Diseases of Gladiolus

Wade H. Elmer and Kathryn K. Kamo

Contents

1 Introduction ................................................................................... 2
2 Fungal and Fungus-Like Diseases ........................................................... 2
  2.1 Botrytis Blight (Botrytis spp.): Botrytis gladiolorum Timm and B. cinerea Pers. .... 2
  2.2 Curvularia Spot (Curvularia gladiolus Boerema and Hamers) ......................... 4
  2.3 Fusarium Yellows and Fusarium Corm Rot (Fusarium oxysporum f. sp. Gladioli) ..................................................... 5
  2.4 Gladiolus Rust (Uromyces transversalis Thum) ........................................ 8
  2.5 Stromatinia Rot [Stromatinia gladioli (Drayt.) Whet.] ................................ 9
3 Bacterial and Phytoplasma Diseases .................................................. 11
  3.1 Bacterial Scab Burkholderia gladioli pv. gladioli (Formerly Pseudomonas gladioli pv. gladioli) ............................................................................. 11
  3.2 Aster Yellows (“Candidatus Phytoplasma asteris”) ..................................... 11
4 Viral Diseases ................................................................................... 12
  4.1 Bean Yellow Mosaic Virus ................................................................ 13
  4.2 Cucumber Mosaic Virus .................................................................... 17
References ......................................................................................... 19

Abstract

Gladiolus (Gladiolus spp.) are in the Iridaceae family and are native to South Africa, and over 200 species have been described. Gladiolus have become a major crop in the florist industry. Growers of gladiolus plant their corms in the spring and harvest the flower spikes during the summer and early fall. Although the crop can be propagated sexually from seeds, most of the industry is based on

W.H. Elmer (*)
The Connecticut Agricultural Experiment Station, New Haven, CT, USA
E-mail: wade.elmer@ct.gov

K.K. Kamo
USDA-ARS, Beltsville, MD, USA
E-mail: Kathryn.Kamo@ars.usda.gov

© Springer International Publishing AG (outside the USA) 2016
R.J. McGovern, W.H. Elmer (eds.), Handbook of Florists’ Crops Diseases, Handbook of Plant Disease Management, DOI 10.1007/978-3-319-32374-9_47-1
movement of corms and cormels, which leads to many diseases being disseminated with the crop. Fusarium corm rot, Gladiolus rust, and Curvularia spot are the most limiting fungal diseases, whereas Cucumber mosaic virus and Bean yellow mosaic virus emerge as the more threatening viral diseases affecting gladiolus.

Keywords
Botrytis cinerea • Fusarium spp. • Potyvirus • Integrated disease management

1 Introduction

Gladiolus (Gladiolus spp.) have a high economic value and play a major role in the global flower bulb industry (Benschop et al. 2010). Gladiolus spp. belong to the Iridaceae family, together with Iris and Crocus (Meerow 2012). Over 260 species have been described and all originate from Africa, Madagascar, and Eurasia (Goldblatt et al. 2008). Hybridization of gladiolus began in the 1800s to produce new colors when the Colvillei hybrids were first produced (Hartline 2015). Since then, hundreds of crosses have been developed. Today, gladiolus are a major crop in the florist industry. Growers of gladiolus plant their corms in the spring and harvest the flower spikes during the summer and early fall. The crop is propagated sexually from seeds, and asexually from corms and cormels, but commercial flower spikes are obtained from mature corms. In most northern climates, the corms and cormels are usually dug and stored in the fall. Where data are available, the management of major gladiolus diseases is presented in the following sections. We advise the reader to inform him/herself with the general management strategies found in the introductory chapters on integrated disease management.

2 Fungal and Fungus-Like Diseases

2.1 Botrytis Blight (Botrytis spp.): Botrytis gladiolorum Timm and B. cinerea Pers.

Geographic Occurrence and Impact
Botrytis blight develops on all florist crops. The fungi are ubiquitous and can attack gladiolus in the field when environmental conditions are conducive, but it causes more problems reducing shelf life as a postharvest disease. The first major report of the disease was in Florida in 1940 (Dimock 1940).

Symptoms/Signs
Symptoms of Botrytis blight are characterized as three distinct spots: (1) very small, rust-colored spots that appear on only one side of the leaf; (2) small, yellowish brown spots that develop reddish brown margins; and (3) the large, oval spots that develop
long, reddish margins (Magie 1956) (Fig. 1). Pinpoint water-soaked lesions also appear on flowers if the flower spike stays wet for at least 14 h (Magie 1956). Flower lesions enlarge and are first watery then dry and turn light brown unless the relative humidity is very high, and then the whole lesion becomes wet and slimy. Latent infections are common and cause postharvest losses during transit to market (Magie 1956). The fungus causes basal stem infections which can extend downward to the corm causing a neck rot. In severe cases, the fungus infects the corms and continues to rot the tissue in cold storage conditions.

