Predicting in-season risk of botrytis bunch rot in Australian and New Zealand vineyards

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Introduction

Rain during grape harvest in cool climate viticultural regions, like Tasmania, southern Victoria and New Zealand, often leads to botrytis bunch rot that can reduce yield and wine quality. In some wine growing areas this happens in most years; in other areas, it happens only occasionally. Good vine canopy management and skilful use of fungicides can lessen the risk, but the chance of botrytis losses seems to depend on rain during the ripening period. Fungicides can give excellent control of botrytis, but the most effective ones cannot be used after bunch closure because of fungicide residue risks. We need a way of knowing, well in advance, if a given season is shaping up to be a bad botrytis year so that fungicides and canopy management can be used to best effect. The grape and wine industries on both sides of the Tasman are grappling with these issues.

Trans-Tasman cooperation

Predicting where and when botrytis epidemics will occur is the goal of a project being carried out by the University of Tasmania, the Victorian Department of Primary Industries and HortResearch (New Zealand) on behalf of the Grape and Wine Research and Development Corporation and New Zealand Winegrowers. Vineyard trials in five climatically contrasted regions seek to quantify effects of weather, fungicides and vine management on botrytis risk. The project draws on a vast body of existing knowledge about botrytis biology, grape vine physiology, fungicide performance, biological controls, computer models and web-based decision support systems. These are being drawn together into a predictive framework that will help vineyard managers to optimise fungicide applications and vine canopy management so that they can minimise late-season botrytis risk, minimise costs and avoid fungicide residues.

This report describes preliminary analyses of vineyard trials conducted in five regions and five seasons to identify weather and botrytis inoculum factors that are associated with botrytis epidemics. Further analyses will be carried out incorporating data from the third and final year of the collaborative project (2008–2009).

Methods

Datasets, disease measurements and vine development

Throughout this report, the bunch rot disease of grapes caused by the fungus *Botrytis cinerea* is referred to as botrytis. This study examined variation in the severity of botrytis epidemics in various regions of Australia (southern Tasmania and southern Victoria) and New Zealand (Marlborough, Hawke's Bay and Auckland) and the associated variation in a range of climate and inoculum variables.

Botrytis severity at harvest (mean percentage of berries per bunch affected) in unsprayed field plots was analysed from 44 vineyard trials (site-years). Data were collected in five seasons, from 2000–2003 (Beresford et al. 2004) and from 2006–08 in the trans-Tasman study (Table 1). The grape variety most frequently used was Sauvignon Blanc, but other varieties were also included (Table 1).

For analyses, harvest botrytis severity in the unsprayed vineyard plots was divided into two categories, <3%, representing minor epidemics and ≥3%, representing major epidemics. Many wineries impose price penalties for botrytis-affected grapes if harvest severity is 3% or greater. Thus, for major epidemics, the economic impact of botrytis is potentially greater than just the percentage of the crop that is affected.

To identify how climatic factors during different parts of the growing season affect harvest botrytis severity, each site-year was divided into three growth-stage intervals: 1) early-season (5% capfall to pre-bunch closure, or PBC), 2) mid-season (PBC to veraison) and 3) late-season (veraison to harvest).

Weather factors

The weather factors investigated for relationships with harvest botrytis severity included surface wetness duration, temperature during wet periods, rainfall and daily mean, minimum and maximum temperature. Surface wetness and temperature during wet periods were summarised in the output of the Bacchus botrytis risk model (Kim et al. 2007), using the HortPlus™ Metwatch (www.hortplus.com) implementation (Figure 1). This model sums a risk index for each hour that plant surfaces remain wet and the hourly value is determined by a quadratic temperature response, with an optimum around 20°C. A wet period with a Bacchus index sum of ≥1 is considered to represent an 'infection period'.

To relate the Bacchus index to harvest botrytis severity, firstly the hourly Bacchus index sum was determined at the end of each wet period (Figure 1). Then the sums for all the wet periods within each of the vine growth-stage intervals were either accumulated or averaged. This was done separately for the wet periods where the Bacchus index was ≥1 and for any wet period of ≥5 h duration.

In total, 12 weather variables based on Bacchus index, rainfall, number of days with rain and daily mean, minimum and maximum temperature were accumulated or averaged over the three vine growth-stage intervals.

