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Powdery Mildew of Dogwoods: Current Status and Future Prospects

Cornus is a large genus of trees and shrubs that are collectively referred to as dogwoods. Flowering dogwood (*C. florida* L.) and kousa dogwood (*C. kousa* (F. Buerger ex Miq.) Hance) and interspecific hybrids of these species are popular ornamental trees that are known for their showy bracts, red berries (drupes), and/or fall color. Other species that are commercially grown for specialty markets include the pagoda dogwood (*C. alternifolia* L.), giant dogwood (*C. controversa* Hemsl.), cornelian cherry (*C. mas* L.), Pacific dogwood (C. *nuttallii* Aud.), and redosier dogwood (*C. sericea* L.). The foliage of native species, such as flowering dogwood and pagoda dogwood, is high in calcium (12) in quantities above what is needed for skeletal growth of wildlife; it is the preferred browse material for lactating does in late spring while many other trees are still leafless (13,22). The berries of flowering dogwood have high oil content and provide mast for numerous species of migrant songbirds, wild turkeys, and large and small mammals (22).

For many years, nurseries that produced flowering and kousa dogwoods had the luxury of working with relatively disease-free crops. Disease management and control costs were minimal and estimated at approximately $120/ha/year. In the late 1970s, flowering and kousa dogwoods were threatened by a new disease, dogwood anthracnose, caused by *Discula destructiva* (39), which was reviewed by Daughtrey et al. (3). In 1994, another disease, powdery mildew, reached epiphytotic levels in flowering dogwoods. Tens of millions of dollar's worth of dogwoods were destroyed and millions of cultivated seedlings lost their commercial value because formal management strategies were not formulated. In subsequent years, fungicide management costs were estimated to be $1,975/ha/year. Many small producers of dogwoods terminated production of the tree because they could not afford the additional overhead or were not inclined to continue routine fungicide sprays every 2 weeks from May to October.

Powdery mildew on *C. florida* was first reported in 1887 by Burrill and Earle (1), but this disease was rarely reported on flowering dogwood in the United States before 1994. However, the disease appeared simultaneously in forest, landscape, and nursery plantings statewide in Alabama in 1994 (8). Similar outbreaks of powdery mildew were observed in Tennessee, where many nursery fields of flowering dogwood were abandoned (Fig. 1). Powdery mildew has emerged as a nationwide disease of flowering dogwood (2). Although the host side of the disease triangle remained constant, we do not know whether the change of frequency and severity of powdery mildew in flowering dogwood was due to a change in the pathogen or a change in the environment.

Pathogen

Two powdery mildew species have been reported to infect dogwoods. *Erysiphe pulchra* (Cooke & Peck) U. Braun & S. Takam. (syn. *Microsphaera pulchra* Cook & Peck) is considered to be the more prevalent (6,16,21,23), while *Phyllactinia guttata* (Wallr.:Fr.) Lev. is occasionally found on dogwood leaves (2,5,16,23). Klein et al. (16) found ascocarps of *E. pulchra* and *P. guttata* on *C. florida* and *C. amomum*, silky dogwood, but concluded that ascocarps of *P. guttata* did not develop on *C. florida*, whereas ascocarps of *E. pulchra* did. Windham et al. (46) found that *E. pulchra* infected and produced ascocarps on *C. florida*, *C. kousa*, and *C. nuttallii,* whereas *P. guttata* infected and produced ascocarps on *C. alba, C. amomum, C. drummondii, C. macrophylla, C. obliqua, C. racemosa, C. sericea,* and *C. stricta*.

In the sexual stage, both fungi belong to division *Ascomycota* but have distinctive appendages; *E. pulchra* has dichotomously branched and tapered appendages (Fig. 2A), whereas the bulbous base of appendages distinguishes *P. guttata* (Fig. 2B). Immature chasmothecia (syn. cleistothecia) of *E. pulchra* are yellow- to amber-colored, then turn dark brown to black when mature; the size ranges from 75 to 128 µm in diameter (Fig. 2C) (16,41,44). The length of appendages ranges from 110 to160 µm (16). There are three to five asci in a chasmothecium and four to eight ascospores in an ascus of *E. pulchra* (Fig. 2D). Ascospores are single-celled, globose, and measure 18-28 µm × 13-15 µm.

