# Aphid-Transmitted Viruses of Cucurbits in Florida

**Tom Kucharek and Dan Purcifull, Respectively Professor and, Professor, Plant Pathology Department, University of Florida, Gainesville, 32611. April 1997 (Revised 2001)**

Cucurbit crops (Cucurbitaceae, cucumber & gourd family) are of major importance to the state of Florida and its agricultural communities. For the 1994-1995 marketing year, watermelons, squash, and cucumbers were valued at $146,079,000 in Florida. This was 9.9 percent of the total value of vegetables at the farm-gate and does not include other cucurbits such as cantaloupes and pumpkins. Florida produces more watermelons than any other state. In addition to several fungal diseases, viral diseases have strongly interfered with the establishment of a pumpkin industry in Florida.

For at least the past three decades, the most important impediment to consistent production of squash, watermelons, and some other cucurbits in Florida, has been the annual occurrence of aphid-transmitted viruses. Both yield and fruit quality have been reduced significantly by these viruses. Growers constantly ask about the availability of useable control measures. Interestingly, cucumber has not incurred many viral problems for the past three decades or so, except where some exotic varieties were used in the greenhouse or in the field.

On a world-wide basis, more than 50 viruses and four viroids have been reported to infect at least one member of the cucurbit family. At least half of the viruses are economically important pathogens of commercial cucurbits. Currently, five aphid-transmitted viruses of cucurbits have been found in Florida. These viruses are composed of a ribonucleic acid core encapsulated by a protein "coat". Table 1 summarizes the current nomenclature of these viruses.

**Table 1. Aphid-transmitted viruses found naturally in Florida-produced cucurbits.**

| Virus | Acronyms |
|---|---|
| Paypaya ringspot virus type W | PRSV-W(WMV 1) |
| Watermelon mosaic virus 2 | WMV 2(WMV) |
| Zucchini yellow mosaic virus | ZYMV |
| Cucumber mosaic virus | CMV |
| Unnamed potyvirus | none |

Papaya ringspot virus type W (PRSV-W), previously known as watermelon mosaic virus one (WMV 1), and watermelon mosaic virus two (WMV 2) have been the most commonly occurring aphid-transmitted viruses in Florida for the past several decades. Zucchini yellow mosaic virus has occurred in Florida sporadically since the fall of 1981. Cucumber mosaic virus has been less prevalent during the past 30 years when compared to earlier periods, but it has recently increased somewhat in peppers and tobacco in north central Florida. Little is known at this time about the unnamed potyvirus, except that it is distinct from the others.

## Transmission

The predominant method of natural transmission of the viruses listed in this publication in the field is by aphids (sometimes called plant lice, Figure 1) in a non-persistent manner. This means the viral particles (virions) are acquired by the aphid on its stylet (tubular mouthpart which is inserted into plant tissue for feeding purposes) and are retained in association with the stylet for "short" periods of time. Although an aphid is likely to lose its ability to transmit the virus within a few minutes or a few hours, longer periods of retention can occur. For example, two species of aphids, *Aphis gossypii* and *Myzus persicae*, were able to transmit ZYMV at levels of 12.5% and 5.6%, respectively, for 3 hours at 68° F (21° C) but not at all after 5 hours. In contrast, at 46° F (8° C). *A. gossypii* could transmit ZYMV at a 1% level for up to 20 hours and *M. persicae* could transmit at a 1% level for up to 30 hours. The actual retention time for survival of virions on stylets is likely to vary.

In watermelon, no difference in susceptibility to infection to WMV 2 existed in plants from 1 1/2 to 7 1/2 weeks old in an experimental situation. However, symptoms develop at different rates depending upon the age of the plant at the time of infection. Older plants have an uneven distribution of virus and lower levels of virus when compared to the younger plants. However, it is common for plants much older than 7 1/2 weeks in commercial fields to become infected with WMV 2 or other viruses. Low relative humidity (e.g. 40%) has reduced transmission of ZYMV by the aphid species *A. gossypii* but not by the aphid species *M. persicae*. The retention time of non-persistent viruses is typically further shortened as feeding periods lengthen. Thus, feeding on non-host tissue after acquisition of the virus, and before the susceptible crop is reached and probed by the aphid, is likely to deplete viral inoculum. Retention time is affected by so many variables that it is not advisable to provide generalizations for a specific situation.

