Diseases of Anthurium

12

Anne M. Alvarez

Abstract

Anthuriums, characterized by a colorful spathe and spadix, are neotropical ornamentals belonging to the family Araceae. Nineteen *Anthurium* species with horticultural significance and value in breeding programs have been described, and among these, hybrids of two *Anthurium* species, *Anthurium andraeanum* Linden ex André and *A. antioquiense* Engler, are predominantly used in cut flower and/or potted plant production, respectively. Numerous hybrids of *A. andraeanum* Hort. and other species are grown throughout the tropics and are characterized by unique shapes and colors and a long shelf life. Bacterial pathogens have caused the most devastating diseases of anthurium and have limited the production of susceptible hybrids in Florida, the Caribbean, and the Pacific islands. Fungal and fungal-like diseases include anthracnose (black nose), foliage, and stem and root rots caused by *Phytophthora nicotianae*, *P. tropicalis*, and *Rhizoctonia solani*. Viral diseases have been described but do not cause appreciable economic damage. Anthurium decline caused by the burrowing nematode, *Radopholus similis*, currently poses a major challenge to anthurium production due to prohibition of available nematicides. Anthuriums can be successfully produced by constant vigilance and implementation of fully integrated disease management practices.

Keywords

Xanthomonas axonopodis pv. *dieffenbachiae* • *Ralstonia solanacearum* • *Acidovorax anthurii* • *Colletotrichum gloeosporioides* • *Pythium splendens* • *Phytophthora nicotianae* var. *parasitica* • *Rhizoctonia solani* • *Radopholus similis* • Integrated disease management

A.M. Alvarez (✉)
Department of Environmental Protection Sciences, University of Hawaii, Honolulu, HI, USA
e-mail: alvarez@hawaii.edu

R.J. McGovern, W.H. Elmer (eds.), *Handbook of Florists' Crops Diseases*, Handbook of Plant Disease Management, https://doi.org/10.1007/978-3-319-39670-5_13

Contents

1 Introduction

Anthurium belongs to the family Araceae, which includes *Aglaonema*, *Dieffenbachia*, *Epipremnum*, *Philodendron*, *Syngonium*, *Spathiphyllum*, *Xanthosoma*, and other aroids. More than 1500 species have been described from Southern Brazil through Central America, Mexico, and the Caribbean islands (Kamemoto and Kuehnle 2006). Two *Anthurium* species, *A. andraeanum* [sect. Calomystrium] (Fig. 1) and *A. antioquiense* [sect. Porphyrochitonium] (Fig. 2), are most commonly used in the cut flower and/or potted plant industry, respectively (Kamemoto and Kuehnle 1996). The latter species is characterized by an upright spathe and spadix (tulip type), and its hybrids are usually smaller and used commercially as potted plants. In contrast, *A. andraeanum* cultivars are characterized by a wider spathe and are used as cut flowers desired for their long shelf life. These two species show differential susceptibility to the most devastating disease of aroids, bacterial blight caused by *Xanthomonas axonopodis* pv. *dieffenbachiae* (Vauterin et al. 1995) [= *Xanthomonas campestris* pv. *dieffenbachiae* (McCulloch & Pirone) Dye]. Other important bacterial diseases are bacterial wilt caused by *Ralstonia solanacearum* and leaf spot caused by *Acidovorax anthurii*. Fungal diseases, including anthracnose, foliar spots, and root rots are those common to other crops. Viral diseases have been described but do not pose major production problems. In contrast, root damage caused by the burrowing nematode, *Radopholus similis*, is a serious hindrance to production and export due to the lack of effective registered nematicides. Cultural guidelines to optimize nutrition, production, and shipping have been described (Chen et al. 2003). Specific management practices for diseases of anthurium are provided in the text, and additional information may be found in the introductory chapters on integrated disease management.

Fig. 1 Characteristic spathe and spadix of *Anthurium andraeanum* Linden ex. Andre, progenitor of modern anthurium hybrids (H. Kamemoto © 2017. All Rights Reserved.)

Fig. 2 Characteristic spathe and spadix of *Anthurium antioquiense* Engler. This species is currently used as a source of resistance to bacterial blight. Primary hybrids between *A. antioquiense* and *A. andraeanum* are backcrossed to *A. andraeanum* to achieve desirable cultural characteristics with improved blight resistance (H. Kamemoto © 2017. All Rights Reserved.)

2 Fungal and Fungal-Like Diseases

2.1 Anthracnose (Also Called Black Nose or Spadix Rot) [*Colletotrichum gloeosporioides* (Penz.) Sacc.]

Geographic occurrence and impact. Anthracnose occurs worldwide on a number of tropical and subtropical crops. When first reported, anthracnose was widespread on the Island of Hawaii but rare on Oahu. Plant damage was not severe, but black spots on the spadix limited marketability and caused more than 50% loss of flowers (Aragaki and Ishii 1960; Aragaki et al. 1968). When disease incidence is high, the spadix deteriorates rapidly resulting in the typical "black nose" disease.

Symptoms/signs. Small dark angular spots first appear on individual flowers on the spadix infected with *Colletotrichum gloeosporioides* (Fig. 3). Necrosis of tepal tissue forms a diamond pattern as the disease progresses. [Tepals are perianth segments or fused sepals surrounding the base of the anthurium flower.] In most cases, there is little indication that the spots will fuse. However, at a high level of infection, a spadix may be covered with more than 50 spots. Under warm, wet conditions, the entire spadix may be covered with mycelium (Fig. 4).

Biology and epidemiology. *Colletotrichum gloeosporioides* produces large numbers of asexual spores in open fruiting structures (acervuli) on anthurium flowers. Spores require moisture for germination, penetration, and infection, and during the rainy season, the disease may become severe. The fungus also can infect petioles and pedicles directly through the cuticle and/or through wounds (Aragaki 1968). Acervuli are produced on dead leaves and stems, and spores are carried by air currents, irrigation water, and splashing rain to leaves and spathes of other plants.

Management

- ***Cultural practices*** – Anthracnose incidence increases during warm moist months and should be monitored closely when conditions of high humidity occur. Culturing anthuriums in a covered greenhouse to keep rain off the flowers reduces infection. Fungicidal sprays should be applied when disease reaches the economic threshold.
- ***Sanitation*** – Infected flowers and plant debris should be removed and burned.
- ***Fungicides* –** Weekly or biweekly sprays of mancozeb or thiophanate methyl are commonly used at the recommended dosages. Visible chemical residues are unsightly for ornamentals, requiring the added step of washing flowers to restore their appearance. As a result, use of chemicals is generally discouraged (Norman and Ali 2012). Soluble, non-residue fungicides are more effective when anthuriums are cultured under a roof (Aragaki 1968). Other fungicides that can be used include chemicals such as propiconazole, bitertanol, and prochloraz (UWI 2004–2016).

Fig. 3 Anthracnose symptoms on spadix of *Anthurium andraeanum* var. "Kauai" caused by *Colletotrichum gloeosporioides*. Note small eruptions, which are the true flowers, and the tepals or perianth segments, which are fused sepals surrounding the base of the flower. Dark angular spots are infected tepal tissue (T. Amore © 2017. All Rights Reserved.)

Fig. 4 Anthracnose or "black nose" symptoms on an anthurium spadix caused by *Colletotrichum gloeosporioides* (J. Uchida © 2017. All Rights Reserved.)

Fig. 5 Anthracnose or "black nose" on spadix of *Anthurium andraeanum* var. "Kaumana" used as a susceptible check for screening for "black nose" resistance in breeding trials (A. Martinez © 2017. All Rights Reserved.)

- ***Resistance*** – In the breeding program in Hawaii, hybrid selections were screened for anthracnose resistance prior to cultivar release. The varieties Kaumana, Kansako No. 1, and Kozuhara are highly susceptible, and Kaumana is used as a standard to rate resistance in other cultivars (Fig. 5). Nitta Orange and Uniwai have intermediate resistance, whereas Abe Pink, Kansako No. 2, and Marian Seefurth are highly resistant (Aragaki 1968). Most of the varieties produced in Hawaii have now been indexed for anthracnose, and a reasonably large selection of resistant cultivars is available. The University of Florida also has a wide range of resistant cultivars (Norman and Ali 2012).
- ***Integrative strategies*** **–** Anthracnose can be effectively managed through the combination of cultural practices, fungicidal sprays, and deployment of resistant cultivars.

