**Introduction**

Viruses can cause substantial economic losses for greenhouse growers, and proper management is needed to produce healthy plants. There are many viruses known to infect floral crops grown in the greenhouse, including many that are moved by insects, which increase management difficulties. Although viruses often produce obvious, distinctive symptoms, some virus symptoms mimic other diseases and disorders making it necessary for positive identification by a plant diagnostic laboratory. Fortunately, most viruses are not a problem on a given crop. The bad news is that the few common viruses that do cause significant losses have extremely wide host ranges, which often includes many ornamental species, weeds, and even vegetables. Most virus diseases in the greenhouse are caused by several common viruses: *Impatiens necrotic spot virus* (INSV), *Cucumber mosaic virus* (CMV), *Tobacco mosaic virus* (TMV), and to a lesser extent *Tomato spotted wilt virus* (TSWV).

**What Is a Virus?**

To understand how to manage diseases caused by viruses in the greenhouse, it helps to understand what viruses are, and how they differ from other pests and pathogens. A virus is a non-living infectious agent, whose survival structure is called a virion, which is comprised of nucleic acid (RNA or DNA) surrounded by a protein coat. Viruses can produce millions of virions in each infected cell, and it only takes a few to infect a healthy plant. Unlike fungi, bacteria, nematodes (small worms), and insects, viruses are non-living, and are totally dependent upon their host (plant) to multiply and move within the plant. Consequently, there are no chemicals that can kill a virus; a virus-infected plant remains infected for its entire life.

**Entry**

There are three main routes through which viruses gain entry into a greenhouse: infected plant material, people, and vectors. Sound greenhouse management practices should address the first two risks. Scouting and timely vector management should minimize the third risk. Infected cuttings or infected plugs/liners might not show obvious symptoms initially. Some viruses are seed borne, meaning that a certain (often small) percentage of the seeds carry a virus, and these plants become infected soon after germination. Stock plants maintained in an operation can be an internal source of infected plant material.

Anyone entering the greenhouse has the potential to introduce viruses through contaminated hands or clothing. Workers must be instructed to wash hands before beginning work, and guests should be instructed not to handle any plant material. Propagation areas should be off limits to workers handling older plant material. Mechanically transmitted viruses like TMV can arrive on infected cuttings or be introduced by workers after handling tobacco products or other TMV-contaminated plant material. Vectors can arrive with or without a virus, yet still pose a problem. Vectors can acquire a virus from an infected plant once inside the operation, and spread it...
to healthy crops. Vegetables or weeds growing adjacent to a greenhouse can attract and be the source of significant populations of vectors that can enter a greenhouse.

**Spread**

Viruses can spread within a greenhouse in several ways. Viruses are transmitted when there has been some type of wounding in the presence of sap from an infected plant, which can occur during pinching, vegetative propagation, plants rubbing together, or touching a plant. Secondary spread of viruses like TMV occurs after handling infected plants prior to touching healthy plants. Virus contaminated tools are a concern and tools must be regularly disinfected. Also, some insect vectored viruses such as CMV are easily mechanically spread.

The majority of viruses infecting floriculture crops are spread with the help of insect vectors (thrips, aphids, and whiteflies). Insect vectored viruses are spread after an insect has fed on an infected plant and acquired the virus. Aphids can spread a virus shortly after they have fed on an infected plant and then moved to a healthy plant. Western flower thrips (WFT), however, can only acquire INSV or TSWV as juveniles and transmit a virus only as adults. WFT juveniles present on the INSV-infected plants will be responsible for additional spread of INSV upon maturity. Vectors can move viruses between vegetable transplants and floriculture crops, and either could be the source of an outbreak. Ideally, vegetables and ornamentals should be grown in separate greenhouses.

**Symptoms**

Viruses disrupt the normal growth and developmental processes in the plant. Hence, a variety of changes in the leaf and petal coloration, texture, and shape often occur. Viruses tend to move to the growing points in the plant, and symptoms are often most severe in the shoot tips. However, some viruses cause distinguishing symptoms on lower leaves. Symptoms can also mimic those caused by other pathogens and abiotic disorders. Symptoms are irregular—often more severe on one leaf or one plant than another. Viruses often cause irregular dark and light green patches (called mosaic or mottle) on the leaves. Viruses can cause chlorosis (yellowing), necrosis (tissue death) or vein clearing (Figure 1). Chlorosis (yellowing) can take the form of circular ring spots or mosaic. Virus symptoms can also include stunting, leaf deformation (e.g., shoestring, puckering, irregular leaf edges), which are often associated with a mosaic. Many viruses cause flower break symptoms (changes in normal pigmentation) on flowers (Figure 2). However, despite causing severe symptoms on one some hosts, viruses can infect other hosts or cultivars without producing symptoms. These asymptomatic plants can be a hidden source of virus infection in the greenhouse. As you become more familiar with the symptoms caused by the most important viruses on the major crops you grow, or on crops that have been problematic to grow in the past, suspect plants will begin to stand out.