**Biology and Epidemiology**

There is much known about the Botrytis blight fungi. The fungi survive in soil as sclerotia and as mycelium on plant debris. The fungus requires very high humidity to infect and sporulate, so weather plays a key role in the development of the disease. The optimal temperature for disease development was found to be 20°C ± 10°C (68 ± 18°F), and disease severity will increase with increasing periods of leaf wetness reaching the maximum at 96 h (Sehajpal and Singh 2014).

**Management**

- **Cultural practices** – Reduction of the relative humidity and leaf wetness are critical for suppression of Botrytis blight. In field plants, growers should space plants in the row to allow for maximum airflow. Plants should be watered in the morning to allow time for leaves to dry.
- **Sanitation** – Careful inspection of corms for lesions can reduce the damage of Botrytis blight. Remove and discard senescing blossoms and plant debris in packing sheds and during postharvest.
- **Fungicides** – Botrytis blight is suppressed very effectively by fungicides. Care should be taken to rotate chemicals in different classes to delay the development of resistance. Many fungicides are effective against the disease. The fungicides chlorothalonil, iprodione, mancozeb, and strobilurins are all effective (Singh et al. 2005, 2008, 2011). The benzimidazoles may also be effective against certain species/strains, but resistance has emerged in many strains of *B. cinerea*. Copper oxychloride, triadimefon, ziram, difenoconazole, penconazole, hexaconazole,
and tridemorph have also been shown to be effective. Sprays should be started before the appearance of the disease, preferably before the plants reach the flowering stage (Singh et al. 2005).

2.2 Curvularia Spot (*Curvularia gladiolus* Boerema and Hamers)

**Geographic Occurrence and Impact**
The disease was first noted in Florida, USA, in 1948 (Magie 1948) and in Canada in 1954 (Parmelee 1954). It was identified as *Curvularia lunata* (Parmelee 1956), renamed as *C. trifolii* f. sp. *gladioli*, and renamed again in 1989 as *C. gladioli* Boerema and Hamers (Boerema and Hamers 1989). It has been reported in North America (Magie 1948), South America (Torres et al. 2013b), China, Europe (Parmelee 1954), India (Singh 1968), and Philippines (Mendiola-Ela 1952). There is little information on the economic significance of Curvularia leaf spot, but some cultivars are highly susceptible (Torres et al. 2013b).

**Symptoms/Signs**
The disease affects leaves, stems, and petals. Symptoms usually begin on leaves first as light to dark brown, oval spots. The symptomatic tissues show leaf spots that are oval to circular, brown with dark edges, and surrounded by a yellow halo. Often the lesions become necrotic, and the leaves acquire a dry and wilted appearance (Torres et al. 2013a). The fungus produces a black, powdery mass of spores in the center of the spot. Torres et al. (2013b) noted symptoms were a function of the host resistance. For example, on *G. grandiflorus* var. Red Beauty, the spots were more irregular and necrotic and surrounded by yellow halos. In other species, such as *G. callianthus*, Curvularia spots were round and always surrounded by yellow halos. More tolerant cultivars of *G. grandifloras*, such as Amsterdam, Friendship Rose, Tradehorn, Veronica, and Gold Yester, reacted differently to Curvularia leaf spot and exhibited light to dark brown spots. One report observed vascular discoloration (Forsberg 1957)

**Biology and Epidemiology**
*C. gladioli* is favored by warm, wet conditions. Infection occurs after a 13-h dew period, but actual lesions may take 5 days after infection to appear. Torres et al. (2013a) observed lesions on susceptible cultivars after 3 days. Optimum fungal growth is from 24 to 29 °C (75 to 85 °F). Leaf spots may show up 4–5 days after infection. The fungus can survive on infected corms or in soil for at least 3 years.

**Management**
- **Cultural** – Corms should be inspected for lesions and discarded. After harvest, infected leaves should be removed from the field when practical by deep plowing or raking and burning leaves. All infected corms should be destroyed.
- **Fungicides** – Consult local recommendation guides for approved fungicides. Sprays are most effective when applied preventively during warm, wet weather
when the spores are actively being dispersed. Fungicides known to be effective as preventative contact sprays are chlorothalonil, mancozeb, and benzimidazoles. Magie (1948) reported that mancozeb was superior to other ethylene-bisdithiocarbamates.

- **Resistance** – Many cultivars listed above have moderate resistance, but Picardy is very susceptible. No cultivar is immune but a wide range of reactions are known to occur (Torres et al. 2013a). Growers should combine resistance to augment other strategies for suppressing the disease (Singh et al. 2006)

### 2.3 Fusarium Yellows and Fusarium Corm Rot (*Fusarium oxysporum f. sp. Gladioli*)

#### Geographic Occurrence and Impact

Fusarium corm rot is the most common fungal disease on gladiolus and can be one of the most destructive (Nelson et al. 1981). The disease occurs wherever gladiolus is grown and can be lethal on certain cultivars. Characteristic symptoms of corm rot were first reported in 1912, but it took another 16 years before the disease and the pathogen were formerly described (Massey 1928). The pathogen is the fungus *Fusarium oxysporum f. sp. gladioli*, which inhabits many soils as different biotypes. As a result, the disease occurs wherever gladiolus is grown, in part, due to resident populations of the pathogen and due to latent corm infections that are frequently present (Nelson et al. 1981). About 30% annual losses have been estimated in Germany (Bruhn 1955), whereas 60–80% annual losses were noted in India (Protzenko 1958 as cited by Chandel and Deepika 2010).

