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Control of Rose Powdery Mildew in the Greenhouse and Field

Rose powdery mildew was first recorded in 300 B.C. and remains a major disease of that crop today. Under optimum conditions, the disease is equally destructive in the greenhouse, the home garden, and the field. Numerous published reports document the intensive research devoted to the study of this disease, which was recently reviewed by Wheeler (8). Control of rose powdery mildew has been aided considerably in recent years by the introduction of new fungicides. Unfortunately, the increased selectivity characteristic of many new chemicals often increases the probability of fungicide resistance. Little is known about the ability of the rose powdery mildew fungus to develop fungicide-resistant races or about the interactions between races of the fungus and various rose cultivars.

Characteristics of the Fungus

The causal fungus of rose powdery mildew is generally regarded as *Sphaerotheca pannosa* var. *rosae*, although Blumer (2) also listed *S. macularis* as a pathogen on rose. Other monographers do not consider the latter species distinct from *S. humuli*. Although the sexual (cleistothecial) stage is known to occur, only the asexual (conidial) stage has been implicated in the disease cycle. Cleistothecia are not reported in some geographic areas where the fungus causes considerable damage to roses. In those localities where ascocarps appear, they are usually most prevalent on roses that are least hybridized. Relatively little attention has been devoted to the sexuality of *S. pannosa* var. *rosae*, but the available evidence suggests heterothallism. For example, inability of compatible races to infect a common cultivar or the absence of one of the necessary mating types would prevent ascocarp formation in a heterothallic fungus.

Some evidence indicates that mycelial growth of the fungus on host plants is conditioned by its compatibility with the inoculum source. Yarwood (11) showed that inoculum collected from peach or *Rosa banksiae* caused large necrotic lesions on apricot leaves, but inoculum from the rose cultivar Dorothy Perkins resulted in small lesions. Further work with roses showed that detached shoots infected with conidia from *R. virginiana* were incapable of causing infection on the cultivars Christopher Stone, Queen Elizabeth, Red Garnette, and Triumph de'Orleans, and inoculum from Triumph de'Orleans and Christopher Stone could not cause infection on *R. virginiana* (3). It has also been shown that conidia from *R. virginiana*, although pathogenic on *R. virginiana* and *R. rugosa*, could infect only detached leaflets of Better Times and Fusilier of the 17 rose cultivars tested. More recently, several other races of *S. pannosa* were identified by their reactions on various other rose cultivars.

Apparent changes in susceptibility have been observed occasionally when new cultivars have been introduced and grown in different geographic areas. Resistance to powdery mildew was one of the attributes of the rose cultivar Tropicana (Super Star) when it was first introduced. With continued cultivation in different locations, its susceptibility to the disease varied considerably. It was reported to be highly susceptible in some areas but remained relatively free from infection in other locations. A similar case was observed recently at Corvallis, Oregon, where an unnamed rose seedling was acquired from a plant breeder in 1972. Through the 1979 season, powdery mildew was limited to infrequent small lesions found only on the flower hypanthium (Fig. 1A). In 1980, all parts of the plant supported luxurious growth of the fungus (Fig. 1B). Isolates from field plants were used to inoculate "resistant" rose plants in the greenhouse. Although these plants had been highly resistant to other powdery mildew races, they were extremely susceptible to the new *S. pannosa* var. *rosae* race.

Races can be differentiated by comparing their development on various host cultivars. Spore germination is usually unaffected by the host, and spores germinate readily on incompatible hosts or nonhost substrates, provided temperature and relative humidity (RH) are maintained within acceptable limits. Development of the mycelium becomes affected by host tissue within several

Fig. 1. Infection of an unnamed "resistant" rose with two races of *Sphaerotheca pannosa* var. *rosae*: (A) Typical infection by pre-1980 race limited to small colonies on the flower hypanthium (arrow). (B) Shoot heavily infected with new 1980 race.

