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Effect of grapevine training systems on development of powdery mildew

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Abstract

The effects of two training systems and row spacing on development of powdery mildew caused by *Uncinula necator* on clusters of 'Chardonnay' and 'Cabernet Sauvignon' grapevines were examined. Disease development was monitored in blocks with two different row spacing (2 and 3 m) in vertical shoot positioned vines (VSP) and in free-positioned, topped vines (FC) with no foliage support wires. The FC vines were hedged to about one meter shoot length. No fungicides were applied and disease powdery mildew level was recorded four to seven days after appearance of the first disease symptoms. During five consecutive years (1994–1998), disease incidence was higher in the VSP system than the FC vines. The difference was high when disease level was low (30% of the clusters in VSP vines infected, compared to 5% in the FC vines) and decreased when disease pressure was high (79% in VSP compared to 46% in FC vines). In the 'Cabernet Sauvignon', in four of the years, disease incidence was higher in the narrow spacing of 2 m between the rows than that in the wider 3 m spacing. Microclimate (temperature, relative humidity and light intensity) was monitored in the cluster zone near the spurs of 'Chardonnay' vines during three weeks in the 1998 season. In VSP vines light intensity was lower then that in FC vines both four and one week before disease symptoms appeared (72% and 18% respectively). The differences in temperature and relative humidity were less than 1 °C and 3%, respectively, and most likely did not affect disease development. The results suggested that high light intensity is the primary factor, which limits powdery mildew growth development on field-grown grapevines in the Golan region of Israel. The use of the FC system might be useful in reducing the need of fungicides.

Introduction

Powdery mildew is a widely distributed destructive disease of field-grown grapevines. Cluster and blossom infection with *Uncinula necator* (Schw.) Burr., before or shortly after bloom may result in poor fruit set and considerable crop loss (Bulit and Lafon, 1978; Pearson, 1988) and a decrease in wine quality (Ough and Berg, 1979). The disease develops better under shaded conditions e.g. in the presence of trees nearby the vineyard, or in vigorous vines (Bulit and Lafon, 1978). Since shading is associated with reduced irradiation, reduced temperature and increased humidity, these effects were not dissociated under field conditions. However, increased irradiation, high temperature and low humidity were shown to be unfavorable for the fungus in controlled and semi-controlled conditions (Delp, 1954; Willocquet et al., 1996).

Disease control is generally achieved by the use of fungicides, including sulfur and sterol biosynthesis inhibitors. However, fungicide-resistant strains of the pathogen have developed in vineyards both in Europe and the US (Steva and Clerjeau, 1990; Ypema et al., 1997). Most resistant strains survive for several years, so the risk of reinforcing resistant populations through the use of ineffective fungicides is very high (Dekker, 1987). The need for reduced pesticide levels on food crops, calls for alternative methods of disease control.

Cultural practices and crop phenology may be utilized to develop alternative disease management programs. Removal of basal leaves after bloom can reduce the severity of Botrytis bunch rot (English et al., 1989) and powdery mildew (Chellemi and Marois, 1992). Basal leaf removal, shoot positioning and trellising can, in some cases, improve fruit composition by altering the canopy microclimate (Kliewer et al., 1998). Training systems and pruning practices of grapevines affected the occurrence of Phomopsis cane and leaf spot (Pscheidt and Pearson, 1989). The effect of canopy manipulation on incidence and development of powdery mildew has yet not been examined. This study was undertaken to test the effects of two training systems: the common vertical shoot positioning (VSP) and the hedged, non-positioned, free canopy (FC), and two row spacing (2 and 3 m) on the development of powdery mildew in a vineyard in the Golan region of Israel.