#### Symptoms/Signs

Due to the wide diversity in the pathogen populations, symptoms can be diverse and may include stunting and chlorosis (Fig. 2) and, in severe cases, wilt and death (Fig. 3). Along with the rotting of corms (Fig. 4), the disease can cause vascular
discoloration. The corm rot is usually a dry corky rot that stays localized until the entire corm becomes infected.

**Biology and Epidemiology**

The most common means for long-distance dissemination is via latent infections on the corms and cormels. However, once the pathogen is established in the soil, the fungus survives well as persistent chlamydospores and as mycelium on plant debris. The fungus is very adept at surviving in the absence of gladiolus for many years. The fungus can also endophytically colonize the roots of non-symptomatic plants. New infections result from hyphae that emerge from soil inoculum consisting primarily of
chlamydospores or mycelium. The fungus invades roots intracellularly causing root rot as it advances toward the corm. The corm may be able to compartmentalize invasion, or the infection continues becoming systemic in the vascular tissues. It is not clear whether the resistance of the host or virulence of the pathogenic biotype of *F. oxysporum* f. sp. *gladioli* governs whether vascular invasion occurs. Disease incidence is a linear function of soil inoculum and soil temperatures above 25 °C (77 °F) (Chandel 2004; Sharma and Tripathi 2008).

**Management**

- **Cultural** – While other cultural strategies are limited in their efficacy, sanitation should be highlighted as the most significant approach. Hot water treatment of corms and cormels (30 min at 57 °C/135 °F) followed by biological and inorganic amendments at planting can be effective (Sharma and Tripathi 2008), but temperature baths should be accurately monitored to provide the best disinfestation and to prevent heat damage (Chandel 2004; Magie 1971). Gladiolus requires a well-drained soil with a pH of about 6.5 since acidity promotes Fusarium corm rot. Soil tests should routinely be performed and soil limed appropriately to achieve a soil pH of around 6.5–7.0. Although numerous papers on other plant have shown that *Fusarium* suppression occurs with nitrate fertilization (Elmer 2012; Woltz 1958), excessive nitrogen can be deleterious and result in more disease (Ashour and Gamal 1966). Fertilization with nitrate-N should be used instead of ammonium-N, which lowers soil pH and tends to promote Fusarium wilt in other crops like tomato (Woltz and Jones 1973). McClellan and Stuart (1947) found organic N promoted disease compared to inorganic N. Addition of increasing amounts of calcium superphosphate decreased corm rot (Ashour and Gamal 1966). A survey of 18 fields in Pakistan found higher levels of disease were associated with low soil potassium, manganese, and zinc indicating the importance of micronutrient availability (Riaz et al. 2009).

- **Fungicides** – Ram et al. (2004) found that soaking corms in acidified solutions of benomyl for 60 min gave the best protection against corm rot. However, others have found that benzimidazoles were not effective probably due to tolerant strains being transported on the corms (Magie 1974). Mishra et al. (2000) found exposing corms to combinations of *Trichoderma virens* and carboxin provides superior results in suppressing corm rot. Ramos-Garcia et al. (2009) reported that Biorend® (a biodegradable polymer) applied at 1.5% accelerated corm emergence, the number of flowers, and the vase life. Preplant corm treatments have received much attention as they reduce the cost, labor, and environmental concern compared with soil drenches. Elmer (2006) demonstrated that triflumizole and fludioxonil gave season-long suppression when applied as a corm soak. Many fungicides applied singularly or combined with other chemicals and/or biological products have often provided more suppression than when applied individually.

- **Biological control** – Several researchers have found biological products to be effective (Mishra et al. 2000; Mohamed and Gomaa 2000; Riaz et al. 2010), while others found no control (Elmer 2006). However, given the differences of cultivars, inoculum, and field versus greenhouse, the data are too fractionated to make
consistent claims for most products. Nevertheless, a consensus has emerged demonstrating that *Trichoderma* spp. show greater efficacy than any other biocontrol product. Other reports have shown disease reduction by rhizobacteria and nonpathogenic strains of *Fusarium*. Talc-based formulations that combined two plant growth-promoting rhizobacterial strains (*Bacillus atrophaeus* and *Burkholderia cepacia*) reduced vascular wilt by 48.6% and corm rot incidences by 46.1%, respectively, when compared to the non-treated control (Shanmugam et al. 2011). These treatments were comparable to the fungicide carbendazim that provided a 51.5% reduction in vascular wilt and a 47.1% reduction in corm rot incidence. An increase in the number of spikes (58.3%) and corms (27.4%) were also noted with this treatment when compared to control. Magie (1980) conducted field studies where corms were treated with certain isolates of *F. subglutinans* Snyd. and Hans and *F. solani* and found disease protection was equal to that obtained with benomyl as a corm dip treatment. Biologicals should be used preventatively.