2.2 Stem and Root Rots (*Pythium splendens* Braun, *Phytophthora tropicalis*, and *Phytophthora nicotianae* var. *parasitica*)

Geographic occurrence and impact. *Phytophthora* and *Pythium* are fungus-like oomycetes which form motile spores (zoospores) and require free water for multiplication and infection. These pathogens occur worldwide and cause considerable damage to susceptible crops.

Symptoms/signs. Early symptoms of root damage are yellowing and necrosis of leaves and spathes and necrosis at the base of the plant (Fig. 6). Leaves show characteristic water-soaked lesions (Fig. 7). Stems and leaves lose turgor, wilt, and deteriorate. The spadix also may be infected (Fig. 8), and the spathe will eventually decay (Fig. 9). Roots of affected plants have dark patches of decay. Sloughing off of root tissue is characteristic of several types of root diseases, and culture of the fungus is required for an accurate diagnosis.

Biology and epidemiology. *Phytophthora* and *Pythium* are oomycetes which form motile spores (zoospores) and require free water for multiplication and infection. Thus, as with most soilborne diseases, water-saturated soils are conducive to disease development.

Management

- ***Cultural practices*** – Use disease-free stock plants and light, well-drained, synthetic soil mixes.
- ***Sanitation*** **–** Plants with brown roots or other disease symptoms should be discarded. Benches and propagation equipment should be disinfested. Cutting shears, knives, and tools should be dipped in an appropriate disinfectant between plants (refer to ► Chap. 9, "Sanitation for Management of Florists' Crops Diseases").
- ***Fungicides*** **–** Fungicide drenches are commonly used to control *Pythium* and *Phytophthora*. Fungicides such as mefenoxam, aluminum tris/fosetyl-al, dimethomorph, fluopicolide, and phosphorous acid have been effective.

Fig. 6 Necrosis and decay of anthurium leaves caused by *Phytophthora nicotianae* (J. Uchida © 2017. All Rights Reserved.)

Fig. 7 Leaves of Pigtail anthurium (*A. scherzerianum*) showing decay due to *Phytophthora nicotianae* (J. Uchida © 2017. All Rights Reserved.)

- ***Soil disinfestation –*** Steam-sterilization of potting media is a common management method for soilborne diseases, and potting media should be treated with a fungicide drench. If containers are reused, they should be scrubbed and sterilized.
- ***Integrative strategy*** – A combination of all above control measures is needed for successful production.

2.3 Rhizoctonia Root Rot and Vascular Wilt (*Rhizoctonia solani*)

Geographic occurrence and impact. *Rhizoctonia* is a soilborne fungus that attacks the roots of numerous crops worldwide. The fungus often is associated with damping-off diseases that kill plantlets pre- or postemergence. Rhizoctonia root rots and damping-off diseases are a long-standing and well-known problem for nursery growers and can cause up to 100% loss of seedlings.

Symptoms/signs. *Rhizoctonia solani* attacks roots and lower portions of anthurium stems causing discoloration and rot. Leaves also are affected under particularly wet conditions when severe infections cause blight and decay. The presence of

Fig. 8 Dark angular flecks on spadix tissue caused by *Phytophthora tropicalis* (J. Uchida © 2017. All Rights Reserved.)

characteristic mycelial strands in decayed roots is a diagnostic feature that distinguishes *Rhizoctonia* infections from those caused by *Pythium* and *Phytophthora*.

Biology and epidemiology. *Rhizoctonia* produces mycelial mats containing resting structures (sclerotia) that are resistant to desiccation and low temperatures, permitting the fungus to survive for many years in soil in the absence of a susceptible host. These small, irregular brownish structures resemble soil particles and stick to surfaces of pots and other greenhouse materials without detection (Norman and Ali 2012). Plants are more susceptible to infection when soils are wet and roots are not well aerated.

Management

- ***Cultural practices*** – Provide good drainage and avoid waterlogged soils. Cultivate plants on raised benches.
- ***Sanitation*** **–** Disinfect pots, benches, and tools with appropriate materials, and use pathogen-free soils or pasteurize soils before use. Assure that propagation materials are pathogen-free and have no brown spots or areas of discoloration on

Fig. 9 Distorted spathe of Pigtail anthurium (*A. scherzerianum*) infected by *Phytophthora nicotianae* (J. Uchida © 2017. All Rights Reserved.)

roots. Potting media and additives such as wood chips and sphagnum moss should not be stored in contact with native soil.

- ***Fungicides*** – Several fungicides are active against *Rhizoctonia*, including thiophanate methyl, fludioxonil, and flutolanil (Norman and Ali 2012).
- ***Soil disinfestation*** – Soils and media mixes should be steam-sterilized prior to use. Chemical drenches (above) may be applied after plants have been established.

3 Bacterial Diseases

3.1 Anthurium Blight (*Xanthomonas axonopodis* pv. *dieffenbachiae* Vauterin et al. 1995) [= *Xanthomonas campestris* pv. *dieffenbachiae* (McCulloch and Pirone) Dye]

Geographic occurrence and impact. The disease was first reported in Brazil (Robbs 1960). In 1972 Hayward reported foliar symptoms on *A. andraeanum* at a few sites on the island of Kauai caused by a xanthomonad he then identified as *Xanthomonas* *dieffenbachiae* (McCulloch & Pirone) Dowson (Hayward 1972). Anthurium blight, which includes both foliar and systemic phases of the disease, reached epidemic proportions and killed thousands of plants on the island of Hawaii between 1981 and 1985 (Nishijima and Fujiyama 1985; Nishijima et al. 1988). The epidemic reduced the number of anthurium growers from over 200 to fewer than 10 within 4 years (Shehata et al. 1989; Figs. 10, 11, and 12). Anthurium blight also was reported in California (Cooksey 1985), Venezuela (Guevara and Debrot 1985), Guadeloupe and Martinique (Hostachy et al. 1985), French West Indies (Prior et al. 1985), French Antilles (Rott and Prior 1987), Florida (Chase 1988), Jamaica (Young 1990a b), Tahiti (Mu 1990), the Philippines (Natural 1990), India and the Netherlands (Sathyanarayana et al. 1998), and Reunion Island (Soustrade et al. 2000). Bacterial blight continues to be a destructive disease in most anthurium production areas worldwide.

Symptoms/signs. The first symptoms of a foliar infection are small water-soaked spots at leaf margins which later become chlorotic (Nishijima 1985). Initial infection may occur through stomates and/or hydathodes (openings at leaf margins which lead directly to vascular tissues) (Figs. 13 and 14). Bacteria which enter stomates are generally restricted to mesophyll cells in the leaf, whereas infections occurring through hydathodes lead to rapid colonization of vascular tissue and progression through veins to petioles and the base of the plant, where bacteria can enter uninfected petioles and move upward into newly developing leaves (Alvarez et al. 2006). Systemically infected plants initially show yellowing and wilt followed by

Fig. 10 Anthurium culture under saran with 70% shade in Hawaii (A. Alvarez © 2017. All Rights Reserved.)

Fig. 11 Yellowing and necrosis on leaves of systemically infected plants, *Anthurium andraeanum* var. "Marian Seefurth" (R. Lipp © 2017. All Rights Reserved.)

Fig. 12 Field of *Anthurium andraeanum* var. "Paradise Pink" showing ~30% loss of plants due to bacterial blight (A. Alvarez © 2017. All Rights Reserved.)

