Participation in the International Workshop on Grapevine Downy and Powdery Mildew, Bordeaux, France, 4-9 July 2010



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Research Organisation: **University of Adelaide**

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1. Abstract

Drs Eileen Scott, Katherine Evans and Bob Emmett participated in the 6th International Workshop on Grapevine Downy and Powdery Mildew in Bordeaux, France, 4-9 July 2010, and contributed to four presented papers. Overall, 50 papers and 26 posters were presented, covering new findings on the biology, epidemiology and management of the two diseases. Abstracts of presentations are available at https://colloque.inra.fr/gdpm_2010_bordeaux. New information has been presented at Spring Vine Health Field Days and in university lectures.

Existing links between Australian and international researchers were strengthened and new links were established with researchers in North America and Europe, including Eastern European countries.

2. Executive Summary

Powdery and downy mildew cause considerable losses to the Australian grape and wine industry, in terms of reduced yield and quality, as well as cost of management. Research activities and expenditure world-wide contribute to increasing our knowledge of these diseases. Knowledge of the biology of the pathogens, their effects on the grapevine and other aspects of epidemiology, such as ability to predict epidemics, underpins advances in disease management to reduce loss of yield and quality.

The International Grapevine Downy and Powdery Mildew Workshop, which occurs approximately every 3 years, is the main forum for the exchange of new information on grapevine mildews world-wide. It is important that Australian researchers participate to present their research and keep abreast of the latest research findings internationally. Of the 98 registered delegates, most were European but Australia, with 10 delegates and the USA with 7 were also well-represented. Delegates from China, Israel, Qatar and Tunisia brought new perspectives to the group. Three of the Australian delegates, Drs Bob Emmett (Department of Primary Industries Victoria), Katherine Evans (Tasmanian Institute of Agricultural Research) and Eileen Scott (University of Adelaide) received travel support from GWRDC to attend the workshop. Bob Emmett and Peter Magarey (Magarey Plant Pathology) were members of the scientific organising committee for the meeting.

Sessions at the workshop addressed grape breeding and resistance (including induced resistance and ontogenic or age-related resistance), plant-pathogen interactions, pathogen biology (including population genetics), epidemiology (including detection, monitoring and modelling), economic impact and decision models, and disease management (including fungicides and biological control). In total, 50 verbal papers and 26 posters were presented, with ample opportunity for discussion and networking. Participants also visited the National Agricultural Research Institute (INRA) field station at Latresne, near Bordeaux and viewed research on: (i) the relationship between plant growth and epidemics; (ii) the “Mildium” or “GrapeMildews” project, which aims to avoid yield loss rather than symptoms via strategic application of fungicides and monitoring to determine if additional sprays are required; (iii) new high quality disease resistant wine grapes. The group then visited a node of the “untreated plots network” in a commercial vineyard at Rauzan, Entre-Deux-Mers, Aquitaine. The network is designed to allow validation and improvement of disease forecasting models.

The abstracts of the workshop are available at https://colloque.inra.fr/gdpm_2010_bordeaux. A report on the workshop has been prepared for the Australian and New Zealand Grapegrower and Winemaker magazine and is expected to appear in the December 2010 or January 2011 issue. New information from the international workshop was included in presentations given to grape growers at Spring Vine Health Field Days in September 2010. New information also has been incorporated into viticulture teaching at the University of Adelaide.

This visit was made possible by funding from GWRDC, with assistance from the Department of Primary Industries Victoria, Tasmanian Institute of Agricultural Research and The University of Adelaide. Participation in the workshop strengthened links between Australian and international researchers and provided new opportunities for collaboration. Benefits to the Australian grape and wine industry include increased awareness of new research on these diseases, which will enhance disease management.

3. Background

Powdery and downy mildew are important diseases of grapes in Australia. Powdery mildew occurs in most seasons and can cause loss of yield and quality if not managed effectively. Downy mildew poses a serious risk to vineyards in wet weather. Research in progress world-wide to improve the understanding of pathogen biology and epidemiology underpins successful disease management strategies. This is particularly true of organic and biodynamic systems where access to fungicides is limited.

The International Workshop on Grapevine Downy and Powdery Mildew, which occurs approximately every 3 years, is the main forum for the exchange of new information on grapevine mildews world-wide. It is important that Australian researchers participate to present their research findings and keep abreast of the latest research findings internationally. Two Australian researchers, Bob Emmett and Peter Magarey, are members of the scientific organising committee for the workshop.

The proposal for this project requested support for the following Australian researchers to attend the 6th International Workshop on Grapevine Downy and Powdery Mildew in Bordeaux in July 2010:

South Australia: Eileen Scott (University of Adelaide);
Victoria: Bob Emmett (Department of Primary Industries Victoria);
Tasmania: Kathy Evans (Tasmanian Institute of Agricultural Research, University of Tasmania);
New South Wales: Sandra Savocchia (NWGIC, Charles Sturt University). Dr Savocchia was subsequently unable to attend the meeting.

Under the proposal, these researchers will incorporate appropriate new findings from the workshop into their existing research and into plans for future research projects. In addition, they will strengthen existing research collaborations and build new linkages. Current linkages include the multi-national research project on epidemiology of grapevine powdery mildew, which involves scientists in the USA, Europe and Australia.

The above-named researchers are well-placed to update the Australian Grape and Wine Industry on the latest research findings. This will be achieved through articles in industry magazines, as well as through the GWRDC Innovation Network, and workshops and seminars in grape-growing regions. In addition, new information will be incorporated into teaching materials presented to undergraduate and postgraduate students at the University of Adelaide, University of Tasmania and Charles Sturt University.

Participation by these researchers in this workshop will provide the Australian viticultural industry with:

- increased knowledge of the biology of grape downy and powdery mildew, including pathogen genetics, population genetics and mechanisms of fungicide resistance
- the latest findings from international research on epidemiology, which underpins disease forecasting
- awareness of new developments in disease management, including biological control and agronomic practices
- information about the potential of plant resistance in the management of disease
- improved linkages with international efforts to minimise crop loss due to powdery and downy mildew.

4. Project Objectives and Performance Targets

The objectives of this project were:

1. Attend and participate in the 6th International Grapevine Downy and Powdery Mildew Workshop, 4-9 July 2010, Bordeaux, France
2. Present updates on Australian research on grapevine downy and powdery mildew
3. Obtain the latest information on the biology and management of powdery and downy mildew on grapes
4. Maintain research linkages with international scientists working on grape diseases

Output	Performance Targets	Date
1. Travel report to GWRDC	Travel report completed and submitted to GWRDC	31/10/10
2. Article for grower publication	Inform industry of outcomes of visit	31/10/10
3. Industry workshops	Meetings with growers to disseminate new information	31/10/10

5. 6th International Workshop on Grapevine Downy and Powdery Mildew

The workshop attracted 98 delegates, of whom 10 were from Australia (Fig. 1). Sessions were held at the Faculty of Pharmacy, University of Bordeaux (4-6 July) and Institute des Sciences de la Vigne et du Vin (ISVV), Villenave d'Ornon (8-9 July), with a field trip to Entre-Deux-Mers and St Emilion on 7 July. A summary of the key points of presentations in each session is provided below.