The asexual stage of *E. pulchra* (*Oidium* sp.) forms conidia that serve as inoculum and cause disease epidemics within a growing season. Conidia are single-celled, ovoid to hyaline, and borne on conidiophores singly or in pseudochains (Fig. 2E and F). Conidia (28.1 × 14.1 µm) are highly vacuolated (41). Analysis of DNA sequence of the internal transcribed spacer (ITS) region has shown distinct sequence differences between *E. pulchra* and *P.*

Fig. 1. An abandoned nursery field of powdery mildew–infected dogwoods in Tennessee.

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guttata, whereas there were no sequence variations among *E. pulchra* isolates (25). DNA sequences of the ITS region from Tennessee and New York isolates of *E. pulchra* from *C. florida* (GenBank accession no. AY224136) were 100% identical to each other and to that of Japanese *E. pulchra* isolates from *C. kousa* (GenBank accession no. AB015935). Identical ITS sequences from all *E. pulchra* isolates were obtained. Genetic uniformity in pathogen populations may be a reflection of the recent introduction of the pathogen (37), but studies on *E. pulchra* population analysis are needed.

Infection Process

Conidia of *E. pulchra* germinate and initiate one to four primary germ tubes by 2 h after inoculation (Fig. 3A). However, primary appressoria only differentiate from one or two of the primary germ tubes (Fig. 3B) (17). Penetration pegs form under appressoria and breach the wax and cuticle layers of epidermal cells. Haustoria, globose fungal feeding structures surrounded by extrahaustorial matrix, differentiate in epidermal cells 2 days after inoculation and absorb water and nutrients supporting fungal growth (Fig. 3C). Secondary germ tubes, or primary hyphae, initiate from only one of the primary germ tubes with primary appressoria (Fig. 3D). The primary and secondary appressoria are lobed and form singly or in pairs opposite one another (Fig. 3E). Branched hyphae are differentiated between primary and secondary appressoria or develop directly from secondary appressoria (Fig. 3F). After establishing the host–parasite relationship, fungal hyphae elongate and form colonies (Fig. 3G). Conidia are borne on conidiophores that display a twisted basal cell (Fig. 3H).

Symptoms and Signs

Disease signs first appear on the adaxial leaf surface as circular to irregular white patches that consist of mycelia and conidia of the fungus (Fig. 4A). As the fungus colonizes more host tissues, the leaves are covered by white mildew and develop mottled yellowing or brownish patches. Newly infected leaves curl upward and result in a tree canopy with distorted growth, which is aesthetically unacceptable to growers and consumers alike (Fig. 4B). By mid-summer, reddish-brown blotches appear on infected leaves, and symptoms may mimic those of drought stress, even as colony expansion on the discolored area slows (Fig. 4C). Near the end of the growing season, light brown-to-black chasmothecia may be observed in mildew colonies on either leaf surface, but tend to be produced predominantly on the lower surface (Fig. 4D).

Host Resistance

Susceptibility to powdery mildew varies among *Cornus* species. In general, most *C. florida* cultivars are susceptible and most *C. kousa* cultivars and hybrid dogwood (*C. kousa* × *C. florida*) cultivars are resistant (7,20), whereas *C. mas*, *C. controversa,* and *C. alternifolia* are immune to powdery mildew (46). Hybrids from crossings of *C. kousa* and *C. florida* 'Stellar Pink', 'Stardust', 'Galaxy', 'Constellation', and 'Aurora' have also been reported to be highly resistant to powdery mildew, whereas hybrid 'Ruth Ellen' was moderately resistant at some locations and highly resistant at others (7,15,20,27,46). In *C. florida*, 'Cherokee Brave', a pink-bracted flowering dogwood, has also been reported as resistant to the disease (7,50), but resistance has failed in some years since these reports. 'Jean's Appalachian Snow', 'Kay's Appalachian Mist', 'Karen's Appalachian Blush', and 'Appalachian Joy', all white-bracted flowering dogwoods, are highly resistant to powdery mildew (45,51).

Powdery mildew resistance in dogwoods is often expressed as restricted branching of hyphae without affecting germination of conidia (19). Genes controlling resistance and resistance mechanisms are not yet clear. Some dogwood seedlings express partial resistance to powdery mildew with slower disease progress than susceptible cultivars (19,51). Since *E. pulchra* is an obligate biotroph, sporulation, colony development, and disease spread depend on successful initial penetration of the host and continuous functional haustorium formation. Compared to susceptible cultivars, resistant cultivars delay disease latent period, reduce pathogen infection efficiency, and restrict colony development and asexual reproduction by conidia, all indications of partial resistance (19,20) (Fig. 5). Resistance to powdery mildew in dogwood has been evaluated in nurseries or greenhouses by rating disease severity (7,15,27,38,46,51). However, variation in levels of resistance to powdery mildew in locations and years has been reported for some dogwood cultivars (7,15,27,38,51). A

