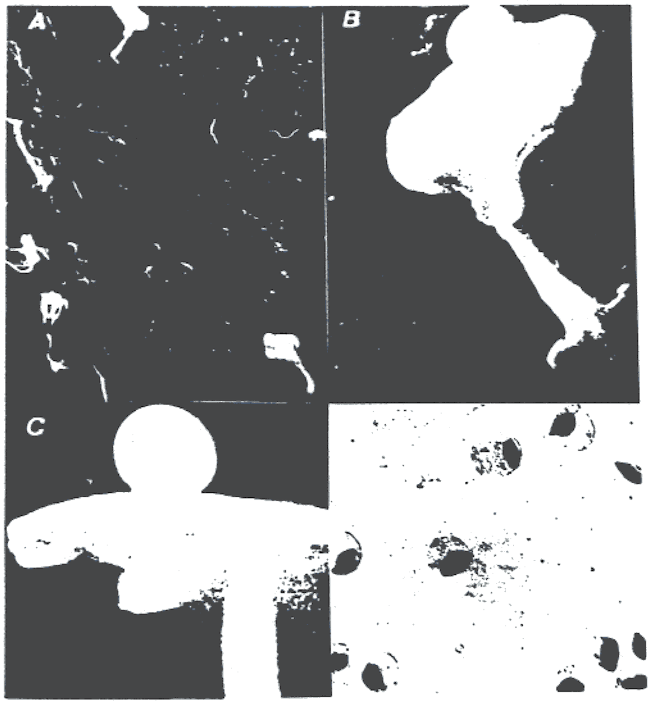

Fig. 2. Scanning electron micrographs. (A) Spermatophores of citrus rust mite on fruit surface. (B) Close-up of spermatophore showing base and stalk. (C) Front view of spermatophore showing sperm capsule. (D) Nonflagellate sperm of citrus rust mite.

humidity and temperature. The optimum temperature for citrus rust mite is about 78°F and the upper temperature limit around 88°F. In the case of a tiny organism, such as the citrus rust mite, the problem of microclimatic variation is important. While development rates may be predicted accurately from temperature, the actual temperature experienced by the mite can be very different from that measured in a weather shelter. Although temperature and humidity appear to be critical in predicting the population increase of citrus rust mite, a sharp decline in population density in the summer is usually caused by the action of the fungus disease Hirsutella thompsonii (Fig. 4). Different horticultural practices such as hedging, host plant physiology, and other factors that influence the microclimate can cause citrus rust mite to increase within a grove.

Seasonal Ecology Within the Tree.--The behavior of the citrus rust mite within the tree is strongly influenced by microclimatic conditions. The mite appears to migrate from the previous years flush to newly formed stems and the undersurface of leaves near the base of the spring flush in late March mainly by crawling. Development on spring flush during April is generally slow but more rapid than corresponding development on old flush. Most rapid population increase appears to take place on leaves that are first infested. Mites are always well-established on new flush before they are detected on fruit. Once they are established on new leaves, they continue to migrate to the fruit. Throughout their seasonal cycle, they reach population levels on the fruit that are generally higher than on the leaves (Fig. 5). The distribution of the citrus rust mite within the tree on leaves and fruit is influenced also by solar exposure. In all cases, citrus rust mite will avoid direct sunlight. In view of this, citrus rust mite generally is more abundant in the north bottom of the tree and lowest in the south top of the citrus canopy

