Evaluation of Ornamental Tropical Plants for Resistance to White Mold Caused by Sclerotinia sclerotiorum

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Abstract. Sclerotinia sclerotiorum (Lib.) de Bary is a fungal pathogen that causes stem rot, crown rot, wilt, and death of many common annual flowering plants. Infested flower beds often suffer significant plant loss each year, and the identification of disease resistant plants would be a useful management tool. Caladium (Caladium × hortulanum Birdsey), canna (Canna × generalis L.H. Bailey), and elephant ear [Colocasia esculenta (L.) Schott] were evaluated for potential resistance to S. sclerotiorum. Plants grown in field conditions in Minnesota in 2012 and 2013 were inoculated through the application of sorghum grains colonized by S. sclerotiorum. The number of plants infected and percent of canopy dieback were recorded weekly for 3 months. The susceptibility of leaves, flowers, and below ground storage organs was also examined through direct inoculation of plant tissue with a mycelial plug of the pathogen in controlled environmental conditions favorable for disease development. Symptoms and progression of the infection were recorded after 24 days. Symptoms of infection on all three species were similar in field and controlled environments. Caladium plants were susceptible to S. sclerotiorum. Petioles, leaves, and corms developed a watery soft rot. Elephant ear was highly resistant to infection. Sclerotinia sclerotiorum infected only wounded or senescent tissue and did not result in significant symptoms under any conditions. Canna had partial resistance to the pathogen. Although canna petals were readily infected, infection of petioles was restricted to small necrotic lesions. Neither infection progressed to the main stem or resulted in plant death. This study indicates that canna and elephant ear have resistance to S. sclerotiorum and could be used in an integrated disease management program for infested landscape beds.

White mold, caused by the necrotrophic fungal pathogen Sclerotinia sclerotiorum, causes stem rot, crown rot, wilt, and death of many common annual bedding plants, including zinnia, petunia, verbena, snap dragon, and salvia (Boland and Hall, 1994; Farr and Rossman, 2017; Grabowski and Malvick, 2015). Infested flower beds often suffer significant plant loss each year in part due to the ability of the pathogen to survive for at least 8 years in soil (Bolton et al., 2006). Infection occurs in cool moist conditions and plant death from white mold occurs in mid to late summer (Abawi and Grogan, 1979; Bolton et al., 2006). At this stage of the growing season, replacement plants for summer flowering annuals are typically no longer available. Garden managers are left with unsightly patches of dead plants or bare soil. Identifying ornamental plants with resistance to white mold would allow growers to avoid disease problems in beds known to be infested with S. sclerotiorum. Over 400 plant species from more than 75 families are known to be susceptible to S. sclerotiorum (Boland and Hall, 1994). Greason et al. (2009) list over 30 genera of herbaceous perennials and Daughtrey et al. (1995) list 10 common flowering potted plants that are susceptible to S. sclerotiorum. New susceptible host plants are regularly identified (Chang et al., 1997; Garibaldi et al., 2008a, 2008b, 2008c, 2001; Grabowski and Malvick, 2015; Gulya et al., 2006; Strauss and Dillard, 2009). Grabowski and Malvick (2015) tested four genera of annual bedding plants with no reported susceptibility to white mold for potential resistance to S. sclerotiorum. Although moderate resistance was found, plants from all four genera became infected by S. sclerotiorum to some degree. To identify plants with reliable resistance to white mold, new taxa of ornamental plants need to be evaluated for resistance.

Ornamental tropical plants are often grown in annual flower beds to add color and texture. Canna, caladium, and elephant ear have a long history of cultivation. Canna originates from South America and was first introduced to European gardeners as a foliage plant in 1595 (Khoshoo and Mukherjee, 1970; Prince, 2011). Caladium originates from tropical regions of Central and South America (Germlnas Resources Information Network, 2017). Breeding of hybrid garden caladium has occurred for over 150 years (Deng et al., 2007). Elephant ear, also known as taro, originates from Southeast Asia and is believed to be one of the oldest domesticated crops (Quero-Garcia et al., 2010). Plants from these genera are readily available to landscape managers in a variety of colors to meet designers’ needs. Cultivation and care of these plants in gardens is well described (Iversen, 1999), allowing for easy adoption of plants should they prove resistant to white mold.