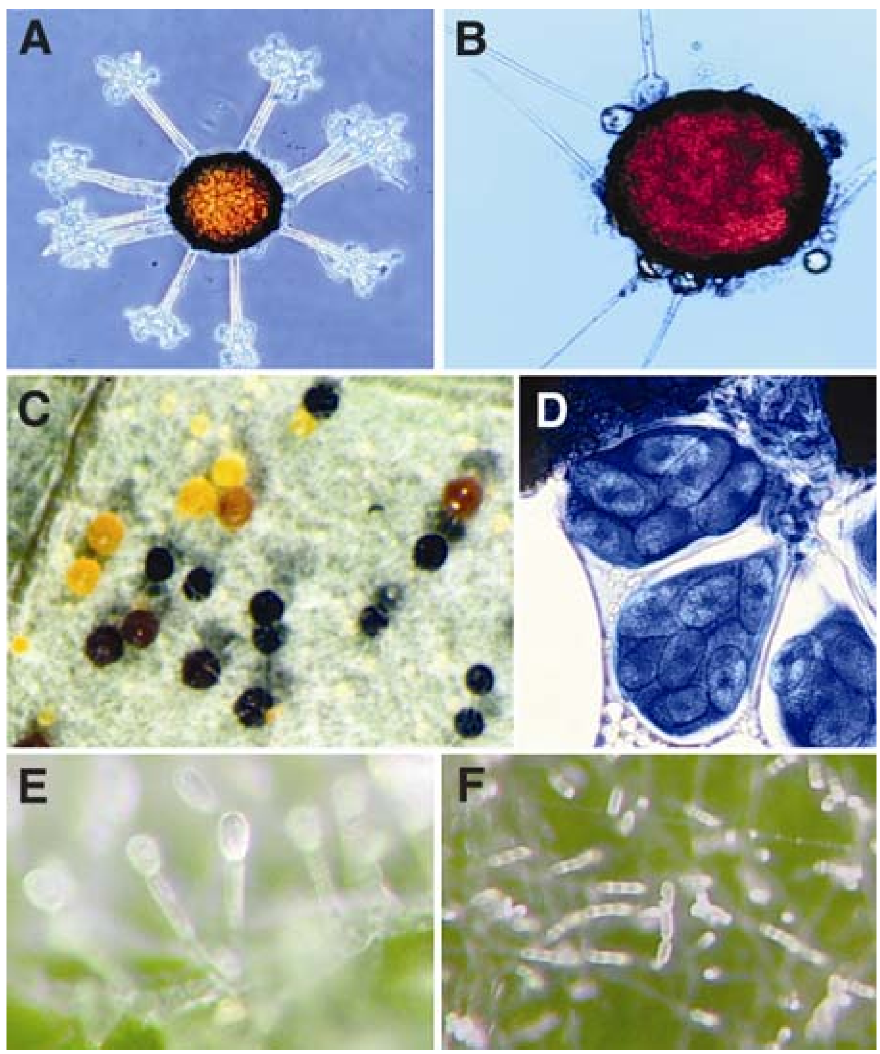

Fig. 2. A, Dark-colored chasmothecium of *Erysiphe pulchra* with dichotomously branched appendages. B, Chasmothecium of *Phyllactinia guttata* with bulbous bases of appendages. C, Chasmothecia of *E. pulchra* on leaf surface. D, Ascospores inside an ascus released from a chasmothecium of *E. pulchra.* E, Singly formed conidia on conidiophores of *E. pulchra.* F, Conidia formed in pseudochain. (A and B adapted from Mmbaga [24])

leaf disk bioassay method has been developed and used to evaluate dogwoods for resistance to powdery mildew in the laboratory. Results were similar to field observations on these same cultivars (19,20).

Epidemiology

Understanding the epidemiology of powdery mildew on dogwood enables us to devise rational disease management strategies that take into account the pathogen's life strategies (52). In middle Tennessee, chasmothecia of *E. pulchra* are the most important overwinter fungal structures, which form abundantly on dogwood leaves but not on stems, even on severely affected plants (16,23). In the northeastern United States, Smith reported that overwintering chasmothecia containing mature asci and ascospores were found on dogwood twigs and on fallen leaves in March (41). The chasmothecia survival was influenced by the timing of chasmothecia formation over the period from September to November (23,24). Ascocarps that form late in the season may not be mature enough to overwinter because they are less developed.