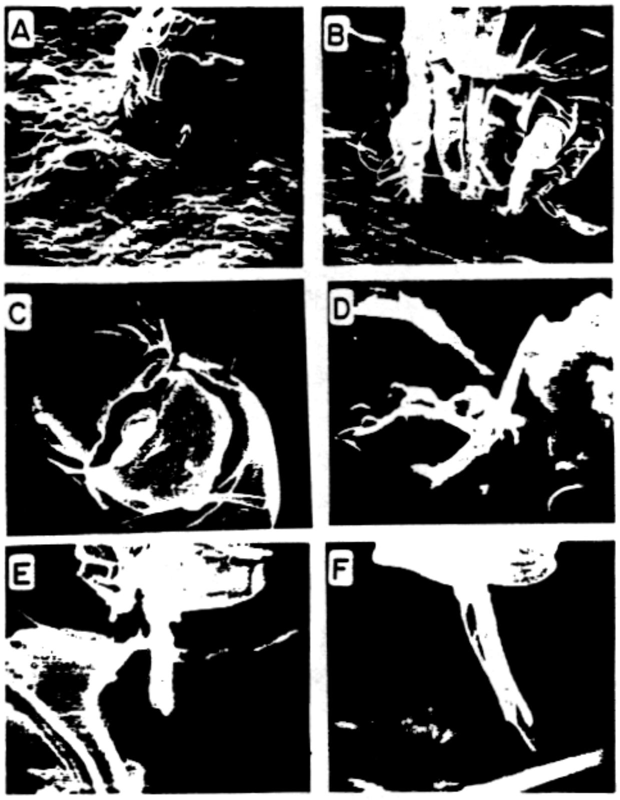

Fig. 3. Scanning electron micrographs of the mouthparts of *P. oleivora*. (A) anterior view of mite in feeding position showing the emergence of the chelicerae beneath the palpal tips (1000X). (B) Close-up showing the position of rostrum in relation to palpi during feeding (2500X). (C) Ventral view of rostrum showing emergence of cheliceral stylets between the paired palpi (11,000X). (D) Ventral view of rostrum showing extended chelicerae (9500X). (E) Close-up of retracted cheliceral stylets stylets and hypostome (10,000X).

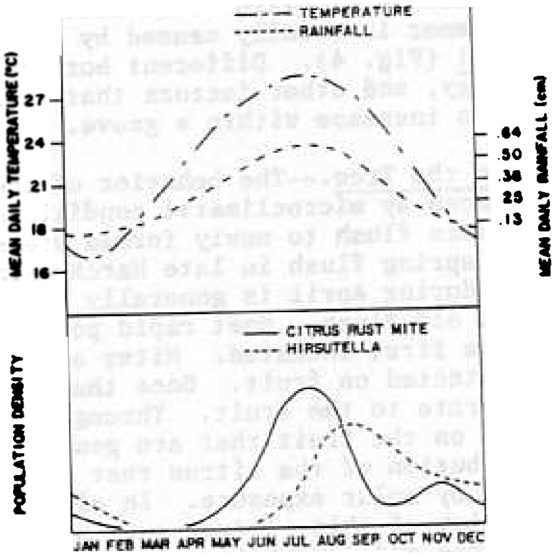

Fig. 4. Generalized scheme of the seasonal realtionship between citrus rust mite population density, incidence of *Hirsutella thompsonii*, and weather parameters (25 year mean) in Florida citrus groves.

(Fig. 6). Although citrus rust mites avoid bright sunlit areas of the tree, they are usually more abundant on fruit and foliage on the margins of the canopy and are relatively low in well-shaded groves or the shaded side of the fruit. The preference of semi-shaded areas by the citrus rust mite may be dictated by optimum temperature or moisture gradient of either dew or water vapor. Trees with thick canopy densities have been observed to have less fruit injury.

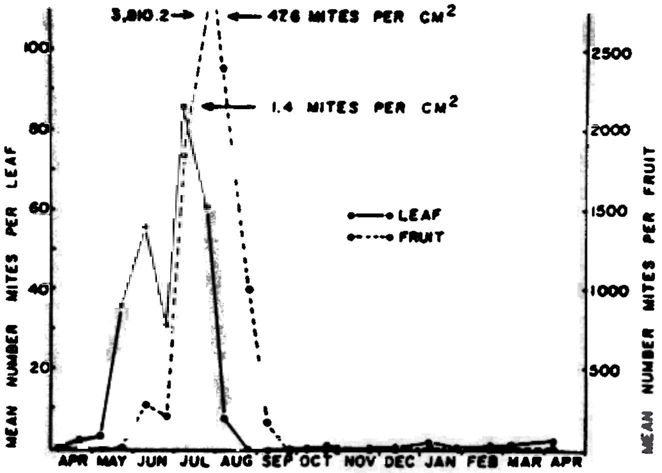

Fig. 5. Relationship between the seasonal citrus rust mite population density on leaves and fruit of 'Valencia' orange.