Perhaps because they are of tropical origin, plants in these genera have few pest problems in temperate climates (Horst, 2001; Iversen, 1999) and no recorded history of infection by S. sclerotiorum (Boland and Hall, 1994; Farr and Rossman, 2017). In addition, all are monocots. Although some monocots are listed as hosts to S. sclerotiorum, economic damage due to this pathogen primarily occurs in dicotyledonous plants (Boland and Hall, 1994; Bolton et al., 2006; Farr and Rossman, 2017).

Although canna, caladium, and elephant ear are grown as annuals in temperate climates, each produces a belowground storage organ (rhizome, tuber, corm) that can be dug up at the end of the season, stored for the winter, and planted the following season. Belowground storage organs can be used to propagate these plants as well (Iversen, 1999). In addition to evaluating resistance to infection of aboveground plant parts, it is important to determine the susceptibility of corms, tubers, and rhizomes. White mold is known to spread in storage on crops such as carrot (Koike, 2007). If corms, tubers, and rhizomes of tropical ornamentals were infected, similar spread in storage would be likely.

The objective of this study was to evaluate three commonly grown tropical ornamentals, canna, caladium, and elephant ear for potential resistance to S. sclerotiorum.

Materials and Methods

Plant materials for field studies. All plants were grown in a composted bark potting mix (Sungro Horticulture, Agawam, MA) with one plant per pot in a greenhouse with 12 h light at 25 °C and 12 h darkness at 20 °C before transplanting into field plots. Cultivars that are readily available to garden managers were chosen for the experiment. Corms of ‘Ruffles’ elephant ear, purchased from a local garden center, were grown in 25.4 cm round pots for 10 weeks. Tubers of ‘White Queen’ caladium that were 3.8 to 6.4 cm in diameter (Classic Caladiums, Avon Parks, FL) were grown for 5 weeks in 10.2 cm pots. Seeds of ‘Tropical White’ canna (Stokes Seeds Inc., Buffalo, NY) were planted 12 weeks before the start of the experiment in 10.2 cm pots. Zinnia elegans × anguissifolia ‘Profusion White’ seedlings, included as a known susceptible control, were purchased from a local garden center and transplanted into 10.2 cm pots two weeks before the start of the

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experiment. All plants had 2–5 fully expanded leaves at the time of transplant.

**Inoculum preparation.** Three isolates of *S. sclerotiorum* were used in the experiment: ORN010, isolated from a petunia plant in Chaska, MN; FC002, isolated from a soybean plant in Renville County, MN; and VEG001, isolated from green bean in Spring Valley, WI. Sclerotia of each isolate were produced and stored as described in Grabowski and Malvick (2015).

**Field studies of disease susceptibility.** All plant entries were transplanted on June 5 in a randomized complete block design with four replications on the Minnesota Agricultural Experiment Station, St. Paul campus. The experiment was conducted twice, in 2012 and 2013. Each experimental unit contained four plants of the same cultivar in two rows of two plants. Plants were spaced to create canopy closure at the same time despite differences in plant size. Zinnia and caladium plants were spaced 25.4 cm apart in 2012 and 2013, respectively, and elephant ear plants were spaced 20.6 cm apart in 2012 and 35.6 cm apart in 2013, respectively. Despite differences in plant size, Zinnia and *caladium* plants were spaced 25.4 cm apart to promote mycelial growth.

