Control of Powdery Mildew in Vineyards Using Single-Application Vapor-Action Treatments of Triazole Fungicides

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ABSTRACT

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The triazole fungicides etaconazole, flusilazole, myclobutanil, penconazole, triadimefon, and triadimenol were applied as formulated products to cheesecloth wicks. The treated wicks, containing fungicide at the rate of 0.2–4.0 g a.i. per vine, were hung beneath the fruiting zone in the grapevine trellis during the period between bloom and 2 wk after shatter. Although no further fungicide treatments were applied for the growing season, fruit in treated vines in the most effective treatments remained free of powdery mildew until harvest. Control of powdery mildew was observed in a zone having a radius of approximately 45 cm from the treated cheesecloth. Control of powdery mildew equivalent or superior to that obtained with cheesecloth wicks was obtained when cotton rope or string was treated with penconazole and deployed as above. Less effective control was obtained when two cellulose sponges per vine were treated with penconazole and similarly deployed.

Additional keywords: sterol biosynthesis inhibiting fungicide, *Uncinula necator*

Powdery mildew, caused by the fungus *Uncinula necator* (Schwein.) Burrill, is the most widespread and destructive disease of grapevine in the United States. Control of this disease in the northeastern United States may require three to 12 fungicide applications per season, depending on the cultivar and the fungicide used. For example, *Vitis labruscana* L.H. Bailey 'Concord', one of the least susceptible and most widely planted cultivars in the Great Lakes region, receives approximately three fungicide sprays per year for control of powdery mildew. Most cultivars of *V. vinifera* L. and many *Vitis* interspecific hybrid cultivars require up to 12 sprays of sulfur or six sprays of one of the sterol biosynthesis inhibiting (SBI) fungicides. Table grape growers may apply even more sprays in the eastern United States to avoid stem mildew and cosmetic blemishes that would not be of concern to wine grape or processing growers.

The vapor phase of certain fungicides has been reported to provide control of powdery mildew of various hosts in greenhouses or other closed environments (1–4,6,12–15) and certain soilborne fungal pathogens (7). However, effective control of fungal pathogens of fruit and foliage has not been demonstrated under field conditions, although Jenkyn et al (5) provided evidence that the vapor phase of SBI fungicides may result in interplot interference in field experiments.

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The trellis system used in vineyards provides a continuous and nearly closed canopy within which the fruit are concentrated. Therefore, this system is a logical step from the closed environment of a greenhouse to the exposed environment of the field within which to determine the efficacy of fungicide vapors alone for the control of grape powdery mildew. The advantages of using this approach in vineyards include improved exposure to the fungicide of fruit in grape clusters, which are hard to penetrate with a spray once the berries touch. Additional benefits might include reduced residues on fruit at harvest, less compaction of soil caused by heavy spray equipment, and reduced pollution of soil and ground water compared to conventional spray applications. Our objective was to explore the feasibility of controlling grape powdery mildew through the vapor phase of triazole fungicides.

MATERIALS AND METHODS

Vapor-action treatments. Control of powdery mildew in the vineyard by vapor activity of various compounds was evaluated by applying suspensions of formulated product to cheesecloth wicks and suspending the wicks from the grapevine trellis. For each vine, a 1.8 × 1.8 m sheet of cheesecloth was folded to produce a 46 cm × 1.8 m wick. The desired amount of test compound on a per vine basis was suspended in 100 ml of water in a 3.8-L plastic bag. The cheesecloth was then added to the bag and wrung by hand until the suspension was absorbed and uniformly distributed throughout the cloth. The damp, treated cloth was wrapped tightly around a wire suspended beneath the fruiting zone of each vine, resulting in a 1.2-m length of treated row. No other fungicide treatments were applied for the season. Fruit and foliar disease levels were evaluated at harvest using the Barratt-Horsfall system and were converted to percentages using Elanco conversion tables (11).