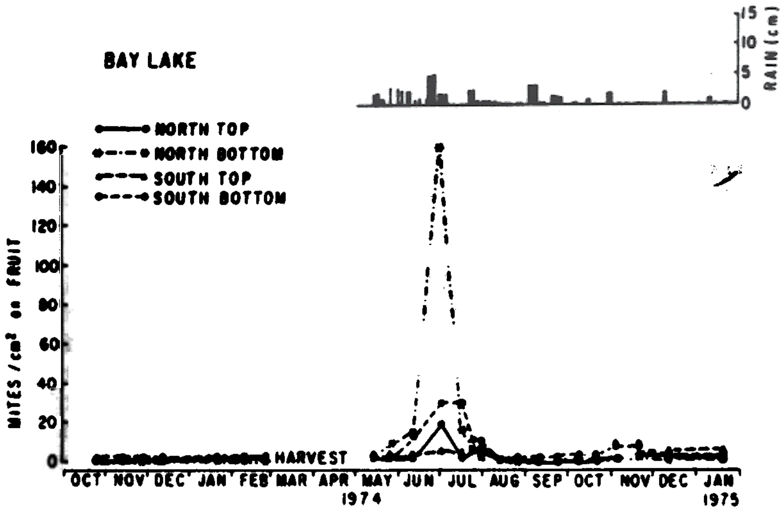

Fig. 6. Seasonal population dynamics of the citrus rust mite in different quadrants of mature 'Valencia' orange trees in central Florida.

Seasonal Ecology on Fruit.--The distribution of the citrus rust mite on fruit is influenced by solar exposure. Mites have a tendency of avoiding areas exposed to direct sunlight on the fruit as well as shaded areas such as the backside of the fruit (Fig. 7). They generally prefer to locate in depressions on the fruit surface, which suggests avoidance of wind. Mites develop on both green and mature fruit showing no strong preference.

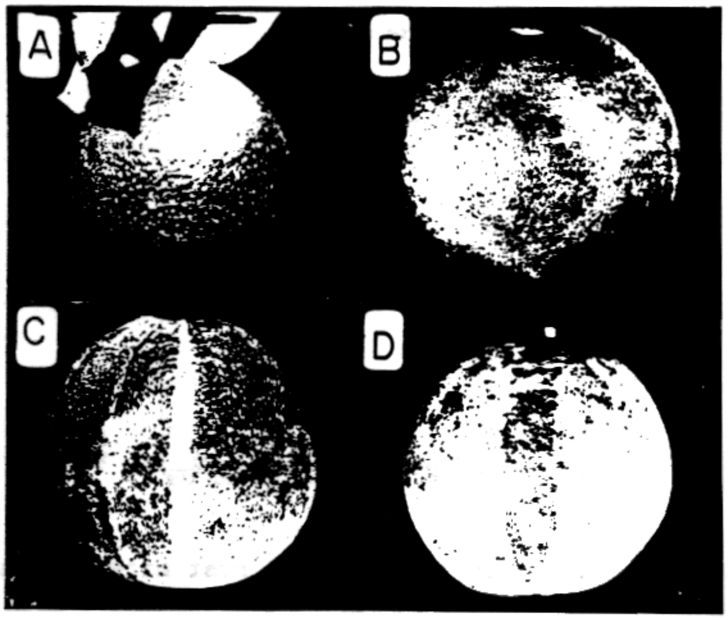

Fig. 7. Variations of citrus rust mite damage to oranges. (A) Rust mite damage around a sun spot area which was uninhabited by citrus rust mite. (B) Ethylene degreened zone (between arrows) from mite injury aruond a sun spot, slightly earlier damage beyond has browned. (C) Chimera on fruit with less citrus rust mite damage than surrounding tissue. (D) Chimera with more damage than surrounding tissue.

Citrus Varietal Preference.--The citrus rust mite infests lemon more severely than any other host and grapefruit much more severely than all orange varieties. Tangerine fruit appears to be the least preferred host (Fig. 8). Varietal preference can vary between leaves and fruit. For example, 'Sunburst' mandarin hybrid leaves are preferred to fruit by the citrus rust mite.