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Table 1. Several modern fungicides with activity against rose powdery mildew

Common name	Trade and other names	Comments
Benomyl	Benlate	Resistance reported
CGA-64251	Vangard	Volatilizes at greenhouse temperatures
Dinocap	Karathane, Isothan, Mildex, Crotothane	Phytotoxic to some rose cultivars
Dodemorph	Meltatox, Milban, dodemorfe	Short residual, good eradicant
Fenapanil	RH-2161, Sisthane	Discontinued
Fenarimol	EL-222, Ridimin, Bloc, Rubigan	Good volatility
Nuarimol	EL-228, Trimunol, Trimidal	Good volatility
Triadimefon	Bay MEB 6447, Bayleton, Croneton	Good volatility, phytotoxic to some cultivars
Triforine	Cela W-524, Saprol, Funginex	Also active for rust and blackspot

hours after germination occurs. Penetration of host tissue by the haustoria may trigger responses in both host and parasite that can be readily observed by microscopic examination. When the fungus and host are extremely incompatible, several host cells die and the fungus stops growing, a condition often referred to as hypersensitivity. Highly compatible reactions are characterized by rapid mycelial growth and development of numerous secondary spores within 3–5 days. Compatibilities between these extremes can be evaluated and used to characterize each host/parasite interaction. When the reaction of an unknown *S. pannosa* isolate is observed on several rose cultivars, it can be classified and compared with other isolates. No standardized system for *S. pannosa* race classification has been proposed.

In addition to host/parasite compatibility, an *S. pannosa* isolate may be characterized by the phenotypical responses, ie, resistance to fungicides, adaptability to wider ranges of environmental conditions, etc.

Environment and Perennation

It is generally believed that *S. pannosa* overwinters as dormant mycelium in the buds and infects newly emerging foliage (Fig. 2). In warmer climates and in greenhouses, the fungus may survive for extended periods in infected dormant buds or as dormant mycelium on infected stems. Secondary spread of rose powdery mildew by conidia continues throughout the growing season during periods favorable to growth and development of the fungus.

Longree (6) studied the relationship between environmental factors and the development of *S. pannosa* var. *rosae* and reported that the optimum, minimum, and maximum temperatures for growth of the fungus were 21, 3–5, and 33 C, respectively. She also determined that conidia germinate best when the RH is 97–99% but that free water seriously reduces spore germination. Price (7) showed that conidia could withstand long periods at 0 C without loss of viability, provided they were incubated in moist conditions. He also observed sporulation of powdery mildew colonies incubated 10 days at 0 C, then transferred to 20 C.

The powdery mildews are probably unique in their ability to germinate at comparatively low RH in the absence of free water. Although infection is greatly enhanced under optimum RH values, a small percentage of conidia often germinate at low RH and develop sporulating colonies. Conidia of the powdery mildews, unlike spores of most other fungi, contain sufficient water to carry out germination and penetrate the host cell. Once haustoria have formed, the host provides sufficient moisture to sustain growth of the mycelium.

S. pannosa var. *rosae* grows over the surface of the rose tissue, penetrates the epidermal cells, and forms haustoria. Under optimum conditions, the asexual cycle may be repeated in as little as 72 hours (Fig. 3). Under greenhouse or field conditions, however, 7–10 days are more commonly required between spore germination and development of new conidia. Completion of the asexual cycle is a function of time, temperature, RH, and host/fungus compatibility. Dispersal of mature conidia by wind or air currents assures an abundant supply of inoculum with high potential for germination and growth. Greenhouse growers have long recognized the importance of minimizing drafts near doorways, ventilators, and other openings. The disease often begins at these points and spreads rapidly throughout the greenhouse when other environmental conditions are favorable.

Disease Resistance

Surveys of rose susceptibility to infection by *S. pannosa* var. *rosae* indicate that individual cultivars often vary widely from one geographic region to another or in the same area during different seasons. Recently, a panel of directors of large public rose gardens across the United States rated some of the more widely grown rose cultivars for disease susceptibility. They listed Tropicana among "the most resistant hybrid teas," yet this cultivar is often rated among the most susceptible in other surveys.

Several theories have been presented to explain the mechanism of resistance of roses to infection by the powdery mildew fungus. Early workers suggested that mechanical factors, ie, thick cuticle layers, prevented penetration of the host, thereby imparting varying degrees of resistance. Other investigators have shown that cutin acids were more inhibitory to mildew spores than were other components of the wax or cuticle. Little evidence supports a correlation between the levels of wax or cutin deposition and resistance to infection.

The relationship between certain nitrogenous compounds and resistance has also been studied. High levels of cysteic acid were found in the leaves of the

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cultivars Pink Favorite and Sarabande, both of which are highly resistant to the disease. Based on field performance available at the time the study was in progress, Tropicana was also selected as a resistant host. This cultivar had a comparatively low level of cysteic acid, however, and the apparent anomaly was later corrected when Tropicana became susceptible to the disease.