Materials and methods

Field experiments

Field experiments using *Vitis vinifera* L, cvs. 'Cabernet Sauvingnon' and 'Chardonnay' grapevines on Richter 110 rootstock were conducted in 1994–1998 using a vineyard planted in 1986 on an experimental farm in the Golan region of Israel. Both cultivars are susceptible to powdery mildew, and disease had been evident in the vineyard in previous years. The vineyard was irrigated and maintained as recommended to commercial growers in this region. In general, drip irrigation starts at the end of April with 0.5 mm/day and increased gradually up to 2.5 mm/day at 'veraison'. The annual rainfall in this region is 750–850 mm (winter rains only), and the average midday relative humidity (RH) and temperature in summer are 35–40% and 30 °C, respectively. The sky is cloudless during most of the summer (950 W/m^2/s). Basal leaf removal (Chellemi and Marois, 1992), was conducted on the east side of the VSP vines four weeks after bloom. This was usually performed one to two weeks before the occurrence of the first symptoms of powdery mildew.

Experimental design

Chardonnay and Cabernet Sauvignon vines, grafted on Richter 110, planted in 1986 at distances of 2×1.5 and 3×1.5 m were chosen. The vines were trained to a one directional horizontal cordon at 1 m height. The canopy, in half of the vineyard, was positioned using one pair of moveable positioning wires (VSP). In the other half, the canopy was free, not positioned but topped to about one meter length after fruit set and hedged once or twice during the growth period before harvest (FC).

Experimental plots consisted of six adjacent vines at the end of the rows. These were replicated six times (six end rows) for each treatment and used in each of five consecutive years (1994–1998). Vines in these plots remained untreated against powdery mildew until the appearance of the first symptoms of the disease on the young berries.

Assessment of powdery mildew in the field

Fruit clusters were rated four to seven days after appearance of the first symptoms of powdery mildew on the grape berries (5–7 mm in diameter). Ten fruit clusters were randomly selected from each of the four central vines in each plot (row) and rated for disease severity based on percentage of fruit cluster area covered with powdery mildew. A 0–4 scale (Reuveni and Reuveni, 1995) was used for rating the disease on fruit clusters: 0 = no powdery mildew colonies observed on tissue, 1 = 1–10%, 2 = 11–25%, 3 = 26–50%, and 4 = >50% of the surface area of the selected clusters infected with powdery mildew. In addition, in order to determine disease incidence, the percentage of infected cluster in each treatment was determined.

Environmental monitoring

Microclimate measurements were made in cv. Chardonnay during three different weeks in the 1998 growing season, within May and June. Temperature, relative humidity and light intensity (in lumens) were recorded using a portable micrologger (HOBO, Onset Computer Corp. Pocasset, MA USA). The sensors were placed inside the vine foliage in the cluster's zone of each training system. The position of the sensors along the row was changed every two days. The data presented for each training system is an average of the diurnal microclimatic conditions of four different points. Results presented are of data measured from 06:00 am to 06:00 pm.

Light intensity was also measured with a Sunlink apparatus (Decagon, Pullman, WA USA), consisting of 80 light sensors attached to an 80 cm rod. The rod was placed inside the vine foliage parallel to the ground and vertical to the row with 40 sensors at each side of the vine's cordon. With this, Light intensities at 80 points through the width of the vine foliage at the clusters height were obtained. Ten measurements were made for each of four replicates at mid-day. Only data of the center 40 cm (the actual cluster zone) was compared.

Data analysis

Analysis of variance (ANOVA) using the SAS GLM (SAS Institute, Inc., Cary, NC) procedure was applied to data. An arcsin transformation was performed on percentage data of disease before ANOVA. Duncan's Multiple Range Test was used to determine significant differences between treatments. Bars in figures represent means and standard errors of the means.

Results

Disease development

Throughout the five years, disease development on berries of VSP vines was higher than on FC vines. Disease incidence as determined by the percentage of infected clusters was 2–4 times higher and significantly different in four of five years on 'Chardonnay' and three of five years on 'Cabernet Sauvignon' (Figure 1). These differences were more pronounced when disease level in the vineyard was relatively low (about 30.0% of clusters of VSP vines infected, compared to 5.0% of FC vines). In years with relatively high disease level, the differences between the two training systems were lower (about 79% in VSP, compared to 46% in FC vines). Disease severity was also significantly ($P < 0.05$) higher on clusters of VSP vines than on those of FC vines in four out of five years on 'Chardonnay' and three out of five years in 'Cabernet Sauvignon' (Figure 2). It should be noted that in both cultivars the incidence and degree of disease increased during the five years of the experimental period. This was most consistent for cv. Chardonnay, in both training systems and slightly less for Cabernet Sauvignon showing in 1995 for VSP a somewhat higher and for FC in 1997 a somewhat lower disease than the general pattern. Further analysis of data indicated that the distance between rows in the vineyard had affected the level of disease incidence. The difference was found for both the VSP and FC training systems, particularly with the more vigorous Cabernet sauvignon. The percent of infected clusters was higher in the denser planted