Aphids are efficient vectors of viruses. First, they are sometimes able to acquire viruses in less than eight seconds of probing and transmit them in less than four seconds. Probes of 15 to 60 seconds can enhance transmission, but longer probes tend to result in lower levels of transmission. However, aphids may feed for hours at one site if the host is suitable. Second, aphids reproduce rapidly, resulting in millions of aphids in a short period of time. Thirdly, alate (winged forms, Figure 1) aphids are capable of movement from one location to another either by flying or by passive movement with the wind. Winged forms tend to develop in response to crowding from other aphids or when plants deteriorate. Fourth, aphids can feed on a number of plants within a short period of time. They have "personal" feeding preferences and will move from plant to plant of the same or different plant species until they find a satisfactory feeding site. Fifth, numerous species are capable of vectoring viral diseases. For example, at least 60, 42, 25, and 12 species of aphids are known to be capable of vectoring CMV, WMV 2, PRSV-W, and ZYMV, respectively, on a world-wide basis.

In Florida the number of aphid species known to vector WMV 2, PRSV-W, and ZYMV, are 16, 9, and 13, respectively. Most of the species do not reproduce on watermelon, but they may land and probe while searching for their preferred host. It is noteworthy that of these species only a few species may account for a majority of the transmissions in any given situation.

Aphid transmission of viruses is affected by an enormous number of variables, and the interactions between variables. For example, the efficiency of aphid transmission may or may not be altered when the aphid is carrying more than one virus. In one situation, maximum aphid transmission of CMV into cantaloupe was delayed by one week when aphids acquired a combination of CMV and WMV 2

when compared to CMV alone. Another example is the extensive variation that exists in transmission efficiency between aphid species and clones of aphids within species as they interact with other variables. For example, the amount of transmission of WMV 2 from 10 different cucurbit species to cucumber with the aphid species *Aphis gossypii* varied between 8 and 80% in one test.

The percentage of naturally occurring, migratory, alate (winged) aphids that carry transmissible virions. has been measured to be as low as 1.5% for ZYMV and WMV 2 in one year. In another year, none of 15,122 aphids was found to be carrying transmissible virions. In a situation with Florida-produced watermelons, no aphids with WMV 2 could be detected at the earliest time of epidemic development. However, when 4% of the plants in a commercial field had symptoms, 99% of the aphids in the species *Aphis middletonii* were found to carry WMV 2.

Aphid populations and viral diseases commonly progress over time in a sigmoidal fashion, as do many other diseases. Typically, flights of large populations of aphids occur during dry periods accompanied by moderate temperature. Such a situation occurs on a regular basis in south Florida during the fall (October-November) and in south, central and north central Florida during the spring (March-May). Within one to two weeks after these aphid flights, viral symptoms are likely to appear. Nearby fields will vary considerably with respect to intensities and times of influx of peak aphid flights.

Gradients of viral diseases are commonly encountered in fields, particularly during the early aspects of an epidemic. For example, higher levels of disease often occur near edges of fields or near known sources of inoculum. These gradients become less evident over time as the plants throughout the field become infected from secondary spread.

Primary inoculum of virus comes from weed hosts, abandoned cucurbit fields, nearby cucurbit fields, or volunteer cucurbits. Viruses are introduced into a crop field by flights of aphids where often an extremely low number of aphids contain transmissible virions. It is generally believed that because of the "short" retention times of virions on stylets, sources of virus are likely to be near the field. However, the retention times of 20-30 hours in some situations suggests that more distant sources of virus might also be involved.

The apparent rapid increase in the incidence of diseased crop plants that we commonly see is the function of secondary spread of virus. The percentage of aphids that have acquired virus from infected crop plants increases as the incidence of disease increases. To exemplify how fast epidemics develop, several epidemics in watermelon required only 20 days to progress from zero to 100% incidence.

Leafminers have been shown to transmit WMV-2 and PRSV-W in squash. While this type of transmission can occur, it has not been considered a major method of infection in Florida in cucurbits.