**Inoculation of foliage.** The experiment was a completely random design with two factors, isolate and plant entry, replicated three times with one plant per replication. An 8 mm square of agar containing the leading edge from one of the three isolates of *S. sclerotiorum* culture was placed between the plant stem and the petiole of the oldest leaf of the plant that was still green and healthy. Mock inoculated control plants were inoculated petioles were surface disinfested with an aqueous solution of 0.525% sodium hypochlorite, and five 1 cm cross sections were placed on 1/2 PDA and examined for the presence of *S. sclerotiorum* after 14 d incubation; any plant with infection of elephant ear petioles, the inoculation was repeated as described previously and moved to a growth chamber (Environmental Growth Chambers, Chagrin Falls, OH) with a 12 h photoperiod set to 13 °C to determine if resistance of the tropical plants persisted at the low end of the pathogen’s temperature range for infection (Bolton et al., 2006), which commonly occurs during the growing season in northern states. Symptoms were recorded 28 DAI. All inoculated petioles were surface disinfested with an aqueous solution of 0.525% sodium hypochlorite, and five 1 cm cross sections were placed on 1/2 PDA and examined for the presence of *S. sclerotiorum* after 14-d incubation at 22 °C. The experiment was conducted twice.

**Inoculation of elephant ear petioles.** Natural senescence of the outermost leaf in elephant ear plants confounded results in the foliar inoculation study. To determine if *S. sclerotiorum* can infect nonsenescent petioles of ‘Ruffles’ elephant ear, an 8 mm square of 1/2x PDA containing the leading edge of a culture of isolate ORN010 was placed midway between the base of the petiole and the base of the leaf. Parafilm® (Bemis Company, Inc., Oshkosh, WI) was wrapped around the inoculum and petiole to secure it to the plant. Each plant was inoculated on a newly expanded inner leaf, and the outermost, oldest leaf in the whorl. Mask inoculated controls received a sterile 8 mm square of 1/2x PDA. The experiment was a completely random design with three replications. Plants were inoculated as described previously and moved to a growth chamber (Environmental Growth Chambers, Chagrin Falls, OH) with a 12 h photoperiod set to 13 °C to determine if resistance of the tropical plants persisted at the low end of the pathogen’s temperature range for infection (Bolton et al., 2006), which commonly occurs during the growing season in northern states. Symptoms were recorded 28 DAI. All inoculated petioles were surface disinfested with an aqueous solution of 0.525% sodium hypochlorite, and five 1 cm cross sections were placed on 1/2x PDA and examined for the presence of *S. sclerotiorum* after 14-d incubation at 22 °C.
growing plants from seed for 20 weeks in greenhouse conditions as described previously. Corms of ‘Ruffles’ elephant ear were produced through production of offsets as described previously. Tubers of ‘White Queen’ caladium were purchased from a commercial caladium grower (Classic Caladiums, Avon Parks, FL). Tap roots of food grade carrots, Daucus carota subsp. sativus (Hoffm.) Schübl. & G. Martens, were included as a susceptible control.

All storage organs were wounded by creating a shallow 1 cm wide wedge with a sterile razor blade. A 1 cm square of 1/2x PDA containing the leading edge from a S. sclerotiorum culture, isolate ORN010, was placed directly on the wound. Mock inoculated controls received the same treatment with a sterile square of 1/2x PDA. Following inoculation, the storage organs were placed in a plastic bag, misted with distilled water, and the bags were kept sealed in a growth chamber set to 18°C for 14 h of light and 16°C for 10 h of darkness to optimize conditions for fungal growth and infection. At 10 DAI, samples were cut in half lengthwise and the extent of discolored and decomposing tissue was recorded based on the length of area that was symptomatic relative to the total length. A 1 cm square sample from the leading edge of the infection was removed, surface disinfested with an aqueous solution of 0.525% sodium hypochlorite, and plated on 1/2x PDA. Samples were incubated for 14 d at 22°C and then examined for the presence of S. sclerotiorum. The experiment was a completely random design with four replications and one plant per replication. The trial was conducted twice.

**Statistical analysis.** Data from controlled environment experiments, direct inoculation of storage organs, and field trials were combined after Hartley’s $F_{\text{max}}$ test demonstrated homogenous variance between repeated trials. Data from controlled environment experiments were analyzed as a factorial design using JMP software (SAS Institute, Inc., Cary, NC). Tukey’s honestly significant difference was used to separate means. Data from direct inoculation of storage organs and field trials were not normal and could not be corrected by standard data transformations; therefore, nonparametric methods were used to analyze the data. Friedman’s test was used to calculate a $\chi^2$ for the model and a $P$ value for treatments. Treatments with a $P$ value $\leq 0.05$ were compared using Wilcoxon’s rank testing to determine differences between treatments.