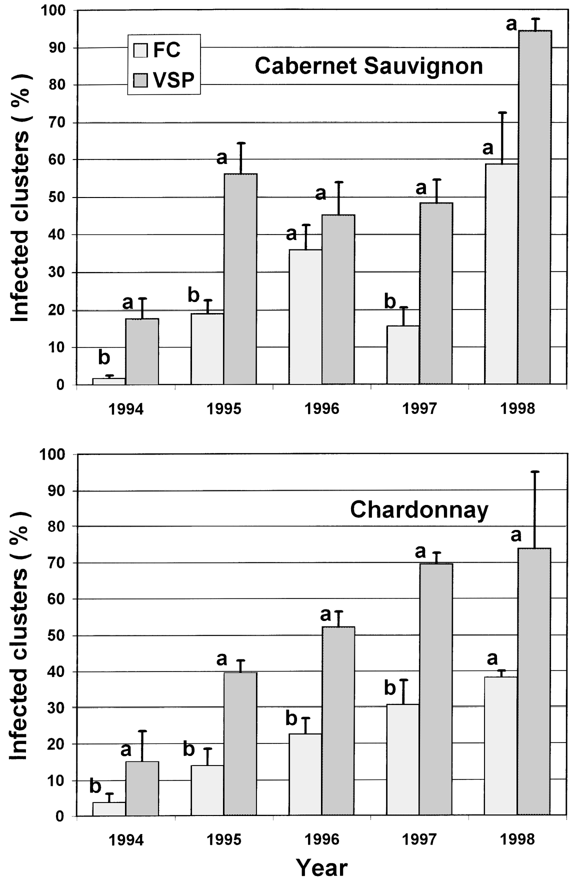

Figure 1. The effect of two canopy management systems, vertical shoot positioning (VSP) and topped free canopy (FC), on incidence of powdery mildew in cvs. 'Cabernet Saouvignon' and 'Chardonnay' over a period of five years. Data represent means of 240 fruit clusters for each treatment and cultivar in each year. Bars represent means and standard errors of means. Different letters on bars in each year indicate significance at $P < 0.05$ according to Duncan's Multiple Range Test.

vines (2 m between rows) then in the more spaced ones (3 m between rows), in all the analyzed years. Although the difference in the level of disease between the two planting densities was consistent, it was statistically significant only in 1996 (Figure 3). In the less vigorous cv. Chardonnay, the effect of spacing had only a minor effect on the level of disease in either of the training systems (Figure 4).

Effect of vegetative growth on light penetration

As presented in Table 1, Lavee et al. (1993) reported that cv. 'Cabernet Sauvignon' in this experimental