The amount of active ingredient applied to the cheesecloth on a per vine basis was determined by calculating the total amount of chemical applied to a hectare of vines during an entire growing season using rates suggested by the manufacturer or equivalent active ingredient rates to compare various compounds. The total amount of chemical was then divided by 1,993, the number of vines planted per hectare.

Positioning of the fungicide-treated wicks within the vine varied with pruning and training systems. In 1981, etaconazole was applied to cheesecloth at 0.2 and 2.0 g a.i. per vine and either wrapped around a wire beneath the fruiting zone of *V. labruscana* cv. Concord vines, trained to an Umbrella-Kniffin system, 6 wk after bloom or suspended from the wire as a sheet. Two-vine plots were replicated four times and arranged in a randomized complete block design. Rachises were examined for powdery mildew, and the proportion of the rachis area colonized by *U. necator* was estimated. On 14 October, 10 clusters per vine were randomly selected and examined, and on 20 October clusters within 30 cm of the wick were selected and examined.

In 1984, etaconazole, penconazole, and triadimefon, each at 0.2 g a.i. per vine, were compared for control of powdery mildew on *Vitis* interspecific hybrid cultivars Rosette and Delaware, each trained to the Umbrella-Kniffin system. Cheesecloth wicks containing the chemicals were wrapped around the middle wire of a three-wire vertical trellis so that the treated cloth was inside the canopy near the fruiting zone. The cheesecloth was hung in the canopy 2 wk after bloom. Single-vine plots were replicated six times and arranged in a randomized complete block design. The percentage of berry surface colonized by *U. necator* was estimated on Rosette and Delaware vines on 28 September and 2

October, respectively. Fruit were examined from each of the following locations within the canopy: 15 cm above the wick, 15 cm below the wick, and >15 cm from the wick. Ten to 20 clusters per vine were examined within 15 cm from the wick, and 44–48 clusters were examined >15 cm from the wick.

In 1985, the vapor activity of penconazole, flusilazole, myclobutanil, and triadimenol, each at 0.2 g a.i. per vine, was compared to a water-treated check on the cultivar Delaware. Single-vine plots were replicated four times and arranged in a randomized complete block design. The cheesecloth wicks were wrapped around the bottom wire of a two-wire vertical trellis 1 wk after bloom. Twenty-five leaves within the upper third, middle third, and lower third of the canopy were examined for powdery mildew on 23 September, and the percentage of the surface area colonized was recorded. On the same date, 25 clusters per vine were selected from a zone within 30 cm of the wick, and the percentage of the rachis infected on each cluster was estimated.

Also in 1985, penconazole at 0.1, 0.2, and 0.4 g a.i. per vine was compared on the *Vitis* interspecific hybrid Chancellor. The vines were trained to a bilateral cordon system, and the cheesecloth wicks containing the fungicides or water were hung on a wire directly beneath the cordon on 21 June, at approximately 50% bloom. Two-vine plots were replicated four times and arranged in a randomized complete block design. No other fungicides were applied during the season. On 3 and 23 September, the basal 20 leaves of five shoots per two-vine plot were examined for powdery mildew. On 8 and 23 September, 50 fruit clusters per two-vine plot were examined for powdery mildew. The percentage of the leaf or cluster surface colonized was recorded.

All chemicals were tested as formulated products: penconazole, Topas 10WP; etaconazole, Vangard 10WP; triadimefon, Bayleton 50WP; triadimenol, Summit 25DF; flusilazole, Nustar 20DF; and myclobutanil, Nova 40WP.

Effects of wick substrates on disease control. Four substrates were selected for use in this study: cotton cheesecloth, 2-mm-diameter cotton twine, 7-mm-diameter cotton rope, and cellulose sponge. The cheesecloth, rope, and twine were cut into 2-m sections and then treated with a suspension of penconazole to yield an application rate of 0.2 g a.i. per 2-m length. Lengths of rope were also treated to yield an application rate of 0.4 g a.i. per 2-m length. Penconazole was applied to cheesecloth, twine, and rope by suspending 2.0 or 4.0 g a.i. of the formulated product (Topas 10WP) in a volume of distilled water that would be completely absorbed by the substrate. These amounts of water were 100, 30, and 10 ml for cheesecloth, rope, and twine, respectively. The fungicide was suspended in the appropriate volume of water and then poured into a plastic bag containing the cheesecloth, rope, or twine. The bag was shaken and compressed until the fungicide suspension was completely absorbed. The wicks were then allowed to dry overnight before they were installed in the vineyard.