**Results**

**Studies under field conditions**

Disease incidence was 100% at 7 DAI for the susceptible control ‘Profusion White’ zinnia (Fig. 1). Disease severity (percent canopy killed) in zinnia plots increased in a monomolecular curve until 98% of the plant canopy was killed at 49 DAI (Fig. 2). Average incidence for canna and caladium was <60% throughout the duration of the trials. Incidence for elephant ear was 0% throughout both years (Fig. 1). Canopy death in caladium never exceeded 11% and no canopy death was recorded for canna or elephant ear in either year (Fig. 2). The AUDPC for incidence and severity was highest for zinnia followed by caladium, canna, and elephant ear (Table 1).

**Studies in controlled environments**

Incubation of foliage. Inoculated caladium cultivars had significantly greater disease severity than mock-inoculated controls. ‘White Queen’ caladium had significantly greater disease severity than all other plants tested. Disease severity of elephant ear and canna was not significantly different from mock-inoculated controls (Table 2).

Inoculated caladium petioles developed soft rot, resulting in wilt of one to several leaves as early as 7 DAI. Mycelia and sclerotia were commonly observed on infected petioles at 24 DAI. The infection progressed into the tuber on 44% of ‘White Queen’ caladium plants and 20% of ‘Fannie Munson’ caladium plants. Inoculated canna leaves developed dry brown necrotic lesions averaging 3.3 cm in length at the site of infection 24 DAI. This lesion resulted in wilt of the inoculated leaf in 8% of plants. Petiole infection of canna never progressed into the...
Table 1. Combined area under disease progress curve (AUDPC) for incidence and severity of white mold in field-inoculated ornamental tropical plants in 2012 and 2013.

| Plant                  | Cultivar     | Incidence AUDPC | Severity AUDPC |
|------------------------|--------------|-----------------|----------------|
| Zinnia elegans × zangastifolia | Profusion White | 170 a b | 3234.5 a |
| Calodium shortulanum | White Queen  | 78.4 b         | 129 b          |
| Canna × generalis | Tropical White | 81.6 b | 4.75 c |
| Colocasia esculenta  | Ruffles      | 0 c            | 0 c            |

Measurements within a column with the same letter are not significantly different at α = 0.001 by Wilcoxon’s rank test.

Table 2. Percent foliage wilted or killed at 24 d after inoculation by Sclerotinia sclerotiorum in a controlled environment.

| Scientific name                | Cultivar         | Treatment                | Percent leaf death |
|--------------------------------|------------------|--------------------------|--------------------|
| Calodium shortulanum           | White Queen      | S. sclerotiorum          | 65.4 a             |
| Calodium shortulanum           | Fannie Munson    | S. sclerotiorum          | 38.9 b             |
| Colocasia esculenta            | Ruffles          | S. sclerotiorum          | 21.1 b             |
| Colocasia esculenta            | Ruffles          | Mock-inoculated control  | 20.7 b             |
| Canna × generalis              | Tropical Yellow  | S. sclerotiorum          | 1.6 c              |
| Canna × generalis              | Tropical White   | S. sclerotiorum          | 0.9 c              |
| Canna × generalis              | Tropical Yellow  | S. sclerotiorum          | 0.0 c              |
| Calodium shortulanum           | White Queen      | Mock-inoculated control  | 0.0 c              |
| Canna × generalis              | Tropical Yellow  | Mock-inoculated control  | 0.0 c              |
| Calodium shortulanum           | Fannie Munson    | Mock-inoculated control  | 0.0 c              |

Measurements with the same letter are not significantly different at α = 0.001 by Tukey’s honestly significant difference test.