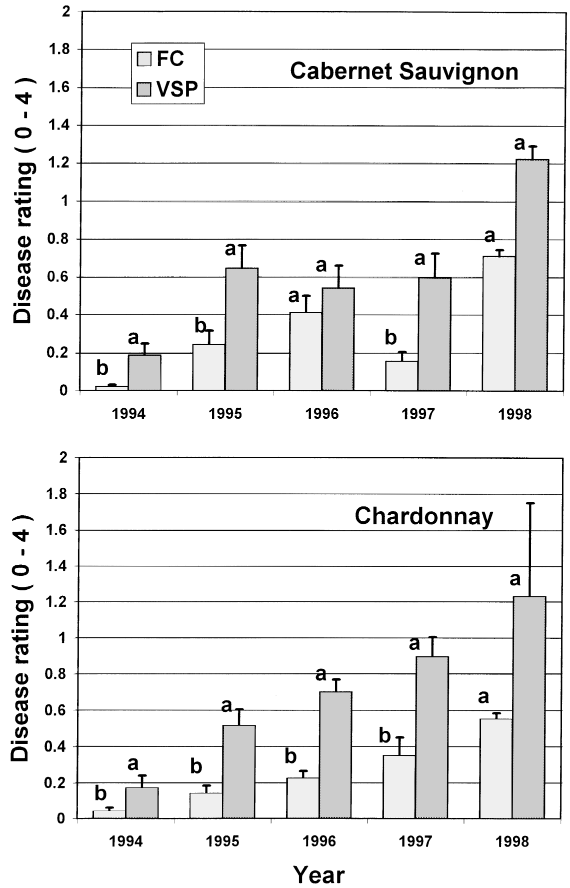

Figure 2. The effect of two canopy training systems (VSP and FC) on severity of powdery mildew in cvs. 'Cabernet Soauvignon' and 'Chardonnay' over a period of five years. Data represent means of disease rating (on a 0–4 scale) on fruit clusters for each treatment and cultivar in each year. Bars represent means and standard errors of means. Different letters on bars in each year are significantly $P < 0.05$ different according to Duncan's Multiple Range Test.

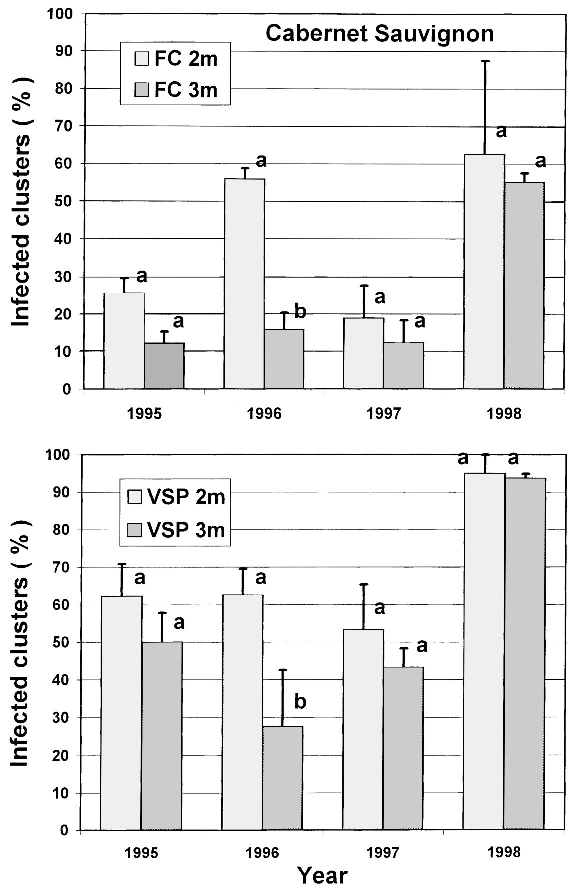

Figure 3. The effect of row spacing and training system on the incidence of powdery mildew in cvs. 'Cabernet Saouvignon' over a period of four years. Data represent means of 240 fruit clusters for each treatment and cultivar in each year. Bars represent means and standard errors of means. Different letters on bars in each year indicate significance at $P < 0.05$ according to Duncan's Multiple Range Test.

plot grew more vigorously than the 'Chardonnay' as expressed by the weight of the pruning wood. Therefore, in this cultivar, the closer row spacing caused mutual shading between rows as expressed by light penetration to the cluster zone.This effect could not be found in the less vigorous Chardonnay where light penetration was higher and not affected by the row spacing (Table 1).

Microclimate measurements

Consistent differences in light intensity were detected in the cluster zone of Chardonnay vines by both the Hobo and Sunlink sensors. Light intensity measured by Hobo sensors near the clusters of FC vines was significantly ($P < 0.05$) greater and reached levels of up to 5.5 times of those measured in the clusters zone of VSP vines (Table 2). Similarly, higher light intensities were detected at mid-day in FC vines than in VSP vines when the Sunlink was placed through the width of the vines at cordon height (Figure 5). Because of western winds the free canopy did not create a symmetric form above the vine cordon, this can be seen especially in the difference in light penetration between the left and right sides in Figure 5 (south-western and north-eastern sides of the rows, respectively). Average temperature,