Injury Terminology.--Citrus rust mite infestations of the fruit are of particular economic importance to the grower in that injury from extensive feeding causes surface blemish which can reduce the marketable quality for fresh fruit sales. Visible characteristics of injury differ according to the variety and the maturity of the fruit. Injury to grapefruit, lemons, and limes during the time of early fruit growth cause a silvering of the peel and if severe may result in a condition known as "sharkskin" (Fig. 9). Injury to orange during the early growing phase results in cracking of the surface epidermis. At maturity, this injury to the orange is called russetting (Fig. 9). Citrus fruit injured during the time of early growth and development will not polish because of the dead epidermis. Late injury which occurs in the fall after the fruit has terminated growth appears as a smooth, brownish staining. On grapefruit, this injury appears to start around the stomata between the oil glands. Fruit with late injury takes a high polish; this type of injury is referred to as bronzing (Fig. 9).

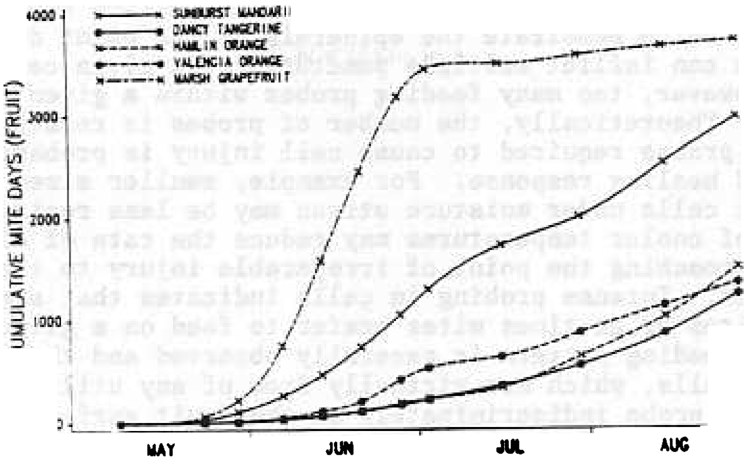

Fig. 8. Seasonal population dynamics (mite days) of citrus rust mite on immature fruit of different citrus cultivars.

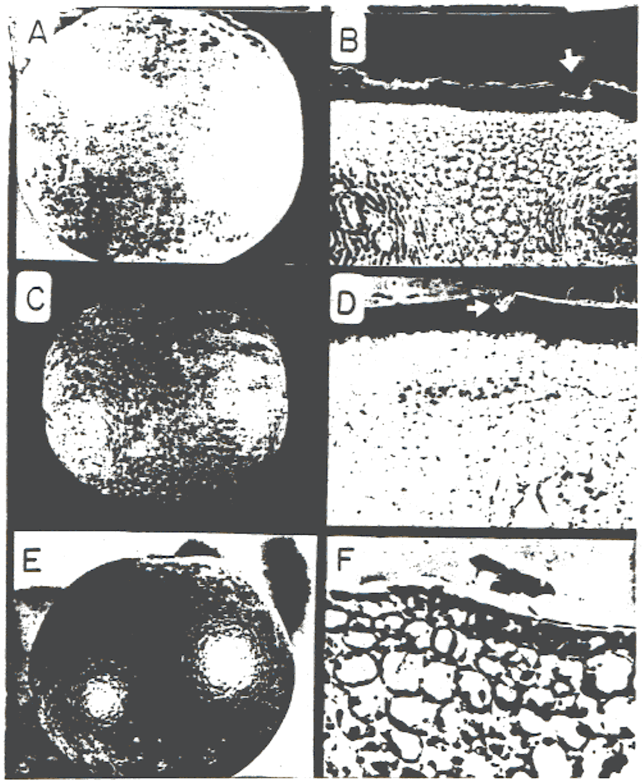

Fig. 9. Appearance of sharkshin (A and B), russet (C and D), and bronzing (E and F) rust mite damage on oranges. The damage conditions as they appear on whole fruit (A, C, and E) are respectively shown (see arrows) in cross sections of the peel in plates B (100X), D (100X), and F (400X).