Cellulose sponges were trimmed into blocks measuring 1 × 5 × 5 cm and were treated with penconazole at the rates of 0.1 or 0.2 g a.i. per sponge. Five milliliters of an aqueous suspension containing 1.0 or 2.0 g a.i. of the formulated product (Topas 10WP) was poured onto each sponge and allowed to dry overnight before installation in the vineyard.

The various wick substrates were installed within the trellis of a bilateral, midwire, cordon-trained vineyard of the *Vitis* interspecific hybrid cultivar Chancellor on 6 July 1988. Vines were treated with a single 2-m length of cheesecloth, rope, or twine fastened to the middle wire of the trellis with clothespins. Two sponges were placed within the canopy of vines, midway between the terminus of the cordon and the trunk of the vine, and were fastened with clothespins to the middle wire of the trellis. The cheesecloth wicks were wrapped around a wire directly beneath the cordons as described above. Replicates consisted of a single grapevine, and treatments were replicated four times. The number of infected leaves per shoot on 10 shoots per vine, the proportion of the leaf surface colonized on infected leaves, and the incidence of fruit infection on 10 clusters per vine were recorded at harvest, on 26 September 1988.

RESULTS

Field efficacy of fungicide vapors. In 1981, etaconazole at 0.2 and 2.0 g a.i. per vine significantly ($P = 0.05$) reduced the severity of disease on Concord grapevines and often reduced disease incidence (Table 1). The 2.0-g rate was more effective than the 0.2-g rate. Whether the cheesecloth was wrapped around the trellis wire or suspended from it as a sheet had no influence on efficacy (Table 1). The greatest reduction of disease was observed within a 30-cm band around the cheesecloth.

In 1984, most chemical treatments provided significant control compared to the water-treated cheesecloth checks (Table 2). However, of the three chemicals, penconazole provided slightly better control of powdery mildew. Although not always significantly different, severity of infection on Rosette vines tended to be less on the clusters beneath the cloth. On both Rosette and Delaware vines, the incidence of infection of clusters was significantly lower with penconazole than with either etaconazole or triadimefon within 15 cm of the cloth. On the Delaware vines, however, there was no significant difference among the three chemicals when severity of infection was assessed within the 15-cm zone of the cloth. Although severity of infection on clusters outside the 15-cm zone was significantly higher than within the zone, irrespective of the chemical used, incidence of disease on these clusters was significantly lower than on the water-treated controls. When assessments for all clusters on the vine were pooled and analyzed, penconazole provided significantly ($P = 0.05$) better control than either etaconazole or triadimefon.

The entire canopy of Delaware grapevines that received vapor-action treatments in 1985 had significantly less disease than the water check (Table 3). Penconazole-treated vines had significantly less foliar disease than vines treated with the other SBI materials. When the foliage was divided into three zones (upper, middle, and lower) and evaluated for disease, only penconazole provided significant control of powdery mildew in the upper third of the canopy. All fungicides provided significant control of foliar powdery mildew in the middle zone of the canopy, but myclobutanil was the least effective of the four

Table 1. Control of powdery mildew on the rachis of fruit clusters of Concord grapevines by etaconazole-treated cheesecloth at Geneva, New York, during 1981

Treatment[y]	Rate of etaconazole per vine (g a.i.)	Whole vine: Rachises infected (%)	Whole vine: Rachis area infected (%)	Band (30 cm) around cheesecloth: Rachises infected (%)	Band (30 cm) around cheesecloth: Rachis area infected (%)
Draped cheesecloth	0.2	96 a[z]	65 b	92 ab	42 b
	2.0	86 b	47 c	70 c	18 c
Twisted cheesecloth	0.2	96 a	62 b	86 bc	28 bc
	2.0	87 b	48 c	58 c	13 c
Untreated	...	100 a	82 a	100 a	78 a