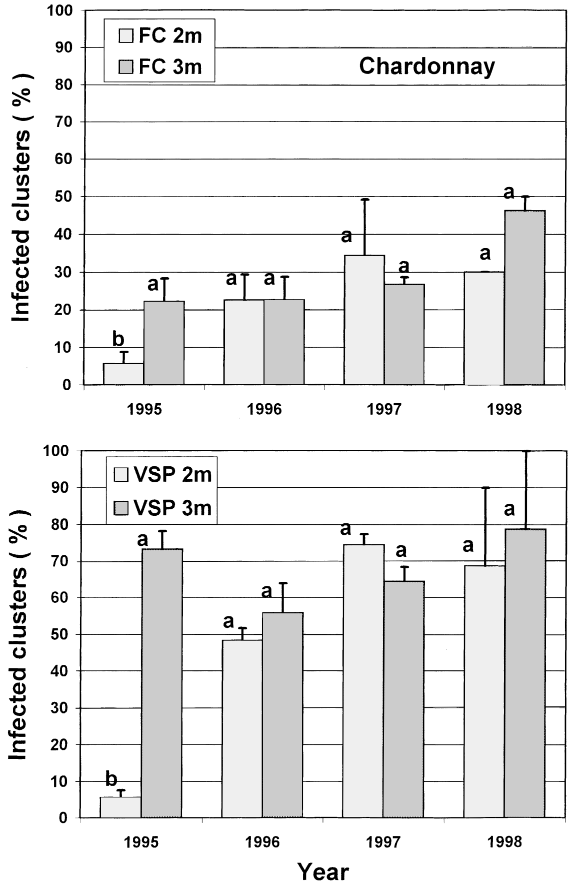

Figure 4. The effect of row spacing and training system on the incidence of powdery mildew in cvs. 'Chardonnay' over a period of four years. Data represent means of 240 fruit clusters for each treatment and cultivar in each year. Bars represent means and standard errors of means. Different letters on bars in each year indicate significance at $P < 0.05$ according to Duncan's Multiple Range Test.

measured during 3 weeks in the canopy of FC vines were slightly higher and average RH slightly lower than in VSP vines (Table 2).

Discussion

This study demonstrates that canopy manipulation in the vineyard can have a significant effect on the development of powdery mildew on fruit clusters of grapevines. During five consecutive years (1994–1998) disease incidence and severity was higher in the VSP system then in the FC one. As the experimental plots

Table 1. The effects of row spacing on the annual vegetative growth[1] and light penetration[2] of cvs. 'Cabernet Sauvignon' and 'Chardonnay' (adapted from Lavee et al., 1993)

Cultivar	Pruning wood (kg/vine)[1]		Light penetration (μmol m^{-2} s^{-1})[2]	
	2 m	3 m	2 m	3 m
Cabernet	1.0 B[3]	1.4 A	16 B	40 A
Chardonnay	0.8 A	0.8 A	43 A	39 A

[1]The vegetative growth was determined by the weighing the pruning wood during the winter expressed as kg pruning wood per vine. The results are means of both training systems.
[2]The light intensity was measured as PAR energy using a LiCor radiation sensor and data logger.
[3]Means within rows (row spacing) for pruning weight or light penetration followed by different letters are significantly ($P < 0.05$) different according to Duncan's Multiple Range Test.

were not sprayed with fungicides, spray penetration, often associated with poor disease control was not an issue in the present study. The differences in disease incidences and severity between the two systems were more pronounced in years when the disease level was low then in years with high disease incidence.

Light intensity in the canopy and especially in the cluster zone, was the only major microclimatic factor which differed consistently and significantly between the two training systems and in the more vigorous cv. 'Cabernet Sauvignon' also between different row-spacing. Light intensity measured near the clusters of FC vines was significantly greater reaching up to 5.5 times higher values than that measured near the clusters of VSP vines. Although significant differences in temperature and RH were detected as well, their levels, in both canopy systems, were in a range that is favorable for the development of the fungus (Bulit and Lafon, 1978). These findings indicate that light intensity is a primary factor limiting powdery mildew growth on field-grown grapevines in this region. In Israel, with a clear sky during most of the growing season, 'powdery mildew years' are those with a relatively cloudy spring. Except for the cv. 'Carignan', which is by far more susceptible then other grape varieties, first symptoms of powdery mildew on untreated vines are usually noted 1–2 weeks after fruit set. At that time, as shoots are actively growing, shaded zones develop and can create favorable infection sites. Our results suggest, that sunlight limit the development of powdery mildew on the vines. Studies conducted on several aerial fungi showed radiation to be a limiting factor for their development. UV light found responsible for this