Evolution of Injury.--As previously stated, the citrus rust mite has piercing-sucking mouthparts which penetrate the epidermis of the plant during the feeding process. The mite can inflict multiple punctures to a given cell without visible adverse affect; however, too many feeding probes within a given time will cause cell injury (Fig. 10). Theoretically, the number of probes is relative to mite density and the number of probes required to cause cell injury is probably relative to cell susceptibility and healing response. For example, smaller sized cells may require fewer punctures or cells under moisture stress may be less resistant to mite feeding. Also, the effect of cooler temperatures may reduce the rate of mite feeding and allow cells that are approaching the point of irreparable injury to temporarily or permanently recover. Intense probing in cells indicates that some cells may be more suitable to the mites or at times mites prefer to feed on a given cell (Fig. 10). However, a random feeding pattern is generally observed and the presence of punctures in the anticlinal walls, which are virtually free of any utilizable nutrients, suggests that mites probe indiscriminately on the fruit surface and are unable to detect various cell organelles. In some cases, the punctures appear in a linear pattern indicating the feeding route taken by a single mite.

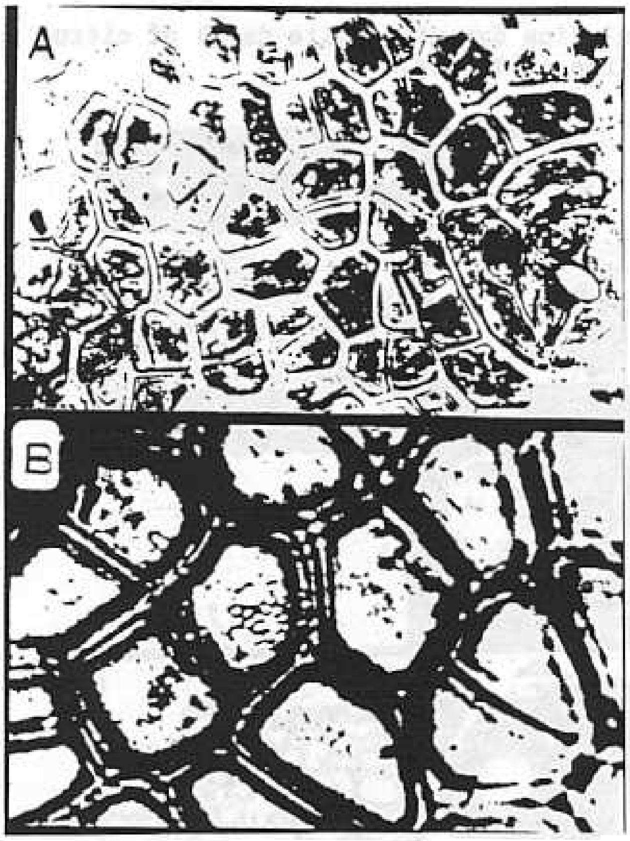

Fig. 10. Phase micrographs showing sections of fruit cuticle extracted from peel exhibiting injury (russet) and feeding punctures caused by P. oleivora. (A) Scattered feeding punctures to the cuticle (500X). (B) Close-ups showing arrangement of feeding punctures within underlying cells and anticlinal wall (1000X).

Active feeding by high populations of the citrus rust mite during the summer and the fall on the surface of different citrus varieties will cause a significant increase in ethylene emission at the time visible injury first appears on the fruit surface. Ethylene production by injured cells also stimulates premature degreening in the fall. Ethylene emission does not occur among fruit exhibiting virtually no visible injury whether low, moderate, or high mite populations exist. Maximum ethylene production is associated with fruit with high mite populations with incipient visible injury. Fruit with low mite populations and advanced visible injury emit the lowest quantity of ethylene indicating the wounding response to cellular tissues injured by mite feeding has stopped.

Fruit surface discoloration or russetting is associated with the oxidation of some substances of the cytoplasm within the injured epidermal cells. Lignin is produced also. In July and August, a wound periderm forms 16 to 21 days after russetting first appeared on the fruit surface. Concurrently, lipids accumulate in the wound periderm cell wall. Injury to fruit after growth termination does not lead to wound periderm formation in late-November. Lignin formation within the cell and subsequent epidermal cell mortality appears to be triggered by high puncture frequencies of the cell which is probably relative to the mite population density. Lignification of epidermal cells and subsequent cell mortality appears to be caused by an interaction involving three basic components, the mite, fruit, and their microclimate. Dead cells resulting from mite injury on the fruit surface appear as concentrated dark group of cells distributed among clear, healthy cells (Fig. 11A). This brownish discoloration of the fruit surface representative of the injured epidermal cells occurs over both the oil glands and adjacent parenchymous areas.