Mechanical movement of plant sap from one plant to another is another method by which these viruses are spread. This can happen anytime people or equipment move within the field and make contact with infected plants. Such has happened with CMV where the act of harvesting cucumbers increased the incidence (number of infected plants) of disease three-fold. Also, for experimental work, rubbing plant sap from an infected plant to a healthy plant is a common way of transmitting WMV-2, ZYMV, PRSV-W, and CMV (Figure 8). While we normally think that aphid-transmission is highly important for the spread of these viruses, we may be underestimating spread of viral diseases by mechanical means—at least where multiple harvests occur or where movement of plant sap occurs in other ways.

Seed transmission has not been demonstrated for PRSV-W or WMV 2. Seed transmission of CMV has been demonstrated in some weed species, which could conceivably serve as a mechanism to perpetuate the virus in weed hosts. Also, strains of CMV were found to be seedborne in cowpea and bean. Seed transmission has occurred with ZYMV at 0.048% in one study but in other studies seed transmission did not occur. Even though seed transmission of ZYMV is infrequent and at low levels, it does provide a mechanism for ZYMV or any of its related strains or any other virus to be distributed to new locations on a world-wide basis.

A virus that is seed-transmitted in cantaloupe and squash and that has occurred rarely in Florida is squash mosaic virus (SMV). SMV is also transmitted by cucumber beetles, but not by aphids. We mention SMV here because sometimes individuals talk about mosaic symptoms in squash as "squash mosaic". The mosaic viruses commonly seen in squash in Florida are WMV 2, PRSV-W, ZYMV, and CMV, not SMV.

## Symptom Expression

Upon mechanical or aphid transmission of viruses to susceptible plants, infection becomes systemic throughout the plant. Expression of symptoms can be modified when mixed infections of two or more viruses occur within the same plant. Mixed infections with PRSV-W, WMV 2, or ZYMV occur fairly often. Variations in temperatures, light regimes, crop varieties, viral strains, host vigor, titer (concentration) of virions in host tissue, and many other factors interact with each other in complex and often unknown ways to cause variation in symptom expression in plants. For example, with PRSV-W, WMV 2, and CMV, symptoms occurred 3 to 7 days after inoculation at 105° F (40.6° C), compared to 8 to 11 days at 65° F (18.3° C). However, progressive diminution of symptoms occurred with five weeks of exposure to temperatures between 86° F (30° C) and 105° F. At the highest temperatures, symptoms were absent or barely visible. At 65° F, symptoms maintained their original integrity.

The first symptoms can appear as early as three to four days after inoculation or as late as 18 or more days. Typically, plants inoculated with infectious sap manually or via aphid transmission will display symptoms seven to 12 days later. The absence of symptoms is no guarantee that the plant is not infected. An asymptomatic (without symptoms) plant may be infected but the incubation period for the virus may not have been completed or in some environmental conditions, the symptoms are not displayed (sometimes referred to as "masked"). Symptoms may be present in one portion of a plant but not in another portion of the same plant. Symptomatic plants are more likely to serve as sources of inoculum.

One should never rely on symptoms alone to identify specific viruses. Also, chemical damage from certain pesticides (usually herbicides) or nutrient imbalances can cause symptoms similar to those caused by viruses. Table 2 lists symptoms that are caused by PRSV-W, WMV 2, ZYMV, or CMV.

Variations of mosaic and mottle symptoms in leaves are common and are exemplified in Figures 2, 3, 4, 5, 7, 8, 9, 10, & 14. Shading the leaves on sunny days usually aids in contrasting the lighter and darker portions of mosaic patterns in leaves (Figures 4 & 8). Vein banding is also common and is shown in Figures 3 & 5. Leaf bronzing (Figures 4 & 5) has been common in recent years in watermelon. Necroses of margins or interior portions of leaves also occur (Figure 6). Crinkling (rugosity) of leaves is fairly common (Figure 6). Linear or stippled greening of fruit is very common (Figures 2, 7, 10, 11, 12, 14, 15, & 16). Bumpiness of fruit is fairly common (Figures 12 & 13). Ringspotting can occur on leaves or fruit (Figures 9, 10, 11, & 15). Chlorotic spotting is sometimes induced in the foliage (Figure 8).