A β-alanine requirement for germination and growth of *S. pannosa* var. *rosae* was suggested when it was found in young leaves of susceptible rose cultivars but not in resistant cultivars or in old leaves of susceptible cultivars. Other workers have shown a relationship between certain leaf toxins and resistance to rose powdery mildew. Anthocyanidin content of rose tissue was directly related to disease resistance. Unfortunately, this new knowledge has not been readily transposed into breeding roses resistant to powdery mildew.

Professionals and amateurs alike have generally taken an empirical approach to breeding for resistance. Many have retained highly susceptible parentage in their breeding lines with little attention devoted to the selection of parents whose tissues are low in β-alanine or high in anthocyanidin. Many new roses show a moderately high level of resistance to powdery mildew, however. How many will retain resistance when they are exposed to widely variable populations of the fungus is uncertain. Selection of disease-resistant roses with highly desirable horticultural characteristics is a continuing, and often frustrating, challenge for rose breeders.

Control with Fungicides

Because many horticulturally desirable rose cultivars are highly susceptible to powdery mildew and because multiple races of *S. pannosa* var. *rosae* appear to frequent rose-growing areas, control of the disease by means other than resistant cultivars is necessary. The use of chemicals to reduce the incidence of rose powdery mildew was first suggested in 1861 when copper sulfate was recommended as a control measure. The treatment was effective but the recommendation was quickly withdrawn because of severe phytotoxicity to roses.

Sulfur, in a number of different forms, came into general use in the mid-19th century and continues to be recommended for use on roses grown in the greenhouse or outside. Although it provides relatively good disease control when applied under optimum conditions, sulfur may also reduce plant growth and flower quality. Low temperatures reduce its efficacy and high temperatures increase its phytotoxicity, so sulfur should not be used when the temperature is expected to exceed 30 C or drop below 15 C.

Chemical control of rose powdery mildew has generally followed the pattern of control for other foliar diseases. Various forms of sulfur and copper were followed by the dithiocarbamates and several antibiotics. Dinocap (Table 1) was widely used but often caused phytotoxicity on certain cultivars, particularly under greenhouse culture. A major problem with many of the older fungicides was the accumulation of visible residue after multiple applications. Because these chemicals were not systemic, applications had to be repeated every 7–10 days to protect rapidly growing and highly susceptible new foliage. Many of the new chemicals leave little visible residue to detract from the aesthetic value of the rose.

Several new fungicides with varying degrees of systemic activity in roses have been developed within the past 15 years. One of the most popular among rose growers was benomyl. It was widely used and provided good to excellent disease control in most areas. Its translocation in rose tissue was limited, however, and repeated applications resulted in accumulation of objectionable residue. Benomyl-resistant races of *S. pannosa* var. *rosae* were identified on roses and have also been reported for powdery mildews of many other crops.

Some interesting new fungicides showing great promise for control of rose powdery mildew are the ergosterol biosynthesis inhibitors. These include CGA-64251, fenarimol, nuarimol, triadimefon, and triforine. Several of the fungicides in this group are efficacious against rose rust and blackspot as well as powdery mildew. Triforine has these properties and is labeled for use on roses. Other fungicides found effective and commonly used on greenhouse roses are piperalin and dodemorph; labeled uses of dodemorph are limited to application in the greenhouse.

Fig. 2. Primary infection (arrow) of young rose leaves with powdery mildew.

Special consideration should be given to the control of rose powdery mildew in the greenhouse because it offers some unique opportunities for the development of new techniques. Little has changed in the practice of greenhouse fungicide application since it was first introduced in the mid-19th century. Sprays were applied using high-pressure equipment with various nozzle designs to control droplet size and improve coverage. More recent developments in this area include ultralow-volume (ULV) systems. Although ULV application of fungicides has enjoyed some success, it has not been widely accepted for use in rose-growing greenhouses. Because of inherent physical properties, some fungicides are more suitable than others for ULV application.