[y]Cheesecloth was treated with a suspension of etaconazole and hung in each vine on 31 July 1981, approximately 6 wk after bloom. The cheesecloth either was draped as a sheet in the trellis or was twisted around a trellis wire beneath the fruiting zone of the vine. Two-vine plots were replicated four times and arranged in a randomized complete block design. Data were collected 14 October (whole vine) and 20 October (30-cm band around cheesecloth).
[z]Treatment means within columns followed by the same letter do not differ significantly ($P \leq 0.05$) as analyzed by the Waller-Duncan exact Bayesian k-ratio LSD rule.

SBI fungicides tested. In the lower third of the canopy, nearest to the wicks, all fungicide treatments had less foliar disease than the check vines. Penconazole, flusilazole, and triadimenol each provided excellent control, and myclobutanil was slightly less effective. Disease incidence and severity on rachises in all of the fungicide treatments were significantly less than in the water check. There was no significant difference in disease control between the fungicide treatments on rachises (Table 3).

Powdery mildew on leaves one to 15 of Chancellor grapevines was not significantly reduced by vapor-action treatments when evaluated on 3 September 1985 (Fig. 1A). On leaves 16–20, there was slightly less disease control at the 0.1-g rate than at the higher rates. In general, disease increased from leaf position one to 20 as the shoot grew away from the fungicide-treated wick and out of the zone of fungicide influence. On the 23 September evaluation (Fig. 1B), powdery mildew on leaves one to 15 was significantly less severe than on the water check. A rate effect became apparent as the leaf position was farther removed from the fungicide wick. On leaves one to 10, the 0.1-g a.i. rate provided less control than the 0.2- or 0.4-g a.i. rates. There was no significant difference between the 0.2- and the 0.4-g a.i. rate at any of the leaf positions. At leaf positions 11–15, there was no significant difference between the fungicide rates, and at leaf positions 16–20, there was no significant difference between any of the treatments (Fig. 1B). An analysis of the pooled foliar data revealed no significant difference among treatments on 3 September, but a rate response was evident by 23 September (Table 4).

There was no significant difference in disease incidence and severity between the three fungicide rates on clusters of Chancellor vines on 8 September 1985. However, all vapor-action treatments had significantly less disease than the water check (Table 4). By 23 September, disease incidence in the water checks had increased from 78 to 99% and disease severity had increased from 11 to 31% (Table 4). Disease incidence in the 0.1-g a.i. rate was significantly lower than that in the check but significantly higher than that in the two higher rates. There was no significant difference in the severity of disease on fruit among the three rates of penconazole (Table 4).

Effects of wick substrates on disease control. Disease levels were very low in 1988, and no fruit were infected on treated or untreated vines. However, incidence and severity of foliar infection did allow for some discrimination among treatments (Table 5). Sponge treatments had no effect on the number of infected leaves per shoot (Table 5). Treated cheesecloth and cotton string provided an equivalent reduction in the number of infected leaves per shoot but were less effective than rope treated with 0.2 g a.i. of penconazole (Table 5). Rope treated with 0.4 g a.i. of penconazole provided the greatest reduction in number of infected leaves per shoot, but the severity of mildew infection was lowest on the cheesecloth-treated vines (Table 5).