B. cinerea inoculum

There are two main infection pathways by which *B. cinerea* can initiate bunch rot in ripening grape berries (Elmer and Michailides 2004). The first is latent infection, in which the berries become

Table 1. Number of site-years of vineyard data used for analysis of factors influencing botrytis epidemic, summarised by region, variety and season.

Region		Grape variety		Growing season	
Auckland	5	Chardonnay	9	2000-2001	3
Hawke's Bay	12	Sauvignon Blanc	28	2001-2002	3
Marlborough	15	Semillon	2	2002-2003	15
Tasmania	6	Riesling	4	2006-2007	10
Victoria	6	Pinot Noir	1	2007-2008	13
Total	**44**		**44**		**44**

infected early-season, possibly as early as flowering, but infection is halted by natural anti-fungal chemicals in the developing berries. The other is via colonised bunch trash (flower caps, aborted berries and other debris), that is invaded by *B. cinerea* early in the season and later provides a source of inoculum. As grape berries ripen, the anti-fungal chemicals disappear, allowing latent infections to express and *B. cinerea* in colonised bunch trash to infect berries. Both pathways lead to bunch rot that spreads by berry to berry contact within bunches and by *B. cinerea* spores between bunches.

To measure the early-season inoculum in the vineyard that might contribute to harvest botrytis severity, we measured both these pathways at PBC. Latent botrytis was assessed as the incidence of *B. cinerea* infection in symptomless grape berries. Berry samples were frozen, surface-sterilised then moist-incubated for 6–12 days. This is called the overnight freezing and incubation technique (ONFIT). *B. cinerea*-colonised bunch trash was measured by counting the number of pieces of trash per bunch that were colonised after incubation in moist trays for 6 days, without surface sterilising.

Results

Weather factors

Relationships between weather variables over the three growth-stage intervals and harvest botrytis severity showed significant correlations for some variables (Table 2). It was found that the duration of the late-season growth-stage interval (veraison to harvest) was significantly correlated with harvest botrytis severity (variable 12). This correlation between the length of the ripening period and disease increased the correlation between disease and any of the accumulated variables during the late-season interval (variables 1, 3, 5, 7 and 8, see Table 2). On the other hand, weather variables that were summarised as means over growth-stage intervals were independent of interval duration and therefore reflected only the influence of weather on disease (variables 2, 4, 6, 9, 10 and 11).

The latter variables, together with interval duration, were subject to further analyses, in which the mean value of each variable for each growth-stage interval was compared for major and minor epidemics.

Bacchus index

A Bacchus index value of ≥1 is considered to represent a botrytis 'infection period' (Figure 1). However, use of this threshold gave no correlation with harvest botrytis severity (variable 4 in Table 2). In addition, its mean value for major epidemics was not significantly different from that for minor epidemics for any growth-stage interval (Table 3).

The mean value of the Bacchus index without any threshold (variable 2) was, however, correlated ($P<0.05$) with harvest botrytis severity for the early- and late-season intervals (Table 2). Furthermore, the mean Bacchus index for major and minor epidemics for those growth-stage intervals (Table 3) differed significantly ($P<0.1$).

Therefore, the Bacchus index averaged over all wet periods of ≥5 h duration, during the early or late season intervals, not only correlated with severity at harvest, but the mean index values for major epidemics were significantly greater than those for minor epidemics. The fact that significant relationships between harvest severity and Bacchus index were not found for wet periods with Bacchus index >1, suggests that shorter wetness durations than

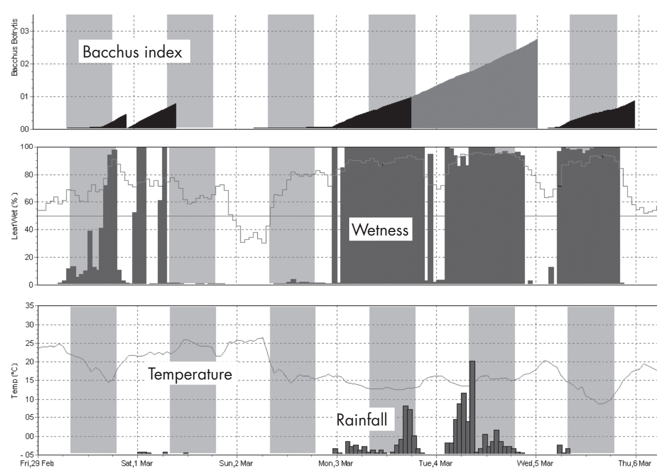

Figure 1. The output of the Bacchus botrytis risk model (HortPlus™ MetWatch, www.hortplus.com) shows that for a given wet period the index increases with each wet hour and turns red when a threshold value of 1 is reached.