## Papaya ringspot virus type W
## (PRSV-W, WMV 1)

It is not known when PRSV-W first occurred in Florida but it is likely to have been in Florida during the early 1930's. Currently, PRSV-W predominates in the southern half of the peninsula throughout the year. PRSV-W occurs in the northern half of the state but its appearance there is usually during the late spring, summer, or fall months. It may occur early in the spring in central or northern Florida if infected transplants from south Florida are used. PRSV-W has been found as far north as New York, but overall, PRSV-W is not found as commonly in other areas of the United States as is WMV 2. PRSV-W tends to occur in tropical climates.

PRSV-W infects 40 plant species with 38 of them being in the cucurbit family and two of them in the goosefoot family (Chenopodiaceae). Type W strains of PRSV do not infect papaya whereas type P strains (PRSV-P) do infect papaya. PRSV-W and PRSV-P are very closely related serologically.

PRSV-W is commonly found in a perennial, cucurbitaceous weed, balsam apple (*Momordica charantia*, Figure 17) in south Florida. Balsam apple is a vine that is an excellent carry-over host for PRSV-W and is commonly infected with this virus. This weed is cold-sensitive and does not grow in north Florida. Thus, it is not a direct source plant for PRSV-W in north Florida. It is particularly common in Palm Beach County. It is found growing along irrigation canals, hedge rows, wind breaks, old cultivated fields, disturbed land, groves, or fences.

**Table 2. Some symptoms that are caused by PSRV-W, WMV 2, ZYMV OR CMV.**

| Leaf | Fruit | Other |
|---|---|---|
| Mosaic | Mosaic | Fewer flowers |
| Mottling | Green mottling | Plant stunting |
| Interveinal chlorosis | Bumps | Flower Clustering |
| Leaf strapping | Shape distortion | Greenish flowers |
| Rugosity (crinkled) | Smaller size | Shortened Internodes |
| Marginal necrosis | Lower sugar | Deformed seed |
| Interveinal necrosis | Ringspots | Slower plant Growth |
| Bronzing | Green spots | Plant deterioration |
| Reduced size | Off color | Shorter vines |
| Curling | Fewer seeds | Distorted Stigmas |
| Vein banding* | External cracks | Distorted Stamens |
| Deep serrations | Abnormal Netting # | Flower necrosis |
| Malformation | Lower weight | Variable flower Color |
| Ringspots | Fewer fruit | |
| Chlorotic spotting | Greenspotting | |
| Dark green spotting | Inclusion Bodies** | |
| Inclusion Bodies** | | |

*Yellow or green; # for cantaloupe; ** Microscopic within cells

Another weed host for PRSV-W is creeping cucumber (*Melothria pendula*, Figure 18). This weed grows as an annual or perennial in fencerows, ditchbanks, abandoned fields, woods, and other non-crop sites. It occurs in north, central and south Florida. Creeping cucumber is commonly infected with PRSV-W in south Florida and sometimes in central Florida. It is a major weed host for PRSV-W and WMV 2 in southwestern Florida. Infected creeping cucumber along edges of watermelon fields has been strongly associated with outbreaks of PRSV-W in southwest Florida even before peak periods of aphid flights. Although freezing weather can kill the vines in south Florida, regeneration of new vines allows the plant to be a continual source of virus because of the systemic infection. Because this weed is cold sensitive and it typically does not grow in the northern portions until after the spring crop is harvested, it is not likely to be a source of PRSV-W or any other virus for the spring crop unless an extremely mild winter occurs. It has not yet been identified as a source plant for virus infections in the fall crop for north Florida.

## Watermelon Mosaic Virus 2 (WMV 2)

WMV 2 was first distinguished from WMV I (PRSV-W) in 1965. It is serologically distinct from PRSV-W. As with most viruses, multiple strains of WMV 2 exist. WMV 2 has been the most common aphid-transmitted virus of cucurbit crops in north Florida, in the United States, and in other places in the world. For a couple of years in the early 1960s, WMV 2 was found commonly even in south Florida.