Fig. 13 Water-soaked lesions surrounded by a yellow halo on the upper side of *A. andraeanum* leaf. At the top left, marginal water-soaking and chlorosis are evidence of invasion through hydathodes. The distinctly circular lesions distributed irregularly over the leaf surface are evidence of stomatal invasion (A. Alvarez)

rapid decline and death of the entire plant (Figs. 15, 16, and 17). Symptoms usually do not appear immediately after infection, giving rise to latent infections which are very difficult for the grower to assess. Colonization of leaf tissue by a bioluminescent strain of *X. axonopodis* pv. *dieffenbachiae* is detected in the dark by covering leaves with sensitive X-ray film, which turns black on exposure revealing the presence of the light-emitting pathogen (Fukui et al. 1996). Stages of disease progress 2–5 weeks after inoculation on plants maintained in a greenhouse at 30–35° C/86–95° F as shown in (Fig. 18). Symptom expression at different stages of disease development varies depending on temperature and other stress factors (Alvarez et al. 2006; Norman and Ali 2012).

Biology and epidemiology. The host range of *Xanthomonas axonopodis* pv. *dieffenbachiae* is generally restricted to aroids (members of the family Araceae). Bacterial strains associated with anthurium blight showed considerable diversity when characterized by bacteriological, serological, and pathogenicity tests (Alvarez et al. 1988; Lipp et al. 1992). Strains initially isolated from anthurium had a broader host range and were generally more virulent than strains isolated from other aroids, such as *Aglaonema*, *Colocasia*, *Epipremnum*, *Syngonium*, and *Xanthosoma* (Lipp et al. 1992). The pathogen also forms various subgroups which are genetically

Fig. 14 Circular water-soaked lesions on the underside of the leaf rarely show chlorosis. Elongated water-soaked lesions at the leaf margins are evidence of invasion through hydathodes. Chlorotic areas border the water-soaked tissues, which later become necrotic (A. Alvarez © 2017. All Rights Reserved.)

distinct (Louws and Alvarez 2000; Khoodoo et al. 2004). The bacteria are spread through contaminated cutting tools, hands, and clothing and through aerosols when sprinkler or rainwater impacts infected leaves. The most common means of spread is through latently infected propagative materials in which the presence of the pathogen is detected by specific immunodiagnostic assays (Alvarez et al. 1991). The impact is difficult to assess because plants appear healthy but nevertheless can result in widespread contamination of healthy stocks on planting benches and later kill the crop (Norman and Alvarez 1996). *Xanthomonas axonopodis* pv. *dieffenbachiae* can survive as latent infections in tissue-cultured microplants, and triple indexing is needed to ensure that pathogens are eliminated (Norman and Alvarez 1994). Nevertheless, pathogen-free microplants which are subsequently infected on the greenhouse bench may become systemically colonized without manifesting foliar symptoms (Ayin et al. 2016).

Management

- ***Cultural practices*** – Use of pathogen-free propagative materials is an important step for blight control. Tissue-cultured pathogen-free microplants are available from various commercial and private sources. Nevertheless, to reduce production

Fig. 15 Leaf margin of *A. andraeanum* showing water-soaking, necrosis, and chlorosis which progresses inward toward the midrib (A. Alvarez © 2017. All Rights Reserved.)

costs, growers continue to make cuttings from symptomless planting stocks, which may harbor latent infections that may not appear up for to 10 months after planting, so the latter practice, though less expensive, is risky (Norman and Alvarez 1996). Higher temperatures reduce the incubation period and increase leaf colonization by the pathogen (Fukui 1999a). Lowering shade-house temperatures through aeration or locating anthurium production at high elevations with corresponding cooler lower temperatures (18–24° C/64–75° F) reduces disease outbreaks.

- ***Sanitation*** – Destruction of infected plants and disinfestation of pruning and harvesting tools are essential to cut flower production. Tools are soaked in disinfectants for 30–60 s before touching the next plant, so fieldworkers may carry two to three tools or commercially available dispensers which permit sufficient bactericidal action between cuts. Commercially available disinfectants are generally broad-spectrum biocides.
- ***Fungicides/bactericides*** **–** Antibiotic sprays (streptomycin sulfate at 200 ppm combined with 200 ppm tetracycline) were initially used to retard the spread of bacterial blight, but the cost and potential development of antibiotic resistance in the bacterial population discouraged the use of antibiotics (Nishijima 1988). By increasing the dose and frequency of sprays, treated plants were protected and

Fig. 16 Anthurium leaf showing advanced necrosis and desiccation of tissues at leaf margins (A. Alvarez © 2017. All Rights Reserved.)

produced flowers in a field where no other plants survived (Fig. 19). In a field study research conducted in Hawaii, plants were sprayed six times over 3 weeks with high doses of streptomycin sulfate and tetracycline; then treatments were discontinued. Leaves became white and bleached following the applications, but foliage later recovered, the natural green color was restored, and plants survived and produced flowers. No resistant bacterial strains were detected 2 months following the last application (Alvarez et al. 1989). Nevertheless, field applications of antibiotics were abandoned and replaced by integrated pest management strategies that included a long list of improved production strategies including use of pathogen-free tissue-cultured planting stocks and strict surveillance when plants were propagated from cuttings (Alvarez et al. 1994). Judicious use of antibiotics is nevertheless warranted and can be effective for decontaminating planting stocks and protecting young plants on propagation benches (Vannini 2010). Products containing copper, mancozeb, and *Bacillus subtilis* are effective against *Xanthomonas* (Norman and Ali 2012). Anthurium leaves are sensitive to the high concentrations of copper used to reduce spread of other bacterial diseases caused by *Xanthomonas* so copper compounds must be used with attention to potential damage. Treatments with fosetyl aluminum 7 days prior to inoculation

Fig. 17 Late stages of foliar infection resemble symptoms of severe water stress (A. Alvarez © 2017. All Rights Reserved.)

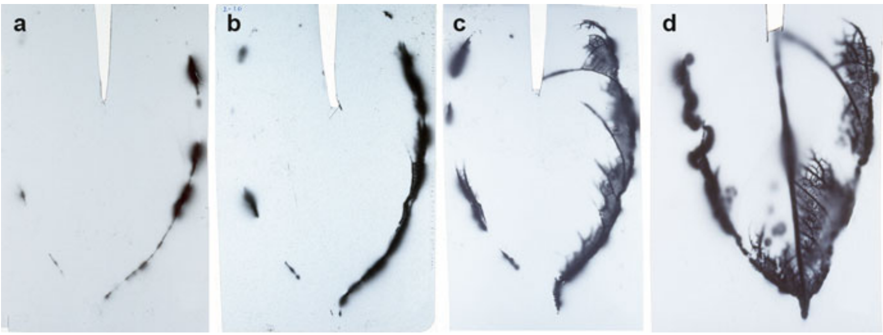

Fig. 18 Autophotographs of the same *Anthurium andraeanum* leaf taken successively 2, 3, 4, and 5 weeks after inoculation with a bioluminescent strain of the pathogen, *Xanthomonas axonopodis* pv. *dieffenbachiae*. (**a**) Two weeks after inoculation, dense areas of bacterial colonization are visible along the leaf margins; (**b**) 3 weeks after inoculation, the right leaf margin has been completely colonized, and bacteria are moving into the veins; (**c**) 4 weeks after inoculation, bacteria have colonized major veins. Bacteria in the topmost vein have reached the petiole, marked by the slit in the X-ray film; (**d**) 5 weeks after inoculation, the midrib has been colonized by bacteria coming from separate veins. The dichotomous pattern of veinlets is revealed when the X-ray film is exposed by bioluminescing bacteria (R. Fukui © 2017. All Rights Reserved.)

Fig. 19 High concentrations of antibiotics were used in early attempts to retard the progress of bacterial blight. Plants in treated rows (marked with signs) were the only surviving plants in a field of infected anthuriums (A. Alvarez © 2017. All Rights Reserved.)

with *X. axonopodis* pv. *dieffenbachiae* significantly reduced infection, possibly due to a concurrent drop in cellular pH from ~ 6.4 to ~5.4 (Alvarez et al. 1991).