5.1 Breeding and host resistance

Downy and powdery mildew resistance

Paule Blasi and colleagues (INRA, Colmar, France) analysed the genetic basis of resistance to downy and powdery mildew for the *Vitis vinifera* cultivar Bronner. Two populations of plants from a cross between cv. Bronner (resistant) and another resistant parent derived from *Muscadinia rotundifolia* cv. Dearing were genotyped and a genetic map was constructed. In separate studies of downy and powdery mildew resistance, plants were artificially inoculated and assessed for resistance. Interval mapping analysis revealed the presence of a major downy mildew gene (quantitative trait locus, QTL) that accounted for 52% of the total phenotypic variation. Two minor QTLs involved in powdery mildew resistance were also identified that explained 8% and 16% of the total phenotypic variation. Sabine Wiedemann-Merdinoglu, representing the same group, outlined the development of a phenotyping platform for assessing grapevine downy and powdery mildew resistance based on a laboratory leaf disc bioassay. The system provided large populations of plants grown in uniform controlled conditions, allowed simultaneous inoculation with different strains of the pathogens, improved throughput, accuracy and reliability of resistance assessment, and reduced the time and space required for the phenotyping process.

Cyrille Zah-Bi *et al.* (INRA, Evry, France) reported on the progress of genetic studies leading to comparative physical mapping between *M. rotundifolia* and *V. vinifera*. Comparative mapping will speed up identification and isolation of different mildew resistance genes from *M. rotundifolia* and increase understanding of the mechanisms associated with introgression of genome segments from *M. rotundifolia* into *V. vinifera*. Two resources under development for *M. rotundifolia* cv. Regale were a genetic map in a full sib progeny and a bacterial artificial chromosome (BAC) library. Parameters for alignment of BAC-end sequences on the *V. vinifera* genome had been determined. Ongoing work was focusing on chromosome regions where quantitative trait loci for resistance to powdery or downy mildew had been detected (e.g. the single dominant gene, *Run1*). Furthermore, marker-based selection for powdery mildew resistance genes in grape hybrid families in Hungary (Aniko Veres *et al*., Szent Istvan University) has confirmed that the *M. rotundifolia*-derived loci RUN1 and RPV1 are linked.

Downy mildew

Jiang Lu *et al.* (China Agricultural University, Beijing, China) examined downy mildew resistance among major Chinese *Vitis* species. *V. quinquangularis* and *V. pseudoreticulata* were the most resistant. Clonal selections and hybrids of *V. quinquangularis* have been used in the viticulture industry in South China where the species originated. *V. amurensis*, the most cold-hardy species, was generally resistant to downy mildew but intraspecific variation in resistance was noticeable among different accessions. Variations of downy mildew resistance were also observed among interspecific hybrids between the oriental species and *V. vinifera*. The genetic variation and level of downy mildew resistance of the oriental species appeared to be comparable to the North American grape species. Likewise, accessions from remnant populations of wild grapes, *V. vinifera* subspecies *silvestris*, in southern Germany were genetically distinct from *V. vinifera* genotypes and exhibited resistance to both downy and powdery mildew. Schroder and Kortekamp (Karlsruhe Institute of Technology, Germany) suggested that they may be a resource for breeding programs.

Pierre-Henri Dubuis and colleagues (AC-W, Nyon, Switzerland) reported a new method for quick and accurate evaluation of grapevine seedlings in breeding programs for resistance to downy mildew. Twenty four hours after artificial inoculation, the accumulation of callus-like material in vine tissue was assessed by fluorescence microscopy. At 48 hours after inoculation, the levels of synthesised stilbenes, ε- and δ-viniferin, were determined by chromatography. Five days after inoculation, the density of sporangia produced on inoculated vine tissue was assessed either visually or using a spectrophotometer. The technique was also used to evaluate the potential activity of elicitors (activators of plant defence

mechanisms) against downy mildew *in vitro* and in greenhouse tests. Susana Boso *et al*. (Spain) reported that the concentration of ε-viniferin was higher in the downy mildew resistant *V. riparia* than susceptible *V. vinifera* 24 hours post-inoculation whereas at 48 and 72 hours post-inoculation the concentration of both δ- and ε-viniferin was higher in the resistant genotype.

Michele Perazzolli *et al.* (IASMA, San Michele all'Adige, Italy) investigated the metabolic effects and molecular processes involved in resistance to downy mildew induced by *Trichoderma harzianum* T39 in susceptible grapevines. Leaf treatments with *T. harzianum* increased resistance against downy mildew both locally and systemically. On treated leaves the reduction in disease severity due to *T. harzianum* was similar to the standard copper treatment. On untreated leaves, resistance activation was comparable after treatment of basal leaves or treatment of leaves on one side of shoots, suggesting acropetal and lateral systemic activation of the resistance. The absence of a direct effect of *T. harzianum* on downy mildew sporangia and the systemic disease reduction on untreated leaves indicated that a plant mediated defence mechanism was involved in the induced resistance. In the absence of downy mildew, repeated treatment with *T. harzianum* did not reduce plant growth. In contrast, applications of benzothiadiazole (BTH), an inducer of systemic acquired resistance, strongly affected grapevine growth from the fifth week of treatment onwards. The absence of metabolic effects in *T. harzianum*-treated plants suggested the activation of a priming state in grapevines. However, gene expression analyses revealed that grapevine markers of defence signalling pathways were not primed for augmented up-regulation after downy mildew infection. On a related poster, Maria Cristina Palmieri, of the same research group, reported expression of proteins which may act as elicitors of defence against downy mildew following induction with *T. harzianum* T39. More information about induced systemic resistance is required to optimize protection via treatment with *T. harzianum* which, to date, has not provided adequate disease control in commercial situations.

Andreas Kortekamp (DLR Research Station, Germany) reported the effects of the herbicide glufosinate (Basta) on downy mildew. Application of glufosinate at concentrations of 0.05 to 0.625 mM to leaf discs of *V. vinifera* cv. Riesling reduced sporulation by *Plasmopara viticola*, but not zoospore release or movement. The herbicide also inhibited mycelial growth of several culturable grape pathogens (*Botrytis cinerea*, *Guignardia bidwellii*, *Penicillium expansum* and *Phomopsis viticola*) *in vitro*. Furthermore, glufosinate at concentrations less than 0.01 mM did not affect fermentation of grape juice by yeast. When applied at sub-lethal concentrations in the vineyard, yield from vines treated with glufosinate at 0.1 mM was similar to that from the fungicide-treated control, leading Dr Kortekamp to suggest that studies of the mode of action of glufosinate may lead to novel alternatives for disease control.

Marie-Cecile Dufour and Marie-France Corio-Costet (INRA Bordeaux, France) compared the efficacy of two phosphonate derivatives, fosetyl-Al and foliar fertiliser PK2, with that of BTH. All three compounds reduced severity of downy mildew on leaves in the vineyard, with fosetyl-Al being most effective, whereas BTH resulted in the greatest yield of berries.

Powdery mildew

Ahmed Mliki and colleagues (Centre de Biotechnologie de Borj-Cedria, Hammam-Lif, Tunisia) studied the susceptibility to powdery mildew of 50 Tunisian grapevine cultivars. Powdery mildew developed on leaves of all varieties 3 weeks after inoculation. However, disease development was slower and severity scores were lower on some varieties, especially Ferrani, 2 weeks after inoculation.

5.2 Plant-pathogen interaction

Downy mildew

Necrosis- and ethylene-inducing peptide-1-like proteins (NLPs) may act as triggers of plant defence responses during host-pathogen interactions. J. Fahrentrapp, Hans-Heinz Kassemeyer *et al*. (Staatliches Weinbauinstitut, Frieburg, Germany) reported cloning and sequencing a NLP from *P. viticola*, claimed to be a first for an obligate biotroph. Studies of expression using quantitative PCR and microscopy showed that transcription of NLP increased rapidly within 12 hours of inoculation, particularly 6 hours post-inoculation when the pathogen formed a vesicle in the sub-stomatal cavity. A second increase in transcription occurred 96 hours post-inoculation when the pathogen formed secondary vesicles and sporulation was initiated. Antibodies have been generated to enable localisation of the NLP.