Both TMV and CMV cause mosaic/mottle symptoms and stunting on many floral crops. In petunia, and other solanaceous hosts, TMV symptoms include mosaic (Figure 3), leaf deformation (Figure 4), and flower break. Because CMV can be seed transmitted in some species, symptoms can be seen in very young plants. In *Impatiens*, INSV causes black or necrotic spots associated with the leaves or stems of small plants or seedlings that can later enlarge or develop into black or necrotic ring spots.

In *Begonia*, INSV can cause concentric chlorotic rings and lines in addition to circular necrotic lesions (Figure 5). INSV induces concentric rings of almost perfect proportion in *Gloxinia, Cineraria*, and *Dahlia*, although INSV can also cause a severe crown necrosis in *Gloxinia* (Figure 6). In *New Guinea impatiens*, symptoms of leaf deformation and necrosis might not be seen until the plants flower, even though plants were infected earlier (Figure 7). Concentric chlorotic or necrotic ring spots are also produced in TSWV-infected plants.

**Disease Management**

**Exclusion**

The goal is to keep viruses and their vectors out of your operation. Buy clean, virus-indexed plant material and seed from reputable sources. Cuttings should
Figure 2. Virus-induced flower break and necrotic ring spots in Cyclamen.

Figure 3. Typical mosaic caused by a petunia strain of TMV in Petunia x hybrida.

Figure 4. Leaf puckering and deformation caused by a petunia strain of TMV in Petunia x hybrida.

Figure 5. Circular necrotic lesions caused by INSV in Begonia spp.

Figure 6. Crown necrosis in Gloxinia caused by INSV.

Figure 7. INSV symptoms in New Guinea Impatiens.
be inspected upon arrival for signs and symptoms of virus infection (deformed leaves, variegated foliage, and necrotic lesions) and insect feeding damage, as these are all red flags. Ideally, suspect cuttings should be tested for virus. However, as a minimum measure of protection, keep them separate from other plants of the same species, and avoid greenhouses that have vectors present. Do not assume that just because all of the cuttings of a particular cultivar have an abnormal appearance that this is normal. Sometimes cuttings are taken from infected stock plants. Cuttings can even be infected with viruses that we traditionally think of as insect vectored. If you grow your own stock plants, these should be maintained in a separate greenhouse under an intensive scouting and vector management program.

**Sanitation**

Some virions can survive for extremely long periods of time outside of the host, as well as in or on dead tissue, benches, tools, or plant debris. TMV can easily be moved from one plant to another by the touch of a hand or the carryover of sap on a cutting knife. For this reason it is extremely important to wash your hands in warm, soapy water. Tools used to take cuttings or clean up plants should be disinfected every few minutes or between contact with stock plants or cultivars. Follow the label recommendations on one of the commercially available disinfectants (e.g., containing the quaternary ammonium salts, hydrogen dioxide) or use a 1:10 dilution of household bleach. Benches and other surfaces that come into contact with infected plant material should also be disinfected. Because virus can be present in roots, pots and plug trays containing infected plants should not be reused without being disinfected. Weeds serve as alternate or secondary hosts for plant viruses as well as their insect vectors. Keeping weed populations in and around the greenhouse to a minimum is a good sanitary practice that will aid greatly in controlling viruses. Infected plants should be destroyed, not composted near the operation.

**Scouting**

The purpose of scouting is to catch problems early enough to save most of the crop. With vectored viruses such as INSV or CMV, an isolated infection can be widely spread in a short period of time. Use sticky cards to regularly inspect the crops for signs of virus-like symptoms, insect damage (e.g., thrips-induced scarring), and vectors. Yellow (or blue) sticky cards need to be placed at crop level and monitored regularly to be effective. Pay particular attention to doorway areas, air intake shutters, high traffic areas, highly vulnerable crops, and plants that are blooming or otherwise favored by vectors (e.g., *Gerbera* or petunia and WFT). Train workers to spot atypical signs and symptoms.

**Management**

Suspect plant(s) need immediate attention. If other plants have a similar appearance and more than one species or cultivar is showing symptoms, a virus disease might be spreading. Because viruses do not move by themselves, look carefully for signs of insect feeding activity (or the insects) and re-examine sticky cards. If you are unsure about a particular symptom, the supplier should be contacted. You might also wish to have samples tested by a diagnostic laboratory. If symptoms are consistent with a common virus such as INSV or TMV, and you have the rapid diagnostic kits such as those produced and sold by Agdia, Inc. (Elkhart, IN), use them! However, one has to understand the limitations and proper application of rapid diagnostic kits. These should only be used to confirm infection by a particular virus (e.g., INSV). A negative test does not guarantee that the plant is virus-free. To prevent additional vector spread as plant material is moved, destroy infected or suspect plants by removing them in bags or covered containers. If potential or confirmed vectors are present (e.g., WFT, aphids, or whiteflies), an appropriate insecticide application should be used as soon as possible. New viruses are continually being discovered, and tests that detect every virus do not yet exist. If possible, grow cultivars that have virus resistance.