- ***Biological control*** – Mixtures of antagonistic leaf-inhabiting bacteria have been successfully used to significantly reduce onset and spread of bacterial blight in the greenhouse and field (Fukui 1999b, c; Toves et al. 2008; Vowell 2009). A combination of four different species of bacterial antagonists sprayed to runoff at weekly intervals reduced field spread of disease to the same degree as application of chemical bactericides (Toves 2008; Vowell 2009). Specific combinations of the beneficial bacteria enhanced microplant growth (Fig. 20) and protected leaves from infection under the moist conditions on propagation benches (Toves 2008; Vowell 2009). Mixtures of beneficial bacteria can be efficiently prepared in the laboratory and applied to microplants when they are deflasked from axenic culture. Microplants are soaked for 30 min in a mixture of four bacterial species and then planted into community pots (Vowell 2009). Although these bacterial strains have yet to be formulated for large-scale commercial use, they have been consistently effective in greenhouse trials (Toves 2008; Vowell 2009).
- ***Soil disinfestation*** – Undecomposed plant materials remaining in infested fields are a major inoculum source for the subsequent crop although xanthomonads generally do not survive for long periods (< 6 weeks) in moist soil. Crop rotation, removal of infected plant debris, and frequent irrigation to accelerate

Fig. 20 Biological control can be achieved by immersing microplants in a mixture of beneficial bacteria immediately after deflasking. Growth enhancement of microplants (20 plants per pot) observed 6 weeks following the initial treatment is an added benefit. The top two community pots contain treated microplants; plants in the two lower pots were nontreated (A. Alvarez © 2017. All Rights Reserved.)

decomposition of anthurium residues are more effective than fumigation, although the latter practice is used for heavily infested fields (Vannini 2010).

- ***Resistance*** – Bacterial blight resistance in commercial anthuriums has been developed by hybridizing highly resistant *A. antioquiense* and its progeny with the more susceptible varieties of *A. andraeanum*. The classical strategy for developing resistance in the highly desired *A. andraeanum* cultivars was hybridization between the two species and subsequent backcrossing to *A. andraeanum* while selecting for desired qualities such as large spathe size, yield, novelty, color, and long shelf life. *Anthurium amnicola*, a new species discovered in 1972 by Robert L. Dressler in Coclé del Norte, Panama, has also been used as a source of blight resistance. The small lavender spathe is upright when young and bends downward as the flowers on the spadix mature (Fig. 21). This species has been used as a parent for variety development for potted plant production. Three hybrids, ARCS, ARCS Hawaii, and Lavender Lady, which are one-eighth *A. andraeanum* Hort. and one-half *A. amnicola* are resistant to the systemic phase of bacterial blight (Fukui et al. 1998; Amore, *personal communication*). Crosses between *A. andraeanum* and the miniature (dwarf) species, *A. antioquiense*, have resulted in relatively resistant compact hybrid *Anthurium* varieties that are widely used for potted anthurium production in Florida. In Hawaii, where the larger spathes of *A. andraeanum* are preferred, *A. andraeanum*-type hybrids are crossed with *A. antioquiense* and then backcrossed to *A. andraeanum* to produce hybrids with

Fig. 21 *Anthurium amnicola*, a new species discovered in 1972 by Robert L. Dressler in Coclé del Norte, Panama (T. Amore © 2017. All Rights Reserved.)

greater blight resistance yet having larger and broader spathes. Bacterial blight remains a constant challenge to production, but with integrated practices, the disease can be controlled. Various methods have been developed for rapid screening of hybrids in order to select cultivars with greater resistance (Fukui et al. 1998; Elibox and Umaharan 2008a, b, Elibox and Umaharan 2010; Ayin et al. 2016). Genetic engineering approaches have also been used to produce transgenic plants with blight resistance (Kuehnle et al. 2004a, b), but to date, no transgenic varieties are commercially available.

- ***Integrated management strategies*** – Anthurium blight has been successfully managed using a combination of approaches that start with pathogen-free planting stocks, disease-free fields, and rigorous sanitation (Alvarez et al. 2015). Tissue-cultured plantlets confirmed to be pathogen-free by triple indexing should be used as planting stocks. Leaf surfaces should be kept as dry as possible to avoid bacterial spread through aerosols and wounds. When overhead irrigation is used on propagation benches, biocontrol agents or biocides can be applied to closely growing microplants to reduce pathogen spread via irrigation water and aerosols. Frequent inspection followed by roguing of symptomatic plants from propagation benches and shade houses is essential. Decontamination of tools and worker's clothing is a standard practice, and highly susceptible plants are often cultivated and harvested separately in order to prevent spread to other sites. Highly susceptible cultivars are grown at higher elevations in the tropics where cooler temperatures (18–24° C/ 64–75° F) retard disease expression as well as plant growth. In warmer climates, growers often focus on the dwarf tulip-type hybrids that have greater blight resistance. A complete list of these and other disease management strategies for anthurium and other aroids with a clear rationale for each has been provided by Vannini (2010). Integrated disease management practices that have led to a productive industry in Florida have been described by Norman and Ali (2012).

3.2 Bacterial Wilt [*Ralstonia solanacearum* Smith (Yabuguchi 1995)]

Geographic occurrence and impact. *Ralstonia solanacearum* is a generally warm-weather pathogen present worldwide, predominantly in tropical and subtropical environments, but cold-tolerant strains also are prevalent in Europe. Anthuriums in Florida are affected by a group of strains formerly designated as race 1 and later more fully characterized as Race 1 Biovar 1 Phylotype II (Norman et al. 2009). A new strain of *Ralstonia solanacearum* (Phylotype II – sequevar 4NPB) was identified in 2002 during the dry season on a farm in Trinidad where local pink, white, and red cultivars were affected (University of the West Indies 2004–2016). *Ralstonia solanacearum* (race 1) was detected in the Netherlands on imported anthuriums in August 2015. Bacterial wilt of anthurium has not been observed in Hawaii or other islands of the Pacific although *R. solanacearum* is destructive on other crops throughout the Pacific and Asia.

Symptoms/signs. The first signs of bacterial wilt resemble water stress. Lower leaves of plants are yellow and petioles are flaccid. The bacteria colonize the vascular system rapidly causing stems and leaf veins to show a bronze color. A cross section of the stem or petiole will reveal vascular browning accompanied by abundant bacterial ooze, which is cream to brown in color. Plants do not recover after additional irrigation. As the disease progresses, leaves and stems become necrotic and plants die (Norman and Ali 2012; Figs. 22 and 23).

Biology and epidemiology. *Ralstonia solanacearum* spreads throughout anthurium farms via contaminated soil, water, tools, shoes, or worker contact with infected plants (Norman and Ali 2012). The bacteria survive for long periods in contaminated soil and are easily spread via infected cuttings. Detection of low

Fig. 22 Bacterial wilt of anthurium caused by *Ralstonia solanacearum* (D. Norman © 2017. All Rights Reserved.)

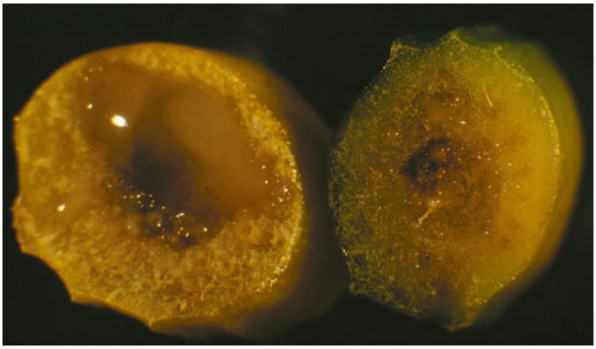

Fig. 23 Vascular discoloration and bacterial ooze of an anthurium infected with *Ralstonia solanacearum* (D. Norman © 2017. All Rights Reserved.)

populations in soil and potting medium has been improved by the development of specific immunodiagnostic and molecular assays (Paret et al. 2010b; Kubota et al. 2011a, b, c). Plants may be symptomless during cool weather, giving time for bacteria to colonize additional plants as latent infections (Norman and Ali 2012). Wilt symptoms generally appear rapidly during warmer weather (above 28° C/82° F).