Pere Mestre and colleagues reported research on avirulence genes in *P. viticola*, which encode proteins (called effectors) that trigger grapevine defence responses. Identification and characterisation of avirulence genes will contribute to understanding of host-pathogen interactions and assist with designing strategies for deployment of durable resistance. In view of the limited genetic information currently available for *P. viticola*, the researchers first generated two cDNA libraries, one from infected grapevine leaves, the other from zoospores germinated in the absence of host tissue, as tools for distinguishing between nucleic acid sequences of the host and pathogen. Sequencing of 1920 cDNA clones from germinated zoospores resulted in 1063 expressed sequence tags (ESTs) of nuclear origin, 58 of which appeared to be associated with pathogenicity and hence candidates for avirulence genes. The researchers intend to generate sequence data from germinated zoospores to allow identification of avirulence genes using a candidate gene approach. On a related poster, Mestre and colleagues reported methods for investigating transient expression of chitinases after infection by *P. viticola* and *E. necator*. *Agrobacterium*-mediated transfer is being used to introduce two chitinases into grapevine leaves and preliminary experiments suggested that sporulation by *E. necator* was reduced compared with controls.

Powdery mildew

Recent studies of early stages of the interaction between *Erysiphe necator* and grapevine were reported by Hans-Heinz Kassemeyer (C Tisch *et al*., Staatliches Weinbauinstitut, Frieburg, Germany). Germination of conidia on the leaf surface, development of the primary hypha, formation of the appressorium (infection structure) on the primary hypha and initiation of the secondary hypha at the other end of the conidium were similar on the susceptible and resistant genotypes, *V. vinifera* cv. Muller-Thurgau and *V. riparia* cv. Gloire, respectively. However, growth from the secondary hypha resulted in mycelium on the susceptible grapevine and not on the resistant genotype. Furthermore, activation of the defence response, including transcription of pathogenesis-related proteins (1,3-glucanase, chitinase) and a lipoxygenase, was more efficient in the resistant than the susceptible grapevine. Prof Kassemeyer suggested that the defence response was initiated after appressorium formation but before mycelium development, and was delayed and inefficient in the susceptible genotype.

Bob Seem and colleagues at Cornell University presented research on signalling and gene expression during development of *E. necator* (see also 5.3 Biology of pathogens), with the premise that strategies for reducing sporulation have potential in disease management. Gene expression was examined following extraction of fungal ribosomal nucleic acid (RNA) from colonies of *E. necator* in the vegetative state (3 days after inoculation), early sporulation (5 days), abundant sporulation (8 days) and when cleistothecia were mature (28 days after inoculation). Of a total of 1600 fragments obtained, 620 were differentially expressed, suggesting changes in gene expression as the powdery mildew colony develops. Based on sequence analysis, five classes of differentially expressed fragments were identified, and 45% of the sequences had no match in the databases used. Thirteen percent of the differentially expressed fragments were identified as being related to metabolism and others included transcription factors, signalling and transport proteins in other fungi. Gene expression in *E. necator*, an obligate biotroph, was clearly different from that of fungi such as *Aspergillus* and *Neurospora* species used as models by developmental biologists. This research provides a basis for further study of factors affecting sporulation and may open up new avenues for disease control.

5.3 Biology of the pathogens, ontogenic resistance, pathogen impact on plant physiology

Powdery mildew

Researchers from Cornell University (Michelle Moyer, David Gadoury *et al.*) reported the impact of early season cold temperature events, specifically non-freezing low temperatures of 2–8^{o}C, on the development of powdery mildew. The latent period for infection by *E. necator*, or generation time, is the time between spore germination and sporulation by the fungus. Previously reported relationships between temperature and the latent period for *E. necator* did not appear to account for the fact that mildew colonies are rarely detected until 4-5 weeks after budburst in cool climate vineyards. Chardonnay leaves sampled from the field were exposed to low temperatures that might typically occur during the night in the period before flowering. Exposure of leaves for at least 2 h to temperatures in the range 2–8^{o}C resulted in a reduction in colony development when leaves were inoculated after the cold treatment. When Cabernet Franc leaves were inoculated at defined periods after a cold treatment (8 h at 2^{o}C), cold-induced disease resistance was observed 24 h after treatment as evidenced by significantly more conidia failing to infect leaves at this time. This effect was not observed by 48 h after the cold treatment, suggesting that the induced resistance was

transient. Exposure of very young colonies of powdery mildew (post infection) to low temperatures caused hyphal mortality to an extent that depended on the age of the colony. The negative impact of these low, non-freezing temperatures appears to cause longer latent periods than expected from controlled-environment studies and this knowledge could be built into decision support systems for managing powdery mildew. Moreover, the researchers demonstrated that radiational cooling of the leaf surface may lead to a drastically different microclimate experienced by developing powdery mildew colonies than what would be suggested from ambient air temperature measurements. The significance of this research for Australian vineyards can be seen in the number of days between budburst and flowering with average daily minimum temperatures of ≤ 6^{o}C for the period 2005-2007: in Loxton, South Australia there are 17 days and in Hobart, Tasmania, there are 21 days. This means that cool night temperatures can affect powdery mildew development in both warm and cool climate regions.

Researchers from Cornell University (David Gadoury *et al.*) then described the changes that occur when a powdery mildew colony switches from vegetative growth to asexual sporulation. Removal of the central section of a mildew colony on a leaf 4 days after inoculation delayed the time to sporulation in the remaining part of the colony. This “microsurgery” provided evidence that asexual sporulation is triggered through a coordinating signal. Once the sporulation process has been initiated it cannot be reversed by excising the colony centres. Increasing the inoculum density (on leaves) decreased the latent period, suggesting that colony density might be the factor driving the promulgation of the sporulation signal. These findings have implications for the design of experiments where treatments affect latent period. In nature, airborne conidia are presumably deposited on leaves as single spores and the time to sporulation may be longer than in controlled-experiments with high inoculum densities. Sporulation also appears to require light. This information can inform the design of experiments to understand the sporulation process and ways to inhibit the process for disease control.

Ontogenic or age-related resistance is when a plant organ (leaf or berry) becomes less susceptible to infection as it ages. Researchers from INRA, Bordeaux (Sylvain Schnee, Agnes Calonnec *et al.*), described the change in the intensity of sporulation with leaf age and the corresponding steep increase in leaf glucose concentration when older leaves ceased producing high densities of spores. Leaves produced relatively few spores when they were ≥ 10 days old. For these assays, Cabernet Sauvignon shoots were sampled from the field when they were at the phenological stages “5-6 leaves” or “10-12 leaves”. The magnitude of sporulation on the most susceptible leaf was two-fold greater at the later phenological stage. Shoots were also sampled from sections of the vineyard block classified as high or low vigour. While the maximum intensity of sporulation was similar for leaves from high and low vigour shoots, the age of the leaf for maximum sporulation was less for low vigour shoots and fewer leaves on the shoot had sporulating colonies of powdery mildew. Again, the glucose concentration increased with leaf age but the increase occurred earlier (at a younger leaf age) for low vigour than for high vigour shoots. Low vigour appears to modify the susceptibility of leaves to powdery mildew by resulting in an earlier onset of ontogenic resistance with regard to leaf age. Canopy management is likely to influence how the powdery mildew epidemic develops on leaves, especially prior to flowering when the position of infected leaves (source of inoculum) and quantity of inoculum on leaves is likely to influence berry infection.

Researchers from the Tasmanian Institute of Agricultural Research, University of Tasmania (Angela Smith, Kathy Evans *et al.*) described the expression of powdery mildew on leaves of primary shoots of Cabernet Sauvignon when these shoots had developed in different environments prior to inoculation with *E. necator.* The different environments, with different average temperatures, resulted in shoots with different rates of leaf emergence. On average, a higher rate of leaf emergence resulted in a greater proportion of diseased leaves per shoot and a higher disease severity per leaf position. There was a clear association between the leaf position for maximum severity of powdery mildew and the position of the leaf completing the sink to source transition for shoots exposed to either pre-inoculation environment.