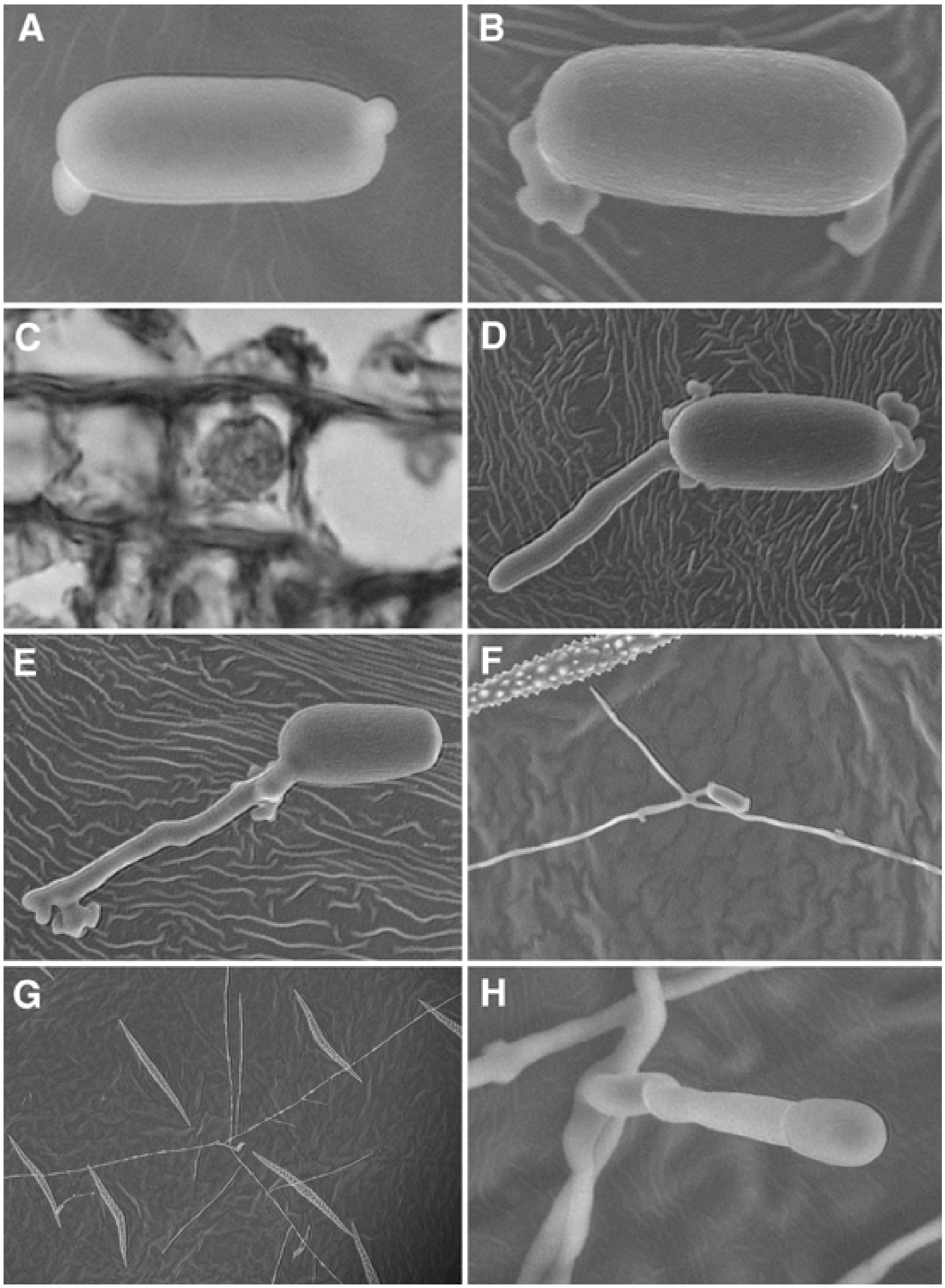

Fig. 3. Micrographs of infection process of *Erysiphe pulchra.* A, Primary germ tubes on both poles of a conidium. B, Primary appressoria from primary germ tubes. C, Globose haustorium in a host epidermal cell and the haustorial neck connecting haustorium body and appressorium on the surface of epidermal cell wall. D, Hyphal growth from the primary appressorium. E, Germinated conidium with secondary appressorium. F, Branched hypha from hypha and from secondary appressorium. G, Growth of branched hypha from hypha and secondary appressorium. H, Close-up of conidium and conidiophore with arched basal cell. (adapted from Li et al. [17]).