Management

- ***Cultural practices*** – Use of pathogen-free propagation material followed by a strict sanitation program is needed to stop disease spread and eventually eradicate it from a production facility.
- ***Sanitation and plant quarantine*** – Sterilization of knives and clippers with a disinfectant containing a quaternary ammonium compound or diluted solution of bleach to prohibit spread is recommended (Norman and Ali 2012). Contaminated plant material and the supporting soil should be discarded. Soil should be removed completely from contaminated pots and trays followed by soaking in a bactericidal disinfectant. In the Netherlands, all imported anthurium planting stocks are screened for pathogens. Following the early detection of *Ralstonia solanacearum* on anthuriums in the Netherlands, eradication measures were undertaken immediately and affected plants were destroyed. All plants in two neighboring rows on either side of the infected plant were also destroyed. Specific hygiene measures for staff, equipment, and storage containers were imposed on companies that had infected plants. In addition, a specific surveillance program to confirm the absence of *Ralstonia* in anthurium plants was planned. (NPPO 2015).
- ***Fungicides/bactericides*** – Fungicides that contain phosphorous acid protect geranium plants from new infections, but once plants are systemically colonized by the pathogen, these chemicals are no longer effective (Norman et al. 2006).
- ***Soil disinfestation*** – Bacterial wilt of other crops (tomato, pepper, ginger) has been reduced through application of oil extracts of thyme, lemongrass, or palmarosa, all of which have biocidal activity against the common pathogen, *Ralstonia solanacearum* (Paret et al. 2010a; Pradhanang et al. 2003). As this

pathogen is not specific to anthurium, the same control measures should be effective for potted anthuriums. Botanicals are most effective in potting soils where soil applications can be closely monitored.

3.3 Bacterial Leaf Spot [*Acidovorax anthurii* (Referred to Earlier as Pseudomonas Blight)]

Geographic occurrence and impact. Bacterial leaf spot was first observed during the 1980s in Guadeloupe and Martinique (French West Indies) and Trinidad (Prior et al. 1985; Prior et al. 1986; Prior and Rott 1987) and confirmed in the 1990s in Trinidad and Tobago (Dilbar 1992; Gardan et al. 2000). The disease has not been observed in Hawaii or the Pacific islands. Bacterial leaf spot can cause extensive damage particularly during early stages of crop development, resulting in decreased cut flower production. Similar to bacterial blight, the labor and materials needed to control bacterial leaf spot are expensive, and this disease is responsible for decreased flower production in the Caribbean.

Symptoms/signs. Angular water-soaked leaf spots first appear on the undersides of leaves followed by necrosis of leaf tissue. Leaf lesions are surrounded by a chlorotic halo, typical of many leaf spot diseases caused by bacterial pathogens (Figs. 24 and 25). Lesions may expand to cover broad patches of leaf tissue which turns brown and becomes distorted. When the spathes are affected, the halos are often violet rather than yellow (Fig. 26). During periods of high humidity, bacterial ooze may emerge from margins of affected tissues. The disease also can become systemic when bacteria colonize vascular tissues. Water-soaked tissues occur at the junction between the petiole and veins resulting in leaf decay and abscission of flowers. Water-soaking also occurs at leaf margins, veins, and midribs. Multiple suckers may

Fig. 24 Bacterial leaf spot of anthurium caused by *Acidovorax anthurii* showing leaf spot and chlorotic halo (P. Rott © 2017. All Rights Reserved.)

Fig. 25 Anthurium leaf showing necrotic lesions caused by *Acidovorax anthurii* (P. Rott © 2017. All Rights Reserved.)

Fig. 26 Necrosis of the anthurium spathe caused by *Acidovorax anthurii* (P. Rott © 2017. All Rights Reserved.)

arise from the base of a dying plant, but they do not always show symptoms and may harbor latent infections (UWI 2004–2016).

Biology and epidemiology. *Acidovorax anthurii* is similar to bacterial pathogens in the genus *Pseudomonas* which are generally transmitted by watersplash, aerosols, and irrigation water. The bacteria survive in contaminated soils and are carried to healthy plants on tools and workers' hands, shoes, and clothing if plants are handled when wet.

Management

- ***Cultural practices*** – Propagative materials should be thoroughly inspected to ensure that they are pathogen-free and do not harbor latent infections. Avoid handling plants when fields are wet.
- ***Sanitation*** – Infected leaves and flowers should be removed and burned. When disease has become systemic, entire plants should be removed with the surrounding soil. Tools and clothes can be disinfected with 70% alcohol. Sodium

hypochlorite (10%) can be used for boxes and benches, but because it is corrosive, metal tools and equipment are better disinfested with alcohol or quaternary ammonium compounds or other disinfectants.

- ***Fungicides/bactericides*** – Leaves can be sprayed with copper fungicides to reduce infection, but some anthurium cultivars are sensitive to copper compounds and plants should be inspected for signs of phytotoxicity.
- ***Resistance*** – The search for resistant cultivars is underway at the St. Augustine campus of the University of the West Indies (Holder 2006). A two-phase screening method has been applied in an effort to determine sources of resistance. Several varieties have been identified that will be used in the future breeding program (UWI 2004–2016).

4 Viral Diseases

Viral diseases have been reported on anthurium, but following the advent of tissue culture to produce virus-free plantlets, they rarely have caused major problems for commercial anthurium production. Dasheen mosaic virus (DsMV) is an aphid-borne potyvirus virus that occurs worldwide and has been reported on 13 genera in the family Araceae (Zettler et al. 1970). Anthurium seedlings were susceptible following inoculation, but naturally infected anthuriums were not found in Florida (Hartman and Zettler 1972). DsMV is prevalent on taro, an edible aroid and important tropical food crop in the Pacific (Hu et al. 1995), but this virus is rarely found on anthurium. Although DsMV was reported on *Anthurium andraeanum* in Hawaii (Raabe et al. 1981), the virus did not cause major losses for the anthurium industry. Cucumber mosaic virus (CMV) caused severe mosaic and leaf deformation in commercial anthurium production in Brazil (Miura et al. 2013). Tomato spotted wilt virus (TSWV) vectored by a number of thrips species is occasionally observed on anthurium in Hawaii (Uchida et al. 1999) (Figs. 27 and 28).

Fig. 27 Concentric rings of chlorosis and necrosis on *Anthurium andraeanum* leaf caused by tomato spotted wilt virus (*TSWV*) (J. Uchida © 2017. All Rights Reserved.)

Fig. 28 Symptoms of TWSV at later stage showing broad patches of necrotic and chlorotic tissue (J. Uchida © 2017. All Rights Reserved.)

5 Nematode Diseases

5.1 Anthurium Decline [Burrowing Nematode, *Radopholus similis* (Cobb) Thorne]

Geographic occurrence and impact. Burrowing nematode is a migratory endoparasite which occurs throughout the tropics and subtropics and feeds on roots of many plants including anthurium. *Radopholus similis* was first reported on anthurium in Hawaii (Sher 1954) where it caused a severe decline and continues to be a major problem during wet seasons. Root feeding by the nematode increases the incidence of secondary root rots and results in poor plant growth, decreased cut flower production, and decreased flower size and quality (Aragaki et al. 1984; Sipes and Lichty 2002). Burrowing nematode also is a problem in the West Indies and in anthurium glasshouse production in Europe, North America, and Japan (UWI 2004–2016).

Symptoms/signs. Small leaves and flowers, premature leaf yellowing, and poor plant vigor are characteristic of decline. Plants are stunted and lower leaves are yellow and dry, showing signs typical of nutrient deficiency (Fig. 29). Stems, petioles, and peduncles are abnormally short, and the declining plants develop few suckers. Roots will have light orange lesions which later turn dark brown (Fig. 30). Basal stems and roots show severe rot about 6 months after initial infection (UWI

Fig. 29 Plant damage caused by burrowing nematode, *Radopholus similis* (T. Amore © 2017. All Rights Reserved.)

Fig. 30 Anthurium decline, caused by *Radopholus similis*, is characterized by stunting and necrosis of cataphylls (bract-like coverings of the stem). Burrowing nematodes feed on the roots causing elongated lesions (B. Sipes © 2017. All Rights Reserved.)

2004–2016). Dark lesions occurring on the stem just above the soil surface is a clear distinction between burrowing nematode damage and root rot caused by *Phytophthora* or *Rhizoctonia*. The nematodes will be visible with a dissecting scope.