The significance of these four studies, and the study of Calonnec *et al.* described in Section 5.5, is that the environment in which the shoot develops influences the expression of ontogenic resistance and development of the powdery mildew epidemic. Moreover, viticultural practices influence carbohydrate sink-source relations among plant organs and hence the capacity of a leaf to support a high level of parasitism and pathogen sporulation. Early season growing conditions, canopy manipulations and viticultural inputs (fertiliser, water) can influence shoot vigour and the risk of powdery mildew on leaves. These leaves, in turn, provide inoculum for berry infection.

Downy mildew

Researchers from the Universita Cattolica del Sacro Cuore, Italy (Tito Caffi *et al.*) studied the effect of *Plasmopara viticola* on grapevine leaf photosynthesis during the asymptomatic stage of infection (incubation). They described the 'virtual' lesion as being the visible lesion plus the area surrounding the lesion. The authors measured gas exchange of leaf tissue during the asymptomatic stage of infection and in the green tissue surrounding the visible downy mildew lesion. Reduced photosynthesis occurred before the appearance of the lesion even though the chlorophyll concentration was similar to that found in healthy leaves. Photosynthesis was also reduced in the green tissue surrounding the downy mildew lesions, confirming that the pathogen reduces assimilation in an area larger than occupied by visible lesions. The research raised questions about whether or not the vine can compensate for the loss in assimilates.

Researchers from Agroscope in Switzerland (Mauro Jermini *et al.*) described downy mildew as a type of stress factor on the plant. They argued that disease control strategies should not be evaluated based on the level of disease symptoms, but on the level of "damage" to the plant and the capacity of the grapevine to recover from such damage. There may be scope to reduce fungicide inputs if growers are less concerned about visible symptoms and more concerned about the impact of disease on plant biomass and organ quality (e.g. juice characters such as ^{o}Brix). This group compared a reduced spray schedule (3-4 fungicide applications) with a full spray schedule (7-8 applications) and a non-treated control on cultivar Merlot, double cane pruned and with vertically trained shoots (double Guyot). After three growing seasons of the reduced spray schedule, there was a reduction in shoot length, slight reductions in yield and ^{o}Brix, with TA increasing slightly. After one "recovery" season of a fully fungicide program, the grapevine returned to the previous number of leaves per shoot. The authors argued that the grapevine can compensate for the "energy drain" on the plant as there are carbohydrate reserves stored in the wood.

5.4 Population genetics

Powdery mildew

There are at least two genetic groups (A and B) in populations of *E. necator* in Australia, Europe and North America. Researchers at INRA, Bordeaux (Francois Delmotte *et al.*) described the partitioning of groups A and B in space and time in 32 vineyards across grape-growing regions in France. The molecular method used to differentiate genetic groups was the amplification of the β-tubulin gene exhibiting a T/C single nucleotide polymorphism (SNP) between group A and group B isolates. SNP creates a recognition site that allows characterisation by Cleaved Amplified Polymorphic Sequence (CAPS) analysis. In early April (spring), isolates from any one site can comprise all group A, all group B or varying proportions of group A and B (co-existence). However, by pre-harvest (early September), ALL isolates at all sites were group B, even if they were all group A at the start of the season. Both genetic groups have been found on flag shoots (all A or all B) and laboratory crosses indicate that A and B isolates can emanate from the same cleistothecium. It is not known if the genetic groups mate in the field. Group A isolates had larger colonies and sporulation intensity but a smaller germination percentage in infection efficiency than group B isolates. The Bordeaux group hypothesised that group B isolates are more aggressive during infection of berries, although further research is required, including a study of the temporal course of genetic group frequencies during the growing season. The impact of the different genetic groups on disease epidemiology, and hence management, remains unknown.

Group A genotypes appear to be more sensitive to DMI fungicides than Group B genotypes, and a real-time PCR assay developed by Marie Cecile Dufour *et al*. (INRA Bordeaux) to determine genetic group and DMI resistance may facilitate studies of population biology and the management of fungicide resistance.

Tirtza Zahavi *et al.*, from the Ministry of Agriculture in Israel, applied RAPD markers to describe five genetic groups and significant variation among isolates of *E. necator* from Israel. Isolates from flag shoots from the same vineyard did not have identical DNA banding patterns.

Downy mildew

Researchers at INRA, Bordeaux (Francois Delmotte *et al.*) described population genetic studies that demonstrated which genetic group/s of the downy mildew pathogen invaded Europe from North America (from where the pathogen originated). After sampling isolates from North America (Michigan, Florida, other eastern US sites), three genetic groups (A, B and C) with 9 haplotypes were identified using markers from

the β-tubulin (nuclear) gene. Group A was found mainly on *V. riparia* and interspecific hybrids. Group B was found on *V. labrusca* and *V. aestivalis* and Group C was found on interspecific hybrids. In contrast, only one haplotype of Group B was found in Europe. A subset of the North American population was also found in Europe when mitochondrial markers were used (*cyt*b). The researchers postulated that there was a primary introduction of the pathogen from North America to Europe. The pathogen then spread to South Africa and Australia, which also have populations of the pathogen that comprise genetic group B. The genetic structure of the pathogen in Europe was also studied with 8 SSR markers. This study revealed a low spatial structure, a high effective population size and sexual recombination. An East/West genetic gradient was detected using Bayesian analyses.

Populations of *P. viticola* are prone to developing resistance to the family of fungicides known as QoI fungicides (quinone outside inhibitor fungicides). Researchers at INRA, Bordeaux (Corio-Costet *et al.*) found that 'resistant' isolates were as fit as "sensitive" isolates. At the beginning of the growing season, before fungicide selection pressure, most isolates of *P. viticola* were sensitive to QoI (after the sexual reproduction cycle).

Resistance to the carboxylic acid amide (CAA) fungicides occurs in France and Germany. Machefer *et al.*, from INRA Bordeaux, compared the microsatellite diversity (neutral molecular markers) among populations that were resistant (R) or susceptible (S) to CAA. The study suggested a lack of spatial or temporal genetic structure between R and S populations of *P. viticola* and a single panmictic (interbreeding) population. Since resistance to CAA is recessive, an annual generation of sexual reproduction results in a decrease of RR isolates. Rotation with other fungicides appears to be a good strategy.

5.5 Epidemiology: detection methods, monitoring, epidemiological modelling

Powdery mildew

Researchers from Quebec, Canada (Odile Carisse *et al.*) reported that conidia of *E. necator* could be trapped from the air a couple of weeks before disease was observed. There was a relationship between the proportion of seasonal airborne conidia trapped and the degree days (base temperature of 6^{o}C) cumulated since "growth stage 7". There was also a relationship between the cumulative number of conidia trapped and the proportion of diseased leaves. The threshold for spore detection was considered to be 50 conidia per m^3 per day and the first spray could possibly be timed according to thermal time (degree days). However, the method is not a practical tool because it requires time-consuming spore trapping and technical expertise in observing and detecting conidia trapped. The group has since developed a molecular method for quantifying the DNA from conidia trapped. Their plan is to have one spore collector for each grower, who also pays for a "scout" to collect the samples three times per week and access to weather data. The approach will require calibration and further testing before it becomes a viable service, possibly costing about Canadian $1,200 per season. Ana Diez-Navajas from NW Spain also described the collection of conidia on sticky glass traps, with conidia being collected twice per week.