WMV 2 has a much broader host range than does PRSV-W. Over 160 dicotyledonous species in 23 families are susceptible. Many legumes are susceptible. In central Florida, WMV 2 has been found in ornamental hibiscus plants, which are perennials and could serve as carryover hosts. Annual plants found to be infected with WMV 2 in central Florida include citron, showy crotalaria, hairy indigo, and one-leaf clover. Balsam apple and creeping cucumber (see PRSV-W section about these two weeds), both natural carry-over hosts for PRSV-W, have not been found naturally infected with WMV 2 in the field, even though both are susceptible. One of the probable reasons that WMV 2 has not been found in creeping cucumber or balsam apple is that WMV 2 is not found commonly in south Florida where creeping cucumber and balsam apple abound. Also, the growth of creeping cucumber in north and central Florida follows the spring cucurbit crops.

## Zucchini Yellow Mosaic Virus (ZYMV)

Zucchini yellow mosaic virus was first found in northern Italy in 1973 and in Florida in the fall of 1981. ZYMV has occurred throughout the main cucurbit-growing areas of Florida and the United States, including Hawaii. ZYMV has occurred in Africa, the Middle East, Asia, Australia, and South America. It can be a problem in both tropical and temperate areas. During the early 1980's, ZYMV appeared in numerous places in the world in a short period of time (see an above section about seed transmission of ZYMV). Recently, ZYMV remains as an important virus, but it has not dominated the spectrum of cucurbit viruses in Florida as do WMV 2 and PRSV-W.

One of the initial concerns about ZYMV was the intensity of the resulting symptoms. ZYMV seems to be associated with severe symptoms, i.e. excessive leaf deformation, intense spotting, pronounced bumpiness of fruit, etc.

Although ZYMV has a large host range as determined by experimental inoculations, it seems to be a commercial problem only in cucurbits. It has occurred naturally in creeping cucumber in central Florida. ZYMV has not been found naturally in balsam apple nor has this host been susceptible when inoculated with isolates from Florida. However, balsam apple has been infected by isolates in France.

## Cucumber Mosaic Virus

Cucumber mosaic virus (CMV) has an extremely wide host range and is found worldwide. About 800 monocotyledonous and dicotyledonous plant species in 40 families are susceptible. Perennial ornamentals such as gladiolus, periwinkle, easter lily, and amaryllis are examples from the host range.

Like ZYMV, CMV is capable of causing extremely severe symptoms. CMV was identified in numerous vegetables, ornamentals, and weeds in south and central Florida from the 1930s to the 1950s, but it was particularly a problem in celery (then called southern celery mosaic virus on celery and CMV on other crops) at that time. By the late 1950s and early 1960s, progressively fewer reports about CMV were available. From the mid-1960s till the late 1980s, CMV was present but of no economic consequence to cucurbits, vegetables, or agronomic crops in Florida.

CMV had a negative economic impact on the gladiolus industry which was solved in part with the continual renewal of plant materials with tissue culture-generated plants that were free of CMV. CMV is considered to be the cause of the demise of the Easter lily business in Florida

During the 1990s, the incidence of CMV has increased considerably in squash, peppers, and tobacco in the Alachua County area. Interestingly, dayflower (*Commelina communis*, Figures 19 & 20) has been found commonly in Alachua County during this time in lawns, gardens, open woods, fields, and hedgerows, often in wet or shaded sites. It can grow as an annual or perennial. A different species of dayflower (*Commelina nudiflora*) was found to be associated strongly with epidemics of CMV in celery in the 1930s. In recent years, *C. benghalensis* has been infected with CMV in Hamilton County and associated with severe epidemics of CMV

in tobacco. Over the past 30 or so years, CMV has not been a problem in cucurbits in Florida, including cucumber. Some consider CMV to spread more slowly than the other viruses, but if infected *Commelina* spp. are in the vicinity, CMV can be devastating in a short period of time. Strains of CMV vary in their ability to infect watermelon, but for at least the past three decades, CMV has not been a problem in watermelon in Florida.

## Control

**Resistant varieties** are the best controls for viral diseases. Resistance to CMV became available in 1928. Since that time, breeding programs have successfully incorporated resistance to CMV, other viruses, and fungal diseases in pickling and slicing types of cucumbers. This is the primary reason why viral problems in cucumber are not common in Florida.