Table 2. Correlation coefficients (r) between harvest botrytis severity in grapes for each of 44 site-years and 12 climatic variables summarised over three growth-stage intervals. R-values greater than 0.30 or less than -0.30 are significant (P<0.05) and are bold.

	Weather variable	Growth-stage interval: Early-season	Mid-season	Late-season
1	Accum. Bacchus index	**0.46**	0.26	**0.54**
2	Mean Bacchus index/wet period	**0.33**	0.22	**0.44**
3	Accum. Bacchus index >1	**0.40**	0.12	**0.53**
4	Mean Bacchus index >1/wet period	0.11	-0.18	-0.01
5	Accum. rainfall	0.14	0.02	**0.47**
6	Mean daily rainfall	0.22	0.25	0.12
7	No. days with rain	**0.37**	0.10	**0.44**
8	Accum. mean daily temp.	0.14	-0.10	**0.37**
9	Mean daily temp.	-0.03	-0.18	-0.22
10	Mean daily min. temp.	0.12	-0.09	-0.07
11	Mean daily max. temp.	-0.23	-0.24	-0.28
12	Interval duration	0.13	-0.03	**0.38**

Table 3. Mean values for selected weather and time variables between key growth-stages for 21 major botrytis epidemics (harvest severity ≥3%) and 23 minor epidemics (harvest severity <3%) in grapes. Probabilities are for t-tests that each pair of means was not significantly different. Significantly different pairs of means are in bold (P<0.1).

	Weather variable	Epidemic type	Growth-stage interval: Early-season	Mid-season	Late-season
2	Mean Bacchus index/ wet period	major	**0.71**	0.68	**0.77**
		minor	**0.63**	0.63	**0.67**
		Prob.	0.094	0.323	0.026
4	Mean Bacchus index >1/ wet period	major	1.48	0.86	1.39
		minor	1.42	1.10	1.47
		Prob.	*0.473*	*0.293*	*0.203*
6	Mean daily rainfall	major	1.93	1.48	1.49
		minor	1.71	1.13	1.37
		Prob.	*0.371*	*0.266*	*0.576*
11	Mean daily max. temp. (°C)	major	**22.36**	**23.44**	**22.12**
		minor	**23.23**	**24.68**	**23.80**
		Prob.	*0.052*	*0.016*	*0.008*
12	Interval duration (days)	major	44.9	34.9	**50.5**
		minor	46.3	33.9	**39.3**
		Prob.	*0.453*	*0.652*	*<0.001*

previously thought are associated with the development of botrytis epidemics.

Rainfall

Mean daily rainfall (variable 6) showed no relationship to harvest botrytis severity (Tables 2 and 3). The variables, accumulated rainfall and number of days with rain, tended to be significantly correlated with Bacchus variables (data not shown), reflecting the effect of rainfall on surface wetness duration.

Temperature

Temperature variables 9, 10 and 11 tended to be negatively associated with harvest botrytis severity, although correlations were not significant (Table 2). Mean daily maximum temperature (variable 11) showed the strongest association, and mean daily maximum temperature was significantly (P<0.1) lower for major epidemics than for minor epidemics for all growth-stage intervals (Table 3). This suggests that lower temperatures encourage botrytis epidemics. The greater botrytis severity associated with lower maximum temperatures was not caused by a negative correlation between Bacchus index (wetness duration) and temperature (data not shown).

Ripening period and botrytis risk

The mean late-season growth-stage interval (veraison to harvest, variable 12) associated with major epidemics was 50.5 days, which was significantly longer than the 39.3 days associated with minor epidemics (Table 3). This demonstrates the way in which a delayed harvest date greatly increases the risk of botrytis losses. The late-season interval was significantly negatively correlated with the temperature variables 9, 10 and 11 (data not shown), reflecting the fact that harvest occurs earlier in warmer regions.