- **Resistance** – The management of Fusarium corm rot has been difficult. Although partial resistance has been identified in some lines (Straathof et al. 1998), the wide diversity of biotypes of the pathogen and the lack of persistent screening for resistance have hindered efforts to identify highly resistant cultivars. Growers are advised to check with current information regarding resistance/tolerance of cultivars in their regions.

### 2.4 Gladiolus Rust (*Uromyces transversalis* Thum)

#### Geographic Occurrence and Impact

Gladiolus rust is a disease of quarantine significance in the USA since it was first detected in Florida in 2006 (Schubert et al. 2007). The disease apparently evolved along with the host in Southern Africa. The fungus spread to Southern Europe in the 1960s and reached England in 1996. Since then, major eradication efforts have been initiated to slow the spread of gladiolus rust in the USA. Reports of gladiolus rust have been made from California (Blomquist et al. 2007), South and Central America (Rodríguez-Alvarado et al. 2006; Valencia-Botín et al. 2013), and Australia (Beilharz et al. 2001).

#### Symptoms/Signs

Symptoms are very distinct. The orange uredinia form transverse lines across gladiolus foliage. Under severe inoculum pressure, lesions can be observed on flower spikes (Fig. 5).

#### Biology and Epidemiology

*U. transversalis* is an autoecious rust that has no alternate host. It produces only two spore types, urediniospores and teliospores. It infects *Gladiolus* spp. and
Anomatheca, Crocosmia, Melasphaerula, Tritonia, and Watsonia spp. The rust spores are airborne (uredinospores) and infect and cause profuse sporulation on the leaf surface. Severely infected plants cannot photosynthesize sufficiently. They remain stunted and will not produce flower spikes. The fungus overwinters as teliospores on the foliage.

Management
- **Sanitation** – Currently, gladiolus rust is a quarantinable pathogen in the USA. Strict rust management guidelines and fallow host-free periods need to follow the appearance of the disease.
- **Fungicides** – In Mexico, where the disease was more common, fungicide trials found that the triazole fungicides, cyproconazole, difenoconazole, epoxiconazole, myclobutanil, propiconazole, and tebuconazole gave excellent control.

2.5 **Stromatinia Rot [Stromatinia gladioli (Drayt.) Whet.]**

**Geographic Occurrence and Impact**
The disease was recognized in 1883 in England and known to occur wherever gladiolus is grown. The fungus was first described as Sclerotinia gladioli (Hawker et al. 1944) but was changed to Stromatinia gladioli. The disease was reported along the USA Gulf Coast (Magie 1954; Drayton 1934).

**Symptoms/Signs**
Symptoms appear as a dry rot of the corm (Fig. 6). Individual lesions may appear as superficial small, round, reddish brown spots that can have brown to black centers. Lesions more frequently appear at the point of the husk attachment. The actual husk can appear dark colored, brittle, and shredded. One diagnostic characteristic of Stromatinia rot is the presence of black sclerotia in rotted cortical tissue of the roots (McRitchie and Leahy 1988).
Biology and Epidemiology
The fungus overwinters in the soil in the form of sclerotia, which can last in the absence of a host for 10 years (Nelson 1948). The disease is more severe when cool, wet conditions prevail. Young corms (1–2 years) tend to be more susceptible than older ones. Wounds are not required for infection (Hawker et al. 1944). The disease spreads faster when plants are planted in close proximity. Inoculation of the top of an old corn is more effective than that of the side or base. The percentage of diseased new corms produced from infected parent corms varies from 0% to 100% according to soil conditions. Disease is favored by wet soil.

Management
• Cultural practices – Crop rotation should be practiced at 3–4-year intervals to reduce soil densities of the sclerotia. Any volunteer gladiolus plants should be rogued as they can serve as sources of inoculum. Since cool, wet soil favors the disease, delaying the time of planting and improving drainage can lessen the loss due to Stromatinia rot. Removal of “husks” (leaf bases) increases the susceptibility of corms planted in contaminated soil, but the removal of husks is not an effective control. Dehusking did not increase the number of diseased young corms in infected stock planted in new soil. No variety was strikingly more resistant than the rest.
• Fungicides – Corm and soil treatment with fungicides should be done where there is a history of the disease. Good control was obtained when corms of a diseased stock were treated with mercuric chloride, mercurous chloride (calomel), or the proprietary mercury fungicide Aretan. Calomel gave the most consistent results. Various other treatments were tested in small-scale trials with some success. Red copper oxide, formalin, and the proprietary mercury compound, Ceresan, were harmful. Sterilization of contaminated soil with formalin, mercuric chloride, Aretan, or Uspulun gave good but not complete control. Formalin was the least effective.
3 Bacterial and Phytoplasma Diseases

3.1 Bacterial Scab *Burkholderia gladioli* pv. *gladioli* (Formerly *Pseudomonas gladioli* pv. *gladioli*)

**Geographic Occurrence and Impact**

Bacteria scab is not a major problem for gladiolus growers. Unlike the fungal corm rot diseases, bacterial scab does not kill the affected plants or affect the flower spikes.