Recently, useable and stable resistance to viral diseases in varieties of yellow and zucchini summer squashes has become available. The sources of resistance have been of two types, host resistance and pathogen-derived transgenic resistance. Genes from breeding lines of squash with host resistance to WMV 2, ZYMV, and CMV have been incorporated into horticulturally acceptable varieties (e.g. 'Dividend' & 'Revenue', zucchini types). Near 100% control of WMV 2 was measured in a test in Florida. Additional varieties will be available in the future.

With another form of host resistance, a masking of greening in fruit occurs in infected plants. Thus viral symptoms occur in the leaves but are delayed in the fruit. This form of resistance has been noted as having the "precocious-yellow-character" (e.g. varieties 'Multipik', 'Supersett', 'and Meigs') and has been effective for WMV 2. In the future, more varieties of this type may be available.

Another source of resistance has been de-

rived from the viruses themselves. It has been known for some time that introduction of coat protein of some viruses into plants can confer an "immunogenic"-like response in plants. By incorporating segments of nucleic acid from the virus that encode for the protein coat into "messenger" bacteria which in turn deliver a new form of the gene into plant cells, plants are produced, via -tissue culture, that carry these new genes that confer resistance. This new type of resistance is referred to as pathogen-derived, "transgenic resistance" (e.g. as developed in the yellow summer squash varieties 'Prelude II', 'Liberator III', and 'Destiny III'). In a test in Florida 100% control of WMV 2 was obtained with all of these varieties. Additional varieties are likely to be available in the future.

Although these forms of resistance have been successful in Florida, one should remember that the incorporation of resistance is subject to "overthrow" by new strains of the virus for which resistance was not incorporated originally. Also, resistance to one virus does not typically confer resistance to other viruses. Interestingly, some coat protein-mediated resistance to one virus has conferred some resistance to other viruses. A lot of uncertainty still exists about transgenic resistance.

With the current resistance to WMV 2, ZYMV, and CMV in summer squash, geographical areas that commonly have these viruses will have some control. Such is the case in north Florida in the spring. However, in the fall in north Florida, when PRSV-W is likely to be present, the resistance to the three other viruses will not control PRSV-W. Likewise, in south Florida where PRSV-W abounds all year, the varieties with resistance to WMV 2, ZYMV, and CMV will not suppress PRSV-W. Resistance to PRSV-W in squash is being pursued.

Some resistance to WMV 2 and ZYMV has been found in breeding lines of watermelon. At the present time, these lines lack horticultural acceptance, but work is being done to de-velop varieties of watermelon with resistance to WMV 2.

**Plow down abandoned fields** as soon as harvesting is complete. This will eliminate potential sources of inocula for viruses and other pathogens.

**Destroy weed hosts (primarily creeping cucumber and balsam apple)** in the near vicinity of the field. Weed hosts can be major sources of inocula for aphid transmission.

**Destroy volunteer cucurbits** in the vicinity of your production fields or on the farm as they can serve as reservoirs for viral inocula.

**Windbreaks** have been used with partial success to reduce spread of viral diseases from one site to another. Windbreaks are particularly useful where sequential plantings occur. When aphids move from their original site they may be "trapped" by the windbreak plants where their feeding might deplete the virus from their stylets before the aphids move to the susceptible crop. This technique has been used successfully in southeastern Florida where spaced windbreaks of tall grasses, sugarcane, palm trees, melaleuca (naturally occurring), etc. running north and south trap some aphids that migrate in conjunction with predominate easterly winds. It would be best not to use melaleuca as a windbreak because it is a good host for the aphid, *Aphis gossypii.*

**Roguing** infected plants at first occurrence of disease can be attempted, but generally this technique does not keep pace with an ongoing epidemic. Also, the risk of spreading disease by shaking off aphids or by mechanical spread exists.

**Insecticidal sprays** are not effective for the viruses mentioned herein. By the time the aphid has received a lethal dose, the virus has been transmitted. Most studies have demonstrated either no control, extremely slight control, or

increased disease. The latter occurs when the aphids are agitated by the spray and thus move to a new site where they inoculate other plants before dying.