Relationships between weather and disease across regions

Relationships between harvest botrytis severity and weather factors were also investigated using regional averages, separately for each growth-stage interval. Selected variables, which were considered to have potential for predicting harvest botrytis severity, were examined.

Mean early-season Bacchus index showed a linear relationship with harvest botrytis severity across regions (Figure 2). The Victorian data indicated a relatively high Bacchus index value for the observed botrytis severity. The mean Bacchus index over the early-season interval explained a greater proportion of the variation in harvest severity than the indices over either the mid- or late-season intervals (see R^2 values in Table 4).

Harvest botrytis severity increased exponentially with increasing late-season interval, with an average value of 40.8 days at 3% harvest severity, the threshold used to define minor and major epidemics (Figure 3).

Mean early-season maximum temperature showed a strong negative association with harvest botrytis severity (Figure 4). The Marlborough data indicated a relatively low mean maximum temperature for the observed botrytis severity. The relationship in Figure 4, and the ones for other growth-stage intervals (data not shown) were heavily influenced by the relatively higher temperatures in Victoria. The strong negative correlation between temperature and late-season interval reflects the fact that harvest occurs earlier in warmer regions.

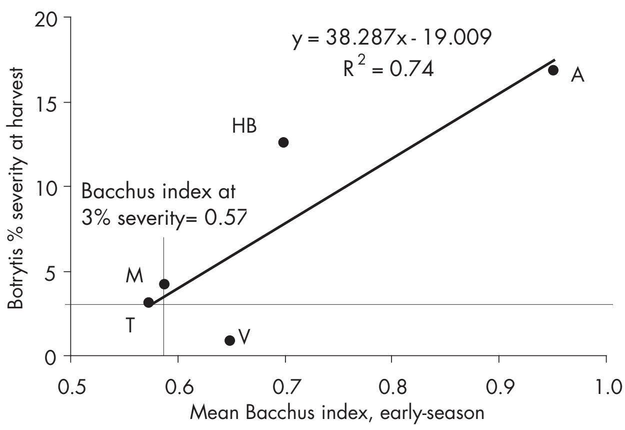

Figure 2. Regional means of early-season Bacchus index versus harvest botrytis severity in grapes. Regions are Victoria (V), Tasmania (T), Marlborough (M), Hawke's Bay (HB) and Auckland (A). See Table 1 for number of site-years for each region.

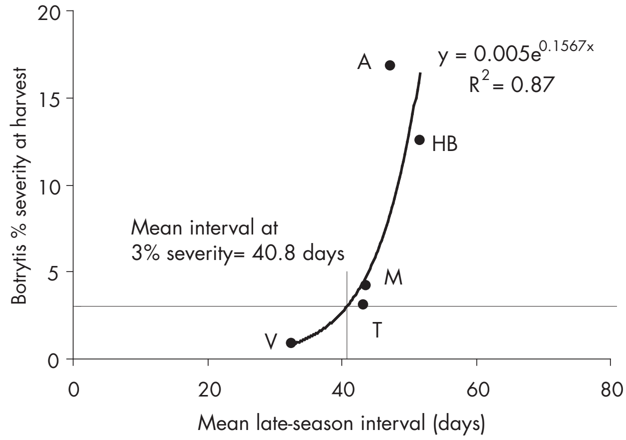

Figure 3. Regional means of late-season interval versus harvest botrytis severity in grapes. Regions are Victoria (V), Tasmania (T), Marlborough (M), Hawke's Bay (HB) and Auckland (A). See Table 1 for number of site-years for each region.