**Symptoms/Signs**

The lesions are very dark and appear on the surface of the corm. Scab lesions are sunken with a concentric border. Most lesions develop a shiny black layer over the surface of the lesion. Bacterial scab can be differentiated from Stromatinia by where the lesions tend to appear. Bacterial scab lesions appear more frequently at the base of corm, whereas Stromatinia lesions appear more commonly on the top of the corm (Forsberg 1965).

**Biology and Epidemiology**

The bacteria are ubiquitous and can be introduced on previously infected corms or through wounds made from handling or insect feeding. The bacterium also infects a number of other horticultural crops including lisianthus.

**Management**

Inspect corms for lesions and discard infected corms. Avoid planting in areas where the disease has appeared. Efforts to suppress bulb mites will also reduce infection sites.

3.2 Aster Yellows (*Candidatus Phytoplasma asteris*)

**Geographic Occurrence and Impact**

Aster yellows has been reported in *Gladiolus* in the USA, and it infects a wide range of plant species (Treeful and Ash 2000).

**Symptoms/Signs**

*Gladiolus* plants mature early, have an arrested root development, and have small or few corms (Fig. 7) during the season when they are first infected. The next year, multiple shoots that are thin and weak develop from the corm giving the appearance of their nickname “grassy top” (Koike et al. 2007) (Fig. 7). The flower spike grows in a spiral pattern (Fig. 7).

**Biology and Epidemiology**

This disease is caused by phytoplasmas formerly known as mycoplasma-like organisms and not by a virus. Phytoplasmas are microscopic organisms similar in size and composition to bacteria (Treeful and Ash 2000). Transmission is by *Macrosteles sexnotatus* leafhoppers (Koike et al. 2007). An infected leafhopper will remain infected throughout its life and will inject phytoplasma into the phloem cells of a
When feeding (Missouri Botanical Garden). Plants will exhibit symptoms in 10–40 days. Aster yellows has been reported to occur in many floral crops and in a number of weed species (Convolvulus, Capsella, and Cirsium) (Vicchi and Bellardi 1988). Aster yellows spreads more readily in cool, wet summers because phytoplasmas and leafhoppers do not thrive as well in dry, hot weather (Missouri Botanical Garden). Massive spread of aster yellows is rare (Stein 1995).

**Management**

Infected plants should be destroyed (Koike et al. 2007). Weeds, particularly dandelions and plantains, should be controlled in the area where Gladiolus is being grown. Monitor plants for leafhoppers. Fine mesh fabrics and strips of aluminum foil between rows of plants can be used to keep leafhoppers away from the plants (Missouri Botanical Garden).

**4 Viral Diseases**

Twenty viruses have been reported to infect Gladiolus (Stein 1995; Asjes 1997). The predominant viruses that infect Gladiolus are Bean yellow mosaic virus (BYMV) and Cucumber mosaic virus (CMV). Other viruses that have been reported in
Gladiolus are listed in Table 1. A number of companies offer testing services and/or ELISA kits to detect various gladiolus viruses. Nine Gladiolus viruses can be detected immunologically by Agdia, Inc., Elkhart, IN, USA, in their “Gladiolus Screen” (www.agdia.com/testing-services/Gladiolus.cfm). Bioreba AG, Reinach, Switzerland, can test for the presence of six gladiolus viruses by ELISA (http://www.bioreba.ch/files/Tecnical_Info/TS_Broschuere_2011_e_CHF.pdf). Neogen Europe, Ltd., Auchincruive, Scotland, UK, manufactures ELISA kits which can detect a number of gladiolus viruses.

The viruses in Gladiolus differ for each country, but two viruses, BYMV and CMV, are by far the most prevalent viruses found worldwide in Gladiolus.

4.1 Bean Yellow Mosaic Virus

Geographic Occurrence and Impact
Almost all Gladiolus plants are infected with Bean yellow mosaic virus (BYMV) as reported for plants grown in the USA (Zettler and Abo El-nil 1977), Ontario Canada (Berkeley 1953), the Netherlands (Brunt 1970; Nagel et al. 1983), Israel (Stein 1995), Argentina (Arneodo et al. 2005), Iran (Kaniran and Izadpanah 1982; Dorrigiv et al. 2013), Italy (Bellardi and Pisi 1985a), Japan (Wada et al. 2000), Korea (Park et al. 2002), Russia (Gnutova et al. 1989), the Czech Republic (Duraisamy and Pokorny 2009), Belarus (Voinilo and Burgansky 1999), Lithuania (Navalinskiene and Samuitiene 2001), New Zealand (Fry 1953), and India (Katoch et al. 2002). Bean yellow mosaic virus is also known as the Pea mosaic virus.