Biology and epidemiology. Burrowing nematodes do not spread more than a few cm a year on their own, but they are moved relatively long distances by irrigation water, rain, or subsurface water movement. Nematodes can also be moved in infected planting material. Once nematodes penetrate the roots, they can spread to stem tissues and leaf petioles. As stem cuttings may be contaminated with *R. similis*, they are not considered reliable nematode-free propagation materials (Wang et al. 1999).

Management

- ***Cultural practices*** – Use of nematode-free planting materials is essential to disease management. Growing media should be steam-sterilized prior to use. The possibility of spread on footwear, tools, and equipment can be reduced through worker-awareness practices and by disinfecting items with appropriate biocides.
- ***Sanitation*** – Infected plant materials should be destroyed. Tissue-cultured anthurium plantlets can be used to ensure that planting materials are nematode-free (Higaki et al. 1995).
- ***Nematicides*** – Use of chemical nematicides is strictly regulated, and few effective nematicides are available for anthurium. In Hawaii, drenches with fenamiphos were effective in reducing root damage and enhancing plant growth (Fig. 31). Declining plants treated with fenamiphos produced 50% more flowers after 1 year, and the commercial value of the flowers from treated plants was approximately 60% greater. Although they are effective, chemical nematicides have restricted use, and availability will vary depending on location. In the Caribbean, growers may apply the nematicide aldicarb with a knapsack sprayer at manufacturer's specifications (5–10 g/m^2) (UWI 2004–2016). Applications are limited because aldicarb is highly toxic, and growers are advised to limit entry into treated fields during 3 months following treatment and then usually just to harvest mature cut flowers. Other chemicals such as oxamyl (3–5 L/ha) may be applied and repeated every 3 weeks.
- ***Control with natural products*** – Restrictions on use of chemical nematicides and subsequent lack of availability have stimulated research into greater exploration of natural products. Plant extracts from neem (*Azadirachta indica*) and leucaena (*Leucaena leucocephala*) are toxic to *R. similis* when applied to soils at 500 g/l and have been used in Trinidad and Tobago. Similarly, natural products (chitin, hydrolyzed protein, fatty acid-based products, and ground sesame plants) have been investigated for efficacy in burrowing nematode management on anthurium in Hawaii (Sipes and Delate 1996). None of the compounds tested reduced burrowing nematode damage as effectively as the synthetic nematicide, fenamiphos. However, ground sesame plant at 258 kg/ha reduced root and stem damage as compared to the untreated control (Fig. 32).
- ***Soil and root disinfestation*** – Nematodes in soil and plant debris were eliminated after a 3–6-month bare-soil, weed-free fallow period to achieve thorough

Fig. 31 Improved root and plant growth of anthurium plants treated with the nematicide fenamiphos (*left*) compared with the nontreated plants (*right*) (M. Aragaki © 2017. All Rights Reserved.)

Fig. 32 Reduced root damage and increased plant size (plant on *right*) following treatment with ground sesame plant used to reduce damage due to burrowing nematode. The nontreated plant is on the *left* (B. Sipes © 2017. All Rights Reserved.)

decomposition of plant parts (Hara et al. 2004). Hot water drenches can be used to disinfest roots of potted anthuriums. Temperature sensitivity of specific anthurium cultivars must be considered before applying hot water treatment to control burrowing nematode. Most cultivars are heat tolerant but “Marian Seefurth” may show some reduction in growth after 3 months. (Tsang et al. 2004). Roots and media should be drenched continuously in hot water (50° C/122° F) for 5–20 min depending on the severity of the infection and the heat tolerance of the anthurium cultivar. After 2 months, a second drench can be applied to further reduce the nematode populations. It is not necessary to treat bare roots by removing the soil (Tsang et al. 2004). Hot air at 50° C/122° F, 60% RH for 15 min may also disinfest stem pieces (Hara et al. 2004).

- ***Soilless media*** – Growing anthurium in soilless media in pots on raised benches offers another level of protection from nematode infection. When plants are already infected with burrowing nematodes, they suffer less damage if planted in soilless media, such as cinder rock, with less compost or peat. This practice is commonly used by anthurium growers in Hawaii (Wang et al. 1997a).
- ***Resistance*** – A screening method has been developed to assist in identification of resistant cultivars (Wang et al. 1997b). Among the most popular commercial *A. andraeanum* cultivars used for the cut flower industry in Hawaii, none was resistant to burrowing nematode. Cultivar “Nitta” was classified as the most susceptible (showing the highest nematode reproduction rate). Cultivars “Blushing Bride” and “Midori” were identified as nematode tolerant (suffering less damage from nematode infection). Cultivar “Ozaki” was highly intolerant (suffering most damage from nematode infection). Two closely related anthurium species, *A. pittieri* and *A. ravenii*, were more tolerant to burrowing nematode than “Midori” (Wang et al. 1998). In future breeding programs aimed to increasing tolerance against burrowing nematode, breeders should consider crossing *A. andraeanum* with other *Anthurium* species.

5.2 Other Plant-Parasitic Nematodes

Meloidogyne spp. (causal agents of root knot) are occasionally found on anthurium roots, but to date, root knot has not caused significant yield losses in anthurium production.

References

Alvarez AM, Lipp R, Bushe B (1989) Resistance of bacteria to antibiotics used for control of anthurium blight. In: Fernandez JA, Nishijima WT (eds) Proceedings of 2nd anthurium blight conference. Hawaii Institute of Tropical Agriculture and Human Resources University of Hawaii, Honolulu (HITAHR) 02.22.89. pp 11–12. http://cms.ctahr.hawaii.edu/anthuriumblight/Research.aspx

Alvarez AM, Lipp R, Norman DJ (1988) Detection and serological studies In: Alvarez AM (ed) Proceedings of 1st anthurium blight conference. Hawaii Institute of Tropical Agriculture