Table 2. Control of powdery mildew on Rosette and Delaware grapevines by single-application vapor-action treatments at Geneva, New York, during 1984

	Rosette		Delaware	
Treatment[y] Position	Clusters infected (%)	Surface area infected (%)	Clusters infected (%)	Surface area infected (%)
Water check				
15 cm above wick	100.0 a[z]	56.1 a	100.0 a	45.0 a
15 cm below wick	100.0 a	61.9 a	100.0 a	39.4 a
>15 cm from wick	100.0 a	44.2 b	100.0 a	44.6 a
Etaconazole, 0.2 g a.i.				
15 cm above wick	95.7 a	16.0 b	40.1 bc	0.8 bc
15 cm below wick	66.1 b	5.1 cd	20.2 de	0.3 bc
>15 cm from wick	98.4 a	31.0 b	89.3 b	15.0 b
Penconazole, 0.2 g a.i.				
15 cm above wick	37.0 c	1.5 de	8.3 ef	0.1 c
15 cm below wick	26.8 c	0.6 e	2.4 f	0.0 c
>15 cm from wick	100.0 a	32.4 b	48.7 c	2.5 c
Triadimefon, 0.2 g a.i.				
15 cm above wick	78.5 b	10.6 bc	42.3 b	0.9 bc
15 cm below wick	76.2 b	4.4 cd	26.1 cd	0.5 bc
>15 cm from wick	100.0 a	31.0 b	87.9 b	12.1 b

[y] Cheesecloth treated with fungicide was wrapped around the middle wire of a three-wire vertical trellis inside each vine canopy on 9–10 July 1984, approximately 2 wk after bloom. Single-vine plots were replicated six times and arranged in a randomized complete block design. Data were collected from clusters located within a 15-cm zone above the wick, within a 15-cm zone beneath the wick, or outside of the 15-cm zone surrounding the wick. Disease was assessed on 10–20 clusters per vine within 15 cm of the wick and on 44–48 clusters per vine >15 cm from the wick. Assessments were performed on 28 September and 2 October on Rosette and Delaware vines, respectively.

[z] Treatment means within columns followed by the same letter do not differ significantly ($P \leq 0.05$) as analyzed by the Waller-Duncan exact Bayesian *k*-ratio LSD rule.

Table 3. Control of powdery mildew on Delaware grapevines by single-application vapor-action treatments at Geneva, New York, during 1985

	Leaf surface infected (%) vs. canopy position				Rachis infection	
Treatment[y]	Upper third	Middle third	Lower third	All leaves	Rachises infected (%)	Rachis area infected (%)
Water check	63.4 a[z]	48.5 a	23.3 a	45.0 a	61.5 a	2.0 a
Penconazole, 0.2 g a.i.	21.4 b	0.8 c	1.1 c	7.8 c	7.0 b	0.1 b
Flusilazole 0.2 g a.i.	54.8 a	2.3 c	1.5 bc	19.5 b	9.0 b	0.1 b
Myclobutanil 0.2 g a.i.	61.0 a	9.1 b	4.5 b	24.9 b	7.2 b	0.1 b
Triadimenol 0.2 g a.i.	43.8 a	5.3 bc	0.8 c	16.6 b	2.5 b	<0.1 b

[y] Cheesecloth treated with fungicide was wrapped around the bottom wire of a two-wire vertical trellis inside each vine canopy on 2 July 1985. Single-vine plots were replicated four times and arranged in a randomized complete block design. Percent canopy surface area infected was determined by rating the canopy surface area infected on each vine on 23 September by the Barratt-Horsfall system and converting to percent with Elanco conversion tables. Percent rachis infection (incidence) and percent rachis area infected (severity) were determined by rating 25 clusters in the vicinity of the wicks on each vine on 23 September by the Barratt-Horsfall system.

[z] Treatment means within columns followed by the same letter do not differ significantly ($P < 0.05$). Arcsine-transformed data were analyzed by the Waller-Duncan exact Bayesian *k*-ratio LSD rule.