Chasmothecia on leaf debris may be yellow, brown, or black, indicating the maturity levels from immature to mature (Fig. 2C). Chasmothecia maturation requires several weeks (23,24,53); thus, variation in the initiation of chasmothecia formation from year to year may cause variability in winter survival and primary inoculum density. Studies under controlled environment showed that temperature affected the formation of chasmothecia. Cooler temperatures of 18/10°C and 23/15°C (day/night) were favorable to chasmothecia initiation and development. Day length and the physiological stage of affected plants had no effect on chasmothecia formation. Variation in autumn temperatures was associated with the timing of chasmothecia formation (23,24). Where a pathogen overwinters on dormant plants, chasmothecia formed on leaf debris may be of secondary importance in the disease cycle, but in mid-Tennessee, the powdery mildew pathogen did not survive from one season to the next as mycelia in dormant dogwood buds (23).

Moderate to high numbers of chasmothecia on leaves survive during winter months at various locations outdoors, on the ground or hanging on tree branches, and release viable ascospores the following spring. Airborne ascospores were trapped on sticky slides between March and June, and dogwood seedlings used as trap plants developed powdery mildew from airborne inoculum (24). Disease severity corresponded with increasing spore counts on sticky slides and confirmed that *E. pulchra* overwintered on leaf debris primarily as chasmothecia, and ascospores served as primary inoculum (23). Infection on newly expanding dogwood leaves became visible when masses of conidia were formed (23,24). This indicated that primary infections had developed secondary inoculum and that primary infection from ascospores occurred earlier than indicated by disease symptoms. The timing of the initial infection in commercial nurseries varied from year to year by 2 to 6 weeks (early May to late June). High disease severity in 1996, 1998, and 2000 were associated with high chasmothecia frequency in 1996, low frequency in 1998, and very low frequency in 2000 with >50 chasmothecia per 19.6 mm^2 leaf area (high), 25 to 49 (moderate), and >25 (low) frequency (23). These observations suggested that factors other than disease severity influenced the abundance of chasmothecia formed as the source of primary inoculum for the following year (23,24). Ascospores were detected over a period of several weeks (March to June) with peaks in early to late April depending on rainfall and temperature.

Thus, two spore stages of *E. pulchra* occur simultaneously during early spring, with ascospores and conidiophores infecting newly expanding leaves simultaneously, causing rapidly growing polycyclic epidemic. When environmental conditions are favorable, powdery mildew spreads very rapidly, with masses of conidia produced from each new infection within a few days. Epidemiological studies have shown that powdery mildew generally begins during late May to June. This initial disease incidence is followed by a rapid increase in disease severity until early to mid-August (18,24). Disease progress curves of powdery mildew on dogwood were fitted to the logistic model (18). This showed that, overall, temperature and rainfall patterns were likely the main environmental factors that influenced primary inoculum density. Variation in the timing of infection establishment between early May and late June was associated with inoculum density, but it did not affect overall disease severity for the season. The association between prevailing weather conditions and disease severity over a 5-year period has shown that well-distributed (frequent) rainfall events and moderate monthly temperatures favor high incidence of powdery mildew in dogwoods (24).