Andrew Sutherland, a researcher with the UC Davis Plant Pathology Department, is training honey bees to detect plant disease in agricultural crops. Bees have chemosensors on their antennae, so they are able to detect organic molecules. Using Ivan Pavlov's method of "classical conditioning", Sutherland is teaching bees to associate infected plants with a sugar reward. After they are conditioned, the bees are placed inside a box and taken to the field, where if they encounter the same smell, the information is relayed back as a warning sign. A video about this work can be seen at:
http://www.smartplanet.com/people/video/can-bees-be-trained-to-prevent-plant-disease-/427650/
Sutherland and co-workers (including Doug Gubler) were unable to attend the meeting, but the workshop group discussed the feasibility of the approach. Presumably the bees need to be trained to detect individual molecules and their lifespan is limited. Other approaches might utilise e-noses (e.g. portable gas chromatograms) that can detect a "signature" of multiple compounds.

Researchers from INRA, Bordeaux (Agnes Calonnec *et al.*) studied the dynamics of vine growth, in response to different types of crop management, and their impact on powdery mildew. Field plots comprising three rootstocks with Merlot and Cabernet Sauvignon were established and two types of crop management imposed: a perennial cover crop or chemical weed control. One aim was to create different levels of crop vigour. One shoot per five vines was inoculated with *E. necator* at the 2-4 leaf stage. Measures of vine growth over time included the number of leaves, the rate of leaf emergence, shoot length

and elongation. PLS-path modelling analyses were performed to explore the relationships among model components (vine growth, management, disease) and the weight of each component. For Merlot, vine growth had a significant effect on disease severity whereas crop management had less of an effect. For Cabernet Sauvignon only vine growth (and not crop management) had a significant effect on disease severity. The model was also used to simulate the effect of growing season (year) and different "vigour" levels. The work supports earlier observations by this research group that shoot leaf number early in the season influences disease severity. As such, leaf number may be a key variable in disease development, although variation among leaves in their susceptibility to infection is the also the subject of current research.

Elizabeth Legler *et al.*, Universita Cattolica del Sacro Cuore, Italy, presented a prototype model simulating the life cycle of powdery mildew, drawing upon the literature to date. The model requires validation.

5.6 Epidemiological knowledge and disease management

Downy mildew

Peter Magarey (Magarey Plant Pathology, Loxton, SA) and Trevor Wicks (SARDI, Adelaide) described observations of the spatial movement of downy mildew from three inoculated vines after a single secondary infection event in a South Australian vineyard. Severe disease developed on vines 8-12 m downwind of the inoculated vines and little disease was observed up to 34 m downwind. An initial total of around 4,500 oil spots on the inoculated vines produced 60,000-90,000 new oil spots. Sporangia appeared to have moved sufficiently to require disease management 200-300 m from the source of inoculum.

Cesare Gessler and colleagues (Institute of Integrative Biology, Zurich, Switzerland) investigated the use of mixtures of cultivars in organic vineyards to reduce severity of downy mildew and the need for applications of copper fungicides. Disease development and management were studied in vineyard blocks with eight *V. vinifera* and interspecific hybrid cultivars with different disease resistance over three seasons. Blocks containing rows with either a mixture of the cultivars (Mix block) or one cultivar (Mono block) were compared. No difference in genetic structure of *P. viticola* populations in Mix or Mono blocks was observed. Genotypic diversity was less in populations on resistant cultivars than on susceptible cultivars. In the first year, susceptible cultivars had lower disease incidence and severity in the Mix blocks than in the Mono block, but in the second and third year there was little or no difference. Results indicated that use of cultivar mixtures in vineyards was not an effective method for reducing disease severity and fungicide use.

Powdery mildew

Peter Magarey (Magarey Plant Pathology) and Michelle Moyer (Cornell University, Geneva, NY USA) described use of the "epi-season" and "lag phase control" concepts in the application of epidemiological knowledge of powdery mildew to reduce inoculum reservoirs and the number of sprays required for long term control. The concepts were designed to simplify the communication of epidemiology to grape growers and technical advisers. An epi-season (season of an epidemic) for grapevine powdery mildew encompasses two vine growing seasons. Primary inoculum (conidia from flag shoots and/or ascospores from cleistothecia) that initiates epidemics in one season (Season 2) developed because of events (bud infection and/or cleistothecium formation) that occurred in the previous season (Season 1), and this should be addressed for effective long term disease management. The "lag phase" is the period between primary infection and the start of the exponential phase of an epidemic. In "lag phase control" strategies, fungicides are applied when pathogen activity is low to extend the lag phase and prevent the development of carry-over inoculum for the next season.

Craig Austin and Wayne Wilcox (Cornell University, Geneva, NY USA) reported studies of the effects of sunlight, specific ultraviolet radiation and increased surface temperature on powdery mildew development. In the field, disease development was studied on inoculated vines of two cultivars exposed to sunlight or UV filtered sunlight with or without shade. Disease was least severe on fruit exposed to sunlight and was 2-5 times worse on fruit exposed to UV-filtered sunlight. In one season, shading to reduce surface temperature also increased disease severity on fruit of one variety. In growth chamber studies, increased doses of UV-B radiation inhibited spore germination and growth of powdery mildew. UV-B radiation increased the latent period for powdery mildew and had a greater effect at 30^{o}C than at 20^{o}C and 25^{o}C. Increasing the UV-B dose increased inhibition of hyphal growth. The effects of variations in light exposure of bunches on powdery mildew development was also studied on Chardonnay vines with two types of training system, canopy manipulation and basal leaf removal. Powdery mildew severity was lower on vines

with vertical shoot positioning (VSP) than on denser Umbrella-Kniffen (UK) trained vines, regardless of leaf removal. With both training systems, removal of leaves at fruit set (when berry susceptibility to disease was high) reduced the severity of powdery mildew on berries, whereas removal at 5 weeks after flowering had no effect. Without the use of fungicides, VSP training and leaf removal at berry set reduced powdery mildew severity on bunches by 35% in comparison with UK training and no leaf removal.

Peter Magarey (Magarey Plant Pathology), Bob Emmett (DPI Victoria, Mildura) and colleagues outlined the results of a review of powdery mildew control in vineyards of the Riverland district of South Australia in 2006-07. Grape grower spray programs (from spray diaries provided by local wineries) and records of vineyard disease severity were analysed. An unacceptably high percentage (~1-2%) of growers lost their crops when wineries, adopting low disease acceptance thresholds, rejected their grapes at harvest. Conversely, many growers achieved good disease control with an average of 6-7 fungicide applications per season. Some applied 12-13 sprays at high cost but many of these applications were inefficient, poorly timed or unnecessary. As some growers achieved good control with 3-4 sprays, a preliminary target of 4 well-timed sprays per season for powdery mildew control in low input viticulture was established for the Riverland district.

Philippe Cartolaro *et al.* (INRA-Bordeaux) evaluated the use of assessments of early disease symptoms in powdery mildew control programs to reduce fungicide applications. Decision rules for powdery mildew treatments were established and refined in field tests conducted in commercial vineyards from 2003 to 2009. In programs using the rules, treatments were applied at critical times in epidemic development, either systematically or according to thresholds of disease incidence determined by vineyard assessments at specified stages of vine growth. In a typical decision rule program (e.g. in 2005), disease on lower leaves on shoots was assessed when shoots had 5-7 leaves and when shoots had fully developed inflorescences and flowers were separating. Assessment of diseased bunches was conducted at the start of berry touch. Systematic treatments were applied when shoots had 5-7 leaves and at 70% cap-fall. Optional treatments were applied when inflorescences were fully developed and flowers were separating, when berries were pea-size and at the start of berry touch (pre-bunch closure). When decision rule and vine grower programs were compared, the former (2-5 treatments) provided acceptable control but grower programs (mostly 4-8 treatments) often achieved better control. In decision rule programs, powdery mildew treatments were reduced by 35-65%.