Symptoms/Signs
BYMV-infected Gladiolus plants are typically symptomless or have mild symptoms. It is difficult to attribute viral symptoms to a specific virus because Gladiolus is generally infected with BYMV and a second virus (Stein 1995). The symptoms of BYMV have been described as faint, inconspicuous pencil-stripe break patterns that are lighter in color than the normal flower although it may be conspicuous on specific cultivars (Univ. Illinois Extension 1983). The leaves and flower stems may have light or dark green mottling seen in the early summer (Univ. Illinois Extension 1983). Symptoms will be affected by environmental conditions (Asjes 1997). Dry, high-temperature conditions will mask the symptoms (Univ. of Illinois Extension 1983). Katoch et al. (2002) examined 32 cultivars of Gladiolus and reported a BYMV incidence of 0–100% based on visual symptoms, but almost 100% were found to have BYMV as indicated by ELISA.

Biology and Epidemiology
BYMV is of the genus Potyvirus and belongs to the Potyviridae family, which is the largest and most economically important group of viruses as it infects many species of vegetables, forage, fruit, ornamental, and field crops (Jordan and Hammond 1991). BYMV infects many legumes, and the virus overwinters in perennial legumes
### Table 1 Viruses reported in *Gladiolus* other than BYMV and CMV

<table>
<thead>
<tr>
<th>Virus</th>
<th>Occurrence in <em>Gladiolus</em></th>
<th>Transmission</th>
<th>Symptoms</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Arabis mosaic virus</em></td>
<td>Italy, India</td>
<td><em>Xiphinema</em> (nematode)</td>
<td>ND</td>
<td>Bellardi et al. 1986; Katoch et al. 2003</td>
</tr>
<tr>
<td><em>Bearded iris mosaic virus (=Iris severe mosaic virus)</em></td>
<td>USA, Netherlands</td>
<td>Aphids</td>
<td>ND</td>
<td>Brierley and Smith 1948; Brunt et al. 1988</td>
</tr>
<tr>
<td><em>Broad bean wilt virus</em></td>
<td>Korea</td>
<td>Aphids</td>
<td>Symptomless</td>
<td>Park et al. 1998</td>
</tr>
<tr>
<td><em>Clover yellow vein virus</em></td>
<td>Korea</td>
<td>Aphids</td>
<td>ND</td>
<td>Park et al. 2002</td>
</tr>
<tr>
<td><em>Cowpea mosaic virus</em></td>
<td>USA</td>
<td>Beetles</td>
<td>ND</td>
<td>Brierley and Smith 1962</td>
</tr>
<tr>
<td><em>Cycas necrotic stunt virus</em></td>
<td>Japan</td>
<td>Nematodes and seed</td>
<td>ND</td>
<td>Hanada et al. 2006</td>
</tr>
<tr>
<td><em>Impatiens necrotic spot virus</em></td>
<td>France, Iran, Portugal</td>
<td>Thrips</td>
<td>ND</td>
<td>Marchoux et al. 1992; Ghotbi et al. 2005; Louro 1996</td>
</tr>
<tr>
<td><em>Narcissus latent virus</em></td>
<td>Netherlands</td>
<td>Aphids</td>
<td>ND</td>
<td>Stein 1995; Asjes 1997</td>
</tr>
<tr>
<td><em>Ornithogalum mosaic virus</em></td>
<td>India, Netherlands</td>
<td>Aphids</td>
<td>Foliar mosaic, chlorotic spots, floral deformation</td>
<td>Kaur et al. 2011</td>
</tr>
<tr>
<td><em>Plum pox virus</em></td>
<td>Germany</td>
<td>Aphids</td>
<td>ND</td>
<td>Kroll 1978</td>
</tr>
<tr>
<td><em>Soybean mosaic virus</em></td>
<td>USA</td>
<td>Aphids</td>
<td>ND</td>
<td>Stein 1995</td>
</tr>
<tr>
<td><em>Strawberry latent ringspot virus</em></td>
<td>Italy</td>
<td><em>Xiphinema</em> (nematode)</td>
<td>ND</td>
<td>Bellardi et al. 1984</td>
</tr>
<tr>
<td><em>Tobacco mosaic virus</em></td>
<td>Japan, Netherlands, Canada</td>
<td>Mechanical</td>
<td>ND</td>
<td>Berkeley 1951; Fukumoto et al. 1982</td>
</tr>
<tr>
<td><em>Tobacco necrosis virus</em></td>
<td>Russia, Lithuania</td>
<td><em>Olpidium brassicae</em> (fungus)</td>
<td>ND</td>
<td>Stein 1995; Navalinskiene and Samiuatiene 2010</td>
</tr>
<tr>
<td><em>Tobacco rattle virus</em></td>
<td>Netherlands, Israel, Egypt, Poland, India, Korea, Japan, Czech Republic, Lithuania</td>
<td>Tools used during planting, low rate of transmission in <em>Gladiolus</em> seeds, nematodes of the family Trichodoridae</td>
<td>Notched leaf blades, severely distorted plant, chlorotic, brown or dead stripes and spots on leaves, crumpled tissue between veins, stem and</td>
<td>Navalinskiene and Samiuatiene 2001; Univ. Illinois Extension 1983; Stein 1995; Asjes 1997; Yamaji et al. 1998; Park et al. 2002;</td>
</tr>
</tbody>
</table>
such as alfalfa, clovers, or vetch. Hampton et al. (2005) verified the non-circulative (nonpersistent) transmission of BYMV from clover, *Trifolium repens*, to an adjacent field of snap beans, *Phaseolus vulgaris*, by four aphid species (*Myzus persicae*, *Acyrthosiphon pisum*, *Aphis fabae*, and *Nearctaphis bakeri*). Over 20 species of