Table 2. The effect of training system on light penetration, temperature and relative humidity in the cluster zone of cv. Chardonnay

Dates	Light Intensity (lumens)*		Temperature (°C)		Relative humidity (%)	
	FC	VSP	FC	VSP	FC	VSP
21–28/5	270.3 ± 6.74	191.6 ± 6.40	24.3 ± 0.21	23.8 ± 0.20	35.3 ± 0.43	35.3 ± 0.42
3–11/6	263.8 ± 7.07	68.2 ± 3.50	25.3 ± 0.14	24.6 ± 0.12	40.0 ± 0.39	42.7 ± 0.39
21–29/6	357.7 ± 6.77	65.9 ± 4.22	28.0 ± 0.21	25.8 ± 0.14	40.4 ± 0.62	49.4 ± 0.48

*Data was recorded using a Hobo portable micrologger. The data presented for each training system is an average ± standard error of the diurnal microclimatic conditions of four different points. Results presented are of data measured from 06:00 am to 06:00 pm.

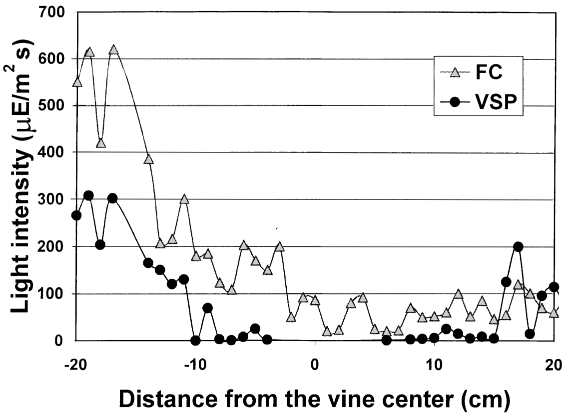

Figure 5. Light intensity, at cordon height, across the width of positioned (VSP) and non-positioned free canopy (FC) Chardonnay vines (as measured at noon with 'Sunlink' apparatus) in SW to NE direction. Data represent an average of 10 'readings' in each of four replicates.

effect (Rotem et al., 1985; Stevenson and Pennypacker, 1988).

At the beginning of the growing season, when canopy density is low, and temperatures are moderate, radiation may represent a limiting factor for the powdery mildew development, especially on the upper side of the leaves. The lower side of leaves, which do not receive direct light, is therefore more prone to infection. Bunches directly exposed to sunshine are also less likely to be infected by *U. necator* than shaded ones. From our results the FC training system, which provided less shade to the cluster zone helped in reducing powdery mildew infection. This could be attributed to the spacing of the shoots in the non-positioned topped training. Removal of basal leaves localized near clusters was shown to reduce infection (Chellemi and Marois, 1992) and thus became a routine practice in vineyards in our region. Leaf pulling usually exposes only one side of bunches to direct light. Such direct exposure of the cluster can lead in hot climates to sun-burns on cluster parts, while the shaded side of the cluster provides niches for fungus development. The FC system allowed light penetration to all parts of the cluster zone during most parts of the day, without a marked increase in bunch temperature. The FC trained vines of both cultivars were also shown (Lavee et al., 1993) to produce a higher annual yield than the VSP vines. The use of the FC system can enable a reduction in the number of fungicide applications, compared to that needed in the common VSP system.

Row spacing was also found to affect the level of powdery mildew incidence. This however, was clearly apparent only on the vigorous Cabernet sauvignon vines. The incidence of the disease was higher in the dense row spacing (2 m) then in the standard (3 m). Due to the high vigor of the Cabernet sauvignon (more then 1 kg of pruning weight per vine), excess shade developed on the bunches of the dense planted rows. Consequently, the incidence of the disease was more apparent in dense rows. This was not the case with the less vigorous Chardonnay (with about 800 g of pruning wood per vine) in which the dense planting did not create excess shade (Table 1).