Fruit Injury Vs. Yield and Packout.--While the primary affect of damage caused by the citrus rust mite appears to be cosmetic, resulting in a reduction of grade, severe fruit injury will also cause reduced size and water loss. The latter can increase the probability of fruit drop particularly during periods of severe water stress. Numerous studies where citrus rust mite was eliminated through chemical treatment have shown that fruit russet and bronzing are generally higher under untreated conditions. In addition, research has shown that both the intensity and duration of the population on the fruit are significant in determining the amount of surface damage on the fruit (Fig. 12). Also, mature fruit (visible color break) are 5 to 10 times more sensitive to mite injury than immature fruit (green). It has been noted that fruit with extensive surface damage by citrus rust mite are usually smaller than undamaged fruit, in some cases, as much as 12.5% smaller. Research has shown that the actual growth rate of fruit is significantly affected over time by citrus rust mite damage that exceeds 75% of the surface area (Fig. 13). Studies on 'Satsuma' orange have shown that diameter, volume, and weight of fruit damaged by pink rust mite were less than those of undamaged fruit. Damaged fruit may actually shrink considerably more than undamaged fruit. This shrinkage is probably related to increased water loss. Since citrus rust mite damage facilitates increased water loss, the probability of fruit drop during severe water stress is likely. Both transpiration rate for on-tree citrus fruit and bonding force can be influenced by the injury of the citrus rust mite (Fig. 14). Transpiration rate is higher for damaged fruit and severely damaged fruit (> 75% surface area) show a reduced bonding force for 'Valencia,' 'Pineapple,' oranges, and 'Duncan' grapefruit. Since the cumulative fruit drop for different damage amounts tends to diverge with time, the largest final effect will be experienced for late season fruit varieties.

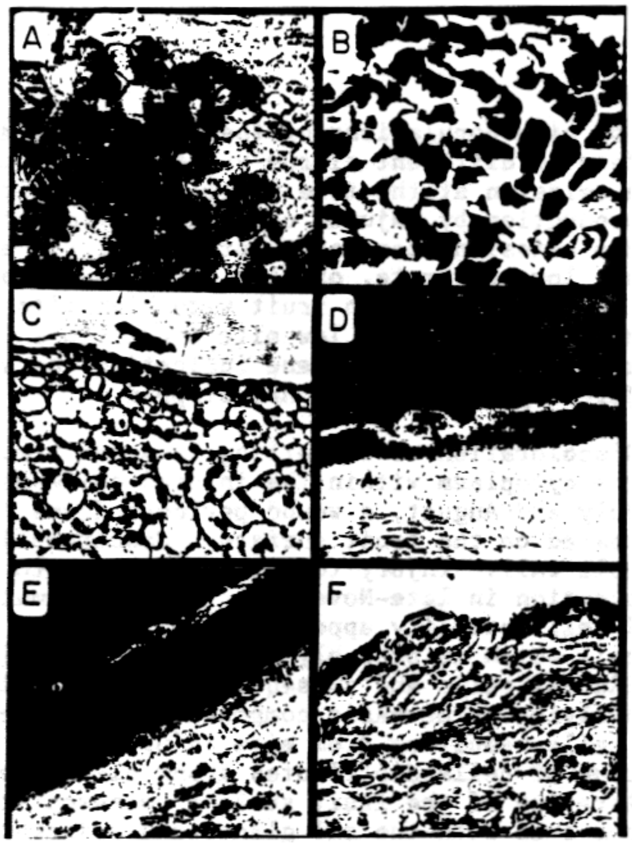

Fig. 11. Micrographs of fruit cuticles and peel sections showing various aspects of injury caused by P. oleivora. (A) Close-up of injured cuticle showing outline of lignified epidermal cells (dark areas) (400X). (B) SEM of lignified epidermal cells still attached to underside of cuticle after treatment with HCl + $ZnCl_2$ (1050X). (C) Lignified cells of epidermal layer (phloroglucinol) (400X). (D) Fresh section showing wound periderm forming beneath the cracking remains of dead epidermal layer (Sudan III lipid stain) (200X). (E) Close-up of the wound periderm after staining for lipid (400X). (F) Fixed cross-sections showing early wound periderm formation (safranin-fast green stain) (400X).