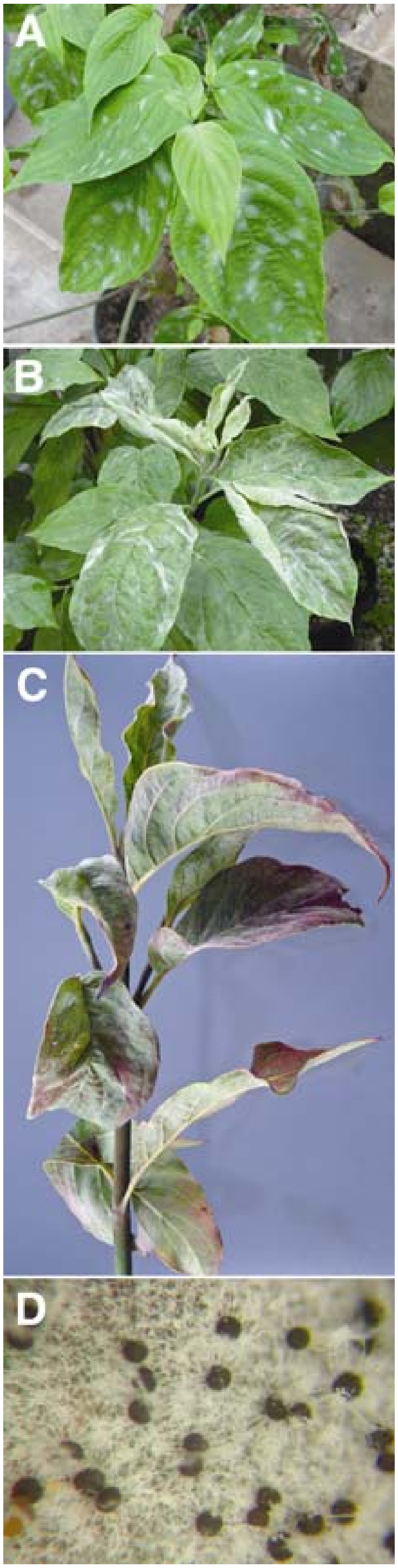

Fig. 4. Symptoms and signs of powdery mildew in dogwood. A, Isolated mildew colonies at beginning of colony development. B, Merged mildew colonies and curled young leaves. C, Red-brown patches under mildew colonies in mid-summer. D, Chasmothecia formed on mildew colonies in late fall.

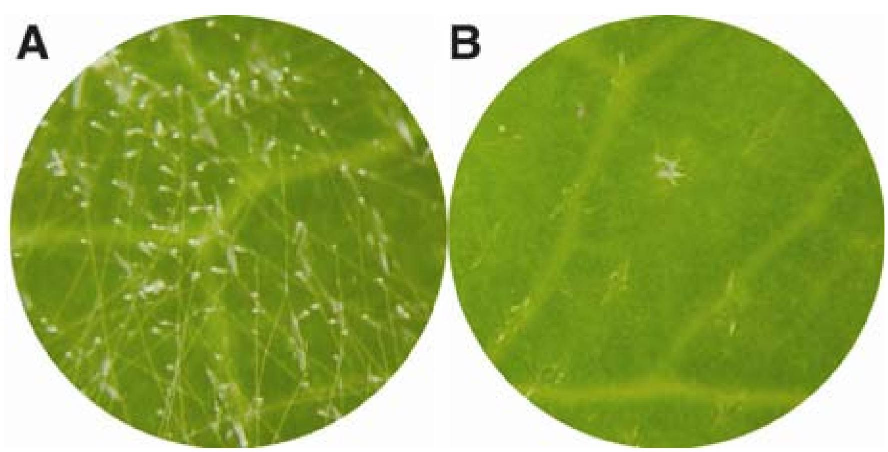

Fig. 5. Resistant and susceptible flowering dogwood cultivars' reaction to powdery mildew. A, Sporulating colony development on susceptible cultivar. B, Restricted colony on resistant cultivar. (adapted from Li et al. [19])

Disease Management

Host resistance. Several mildew-resistant dogwood species, hybrids, and flowering dogwood cultivars are recommended as a key disease management strategy. Resistant dogwood species include the following: *C. kousa, C. sericea, C. mas, C. alternifolia, C. alba,* and *C. controversa*. Hybrids of *C. kousa* × *florida*, including 'Stellar Pink', 'Stardust', 'Galaxy', 'Constellation', and 'Aurora', are also highly resistant to powdery mildew (7,15,20, 27,46). Of all ornamental dogwoods, *C. florida* is the most popular, but powdery mildew resistance is very limited in this species. Selection and release of resistant cultivars are highly valuable to the nursery and landscape industry. New cultivars 'Jean's Appalachian Snow', 'Kay's Appalachian Mist', 'Karen's Appalachian Blush', and 'Appalachian Joy', all white-bracted flowering dogwood, are highly resistant to powdery mildew (Fig. 6). However, breeding for resistant cultivars is nearly impossible because of self-incompatibility and long generation times.

Fungicides. In the mid-1990s, when powdery mildew suddenly became widespread on flowering dogwood in the eastern United States, no one in the green industry had experience in managing the disease. Powdery mildew had been managed on many other nursery crops, such as *Syringa* and *Euonymus* spp., but not on dogwoods. As dogwood powdery mildew became a recurring problem on dogwood each year in the eastern United States, fungicide efficacy against *E. pulchra* was identified. Most fungicides that are labeled for powdery mildew on other ornamental plants have proven to be efficacious against *E. pulchra* (4,33,36,47). Chlorothalonil, benzimidazole fungicides such as thiophanate methyl, and demethylation inhibitors such as fenarimol, myclobutanil, triadimefon, and propiconazole are efficacious at 2-week intervals. QoI fungicides (strobilurins) also have shown promise as a management tool (9,10,32,35,47–49).