The promising results for developing a fully mechanized vineyard (Lavee et al., 1993), together with our findings in reducing powdery mildew as a result of canopy manipulation, make the FC as an important system that should be considered for commercial use in the future. Further investigations are needed, to clarify if differences in disease level are due to a direct effect of the light intensity on the susceptibility of the grape berries, or on the fungus by affecting spore germination, hyphal development, or the retention of cleistothecia on the bark (Cortesi et al., 1995).

References

Bulit J and Lafon R (1978) Powdery mildew of the vine. In: Spencer DM (ed) The Powdery Mildew (pp 525–548) Academic Press, New York

Chellemi DO and Marois JJ (1992) Influence of leaf removal, fungicide applications, and fruit maturity on incidence and severity of grape powdery mildew. American Journal of Enology and Viticulture 43: 53–57

Cortesi P, Gadouri DM, Seems RC and Pearson RC (1995) Distribution and retention of cleistothecia of *Uncinula necator* on the bark of grapevines. Plant Disease 79: 15–19

Dekker J (1987) Build-up and persistence of fungicide resistance. In: Brent EJ and Atkin EK (eds) Rational Pesticide Use. (pp 153–168) Cambridge University Press, Cambridge, UK

Delp CJ (1954) Effect of temperature and humidity on the grape powdery mildew fungus. Phytopathology 44: 615–626

English LT, Thomas CS, Maroi JJ and Gubler WD (1989) Microclimates of grapevine canopies associated with leaf removal and control of Botrytis bunch rot. Phytopathology 79: 395–401

Kliewer MW, Marois JJ, Bledsoe AM, Smith SP, Benz MJ and Silverstoni O (1988) Relative effectiveness of leaf removal, shoot positioning, and trellising for improving wine grape composition. In: Smart R, Thornton R, Rodrigez S and Young J (eds) Proceedings of the Second International Cool Climate Viticulture and Oenology Symposium (pp 123–126) Auckland, New Zealand

Lavee S, Zahavi T and Naor A (1993) A study on density and training for a fully mechanized vineyard of cvs. Chardonnay and Cabernet Sauvignon. Acta Horticulturae 349: 49–53

Ougeh CS and Berg HW (1979) Powdery mildew sensory effect on wine. American Journal of Enology and Viticulture 30: 321

Pearson RC (1988) Powdery mildew. In: Pearson RC and Goheen AC (eds) Compendium of Grape Diseases (pp 9–11) APS Press, St. Paul, MN, USA

Pscheidt JW and Pearson RC (1989) Effect of grapevine training systems and pruning practices on occurrence of Phomopsis cane and leaf spot. Plant Disease 73: 825–828

Reuveni M and Reuveni R (1995) Efficacy of foliar sprays of phosphates in controlling powdery mildews in field-grown nectarine, mango trees and grapevines. Crop Protection 14: 311–314

Rotem J, Wooding B and Aylor DE (1985) The role of solar radiation, especially ultraviolet, in the mortality of fungal spores. Phytopathology 75: 510–514

Steva H and Clerjeau M (1990) Cross resistance to sterol biosynthesis inhibitor fungicides in strains of *Uncinula necator* isolated in France and Portugal. Meded Fac Landbouwwet Rijksuniv Gent 55: 983–988

Stevenson RE and Pennypacker SP (1988) Effect of radiation, temperature, and moisture on conidial germination of *Alternaria solani*. Phytopathology 78: 926–930

Willocquet L, Colomber D, Rougier M, Fargus J and Clerjeau M (1996) Effects of radiation, especially ultraviolet B, on conidial germination and mycelial growth of grape powdery mildew. European Journal of Plant Pathology 102: 441–449

Ypema HL, Ypema M and Gubler WD (1997) Sensitivity of *Uncinula necator* to benomyl, triadimefon, myclobutanil, and fenarimol in California. Plant Disease 81: 293–297