Effect of Citrus Rust Mite Injury on Internal Fruit Quality.--Both early and late season injury caused by the citrus rust mite can have an affect on internal fruit quality (Fig. 15). In the case of 'Valencia,' 'Pineapple,' oranges, and 'Duncan' grapefruit, juice volume decreases with an increase in overall surface injury. In addition, percent soluble solids appears to increase with an increase in damage. This appears to be more pronounced on late season injury as compared to early season injury. Percent acids in the fruit also have a tendency of increasing with an increase in damage for both early and late season damaged fruit with negligible change in the solids/acid ratio. Where 'Valencia' oranges are severely damaged after maturity and the trees are exposed to extreme water stress the following spring, low juice yield and off-flavors are detected. Both acetaldehyde and ethanol concentrations are highest in fruit with extensive surface bronzing and peel shrinkage (Fig. 16).

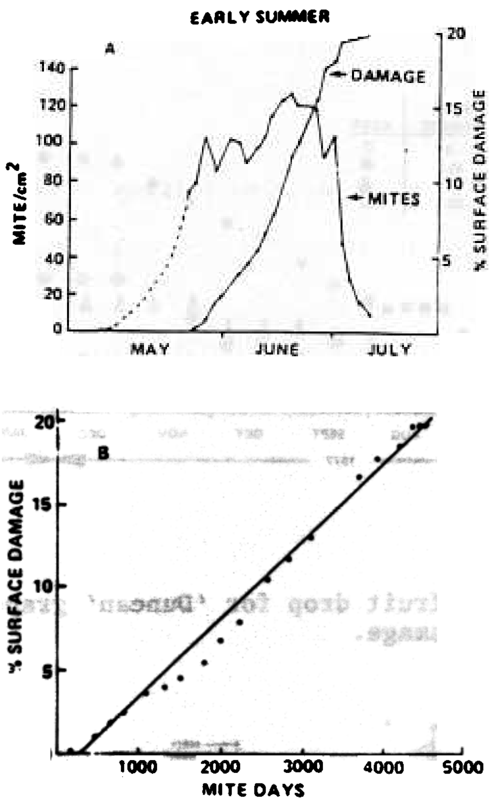

Fig. 12. Relationship between citrus rust mite population density and percent surface area damage on 'Valencia' orange in early summer (A) and straight line relation between mite days (time mite is active on fruit) and damage (B).

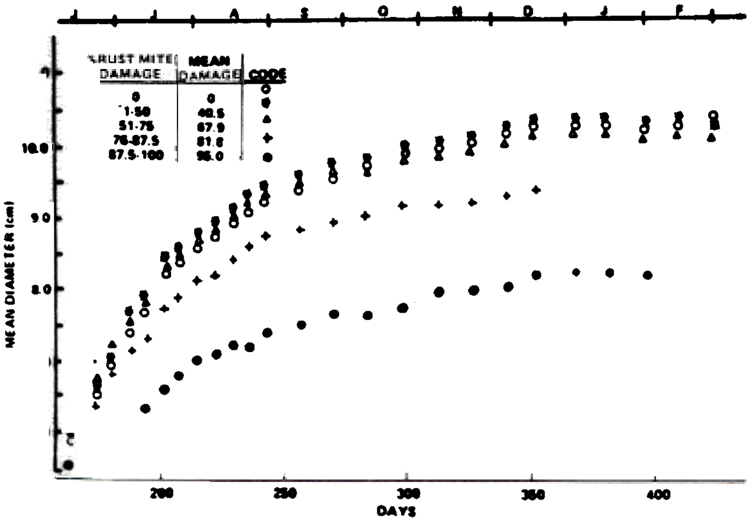

Fig. 13. Mean diameter growth of 'Duncan' grapefruit with different amounts of surface damage caused by citrus rust mites.