Downy and powdery mildew

In France, fungicide dose rates are registered in units of product per unit of soil surface (ha), regardless of the stage of vine growth and the extent of vine canopy development, and for control when conditions favour disease development. Alexandre Davy (French Vine and Wine Institute (IVF), Blanquefort, France) and colleagues reported the results of trials on downy and powdery mildew control using the “Optidose” method to adjust fungicide dose rates according to vine growth stage, the vine surface to be treated and disease pressure. The aim was to develop efficient strategies to reduce the quantity of fungicides used while maintaining acceptable disease control. Optidose decision rules for varying doses of fungicides (percentage of registered dose to be applied) were developed on the basis of tests conducted by IVF Bordeaux since 1996. For the 2009 version of the rules, see the Epicure IVF website (http://www.vignevin-epicure.com). In the trials (2002-2009), plots with Optidose treatments (doses adapted for efficient disease control), reference treatments (full or real doses used by the grower) and no treatment were compared. The average number of sprays applied for downy and powdery mildew control was 8.2 and 5.9, respectively. The average reduction of fungicide dose achieved by Optidose treatments in relation to reference treatments for downy and powdery mildew control was 41% and 45%, respectively. Dose reductions, however, reduced safety margins and use of well regulated efficient vineyard sprayers was imperative. In a poster by the same group, the average spray deposition per cm^2 of foliage was examined as a mean of adjusting fungicide dose. As total leaf area was very variable among plots and deposition of spray decreased with increasing leaf area index, disease resulting from reduced doses when plants were smaller (foliage adjusted doses) was compared with the recommended dose. Although results were somewhat variable both treatments were generally similar, and the Optidose program is now being assessed in commercial vineyards using the growers’ own spray equipment, spray program and chemicals.

Studies of downy mildew epidemics and their relationship with environmental factors in the Shandong Peninsula districts of China were also presented (Yan Jiye *et al.*, Academy of Agriculture and Forestry Sciences, Beijing, China). Observations on the dynamics of downy mildew development in vineyards of the

Venetian region, one of the wettest in Northern Italy, were summarised for the period from 1977 to 2008 (Allessandro Zanzotto *et al.*, Centro di Ricerca per la Viticoltura, Conegliano, Italy).

5.7 Economic impact

Downy and powdery mildew

Bob Emmett *et al.* (DPI Victoria) evaluated the impact of a long term research and development (R&D) program on integrated powdery and downy mildew management in south eastern Australia. The program included 15 research, development and extension projects conducted between 1988 and 2008. Key outputs included procedures for assessing vineyard disease potential and incidence, and for monitoring weather and downy mildew infection events to guide spray timing, and spray programs for more efficient and effective powdery and downy mildew control. Typical spray regimes used by grape growers before and after the R&D program, their levels of adoption and associated crop losses and costs in seasons with low, average or high disease severity were identified and assessed. Major industry changes attributed to the R&D included the adoption of programs with early season sprays for powdery mildew control, and spraying for downy and/or powdery mildew control according to assessments of vineyard disease potential or presence determined from weather and/or the vineyard monitoring.

Industry benefits from adoption of changes in spraying practice were mostly related to reductions in crop loss, with some reduction in costs of disease control. Adoption of systematic preventative programs with early season sprays and aligned with stages of vine growth substantially improved powdery mildew control but often increased control costs. The wider adoption of these programs reflected the low tolerance of powdery mildew severity on crops, especially on wine grapes. Adoption of programs for downy and powdery mildew control using curative and/or preventative sprays based on weather and/or vineyard assessments improved disease control and reduced control costs. The R&D program involved a total industry and R&D agency investment of $4.8 million (net present value). Estimated pay-off from the R&D investment for Australia was $74.5 million (net present value), representing a return of $16.5 for every dollar invested. Other benefits from the R&D investment included those associated with reduced chemical use and increased economic activity in Australian viticulture.

Dominique Steiger (Bayer CropScience, Monheim, Germany) provided an analysis of the global economic importance of grape powdery and downy mildew protection at the farmer level. In 2008, 20.5 and 19.4 million hectares were treated with fungicides for powdery and downy mildew control, respectively. A further 1.4 million hectares were treated with “ready mixed” fungicide products active against both diseases. Wine grape grower investments in downy and powdery mildew fungicides (2005-2008) were 33% and 22% of total grape protection expenditure, respectively. Other major plant protection investments were for fungicides for botrytis control (9%), insecticides (16%) and herbicides (14%). The analysis also provided an overview of the types of products used to control downy and powdery mildew, the level of product use, the average cost of protection for each disease per hectare, the major countries involved and the most widely used treatment strategies.

5.8 Forecasting and decision models

Downy and powdery mildew

Olivier Naud (Cemagref, Montpellier, France) *et al.* described development and testing of the GrapeMildews decision system for integrated protection against grapevine powdery and downy mildew. GrapeMildews is a decision workflow model that describes the tactics required for early assessment of disease activity and disease control using a limited number of fungicide treatments to achieve profitable grape production. The decision system has a sequence of 7 stages (Stages 0-6) based on vine phenology (bud break to ripening) with optional or mandatory actions according to defined thresholds for downy and/or powdery mildew management. Some stages are preceded by plot surveys with protocols to assess disease incidence or severity on vine leaves or bunches. Rain forecasts and expert interpretations of local downy mildew risk based on information from local surveys and bioclimatic risk models are also used in decision making. In the 2008 and 2009 seasons, vineyard treatments for downy mildew and powdery mildew control were reduced by 1-3 and 2-3, respectively by use of the GrapeMildews system in comparison with “farm practice”. Performance of the system was best when seasonal disease pressure was high and there was careful consideration and anticipation of management decisions.

Pascal Leroy and colleagues (INRA, Ivry-sur-Seine, France) presented a report on a bio-economic model to simulate, evaluate and compare the performance of different protection strategies for the control of grapevine downy and powdery mildew. The purpose of the model was to integrate the different aspects involved (agronomical, plant pathological and economical) and assess the technical and economic risks associated with different treatment strategies in different contexts (agronomic, climatic, pathogen pressure) at the plot level. Simulated damage on vine leaves and grapes took into account vine growth and crop development, ontogenic resistance, pathogen activity in relation to climatic conditions, and the effects of plant protection treatments. Economic evaluation considerations included maximum yield permitted by the appellation, grape sale price, cost of treatments and plot observations, agronomic aspects (vine growth through time, vineyard structure, vine management), and disease damage. Simulations of downy mildew damage on leaves and grapes, and assessments of the mean number of treatments and profit margins were reported for five treatment strategies applied to a vineyard at INRA-Bordeaux from 1988-2008. The treatment strategies were:

(a) Three "systematic" strategies where treatments were applied every 14, 21 or 28 days from when vines had 6 leaves until ripening;
(b) The GrapeMildews decision system strategy (Naud *et al.*) using thresholds based on estimates of disease severity instead of disease incidence; and
(c) An untreated strategy for reference.

Average profit margins for the "14 day" systematic strategy (6-8 treatments) and the GrapeMildews strategy (2-6 treatments) were equivalent to an increase in annual grape price of 4% and 10%, respectively.

Marc Raynal *et al.*, Institut Francais de la Vigne et du Vin (IFV), Blanquefort, France, reported on the progress of development of EPIcure, a geographic information decision support system for assessment of the risk of downy and powdery mildew epidemics in vineyards of the Bordeaux region (http://www.vignevin-epicure.com). EPIcure is a cooperative project between Meteo France and IFV that is evaluating the impact of using high resolution meteorological data on the quality of downy and powdery mildew risk assessments. Types of data used to run "Potential System" models to assess disease risk included:

(1) Rainfall data (1 km^2 resolution) developed using radar to locate rainfall areas and rain gauges to quantify falls;
(2) Temperature data (2x2 km^2 resolution) calculated using models; and
(3) Eight day weather forecasts developed with specialist advice (Days 1-3) and from statistical models (Days 4-8).