Table 3. Percentage of below ground storage organ rotten at 10 DAI after wound inoculation with S. sclerotiorum isolate ORN010.

| Scientific name   | Cultivar      | Storage organ | Percent plants infected | Percent storage organ tissue rotten |
|-------------------|---------------|---------------|-------------------------|-------------------------------------|
| Canna × generalis | Tropical White| Rhizome       | 0 b a                   | 0 b                                 |
| Colocasia esculenta | Ruffles  | Corn          | 0 b                     | 0 b                                 |
| Calodium shortulanum | White Queen  | Tuber         | 25 b                    | 11 b                                |
| Daucus carota subsp. sativus | unknown | Taproot       | 100 a                   | 48 a                                |

Measurements with the same letter are not significantly different at α = 0.001 by Wilcoxon’s rank test.

This study demonstrates for the first time that elephant ear and canna have significant resistance to white mold caused by S. sclerotiorum. Although the pathogen was able to colonize both plants to some degree, neither plant developed wilt or dieback in field or controlled environments. This is also the first report of susceptibility of caladium cultivars to white mold. The petioles, leaves, and tubers of tested cultivars were readily colonized by S. sclerotiorum, resulting in soft rot and production of sclerotia. Wilt and death of the canopy and the progression of the infection into tubers makes these cultivars of caladium unsuitable for use in landscape beds infested with S. sclerotiorum.

A significant difference in disease severity was observed between the two caladium cultivars in controlled environments, suggesting that there may be varying levels of resistance to S. sclerotiorum within cultivars of caladium. The pedigrees of many cultivars of Caladium ×hortulanum are unknown, but most are believed to originate from C. bicolor, C. picturatum, C. marmoratum, or C. schomburgkii (Deng et al., 2007). Future studies could be conducted to identify resistance in other caladium cultivars or species.

Canna is the sole genus in the family Cannaceae (Prince, 2011). Modern day cultivars of C. ×generalis are complex interspecific hybrids involving: C. indica, C. glauca, C. tridiflora, and C. varsciciizo (Khoshoo and Mukherjee, 1970). Although this study showed high levels of resistance in Canna to S. sclerotiorum, the study was limited to two varieties. Future studies should examine a broader range of varieties to determine if resistance is consistent across multiple varieties. In addition, orchid cannas (C. ×orchidoids), a complex hybrid involving the four previous species in C. ×generalis and C. flaccida (Khoshoo and Mukherjee, 1970) should be tested for susceptibility to S. sclerotiorum. It may be possible to determine the source of resistance by testing each parent species for resistance.

The results of this study show that susceptibility is not consistent in all members of the Araceae family. Caladium was highly susceptible to infection, suffering soft rot of leaves, petioles, and corneas, whereas elephant ear was highly resistant to infection by S. sclerotiorum. The pathogen infected only wounded or senescent tissue and did not result in significant symptoms under any conditions.

The Araceae includes a wide variety of ornamental plants for indoor and garden use, in addition to several important food crops. Within the Araceae, plants in two other genera are known to be susceptible to S. sclerotiorum: Philodendron spp. and Epipremnum aureum (Boland and Hall, 1994). Cabrera et al. (2008) proposed eight subfamilies of Araceae and Cusimano et al. (2011) proposed 44 clades of Araceae. Philodendron, Caladium, and Colocasia are in subfamily Aroidae. Epipremnum is in subfamily Monsteroideae. The four Aroid genera found to be susceptible to white mold are in different clades. This indicates that susceptible plants can be found in multiple subfamilies and that both resistant and susceptible plants occur in subfamily Aroidae. Future studies should examine multiple genera from the same clade to...
determine if resistance is specific to clade or genus.

This study demonstrates that elephant ear and canna are good candidates for planting in landscape beds infested with *S. sclerotiorum*. Canna varieties come in a wide range of heights, foliage, and flower colors, allowing them to be used in diverse landscape roles. Because of their large size, elephant ear plants could be used where space allows. Because the pathogen was able to colonize tissue of both elephant ear and canna, the use of these plants in infested landscape beds should include the removal of plants from the garden bed at the end of the growing season to minimize overwintering of the pathogen in infected plant debris.

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