Currently, management of powdery mildew on susceptible dogwood seedlings in nurseries is primarily by foliar fungicide sprays, which has increased production cost. Optimum powdery mildew control in Alabama was achieved with spray programs that commenced on 1 June at the first sign of disease and terminated either 1 August or 1 September (11). Acceptable control could be achieved if spray programs were begun when small colonies of powdery mildew were visible on foliage (11,49). Obviously, the goal of nurseries is to keep powdery mildew at acceptable levels with as few sprays as possible. Many spray programs for foliar diseases of ornamental plants that are problematic annually begin prior to symptom development. Initiating fungicide sprays at the first sign of disease is possible only if nurseries are actively scouting for the advent of powdery mildew.

Nurseries that specialize in dogwood production are concerned about any disease that affects quality or grade and slows growth. Fungicide sprays can prevent the most objectionable signs and symptoms of powdery mildew such as white fungal growth, twisted leaves, leaf curl, and stunted growth (4). Leaf scorch is another indirect effect of powdery mildew that can be managed with fungicide sprays. Leaves infected with powdery mildew lose water faster than healthy leaves. In unirrigated fields, trees that are not protected with fungicide sprays are more likely to exhibit marginal necrosis associated with leaf scorch (47). Fungicide sprays not only produce healthier, higher quality trees, but may also increase tree height and caliper. It has been found that dogwoods protected from powdery mildew by fungicide sprays have increased tree height and trunk caliper compared to untreated trees (9,47,48). Delays in reaching desired standard heights or trunk calipers mean tangible losses to nurseries. It is not unusual for flowering dogwood to produce two flushes of growth during the growing season: one in early spring and a second in mid-summer. Dogwoods infected with powdery mildew seldom produce the second flush of growth at mid-summer, which accounts for decreased height.

Cultural controls used to manage other foliar diseases of ornamental plants such as plant spacing to aid in air movement and using drip irrigation to keep foliage dry are insufficient to control powdery mildew on dogwood. Fungicide sprays are likely to remain a viable tool for nurseries, landscape managers, and gardeners to protect dogwood from powdery mildew and to maximize growth. Future studies will look at new fungicides and fine tuning spray schedules to decrease production costs.

Biorationals. Disease control compounds that are less harmful to the environment and nontarget organisms than conventional fungicides have been designated as biorational fungicides (43). Such compounds are also referred to as biopesticides. Different modes of action have been reported such as preventing spore germination, retarding sporulation and mycelial growth, and inducing systemic resistance (14,34,40). Biorationals are most effective when used preventively at short spray intervals; they may be used in fungicide rotations, thereby reducing conventional fungicide use and the development of fungicide resistance (42). Biorational fungicides have several advantages over conventional pesticides: lower toxicity to mammals, pest species-specificity, rapid decomposition, and efficacy in small quantities. On the other hand, biorational fungicides require short treatment reapplication interval (7-day) compared to 14-day or longer intervals used in conventional fungicides (28). The contact mode of action

Fig. 6. Four flowering dogwood cultivars that are resistant to powdery mildew: A, Kay's Appalachian Mist; B, Karen's Appalachian Blush; C, Jean's Appalachian Snow; and D, Appalachian Joy.

may also contribute to lower efficacy in biorational fungicide treatments.

Twenty-one biorational compounds have been evaluated to identify alternative products and reduce conventional fungicides used in dogwood production (30). Household soaps Palmolive and Ajax that contain the antimicrobial compound triclosan are highly effective in reducing disease severity, similar to conventional fungicides, chlorothalonil and thiophanate methyl (Consyst), propiconazole (BannerMaxx), and thiophanate methyl (Cleary's 3336) (Fig. 7). Soap and potassium salts of fatty acids marketed as commercial insecticidal

Fig. 7. ***Cornus florida*** **'Cherokee Princess' grown under field conditions and treated with biorational products to control powdery mildew. Treated with: A, potassium bicarbonate; B, Equate, antibacterial liquid hand soap; C, Palmolive; D, water control; E, Ajax, antibacterial dish soap; F, nontreated. (adapted from Mmbaga and Sauve [28])**

soap M-Pede and Safer Soap, hydrophobic extract of neem seed oil marketed as Triact 70 and Neem Gold, bicarbonate salt marketed as Armicarb 100 and Kaligreen, and the refined light paraffinic horticultural oil Sunspray Ultra-Fine were moderately effective in controlling powdery mildew, and significantly improved plant growth. Weekly applications of biorational fungicides were more effective than 14-day applications and similar to conventional fungicides applied every 14 days (28). Spray regimes with propiconazole rotations at 7-day intervals were more effective than 14-day applications of propiconazole. Using biorationals in rotation with conventional fungicides at 14-day application intervals was as effective as using fungicides alone. Incorporating biorational products and/or biopesticides in fungicide rotations reduced fungicide use by 56% in weekly applications and 66% in bimonthly applications (Table 1) (28).