DISCUSSION

On the basis of the disease control obtained in our vineyard studies, season-long control of powdery mildew in vineyards is possible by the vaporization of triazole fungicides. We assumed that the physical mode of action of these fungicide treatments is largely through their vapor activity, although we cannot eliminate the possibility of distribution of fungicide via rain-splash to nearby tissue or transport of fungicide by internal translocation. The slightly improved control of powdery mildew beneath, as compared to above, cheesecloth wicks (Table 2) indicates that some redistribution of fungicide may be occurring in vineyard trials. Nonetheless, the degree of disease control observed at points above and distant to the wicks indicates that vapor activity is involved. Furthermore, when healthy Chancellor leaves from penconazole wick-treated vines were picked and inoculated with conidia of *U. necator* in the laboratory, they became infected and developed severe disease symptoms. When healthy shoots from penconazole-treated vines were trained into neighboring nontreated vines, the distal portion of the shoot became infected and developed symptoms of powdery mildew. Conversely, when diseased shoots of nontreated vines were trained into neighboring vines containing a penconazole-treated wick, the new growth on the distal end of the shoot was disease-free (R. C. Pearson, *unpublished*).

When *U. necator* infects more than 3% of the cluster surface, off-flavors may be detected in wine made from diseased grapes (10), and wineries and other processors may reject crops with more than this level of fruit infection. Although less than commercially acceptable control of powdery mildew was obtained in our earliest trials in 1981 and 1984, later refinements of trials in 1985 and 1988 yielded a degree of disease control from vapor-action treatments with penconazole that was often comparable to that obtained through the use of several fungicide spray applications. Rosette grapevines in Naples, New York, that were sprayed four times with triadimefon at 0.14 kg a.i./ha in 1985 had 0.1% of the fruit surface colonized by *U. necator* (9), as compared to 0.4% on Chancellor grapevines under a vapor-action treatment with penconazole at 0.2 g a.i. per vine (Table 4). In 1988, Rosette grapevines in Geneva, New York, that were sprayed four times with triadimefon at 0.14 kg a.i./ha had 1.3% of the surface infected on diseased leaves (R. C. Pearson, *unpublished*), as compared to 1.6 and 2.4% on Chancellor vines under a vapor-action treatment consisting of 0.2 g a.i. of penconazole per vine on cheesecloth and rope, respectively (Table 5).

In all trials, 0.2 g a.i. of penconazole on cheesecloth wicks provided excellent control of fruit infection on Chancellor vines. However, the improved performance of penconazole in controlling foliar mildew when applied to rope wicks indicates that the use of certain wick substrates may allow lower rates of application or improved control at equivalent rates of application. The relatively poor performance of cellulose sponge treatments indicates that fungicide vapor concentration rapidly decreases to nonfungitoxic levels as distance from the compound increases.

The potential benefits of vapor-action treatments are numerous and encourage further development of this technology. One benefit is the potential for little or no residue on fruit at harvest. This is especially significant for the table grape industry, where visible residues of inert carriers in pesticide formulations are perceived in markets as chemical residues of the active ingredient. Since sprays are not applied and only vapors are released into the atmosphere, spray drift to nontarget organisms should be minimal. The use of a wick substrate that resisted removal of the active ingredient by rain and irrigation water would minimize loss of the applied fungicide to soil and groundwater. Savings in fuel, labor, and equipment costs of repeated spray applications throughout the season may also be significant. Finally, soil compaction caused by tractor and sprayer travel in the vineyard should be considerably reduced. This can all be accomplished in conjunction with adequate control of powdery mildew.

The application of this technology to the control of grape powdery mildew is important in the northeastern United States, where summer rainfall removes fungicide spray residues and dictates frequent application, but it is perhaps even more applicable to warm, dry climatic conditions such as those existing in California, Australia, southern Africa, and certain areas of Europe and South America. This technique is likely to be effective in California, where irrigated vines have canopies that are generally more dense than those in New York. Additionally, temperatures in most other viticultural regions of the world are higher than in New York, presumably resulting in increased vapor activity. Fungal diseases other than powdery mildew may also be less important or absent in arid viticultural regions outside of New York (8). Finally, this technology may have application for disease control in other crops that may be trellised, such