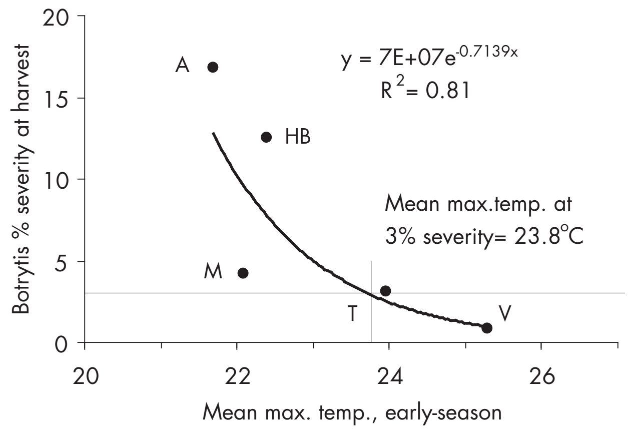

Figure 4. Regional means of daily maximum temperature versus harvest botrytis severity in grapes. Regions are Victoria (V), Tasmania (T), Marlborough (M), Hawke's Bay (HB) and Auckland (A). See Table 1 for number of site-years for each region.

Table 4. Regression of regional means of harvest botrytis severity in grapes on Bacchus index for three growth-stage intervals, using data from five regions. The early-season interval is also shown in Figure 2. See Table 1 for number of site-years for each region.

Growth-stage interval	Slope	Intercept	R^2	Predicted Bacchus index @ 3% severity
Early-season	38.287	-19.009	0.74	0.57
Mid-season	29.607	-12.680	0.42	0.53
Late-season	32.652	-16.573	0.58	0.60

Latent *B. cinerea* at pre-bunch closure

The incidence of latent botrytis at PBC was linked to severity. Major epidemics had a mean latent incidence of 10% and minor epidemics had a mean of 4%. There was much variation in the data for latent botrytis incidence below about 10% (Figure 5), but latent incidence >10% was only associated with major epidemics. It therefore appears that high incidence of latent botrytis at PBC may be useful for predicting major botrytis epidemics.

***B. cinerea*-colonised bunch trash at PBC**

Only nine site-years of data from 2006–07 and 2007–08 in New Zealand were available to investigate the effect of colonised bunch trash on botrytis risk. There was a significant relationship (R^2= 0.65, P=0.009) between harvest botrytis severity and colonised bunch trash (Figure 6). It appears that this measure of *B. cinerea* inoculum as a predictor of harvest botrytis severity is also worth further investigation.

Discussion

These analyses have been guided by the need to identify weather and inoculum factors that are useful for predictive modelling of botrytis risk. The most useful variables should have a causative relationship with botrytis epidemics and be independent of region-specific influences. In addition, useful variables must be readily measured in the vineyard and give meaningful predictions at times in the growing season when disease management actions are able to be taken. It is also necessary to avoid combinations of variables that are highly correlated with one another, as these could just reflect different measures of the same climatic or biological feature.

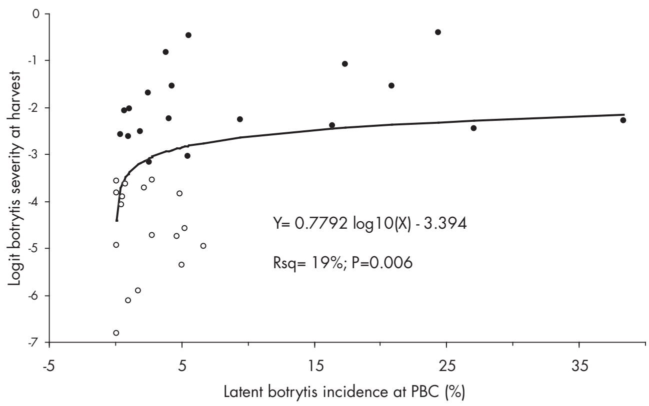

Figure 5. Regression of logit severity at harvest on percentage incidence of grape berries with latent botrytis at pre-bunch closure (PBC). Closed circles are major epidemics and open circles are minor epidemics.