Reports by Bent (1) and Hislop (5) emphasized the importance of vapor-phase activity in fungicides that effectively control powdery mildew diseases. These studies showed that the gaseous phase of several fungicides inhibited growth of powdery mildew fungi at room temperature. Recent work has indicated that the volatile activity of certain fungicides is greatly enhanced by heating (4). Hyphal tips of *S. pannosa* var. *rosae* stopped growing and formed bulbous swellings when exposed to vapors of nuarimol or fenarimol (Fig. 4). Swelling of actively growing hyphal tips is a typical response of powdery mildew fungi to exposure to the gaseous phase of many fungicides. The fact that only hyphal tips in an active growth phase are affected suggests that the mode of action may involve cell wall synthesis. Swelling of hyphal tips is a useful indicator in bioassays to determine effective dose and distribution of fungicides in the greenhouse. Enlarged hyphal tips are evident within 12 hours of exposure to the toxicant.

Rose powdery mildew was controlled in the greenhouse by heating nuarimol to 150 C in shallow containers. Fenarimol also provided good disease control through the vapor-phase application technique (Fig. 5), as did several other fungicides. Because an effective dose is necessary for control by fungicide vaporization, it is essential that greenhouses be tightly sealed during fumigation. Structural leaks, exhaust fans, and ventilating equipment commonly reduce fungicide concentration and decrease efficacy.

Fungicides applied by this technique have several distinct advantages over more conventional methods. Because this treatment requires little labor, more frequent and timely applications are possible, providing improved disease control at reduced cost. Although no data are available, the volatilization technique may reduce the total amount of fungicide required for disease control because the need for routine protective treatment is greatly reduced. Lack of visible residue on the flowers and foliage improves the quality of roses treated with volatile fungicides. Finally, fungicides applied by this technique can be conveniently used during the night when greenhouse personnel would not be exposed. Reduced fungicide residue on plant surfaces would further decrease worker exposure.

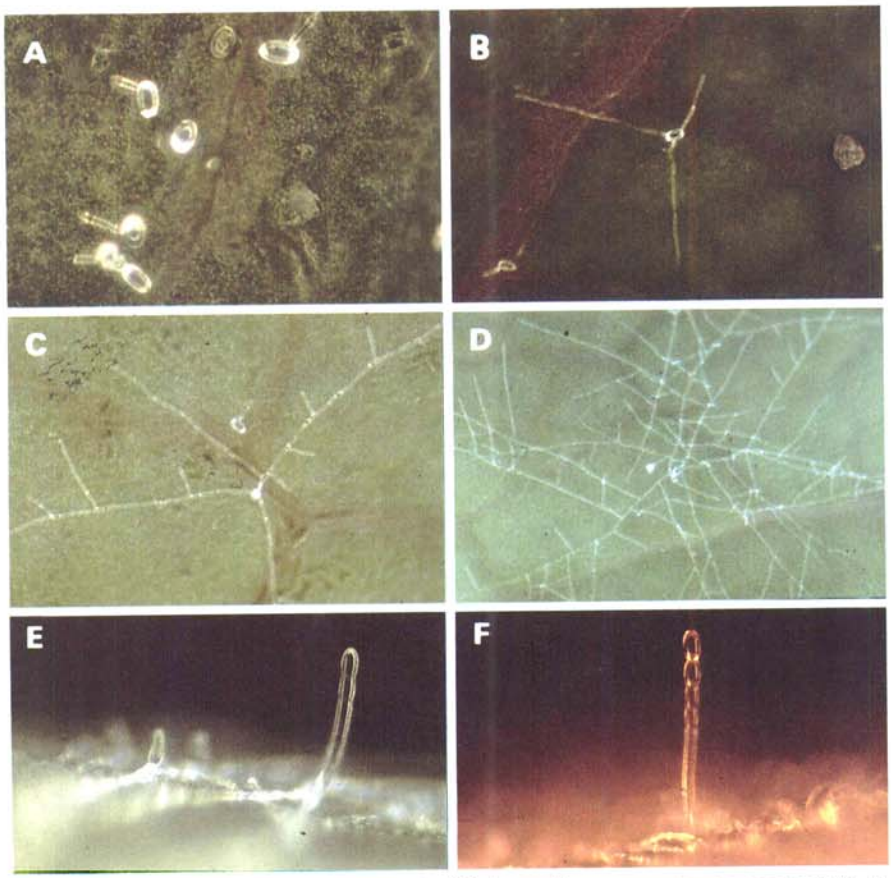

Fig. 3. Typical stages in the development of *Sphaerotheca pannosa* var. *rosae* at 21 C: Germinating conidia at (A) 12 hours, (B) 24 hours, (C) 48 hours, and (D) 60 hours. (E) Immature conidiophores at 72 hours. (F) Conidiophore with conidia at 84 hours.