Although there has been increasing research to identify new biorational products for powdery mildew management, conventional fungicides have remained competitive over biorational fungicides. Efficacy of conventional fungicides has had the test of time and won grower confidence over biorational products. In addition, conventional fungicides have longer residual control, requiring fewer spray treatments and lower labor costs. Using biorational products as a component of fungicide rotations has proven to reduce fungicide usage and maintain the number of sprays and same level of disease control (28). However, marketing and availability of biorationals have not kept up with competing fungicides. Marketing strategies to improve the adoption of biorational products should include information on fungicide/biorational rotations.

Microbial agents such as bacteria, fungi, and yeast that are effective in powdery mildew control have been identified (26,29,31). Selected biological control agents might add to the list of biorational pesticides and provide alternatives to traditional fungicides for dogwood powdery mildew. The ultimate goal of reducing fungicide use in dogwood production will likely be accomplished by using different biorational fungicides in rotations with traditional fungicides.

Highlights

Powdery mildew continues to be the greatest detriment to production of flowering dogwood in the United States and other countries. Fungicide programs, which are very effective in controlling the disease, require spray applications at regular intervals throughout the growing season. These applications add significantly to production costs that may be cost-prohibitive to many small- to mid-size nursery producers across the mid-south. In the deep-south, nurseries have ceased growing flowering dogwood for this reason. Biorational chemical candidates and perhaps even some biological control organisms hold some promise for managing the disease, but additional research is required before these strategies will be viable options. Unfortunately, these approaches suffer from some of the same constraints as fungicide applications, in that they may require repeated and expensive applications of materials over the entire growing season. Natural resistance to powdery mildew has been documented in flowering dogwood (19,20,50,51), and this strategy appears to be the most cost effective way for managing powdery mildew in nurseries and landscapes. Breeding and developing new cultivars for powdery mildew resistance is somewhat problematic. Besides the long generation time, about 7 years, incompatibility between the F_1 generation and either parent occurs as well as inbreeding depression; almost all BC_1 generation plants are weak and have failed to grow and flourish. Our group will continue to select and research alternative breeding methods that are intended to introduce new cultivars of flowering dogwood that have resistance to powdery mildew.

Table 1. Comparisons of powdery mildew disease index on dogwood seedlings treated with biorational products alone and in rotation with propiconazole at 7- and 14-day intervals in field environments (modified from Mmbaga and Sauve [28] and Mmbaga and Sheng [30])

		Disease index[y]		
Treatment	**Interval (day)**	**4-year seedling**	**5-year seedling**	**Overall mean**
Equate	14	2.2 efg	1.9 cde	2.1
Equate	7	0.9 ijkl	0.9 ghi	0.9
Armicarb 100	14	2.6 ef	1.2 defhi	1.9
Armicarb 100	7	0.9 ijkl	0.9 ghi	0.9
Palmolive	14	2.0 efgh	0.9 ghij	1.5
Palmolive	7	0.6 kl	0.5 j	0.6
Ajax	14	1.7 fghi	1.5 defg	1.6
Ajax	7	0.7 jk	0.7 hij	0.7
Propiconazole	14	1.5 ghijk	2.0 cd	1.8
Propiconazole	28	3.6 bcd	2.9 b	3.3
Equate/propiconazole[z]	14	1.4 hijk	1.1 efg	1.3
Equate/propiconazole[z]	7	0.5 l	1.0 fgh	0.8
Armicarb/propiconazole[z]	14	2.7 de	1.4 def	2.1
Armicarb/propiconazole[z]	7	0.5 l	0.6 ij	0.6
Palmolive/propiconazole[z]	14	1.5 hijk	1.2 def	1.4
Palmolive/propiconazole[z]	7	0.5 l	0.6 ij	0.6
Ajax/propiconazole[z]	14	1.6 hij	1.1 efg	1.4
Ajax/propiconazole[z]	7	0.5 l	0.9 ghi	0.7
Water control		5.0 a	4.1 a	4.6

[y] Disease index was assessed on a scale of 0 (no symptom) to 5 (100% leaf covered with powdery mildew signs and symptoms). Means followed by same letters in the same column were not significantly different as determined by least significant difference test ($P = 0.05$).

[z] Biorational/propiconazole rotations consisted of three applications of biorational products followed by one application of propiconazole.

Acknowledgments

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