<table>
<thead>
<tr>
<th>Table 1 (continued)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Virus</td>
</tr>
<tr>
<td>Tobacco ringspot virus</td>
</tr>
<tr>
<td>Tobacco streak virus</td>
</tr>
<tr>
<td>Tomato black ring virus</td>
</tr>
<tr>
<td>Tomato ringspot nepovirus</td>
</tr>
<tr>
<td>Tomato spotted wilt tospovirus</td>
</tr>
<tr>
<td>Tomato aspermy virus</td>
</tr>
</tbody>
</table>
aphids serve as vectors for BYMV transmission. Transmission of BYMV through bean seeds of legumes has been reported (Latham et al. 2000).

BYMV particles are flexuous and filamentous (750 nm in length and 15 nm in diameter) (Guyatt et al. 1996). They consist of single-stranded, positive sense RNA. Various strains of BYMV have been identified serologically using both polyclonal and monoclonal antisera (Nagel et al. 1983; Jordan and Hammond 1991). Virus is readily detectable in leaves and flowers by ELISA (Stein 1995). The low level of BYMV in corms requires that the corm be cut, and then virus can be detected by ELISA in the callus tissue that forms at the wounded areas (Stein 1995). Immunological detection of BYMV in corms of *Gladiolus* has been possible using a tissue blotting technique (Lin et al. 1990). Polymerase chain reaction (PCR) amplification of BYMV RNA has also been used to detect BYMV in corms (Rosner et al. 1992). Another method to increase the sensitivity of detection (10^5 higher than when using ELISA) was achieved by hybridizing PCR products with a radioactive ^32^P-labeled viral riboprobe (Vunsh et al. 1991).

**Management**

Because aphid species spread BYMV, growing *Gladiolus* plants under fine mesh nets was found to greatly reduce virus infection (Stein 1995). BYMV as well as CMV, but not *Tobacco ringspot virus*, were found to be transmitted on tools used when harvesting flowers and corms of *Gladiolus* (Brierley 1962). Tools should be disinfested with 70% alcohol between cuts to prevent cross contamination (Univ. Illinois Extension 1983). Logan and Zettler (1985) developed an efficient tissue culture system that had the potential to produce 50,000 gladiolus plants from a single shoot tip during a 30-week period. *Gladiolus* plants free from BYMV can be produced using meristem culture (Stein 1995). Propagating with the apical meristem of a corm grown under sterile conditions in vitro can eliminate 60–100% of the virus. Removal of three viruses from *Gladiolus* was achieved by performing meristem culture twice, adding ribavirin (5–20 ppm) to the culture medium, and treating with high (38–40 °C) temperature (Li et al. 2003). Regeneration of plants from callus was reported to be more effective than culturing shoot tips from corms for virus elimination (Park et al. 2002). Callus induced from cormels infected with BYMV and CMV was cultured on a medium containing ribavirin (virazole, 1-β-D-ribofuranosyl-a, 2, 4-triazole-3-carboxamide), and after 6–8 weeks, plants were regenerated and certified as virus-free (Singh and Dubey 2007). Virus-free plants must be grown in insect-proof conditions if the *Gladiolus* plants are to remain free of virus or else 80–100% of the crop will become infected with BYMV within one growing season (Stein 1995; Asjes 1997). It is recommended (Univ. Illinois Extension 1983; Moran 1996) that virus-free plants be grown at least 1 km from virus-infected *Gladiolus* plants and legumes, that effective insecticides be used to control aphids on the crop plants and on corms during their storage, and that plants showing viral symptoms be rogued and destroyed by burning or composting. Weeds in the vicinity of *Gladiolus* plants should be eradicated as they may serve as reservoirs of viruses and insects that can be vectors for viruses (Univ. Illinois Extension 1983). Aluminum strips placed
between rows or *Gladiolus* plants can be used to repel aphids and will also decrease the number of weeds present.