The project has established nearly 6000 calculation points that are being used instead of 50 weather stations to generate weather and disease epidemic information for the Bordeaux region (120,000 ha). An internet (web) platform (http://www.vignevinepicure.com/grele/grele.php) connected to the GoogleMap cartography system allows partner observers precisely to locate the parts of vineyards assessed and easily upload information on disease or other damage (e.g. hail damage). Testing of the system in relation to hail storm activity and damage in spring 2009 highlighted the value of damage assessments contributed by partners through the web platform. Future developments include wider use of the web participative platform to acquire data to validate high resolution disease models and the use of "Xray radar" to provide more precise real time assessments of rainfall. Dr Raynal *et al*. also reported, via a poster, that there was no obvious association between type and water holding characters of soil and downy mildew, and suggested that soil cartography is not a useful tool for management of downy mildew. Radar technology (Radar Hydrix) for rainfall data (pluviometry) and fine-scale calibration using weather stations will be compared with disease data to improve modelling of disease risk on a small scale.

Gottfried Bleyer (Staatliches Weinbauinstitut, Freiburg, Germany) and colleagues reported on the integration of downy and powdery mildew risk models into the "VitiMeteo" forecasting system. "VitiMeteo" is a cooperative project between the State Institute of Viticulture and Oenology, Freiburg, Germany, the Swiss Research Station Agroscope Changins-Wädenswil, and GEOsens, Ebringen, Germany. The system consists of data sources (data from weather stations), a database ("Agrometeo", with stored weather data), software modules and internet presentations. Software modules in the system include:

(a) "VitiMeteo Plasmopara" that simulates stages of the downy mildew life cycle and calculates the risk of downy mildew;
(b) "VitiMeteo Oidium" (based on the "OiDiag-2.2" model, see below) that calculates the risk of powdery mildew, dates when spraying for powdery mildew control should begin and time increments between sprays;

(c) “VitiMeteo Growth” that simulates leaf appearance and development on primary shoots of grapevines under several different management systems;
(d) “VitiMeteo DataGraph” that develops and presents graphs of the weather data.

The “VitiMeteo” system provides standard calculations for practical use in vineyards. It also allows the use, as parameters, of stages in pathogen life cycles (e.g. primary infection, sporulation and secondary infection), calculations for selected periods and weather stations, and the continuous development of the expert models. In recent years, the “VitiMeteo Plasmopara” model was validated in northern Italy and South Tyrol by comparing calculated infections with field observations. In 2009, weather forecasts were also integrated into the software modules to provide current forecasts of biological processes (e.g. pathogen incubation period, disease risk or vine growth). “VitiMeteo” weather data and information on disease risk are updated twice daily and can be accessed on the internet (www.vitimeteo.de, www. agrometeo.ch). Latest graphics can be displayed on personal computers using “VitiMeteo Widget” software (GEOsens) downloaded for free.

Downy mildew

Jodie Armstrong (Integrated Viticultural Solutions, McLaren Flat, SA) presented a report on the McLaren Vale CropWatch system and the practical application of downy mildew modelling (DModel) in the McLaren Vale region of South Australia. The system involved an automatic weather station network to provide vineyard microclimate data to determine downy mildew infection events and dates of oil spot appearance, a monitoring system to confirm the presence of diseases and pests in vineyards, and a bulletin-style newsletter to provide disease alerts and management advice to grape growers. Changes to the system since its inception in 2003, strategies for managing downy mildew primary infection and recent issues related to model application were discussed.

Powdery mildew

Walter Kast (State Research Institute for Viticulture, Oenology and Fruit Technology, Weinsberg, Germany) outlined the development and use of the OiDiag-2.2 expert system for predicting the risk of powdery mildew and scheduling fungicide sprays for powdery mildew control in vineyards, especially in Southern Germany where climatic conditions were very favourable for the disease. Calculation of dates for the first fungicide application (time lag related to vine phenology) used a regression function developed from an analysis of 53 years of records of temperature and powdery mildew severity for the Wuerttemberg wine region. Dates ranged from the 3-leaf stage to up to 5 weeks later. Other functions used in the system accounted for the effects of vine growth and ontogenic resistance of grapes (Ontogenic Index) and climate (Climatic Index) on powdery mildew development. Climatic parameters used to determine the Climatic Index included daily mean temperature (^{O}C), humidity 65-80% (hours), humidity >80% (hours), leaf wetness (hours) and rainfall (mm). Daily OiDiag indices, indicating disease pressure, were the product of the daily Ontogenic Index and Climatic Index. Periods for complete coverage and disease prevention from applications of different fungicides were defined for five ranges (sliding means) of the OiDiag Index. Definition of the periods of protection was based on information provided by researchers, fungicide product manufacturers and trade organisations. Periods of full protection provided by applications of different fungicide products in relation to OiDiag Index values ranged from 6-23 days.

5.9 Fungicide efficacy and biological control

Fungicides against powdery and downy mildew

Gilbert Labourdette (Bayer CropScience, Lyon, France) and colleagues summarised the fungicide groups currently in use to control powdery mildew (*viz*. sterol biosynthesis inhibitors, quinone outside inhibitors, quinolines, benzophenones, amidoxime and first generation succinate dehydrogenase inhibitors), then introduced Fluopyram as a fungicide in the new chemical class of pyridinyl ethyl benzamides. It is claimed to differ from existing succinate dehydrogenase inhibitors, to have a unique spectrum of activity, to be translaminar and distributed acropetally (therefore to protect new growth) and to have protective, curative and antisporulant activity. Subsequently, Hugh Armstrong and Richard Loveless (Bayer CropScience, Australia) reviewed progress in fungicide development over the last 40 years, detailing the increasing emphasis on safety for users and the environment, as well as efficacy against powdery and downy mildew.

A fortuitous accident with spray equipment allowed Walter Kast and colleagues (Weinsberg, Germany) to report that three applications of synthetic fungicides (just before flowering, during flowering and berries 2

mm diameter) were as effective as seven applications (as above plus one pre-flowering sulfur spray and three post-flowering treatments) for the control of powdery mildew.

Annemiek Schilder *et al.* (Michigan State University) have studied the production of cleistothecia (or chasmothecia) and the ability of fungicides to eradicate colonies and reduce cleistothecium production. As expected, most cleistothecia were trapped from severely diseased vines after rain. Sulforix (calcium polysulfate), Elite (tebuconazole), Kaligreen (potassium bicarbonate) and a mixture of two unidentified organic acids applied in autumn reduced the population of cleistothecia by 82-66% and were considered useful for late-season fungicide application to reduce disease and inoculum.

Recent research on the use of milk and milk components to control powdery mildew was presented by Dale Godfrey, Eileen Scott and others (University of Adelaide). Bioassays using detached leaves showed that diluted milk inhibited germination of conidia. Diluted full cream milk and skim milk acted both preventatively and curatively to reduce colonisation, whereas lactoferrin was ineffective. Two milk fatty acids exhibited curative activity. In small plot field trials, milk and skim milk (both diluted 1 in 10 with water) with or without wetting agent reduced disease severity compared with wetting agent alone or untreated controls. Vines in an organic vineyard failed to develop disease irrespective of treatment. Yield, pH, TA and ^{o}Brix of juice did not differ among treatments.

Nedeljko Latinovic (University of Montenegro) presented research on use of Profiler (fosetyl-Al and fluopicolide, the latter is a relatively new acylpicolide) for control of downy mildew in a vineyard in Montenegro. Profiler applied seven times at 2.25 and 3 kg/ha was as effective as the standard fungicide treatment (Verita, comprising fosetyl-Al and fenamidon). Fosetyl-Al, plus an unnamed phosphonate, was also the focus of a paper by Marie-Pascale Latorse and colleagues (Bayer CropScience, Lyon). The effect of treatment of the model plant, *Arabidopsis thaliana,* with or without downy mildew on transcription of mRNA was examined with a view to understanding mode of action; phosphonates appeared to prime the plant to respond to pathogen challenge.