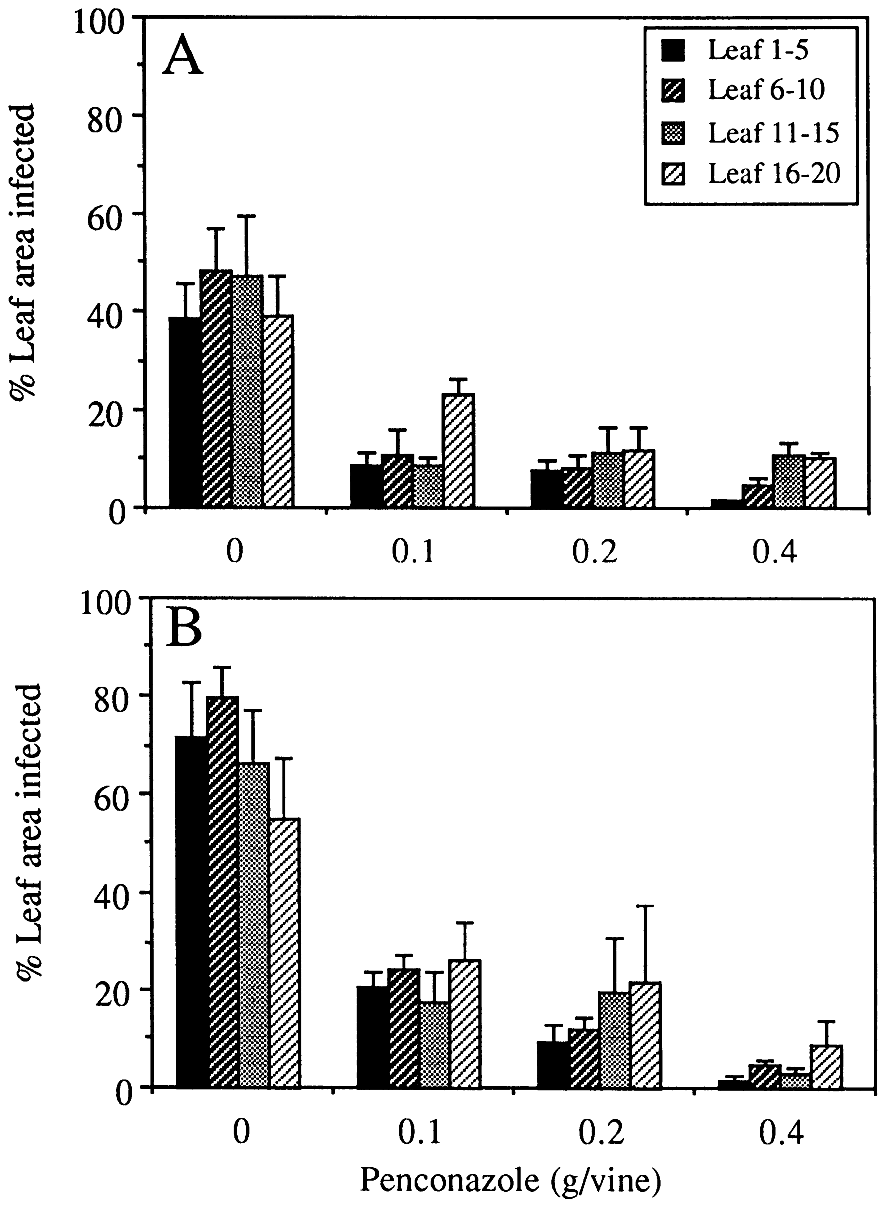

Fig. 1. Influence of leaf position and fungicide rate on the efficacy of penconazole-treated cheesecloth wicks that were wrapped around a wire hung 15 cm beneath the cordons of bilateral cordon-trained vines of the cultivar Chancellor. Data from **(A)** 3 September 1985 and **(B)** 23 September 1985 on severity of infection on the basal 20 leaves of shoots were grouped into five-leaf intervals, and the mean and standard error of the severity of each group were reported. Bars indicate one standard error of the mean.