**Oil sprays** have been known for some time to reduce progress of aphid-transmitted diseases. Currently, the best such oil is one known as 'JMS Stylet Oil'. It is effective if multiple sprays are applied at a spray pressure of 400 psi with the specific nozzles indicated on the label. Reducing primary infections by starting the spray program early will be beneficial whereas waiting until the incidence of disease becomes 10% or more will not provide control. Whenever oils are used, risk of phytotoxicity exists from the oil or its interaction with other sprayed materials.

**Row covers** have been used with partial success in reducing aphid-transmitted viruses in cucurbits. They do so by being a mechanical barrier and by the repellency of aphids with the light and somewhat shiny color of the row cover. However, as soon as the covers are removed for accommodating bee visitation for pollination, one can expect infection to occur with symptoms beginning in 1 to 2 weeks. Interestingly, row covers left on zucchini squash for up to 10-12 days after initial flowering resulted in higher yields compared to those without row covers because delaying disease overrode the benefits of an earlier removal of the covers for pollination. The benefit from row covers is that it delays the initial onset of disease which could at least increase yields of the early pickings. The use of closed systems that exclude aphids but allow for activity of bees would be an excellent control method for these viral diseases.

**Reflective mulches** that have some brightness and shine are repellent to aphids and can delay the onset of viral diseases. Usually silver or aluminum mulches will be more repellent to aphids than white mulches. Once the mulch is covered by plant growth, the effect is lost, but the delay in overall disease progress may be worthwhile. Reduction of disease incidence of WMV 2 has been as high as 97% at a given time and averaged 63% in a test on squash in California with aluminum mulch. In tests in Alabama, delays of 10 to 13 days for onset of viral epidemics from PRSV-W, WMV 2, ZYMV, and CMV occurred with aluminum mulch. In Florida, reductions of viral disease by 72 and 94% have been measured with use of aluminum foil. In another test in Florida, no significant benefit was measured with white on black plastic. Combining the use of row covers with either white or aluminum mulches has significantly reduced viral diseases in cucurbits in Florida and Oklahoma.

**Protection (trap) crops**, where a non-host plant is inter-planted with the cucurbit crop to trap aphids, have reduced viral diseases. This technique could be useful in specialty plantings such as in gardens or "organic" production sites. It would be highly labor intensive and not compatible with logistical operations and equipment.

**Time of planting or transplanting** can influence levels of disease. In north Florida, earlier planting or transplanting will allow the plant to be at a further stage of development before aphid flights begin. At least the earlier pickings might escape some damage. While transplanting rather than planting seed does not always increase yield, transplanted crops tend to have earlier yields.

**Healthy transplants** should always be used. Failure to use disease-free transplants commonly results in significant loss in yield and quality. Avoid purchasing plants from places that have had a history of producing diseased transplants.

**Disease-free seed** should always be used. Unfortunately, the grower has little recourse on this matter except to ask questions of represen-

tatives from the seed companies. Except for SMV and ZYMV, seed transmission of mosaic viruses in cucurbits has been of little conse-quence in Florida.

**Integration** of the above tactics should be done to the extent possible. Integrated disease control systems should



Figure 1. Winged aphid.



Figure 2. Mosaic in squash leaf and fruit (ZYMV).



Figure 3. Green vein-banding in watermelon leaf (WMV-2).



Figure 4. Leaf mottling and bronzing in watermelon leaf (Note: enhancement of symptoms with shading).