### 4.2 Cucumber Mosaic Virus

**Geographic Occurrence and Impact**

*Cucumber mosaic virus* (CMV) is in the genus *Cucumovirus* and is a member of the family Bromoviridae. CMV consists of three spherical particles that are each 28 nm in diameter. Its genome consists of three single-stranded messenger RNA molecules in the sense orientation. There are two subgroups, I and II, of CMV that are distinguished either by their serological response to antibodies or by their nucleotide sequences (Chen 2003; Zitter and Murphy 2009). The CMV that infects *Gladiolus* plants belongs to subgroup I and has the highest nucleotide sequence homology based upon its coat protein to the CMV strain Fny (Chen 2003; Dubey et al. 2010). CMV infects 1,200 plant species that include economically important vegetable crops such as cucumbers, squash, and melons and most floral crops. CMV occurs throughout the world and has been reported in *Gladiolus* in the USA (Brierley 1952; McWhorter 1957); Iran (Dorrigiv et al. 2013); Ontario, Canada (Berkeley 1953); Tasmania (Wade 1984); Israel (Stein 1995); India (Dubey et al. 2010); the Czech Republic (Duraisamy and Pokorný 2009); and Lithuania (Navalinskiene and Samuittiene 2001).

**Biology and Epidemiology**

The worldwide occurrence of CMV in *Gladiolus* can be attributed to the international trade of corms and to the virus’ wide host range. When only 3% of the corms are initially infected with CMV, after one growing season, 60% of the plants may become infected (Stein 1995). CMV transmission occurs by many aphid species in a non-circulative (nonpersistent) manner. Most commercial cultivars of *Gladiolus* are susceptible to CMV. The cultivars Peter Pears, Spic and Span, and White Friendship are readily infected by CMV whereas Trader Horn and Eurovision are more resistant (Aly et al. 1986).

**Symptoms/Signs**

Generally, *Gladiolus* plants with CMV often appear symptomless until flowering when there may be spotting on petals; obvious color break that is more readily visible on purple, lilac, pink, and red flowers than on white or yellow flowers (Fig. 8a–c); and a reduced size of the floret accompanied by a change in the color of the petals, thickened petals, twisted and deformed florets, and flowers that will not fully open. Flowers may have crinkled petals, open slowly, imperfectly, and fade early (Univ. Illinois Extension 1983). Flower bracts can be yellow and wither early in the season. Other symptoms can be deformity of the whole plant. Stunting of infected plants often occurs (Fig. 8d) with severely affected leaves that have gray or yellow-green streaking or spots that are either gray, yellow, brown, or reddish (Fig. 8e, f). Young leaves may have a mosaic or chlorophyll break. Some cultivars
have pitting and discoloration of the corms or corms that are deformed and have a warty appearance (Univ. of Illinois Extension 1983; Stein 1995).

**Fig. 8** Symptoms of viral infection in *Gladiolus* are (a–c) color break on flower petals. In b the left spike is a healthy spike, and the right spike shows color break of petals indicative of virus infection. (d) The two inner plants are stunted in their growth as compared to the two outer, healthy plants. (e) Viral symptoms on leaves (streaking or (f) blotching. (g) Corms infected with CMV are deformed (Photo courtesy of Kath Kamo)
Management
If possible, it is recommended that CMV-tested, certified corms and resistant cultivars be planted. A number of diagnostic companies manufacture rapid detection ELISA kits for CMV. The use of fine mesh nets coated with mineral oil spray or by directly spraying mineral oil on the plants in the absence of nets has been found to help with controlling spread of CMV (Aly et al. 1986). Controlling the aphid population and rogueing infected plants during flowering when symptoms are most obvious on the flowers also help in the field to prevent a large outbreak of CMV. It is advised that *Gladiolus* should not be grown near cucumbers, melons, and tomatoes because of the virus transmission that can occur between CMV-infected crops (Univ. Illinois Extension 1983). The strategies to manage CMV are the same as for BYMV (rogueing, aphid control, eliminate weeds).

References

Bellardi MG, Pisi A (1985a) Survey of gladiolus viruses in Italy. Revista della Ortoflorofrutticoltura Italiana 69:133–144
Berkeley GH (1951) Gladiolus viruses. Phytopathology 41:3–4
Bozarth RF, Corbett MK (1958) Tomato ringspot virus associated with stunt or stub head disease of *Gladiolus* in Florida. Plant Dis Rep 42:217–221
Brierley P, Smith FF (1948) Two additional mosaic diseases of iris. Phytopathology 38:574–575
Dimock AW (1940) Epiphytotic of Botrytis blight on Gladiolus in Florida. Plant Dis Rep 24(8):159–161
Drayton FL (1934) The gladiolus dry rot caused by Sclerotinia gladioli (Massey) n. comb. Phytopathology 24:397–404
Dubey VK, Aminuddin, Singh VP (2010) Molecular characterization of Cucumber mosaic virus infecting Gladiolus, revealing its phylogeny distinct from the Indian isolate and alike the Fny strain of CMV. Virus Genes 41:126–134
Forsberg JL (1957) A vascular form of the Curvularia disease of gladiolus. Phytopathology (abstr) 47:12
Lin NS, Hsu YH, Hsu HT (1990) Immunological detection of plant viruses and a mycoplasmalike organism by direct tissue blotting on nitrocellulose membranes. Phytopathology 80:824–828
McWhorter FP (1957) A localized occurrence of Cucumber mosaic virus in Gladiolus. Plant Dis Rep 41:141–143


Singh RN (1968) Curvularia disease of gladiolus in India. *Plant Dis Rep* 52:552