Human Resources, University of Hawaii, Honolulu (HITAHR) 02.04.88. pp 11–15. http://cms.ctahr.hawaii.edu/anthuriumblight/Research.aspx
Alvarez AM, Norman DJ, Lipp R (1991) Epidemiology and control of anthurium blight. In: Alvarez AM, Deardorff DC, Wadsworth KB (eds) Proceedings of 4th anthurium blight conference. Hawaii Institute of Tropical Agriculture Human Resources, University of Hawaii, Honolulu (HITAHR) 06.18.91. pp 12–18. http://cms.ctahr.hawaii.edu/anthuriumblight/Research.aspx
Alvarez AM, Toves PJ, Vowell TS (2006) Bacterial blight of anthuriums: Hawaii's experience with a global disease. APS Net Feature Article. http://www.apsnet.org/publications/apsnetfeatures/Documents/2006/BacterialBlightAnthuriums.pdf. Accessed 5 Apr 2016
Alvarez AM, Toves PJ, Vowell TS (2015) *Xanthomonas axonopodis* pv. *dieffenbachiae*. In: Wang N, Jones JB, Sundin GW et al (eds) Virulence mechanisms of plant pathogenic bacteria. APS Press, St Paul, pp 399–402
Aragaki M, Ishii M (1960) A spadix rot of anthurium in Hawaii. Plant Dis Rep 44:865–867
Aragaki M, Kamemoto H, Maeda KM (1968). Anthracnose resistance in anthurium. Hawaii Agric Exp Stn Prog Rep 169, 10 pp
Aragaki M, Apt WJ, Kunimoto RK, Ko WH, Uchida JY (1984) Nature and control of anthurium decline. Plant Dis 68:509–511
Ayin CM, Amore TD, Toves PJ, de Silva AS, Alvarez AM (2016) Evaluation of anthurium cultivars for resistance to *Xanthomonas axonopodis* pv. *dieffenbachiae*, the causal agent of bacterial blight. Acta Hortic (in press)
Chase AR (1988) Chemical and nutritional aspects of controlling *Xanthomonas* diseases on Florida ornamentals. In: Alvarez AM (ed) Proceedings of 1st anthurium blight conference. Hawaii Institute of Tropical Agricultural Human Resources, University of Hawaii, Honolulu, pp 32–34. Accessed 5 Apr 2016
Chen J, McConnell DB, Henny RJ, Everitt KC (2003) Cultural guidelines for commercial production of interiorscape anthurium. ENH956. University of Florida Institute of Food and Agricultural Sciences, Gainesville . http://edis.ifas.ufl.edu/EP159. Accessed 5 Apr 2016
Cooksey DA (1985) Xanthomonas blight of *Anthurium andraeanum* in California. Plant Dis 69:727
Dilbar A (1992) Studies on a new bacterial disease and other diseases of anthurium in Trinidad. MSc thesis, University of West Indies, St Augustine.
Elibox W, Umaharan P (2008a) A quantitative screening method for the detection of foliar resistance to systemic infection by *Xanthomonas axonopodis* pv. *dieffenbachiae* in anthurium. Eur J Plant Pathol 121:35–42
Elibox W, Umaharan P (2008b) Genetic basis of resistance to systemic infection by *Xanthomonas axonopodis* pv. *dieffenbachiae* in anthurium. Phytopathology 98:421–426
Elibox W, Umaharan P (2010) Inheritance of resistance to foliar infection by *Xanthomonas axonopodis* pv. *dieffenbachiae* in anthurium. Plant Dis 94:1243–1247
Fukui R, Fukui H, McElhaney R, Nelson SC, Alvarez AM (1996) Relationship between symptom development and actual sites of infection in leaves of anthurium inoculated with a bioluminescent strain of *Xanthomonas campestris* pv. *dieffenbachiae*. Appl Environ Microbiol 62:1021–1028
Fukui H, Alvarez AM, Fukui R (1998) Differential susceptibility of anthurium cultivars to bacterial blight in foliar and systemic infection phases. Plant Dis 82:800–806
Fukui R, Fukui H, Alvarez AM (1999a) Effect of temperature on the incubation period and leaf colonization in bacterial blight of anthurium. Phytopathology 89:1007–1014
Fukui R, Fukui H, Alvarez AM (1999b) Comparisons of single versus multiple bacterial species on biological control of anthurium blight. Phytopathology 89:366–373
Fukui R, Fukui H, Alvarez AM (1999c) Suppression of bacterial blight by a bacterial community isolated from the guttation fluids of anthuriums. Appl Environ Microbiol 65:1020–1028
Gardan L, Dauga C, Prior P, Gillis M, Saddler G (2000) *Acidovorax anthurii* sp. nov., a new phytopathogenic bacterium which causes bacterial leaf-spot of anthurium. Int J Syst Evol Microbiol 1:235–246
Guevara YM, Debrot EC (1985) Bacterial blight of anthurium in Venezuela. In: Proceedings of 6th international conference on plant pathogenic bacteria. University of Maryland, Beltsville p 25

Hara AH, Tsang MMC, Jacobsen CM, Yogi-Chun JAT, Hata TY, Niino-DuPonte RY (2004) Pest management strategies for anthuriums. University of Hawaii, CTAHR IP-17. 23pp.
Hartman RD, Zettler FW (1972) Dasheen mosaic virus infections in commercial plantings of aroids in Florida. Phytopathology 62:804
Hayward AC (1972) A bacterial disease of anthurium in Hawaii. Plant Dis Rep 56:904–908
Higaki T, Lichty J, Moniz D (1995) Anthurium culture in Hawaii, Research Extension Series, vol 152. University of Hawaii HITAR. 28 pp
Holder A (2006) A screening method for identifying resistance to bacterial leaf spot (C.A. *Acidovorax anthurii*) disease in *Anthurium andraeanum* Hort. M Phil thesis, Department of Food Production, The University of the West Indies, St. Augustine
Hostachy B, Jacqua G, Delos M, Calvel D, Beramis M, Anais A, Mauleon H, Prior P, Clairon M, Lamattre M, Francois JY, Fournet J (1985) Études des causes du dépérissement de l'anthurium en Guadeloupe et en Martinique. In: Premières journées d'études sur les maladies des plantes. ANPP Tome 2, Palais des Congrès, Versailles, pp 147–154
Hu JS, Meleisea S, Wang M, Shaarawy MA, Zettler FW (1995) Dasheen mosaic potyvirus in Hawaiian taro. Australas Plant Pathol 24:112–117
Kamemoto H, Kuehnle AR (1996) Breeding Anthuriums in Hawaii. University of Hawaii Press, Honolulu, 132 pp
Khoodoo MHR, Sahin F, Donmez MF, Fakim MJ (2004) Molecular characterization of *Xanthomonas* strains isolated from aroids in Mauritius. Syst Appl Microbiol 28:366–380
Kubota R, LaBarre P, Singleton J, Beddoe A, Weigl BH, Alvarez AM, Jenkins DM (2011a) Non-instrumented nucleic acid amplification (NINA) for rapid detection of *Ralstonia solanacearum* Race 3 Biovar 2. Biol Eng Trans 4(2):69–80
Kubota R, Alvarez AM, Su WW, Jenkins DM (2011b) FRET-based assimilating probe for sequence specific real-time monitoring of Loop Mediated isothermal AMPlification (LAMP). Biol Eng Trans 4(2):81–100
Kubota R, Schell MA, Peckham GD, Rue J, Alvarez AM, Allen C, Jenkins DM (2011c) *In silico* genomic subtraction guides development of highly accurate, DNA-based diagnostics for *Ralstonia solanacearum* race 3 biovar 2 and blood disease bacterium. J Gen Plant Pathol 77:182–193
Kuehnle AR, Fujii T, Chen FC, Alvarez AM, Sugii N, Fukui R, Aragon SL, Jaynes JM (2004a) Peptide biocides for engineering bacterial blight tolerance and susceptibility in cut-flower anthurium. HortSci 39:1327–1331
Kuehnle AR, Fujii T, Mudalige R, Alvarez AM (2004b) Gene and genome mélange in breeding of anthurium and Dendrobium orchid. In: Forkmann G, Michelis S (eds) Proceedings of 21st international symposium on breeding ornamentals Part II. Acta Hort 651 ISHS 2004
Lipp RL, Alvarez AM, Benedict AA, Berestecky J (1992) Use of monoclonal antibodies and pathogenicity tests to characterize strains of *Xanthomonas campestris* pv. *dieffenbachiae* from aroids. Phytopathology 82:677–682
Louws FJ, Alvarez AM (2000) Genetic diversity of xanthomonads isolated from aroids determined by rep-PCR. Phytopathology 90:S47 . Pub no. P-2000-0336-AMA
Miura NS, Beriam LOS, Rivas EB (2013) Detection of Cucumber mosaic virus in commercial anthurium crops and genotypes evaluation. Hortic Bras 31. doi:10.1590/S0102-05362013000200024
Mu L (1990) Anthurium culture and blight in Tahiti. In: Alvarez AM (ed) Proceedings of anthurium blight conference. Hawaii Institute of Tropical Agriculture Human Resources, University of Hawaii, Honolulu (HITAHR) 05.07.90. pp 37–38
National Plant Protection Organization, the Netherlands (2015) Pest report: finding of *Ralstonia solanacearum*, race 1 in anthurium plants for cut flower production; August–September 2015. https://www.nvwa.nl/txmpub/files/?p_file_id=2209100
Natural M (1990) Anthurium blight in the Philippines. In: Alvarez, AM (ed) Proceedings of anthuri um blight conference. Hawaii Institute Tropical Agriculture Human Resources, University of Hawaii, Honolulu (HITAHR) 05.07.90. p 38. http://cms.ctahr.hawaii.edu/anthuriumblight/Research.aspx

Nishijima WT (1988) Anthurium blight: an overview. In: Proceedings of 1st anthurium blight conference. University of Hawai'i, Hilo, Hawaii (HITAHR) 02.04.88. pp 6–8. http://cms.ctahr.hawaii.edu/anthuriumblight/Research.aspx. Accessed 30 Sept 2016

Nishijima WT, Fujiyama DK (1985) Bacterial blight of anthurium. University of Hawai'i, Commodity Fact Sheet AN-4(A) Flower. http://www.ctahr.hawaii.edu/oc/freepubs/pdf/CFS-AN-4A.pdf