**Figure 5. Bronzing and dark and light vein banding in Watermelon leaves (WMV 2).**



**Figure 6. Necrosis and rugosity in pumpkin leaf (WMV 2 and PRSV-W).**
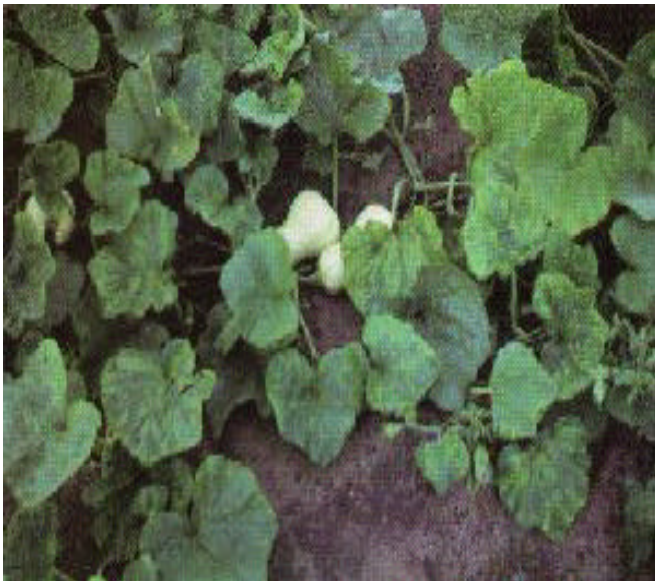


**Figure 7. Vein banding in leaf and mottling in butternut squash leaves and fruit (ZYMV).**



**Figure 8. CMV-inoculated resistant and susceptible squash.**

**Figure 9. Ringspotting in immature pumpkin fruit (WMV 2 and PRSV-W).**



**Figure 10.Ringspotting in mature pumpkin fruit (WMV 2 and PRSV-W).**



**Figure 11. Mosaic in watermelon fruit (WMV 2).**



**Figure 12. Mosaic and bumps in watermelon fruit (ZYMV + WMV 2).**

**Figure 13. Greening and bumps in yellow summer squash fruit (ZYMV).**



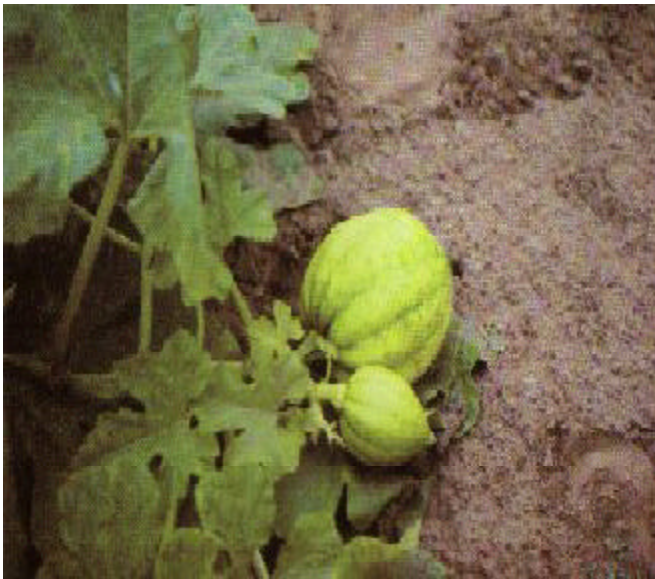**Figure 14. Mottling in yellow squash fruit (ZYMV).**



**Figure 15. Mottling in acorn squash fruit.**



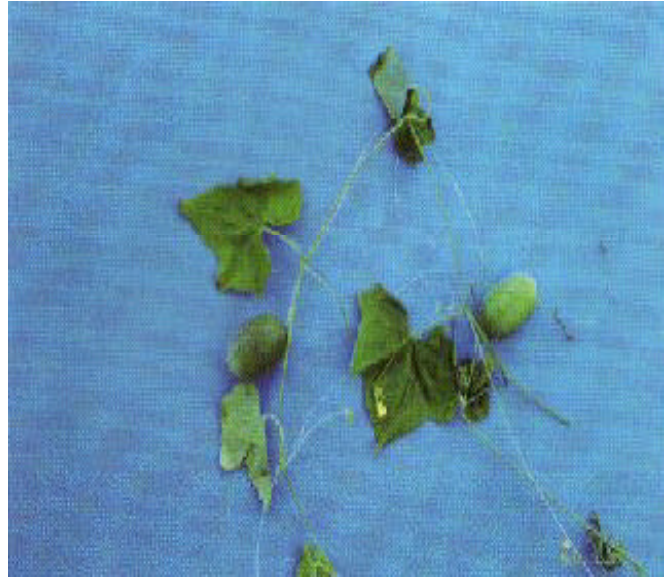**Figure 16. Mottling in yellow summer squash fruit.**

**Figure 17. Balsam Apple.**



**Figure 18. Creeping cucumber.**



**Figure 19. Small dayflower.**



**Figre 20. Dayflower with flowers.**