Biological control powdery and downy mildew

Studies of efficacy of the mycoparasite *Ampelomyces quisqualis* were presented by Dario Angeli *et al*. (IASMA Research and Innovation Centre, Italy). Parasitism of cleistothecia of *E. necator* by naturally occurring strains of *A. quisqualis* in vineyards in northern Italy was not common, although the mycoparasite was widely distributed. Strains of *A. quisqualis* varied in the aggressiveness with which they attacked powdery mildew and strains more aggressive than the current commercial strain, AQ10, have been identified. The researchers hope that these new strains will provide a basis for improving biological control of powdery mildew.

Illaria Pertot and colleagues (IASMA Research and Innovation Centre, Italy) summarised 10 years of research on alternatives to copper for control of downy mildew as part of the European Union REPCO project. A total of 113 substances, including microbial, plant and animal extracts, natural and synthetic substances, biocontrol agents, physical treatments and combinations thereof, was tested for ability to prevent downy mildew. Materials identified as promising in greenhouse trials were then tested in the vineyard, along with untreated and fungicide-treated controls. Although some of the treatments reduced disease severity by 63% and just over one third of the treatments were as effective as copper in greenhouse tests, effectiveness in the vineyard was often disappointing, possibly because of degradation during exposure to the environment. Certain saponin derivatives and sage extracts controlled downy mildew on leaves, however, none of the alternative materials controlled disease on bunches as consistently as copper. Further details of the antifungal activity of sage extracts were presented on a related poster. An ethanolic extract of sage *(Salvia officinalis)* applied to rooted cuttings in a greenhouse or mature vines in a vineyard before inoculation with *P. viticola* reduced disease severity as effectively as copper hydroxide. However, sage extract was not rainfast. Antifungal activity was attributed to two as yet unidentified molecules in the extracts, which are being investigated.

6 Visit to Vine Experimental Unit, INRA Bordeaux and the "Untreated plots network"

Workshop participants visited the field station at Latresne. INRA researcher Philippe Cartolaro explained that activities at the field station are intended to assist with design of environmentally sustainable

production systems, and reduce pesticide use, while improving wine quality and the competitiveness of the wine sector. Three research projects viewed are summarised below:

1. Relationship between plant growth and epidemics. Vine growth is manipulated by combining vinestock and cover crop on one plot or by soil type and pruning on a second plot; vines are inoculated with powdery mildew and susceptibility to disease is related to sugar content and other aspects of metabolism. The aim is to understand the dynamic interaction between vine growth and powdery mildew epidemics and the susceptibility of foliage to disease.
2. GrapeMildews project. The aim is to manage disease to avoid yield loss rather than symptoms. Disease is maintained at a low level by strategic application of fungicides; powdery mildew control applied at between 5-7 and 8-10 leaves unfolded and again mid-flowering, and downy mildew control is applied mid-flowering and early to mid-ripening. Additional treatments are applied if monitoring at 5-7 and 8-10 leaves unfolded, as well as at early bunch closure, indicates that they are warranted (see Forecasting and decision models, Naud *et al*.).

- New high quality disease resistant winegrapes. Resistance to powdery and downy mildew is a priority in developing new cultivars. Evaluation in the absence of fungicide sprays in 2007-09 showed resistance to downy mildew conferred by *Rpv*1 (*M. rotundifolia*) to be better than *Rg*18 (derived from cv. Regent), and a combination of the two genes was best, although better on leaves than on berries when disease pressure was severe. Resistance to powdery mildew conferred by *Run*1 (*M. rotundifolia*) remains complete and combination with *Rg*15 (cv. Regent) is expected to contribute to durability. These genes do not appear to confer any benefit against black rot (*Guignardia bidwellii*), however, some genotypes do display reduced susceptibility. Six genotypes that display disease resistance and perform well in the vineyard and in winemaking will progress to the next stage of evaluation.

The group also visited a component of the “untreated plots network” in a commercial vineyard at Rauzan. The network was established by the Institute Francais de la Vigne et du Vin in 1992 to allow validation and improvement of disease forecasting models. While there was little powdery mildew on the vines examined, foliar Phylloxera was common and severe. This activity was followed by a visit to Chateau Figeac, St Emilion (Fig. 2), where vineyard management and wine quality were discussed.

7 Associated meetings

Eileen Scott presented (by invitation) a Master Class on biology and management of grapevine powdery mildew and trunk diseases to 33 representatives of the UK wine industry at Oxford University, as part of the European Union WineSkills program. She also spent time with the secretary of the UK Vineyards Association.

Bob Emmett visited researchers at Bayer CropScience, Monheim and DLR-Rheinhessen-Nahe-Hunsrueck, Oppenheim in Germany and discussed latest research on fungicides and use of the VitiMeteo mildew forecasting system in Europe.

Kathy Evans visited (by invitation) Chateau d’Yquem, in the Sauterne region of France, to improve her understanding of the production of botrytised wine. This information has been related back to the Tasmanian wine industry.

8 Outcomes

8.1 Main outcomes

Australian researchers gained considerable benefit from attending the workshop. New knowledge about pathogen biology and disease development and management will enhance existing and future research projects on powdery and downy mildew. New information is being communicated to the Australian grape and wine industry, through workshops and an article in the Australian and New Zealand Grapegrower and Winemaker, as well as to students via lectures. This will increase the knowledge base of the industry now and in the future and facilitate improved disease management.

Existing collaboration with American and European researchers was strengthened and new links with researchers in Eastern Europe were established. Dr Zvezdomir Jelev, Agricultural University, Plovdiv, Bulgaria has applied for a Group of Eight European Fellowship to spend 4 months at the University of Adelaide working with Drs Eileen Scott's group on control of powdery mildew and trunk diseases. If successful, this will involve collaboration with other GWRDC-supported researchers including Mark Sosnowski, Trevor Wicks, Dennis Taylor and Paul Grbin.

Dr David Gadoury, Cornell University, USA plans to visit Australian researchers in 2011 to continue collaborative research on the biology and epidemiology of powdery and downy mildew.

Dr Annemiek Schilder, Michigan State University, USA has been invited to visit Australia to enhance collaboration on alternatives to conventional fungicides for control of powdery and downy mildew.

8.2 Communication

An article has been prepared for the Australian and New Zealand Grapegrower and Winemaker magazine and is expected to appear in the December 2010 or January 2011 issue.

New information from the workshop was included in presentations given to grape growers at Spring Vine Health Field Days in September 2010.

New information has been incorporated into viticulture teaching at the University of Adelaide.

The abstracts of the workshop are available at https://colloque.inra.fr/gdpm_2010_bordeaux and are published as:
Calonnec A, Delmotte F, Emmett R, Gadoury D, Gessler C, Gubler D, Kassemeyer H-H, Magarey P, Raynal M, Seem R (2010). Proceedings of the 6th International Workshop on Grapevine Downy and Powdery Mildew. Bordeaux, France, 4-10 July (IBSN 978-2-7380-1279-1).

9 Recommendations

That links established during the workshop be maintained and similar visits by scientists to international workshops be supported to

- keep Australian scientists up to date with latest developments elsewhere;
- promote collaborative work and exchange of ideas among researchers;
- ensure that the GWRDC research providers remain an active component of the international research community, so that they can provide the best outcomes for the Australian grape and wine industry.

10 Figures

Fig. 1. Australian delegates at the workshop venue, Faculty of Pharmacy, University of Bordeaux, France



Fig. 2. Vines at Chateau Figeac, St Emilion, Aquitaine, France