Biocontrol of Powdery Mildew

Biocontrol of rose powdery mildew by various fungi and by at least one insect has been reported for *S. pannosa* var. *rosae*. Yarwood (10) observed that a single thrips apparently killed a rose powdery mildew colony about 6 mm in diameter in 3 days under laboratory conditions. He believed, however, that these insects did not occur in significant numbers in the field to influence the economic importance of powdery mildew. My own observations of *Thrips tabaci* on roses in Oregon suggest that these insects do increase sufficiently to reduce the inoculum potential of *S. pannosa* var. *rosae*. Difficulties associated with the use of *T. tabaci* as a biocontrol agent include early establishment of a high insect population to provide continuing disease control. The problem is further complicated by the inability of *T. tabaci* to reproduce on rose tissue in the absence of powdery mildew.

Several fungi have been reported as mycoparasites of powdery mildews but

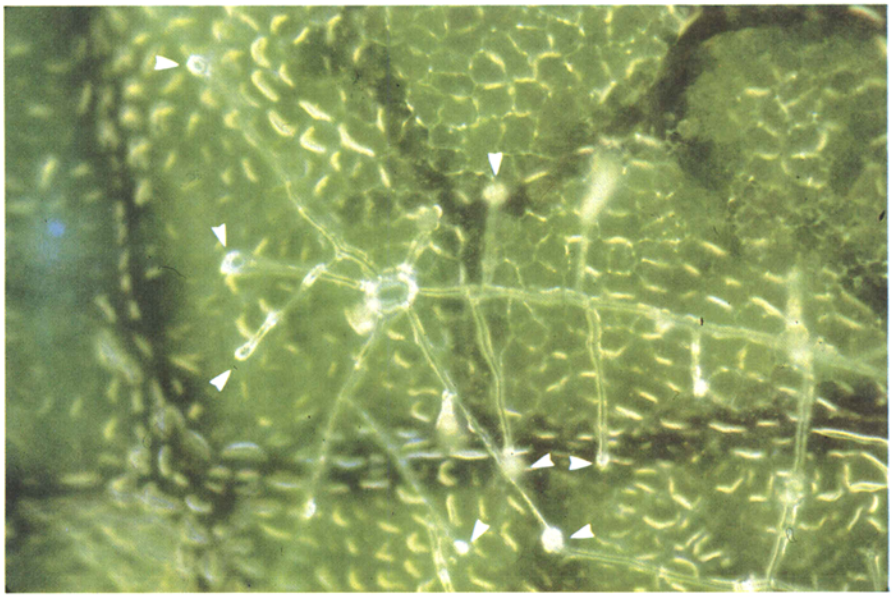

Fig. 4. Swollen hyphal tips (arrows) of a developing powdery mildew colony after 4-hour exposure to volatilized fenarimol.

Fig. 5. Control of powdery mildew by volatilization of fenarimol in the greenhouse: (Top) Heavily infected rose plants before fumigation. (Bottom) Same plants after seven fenarimol treatments at weekly intervals.

none has been investigated intensively to determine its relationship with *S. pannosa* var. *rosae*. Yarwood (9) isolated *Ampelomyces quisqualis* from rose and reported the isolate also attacked red clover powdery mildew (*Erysiphe polygoni*). Because *A. quisqualis* is favored by free water, it would not be particularly suited as a biocontrol agent for rose powdery mildew in arid climates where powdery mildew is most troublesome. Other fungi that have been found closely associated with powdery mildews and are most likely mycoparasitic include *Cladosporium oxysporum*, *Tilletiopsis* sp., and *Verticillium lecanii*. Although several mycoparasites are capable of antagonizing *S. pannosa* var. *rosae* colonies, considerable research is needed before they will play a major role in control of rose powdery mildew. Biocontrol would be best suited for use on outdoor-grown roses where the acceptable disease level may be somewhat higher than for roses grown in the greenhouse.

Future control methods should encompass an integrated management program to maximize the effects of biological control agents. Research should be directed toward determining the effects of pesticides on population dynamics of *S. pannosa* var. *rosae* mycoparasites, selection of more efficient biocontrol agents, and manipulation of environmental factors to enhance hyperparasitism.

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