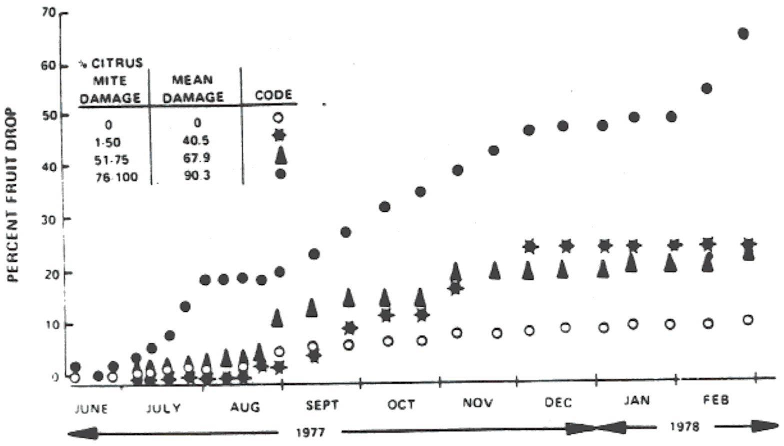

Fig. 14. Cumulative percent fruit drop for 'Duncan' grapefruit with different amounts of citrus rust mite damage.

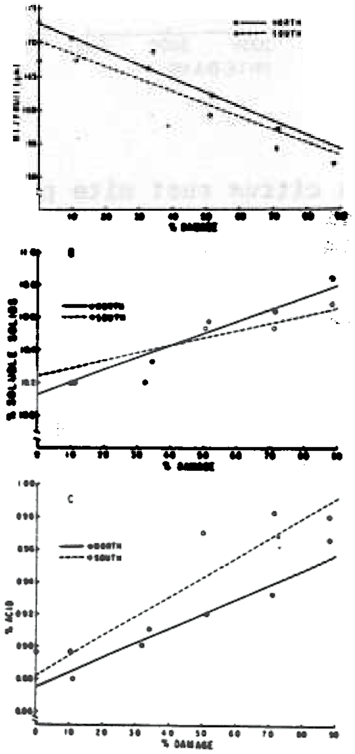

Fig. 15. Weight per fruit (A), percent soluble solids (B), and percent acid (C) plotted against percent early and late season damage by citrus rust mite ('Valencia' oranges).

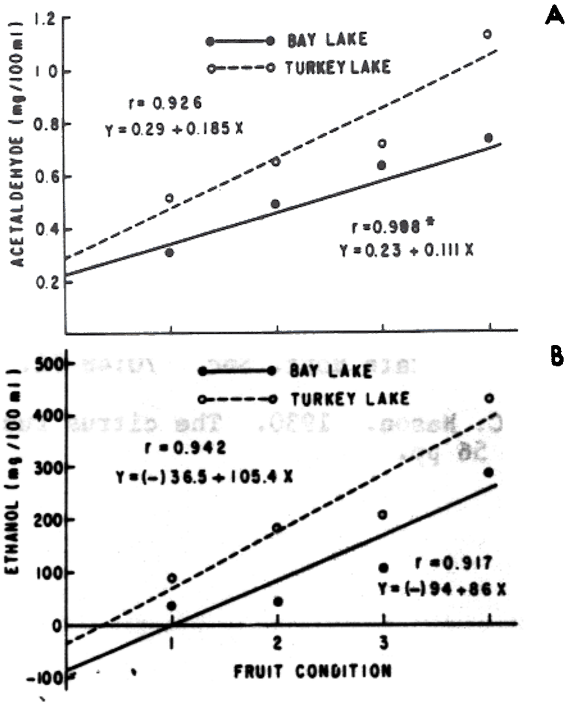

Fig. 16. Linear relationship between mean concentration of acetaldehyde, ethanol, and fruit condition: (1) firm without bronzing; (2) soft without bronzing (Turkey Lake), firm extensive bronzing, but no peel shrinkage (Bay Lake); (3) soft (Turkey Lake) or firm (Bay Lake) with localized bronzing and peel shrinkage; (4) soft (Turkey Lake) or firm (Bay Lake) with extensive bronzing and peel shrinkage.

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