Table 4. Control of powdery mildew on Chancellor grapevines by single-application vapor-action treatments at Geneva, New York, during 1985

	3 September			23 September		
Treatment[y]	**Clusters infected (%)**	**Surface area infected (%)**	**Leaf area infected (%)**	**Clusters infected (%)**	**Surface area infected (%)**	**Leaf area infected (%)**
Water check	77.7 a[z]	10.9 a	42.3 a	99.1 a	31.4 a	69.4 a
Penconazole, 0.1 g a.i.	8.5 b	0.3 b	11.7 b	41.7 b	1.2 b	20.2 b
Penconazole, 0.2 g a.i.	7.5 b	0.3 b	9.4 b	16.5 c	0.4 b	14.1 bc
Penconazole, 0.4 g a.i.	0.0 b	0.0 b	6.1 b	11.0 c	0.2 b	3.8 c

[y]Cheesecloth treated with fungicide was wrapped around a wire hung 15 cm beneath the cordons of two bilateral cordon-trained vines on 21 June 1985 at approximately 50% bloom. Two-vine plots were replicated four times and arranged in a randomized complete block design. Percent clusters infected (incidence) and percent cluster surface area infected (severity) were determined by rating 50 clusters in each two-vine plot on 3 September by the Barratt-Horsfall system and converting to percent with Elanco conversion tables. Percent leaf area infected was determined by rating the basal 20 leaves on each of five shoots per two-vine plot by the Barratt-Horsfall system and converting to percent with Elanco conversion tables.

[z]Treatment means within columns followed by the same letter do not differ significantly ($P \leq 0.05$) as analyzed by the Waller-Duncan exact Bayesian k-ratio LSD rule.

Table 5. Control of powdery mildew on Chancellor grapevines by vapors of the fungicide penconazole applied to various wick materials[y]

Wick material	**Rate of penconazole per vine (g a.i.)**	**Infected leaves per shoot (no.)**	**Leaf area infected (%)**
Cheesecloth	0.2	9.78 c[z]	1.60 a
Cotton rope	0.2	4.40 b	2.40 a
	0.4	2.68 a	5.13 b
Cotton string	0.2	8.27 c	6.60 b
Cellulose sponge	0.2	11.10 d	17.68 c
	0.4	11.63 d	8.63 c
Untreated	...	12.32 d	8.70 c

[y]Wicks were placed in vines on 16 July 1988, and disease incidence and severity were assessed on 26 September 1988.

[z]Treatment means within columns followed by the same letter do not differ significantly ($P \leq 0.05$) as analyzed by the Waller-Duncan exact Bayesian k-ratio LSD rule.

as apples on dwarfing rootstocks, tomatoes, cucumbers, and raspberries.

Nonetheless, this technique raises some questions that should be addressed before commercial application. Although hand labor in vineyards is rare during the part of the season when powdery mildew control is essential, there are numerous tractor operations that must be conducted at this time, e.g., leaf removal and summer pruning in some locations, various pesticide sprays, and occasional cultivation. Worker exposure in applying the delivery system, removing it prior to harvest, and working in proximity to the wicks should be addressed. Although we have investigated the efficacy of the vapor phase alone, it should be pointed out that the vapor phase of triazole fungicides will be present in vineyards treated with conventional spray equipment, and perhaps at levels that briefly exceed those attained in our treatments. Therefore, exposure to the vapor phase of these materials may need to be addressed irrespective of the deployment of wick substrates within the vineyard.

Finally, a potential risk of the vapor action technique for applying triazole fungicides involves selection for resistance within pathogen populations. The system may provide a constant exposure of the pathogen population to a fungicide at risk. The long-term impact of this constant selection for resistance on the sustainability of efficacy of the triazole fungicides is unknown. A number of anti-resistance tactics could be adopted if indeed they are necessary. Applying fungicides of differing modes of action, such as sulfur, early in the growing season during the period of primary inoculum release, and delaying the vapor-action application to just before bloom, may provide the break in the disease cycle that would reduce the risk of selection for resistance to the triazole fungicide applied in the vapor phase.

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