Norman DJ, Ali GS (2012) *Anthurium* diseases: identification and control in commercial greenhouse operations. https://edis.ifas.ufl.edu/pp292. Document PP292 is one of a series of the Plant Pathology Department, UF/IFAS Extension. Original publication date February 2012. Reviewed March 2015. Visit the EDIS website at http://edis.ifas.ufl.edu

Norman DJ, Alvarez AM (1994) Latent infections of in vitro anthurium caused by *Xanthomonas campestris* pv. *dieffenbachiae*. Plant Cell Tissue Organ Cult 39:55–61

Norman DJ, Alvarez AM (1996) Monitoring the spread of *Xanthomonas campestris* pv. *dieffenbachiae* introduced from symptomless anthurium cuttings into production fields. J Am Soc Hort Sci 121:582–585

Norman DJ, Chen J, Mangravita-Nova A, Yuen JMF (2006) Control of bacterial wilt of geranium with phosphorous acid. Plant Dis 90:798–802

Norman DJ, Zapata M, Gabriel DW, Duan YP, Yuen JMF, Mangravita-Novo A, Donahoo RS (2009) Genetic diversity and host range variation of *Ralstonia solanacearum* strains entering North America. Phytopathology 99:1070–1077

Paret ML, Kratky BA, Alvarez AM (2010a) Effect of plant essential oils on *Ralstonia solanacearum* race 4 and bacterial wilt of edible ginger. Plant Dis 94:521–527

Paret ML, Kubota R, Jenkins DM, Alvarez AM (2010b) Survival of *Ralstonia solanacearum* Race 4 in drainage water and soil and detection with immunodiagnostic and DNA-based assays. HortTechnology 20:539–548

Pradhanang PM, Momol MT, Olson SM, Jones JB (2003) Effects of plant essential oils on *Ralstonia solanacearum* population density and bacterial wilt incidence in tomato. Plant Dis 87:423–427

Prior P, Rott P (1987) Bacterial leaf spot of Anthurium caused by a *Pseudomonas* sp. in the French West Indies. J Phytopathol 124:215–224

Prior P, Hostachy B, Sunder P, Rott P (1985) Bacterial blight (*Xanthomonas campestris* pv. *dieffenbachiae*) and bacterial leaf spot (*Pseudomonas* sp.) of anthurium in the French West Indies. INRA, Pathologie Végétale Dorna ne Duclos, B.P. 1232 Pointe-à-Pitre cedex

Prior P, Hostachy B, Sunder P, Rott P (1986) Bacterial blight (*Xanthomonas campestris* pv. *dieffenbachiae*) and bacterial leaf spot (*Pseudomonas* sp.) of Anthurium in the French West Indies. Communication presented at the 22 nd annual meeting of the Caribbean Food Crops Society, St Lucia, 25–29 Aug 1986, 8 p

Raabe RD, Conners IL, Martinez AP (1981) Checklist of plant diseases in Hawaii, Information text series, vol 022. Hawaii Institute of Tropical Agriculture and Human Resources, Honolulu . http://www.ctahr.hawaii.edu/oc/freepubs/pdf/ITS-022.pdf

Robbs, C.F. (1960) Bacterias fitopatogenicas no Brasil (Phytopathogenic bacteria in Brazil). Inst. Econ. Rural, Rio de J. Ser. Divulg. Pesq 2. 63 pp.

Rott P, Prior P (1987) Un dépérissement bactérien de l'anthurium provoqué par *Xanthomonas campestris* pv. *dieffenbachiae* aux Antilles françaises. L'Agronomie Trop 42:61–68

Sathyanarayana N, Reddy OR, Rajak RL (1998) Interception of *Xanthomonas campestris* pv. *dieffenbachiae* on anthurium plants from the Netherlands. Plant Dis 82:262

Shehata S, Nishimoto M, Hamilton M (1989) The impact of anthurium blight on the profitability of the industry. In: Alvarez AM (ed) Proceedings of 3rd anthurium blight conference. Hawaii Institute of Tropical Agriculture Human Resources, University of Hawaii, Honolulu (HITAHR) 05.07.90. pp 3–6. http://cms.ctahr.hawaii.edu/anthuriumblight/Research.aspx. Accessed 5 Apr 2016

Sher SA (1954) Observations of plant-parasitic nematodes in Hawaii. Plant Dis Rep 38:687–689

Sipes BS, Delate KM (1996) Potential of biologically-derived nematicides for control of anthurium decline. Nematropica 26:171–175

Sipes BS, Lichty J (2002) *Radopholus similis* damage to *Anthurium andraeanum*. Nematropica 32:77–81

Soustrade I, Gagnevin L, Roumagnac P, Gambin O, Guillaumin D, Jeuffrault E (2000) First report of anthurium blight caused by *Xanthomonas axonopodis* pv. *dieffenbachiae* in Reunion Island. Plant Dis 84:1343

Toves PJ (2008) Enhancement of biological control of anthurium blight caused by *Xanthomonas axonopodis* pv. *dieffenbachiae*. MS thesis. University of Hawaii, Honolulu

Toves PJ, Vowell TS, Alvarez AM (2008) Identification of amino acids that improve biological control of anthurium blight through inhibition of *Xanthomonas axonopodis* pv. *dieffenbachiae*. Phytopathology 98:S158

Tsang MMC, Hara AH, Sipes BS (2004) Efficacy of hot water drenches of *Anthurium andraeanum* plants against the burrowing nematode *Radopholus similis* and plant thermotolerance. Ann Appl Biol 145:309–316. doi:10.1111/j.1744-7348.2004.tb00388.x

Uchida JY, Ogata D, Nagata N. 1999. Tomato spotted wilt virus on anthurium. University of Hawaii, College of Tropical Agriculture and Human Resource. Plant Dis Bull PD-17 University of the West Indies (2004–2016) Pest and Diseases of Anthurium in the Caribbean. https://sta.uwi.edu/anthurium/pestDiseaseCaribbean.asp

Vannini JP (2010) Experience with an integrated pest management-inspired protocol for suppression of anthurium bacterial blight (*Xanthomonas axonopodis* pv. dieffenbachiae) in an ornamental aroid collection in Guatemala. Aroideana 33:232–240

Vowell TS (2009) Reducing bacterial blight of anthurium caused by *Xanthomonas axonopodis* pv. *dieffenbachiae* by improving survival of beneficial bacteria used for control. MS thesis. University of Hawaii, Honolulu

Vowell TS, Toves PJ, Alvarez AM (2008) Improving survival of beneficial bacteria on anthurium leaves to control bacterial blight caused by *Xanthomonas axonopodis* pv. *dieffenbachiae*. Phytopathology 98:S164

Wang KH, Sipes BS, Kuehnle AR (1997a) Effect of soilless media on the growth of *Anthurium andreanum* infected by *Radopholus similis*. Nematropica 27:77–84

Wang KH, Sipes BS, Kuehnle AR (1997b) In vitro screening for burrowing nematode, *Radopholus similis*, tolerance and resistance in commercial *Anthurium* hybrids. In Vitro Cell Dev Biol 33:205–208

Wang KH, Sipes BS, Kuehnle AR (1998) In vitro tolerance and resistance to burrowing nematode, *Radopholus similis*, in *Anthurium* species. Euphytica 103:23–28

Wang KH, Sipes BS, Kuehnle AR (1999) *Radopholus similis* in anthurium shoot tissue. HortSci 34:296–297

Young F (1990a) Anthurium blight in Jamaica. In: Alvarez AM (ed) Proceedings of anthurium blight conference. Hawaii Institute of Tropical Agriculture Human Resources, University of Hawaii, Honolulu (HITAHR) 05.07.90. p 37. http://cms.ctahr.hawaii.edu/anthuriumblight/Research.aspx. Accessed 5 Apr 2016

Young F (1990b) Farm assessment of bacterial blight disease on Anthurium in Jamaica. Proc Interam Soc Trop Hort 34:11–17

Zettler FW, Foxe MJ, Hartman RD, Edwardson JR, Christie RG (1970) Filamentous viruses infecting dasheen and other araceous plants. Phytopathology 60:983–987