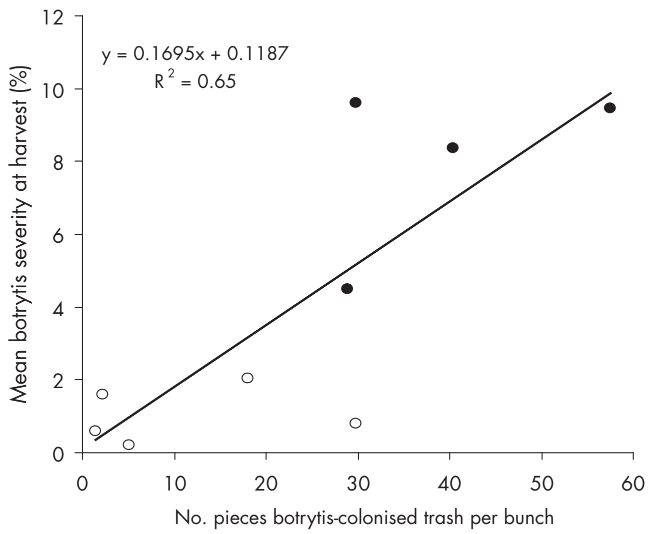

Figure 6. Regression of logit severity at harvest on number of pieces of botrytis-colonised trash (caps and aborted berries) per grape bunch at pre-bunch closure (PBC). Closed circles are major epidemics and open circles are minor epidemics.

Bacchus index

Of 12 weather variables investigated, the Bacchus index appeared to be the most useful predictor of botrytis severity at harvest. It was not correlated with any of the other variables investigated and it is readily monitored using vineyard weather stations. It appears that monitoring the average Bacchus index per wet period for all the wet periods that occur between vine growth stages as the season progresses would give an indication of developing botrytis risk.

The mean Bacchus index values associated with major botrytis epidemics in this study (0.5–0.7) were lower than the threshold of 1 proposed in the original Bacchus model (www.hortplus.com). This study has, for the first time, calibrated the Bacchus risk index against field epidemics of botrytis in grapes. The grape industry can use this new information immediately for botrytis risk assessment.

Rainfall, temperature and ripening period

This study showed, surprisingly, that the amount of rainfall, even late in the growing season, was a poor predictor of harvest botrytis severity. Although accumulated rainfall and number of days with rain both showed correlations with harvest botrytis severity, these variables included a time component and therefore may reflect the influence of time as much as weather on epidemic development.

The negative association between mean daily maximum air temperature and botrytis severity confirms that botrytis is favoured by cooler climates. Either mean maximum temperature or late-season interval may have a use in botrytis risk prediction, but probably not both these variables, as they are highly correlated and both reflect the influence that regional climate has on vine growth.

Latent *B. cinerea* and colonised bunch trash

It appears that use of ONFIT to detect a high incidence (>10%) of berries with latent botrytis at PBC may predict major botrytis epidemics. The amount of *B. cinerea*-colonised bunch trash after incubation may also predict botrytis risk. Both of these methods require further development before they can be used routinely as predictive tools.

Regional botrytis risk

The grape production regions included in this study would be classified as cool to cold viticultural regions (Smart and Dry 1980). Our results show that within this classification, the warmer temperatures associated with the climate in southern Victoria were associated with lower botrytis risk.

Longer surface wetness duration, as identified by the Bacchus index, was associated with greater botrytis risk and explains the greater botrytis severity in Auckland and Hawke's Bay. Gisborne and northern Tasmania would presumably have similarly high botrytis risk associated with longer wetness duration.

Marlborough had similar botrytis severity to southern Tasmania and southern Victoria. Presumably, Wairarapa, Canterbury and Central Otago in New Zealand would also be similar to Marlborough. The associations between climatic factors and botrytis severity from this study may not extrapolate to other Australian regions that have warm to very hot climatic classifications, including northern Victoria, South Australia and Western Australia.

Implementation of botrytis risk prediction models

This study has developed a unified set of methodologies for quantifying botrytis epidemics and used them to define climate and inoculum factors that explain the occurrence of botrytis epidemics on both sides of the Tasman Sea. Ongoing research will use disease progress analysis (Beresford et al. 2006) in conjunction with these findings, to simulate botrytis epidemic progress over time in response to weather and inoculum factors. These analyses will be used to calibrate botrytis risk models in the third year of this collaborative project (2008–2009). Effects of fungicide and vine management factors on disease progress rates are also currently being modelled.

For the implementation of botrytis risk models, quick and reliable techniques are required for assessing both latent botrytis and colonised bunch trash, possibly using immunological- or DNA-based detection methods. The successful application of weather-based predictive models also requires weather station networks that have weather sensors deployed in a standardised way and that are calibrated correctly.

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