

Climate-Based Modeling of Ontogenic Resistance to Fungal Diseases in Grapevine

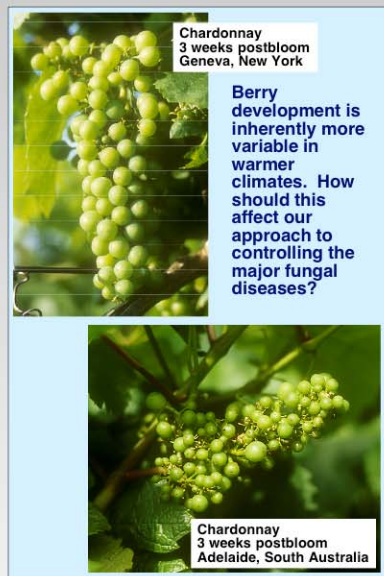
David M. Gadoury, Robert C. Seem, and Wayne F. Wilcox

Department of Plant Pathology, Cornell University, New York State Agricultural Experiment Station, Geneva, NY USA

INTRODUCTION

Most cultivars of the world's finest and most widely planted wine grape species (*Vitis vinifera*) are highly susceptible to powdery mildew (*Uncinula necator*), downy mildew (*Plasmopara viticola*), black rot (*Guignardia bidwellii*), *Phomopsis* fruit rot (*Phomopsis viticola*), and bunch rot (*Botrytis cinerea*). Based upon research in relatively cold climates, we now know that grape berries are most susceptible to infection by the above pathogens during a critical period in their development. This critical period is not the same for each disease, but the development of ontogenic (or age-related) resistance can nonetheless be precisely defined for each disease. With respect to fruit infection, actions taken during the critical periods largely determine success or failure of management programs. Disease on the fruit can be relatively easy to control if everything is done "correctly" during the critical periods, which are generally the bloom and early postbloom stages of berry development.

Here's the problem: the critical period of susceptibility is substantially affected by climate. In the northeastern US, bloom of grapevine is more or less synchronous, and it is not unusual for an entire Chardonnay vineyard to begin and complete bloom in a 2-day period. Contrast this situation with that of a warmer climate, such as Adelaide, Australia where bloom can take 2 weeks or more to complete. The warmer the climate, the longer and more variable is bloom, and therefore the longer and more variable is the period of fruit susceptibility. Thus, phenology and climate are inseparably linked to ontogenic resistance, and consequently to intelligent deployment of fungicides. Our objective is to adapt our findings on the duration of the critical periods of susceptibility to the major grape diseases to warmer areas based upon local climate.



Berry development is inherently more variable in warmer climates. How should this affect our approach to controlling the major fungal diseases?

METHODS

Development of ontogenic resistance under synchronous flowering. Berry age has a marked, but predictable effect on susceptibility to powdery mildew, downy mildew, and black rot in the relatively cold climate of New York State. Similar relationships between berry age and susceptibility have been described for *Phomopsis* fruit rot and latent infections of berries by *Botrytis cinerea*. We developed three simple regression models to describe the onset of ontogenic resistance to powdery mildew, downy mildew, and black rot under the synchronous host development observed in cold climates (Fig. 1). These models generate distributions that can be adjusted based upon the degree of asynchrony and variation in host development observed in warmer climates.

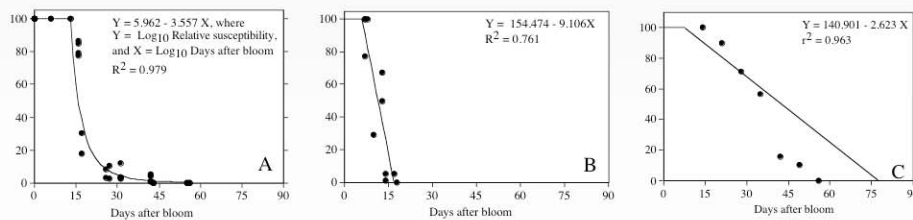


Fig. 1. Development of ontogenic resistance to powdery mildew (A), downy mildew (B), and black rot (C) in berries of *Vitis vinifera*. Data are from Gadoury, et al (Phytopathology 93:547-555), Kennelly, et al (Phytopathology 92:S47), and Hoffman, et al (Phytopathology 92:1068-1076).

Monitoring vine development in different climates.

Vineyards of the cultivars Chardonnay and Riesling were located in the US, Germany, and Australia. Five vines were selected at each site, and bloom (% anthesis or "capfall") of basal and second clusters on proximal, medial, and distal shoots (Fig. 2) was monitored daily. Climatic temperatures (Table 1) were obtained from various databases, and on-site instrumentation provided records of weather during the bloom period. Monitoring began in 2002.

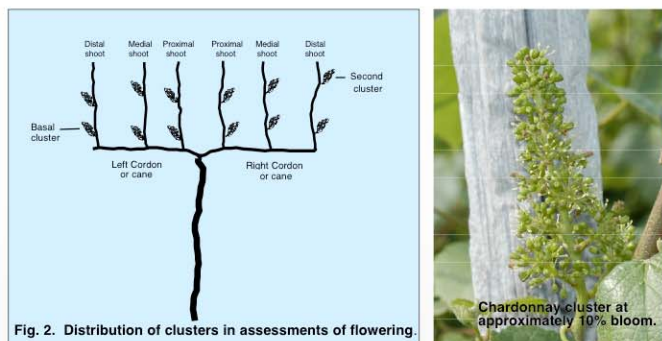
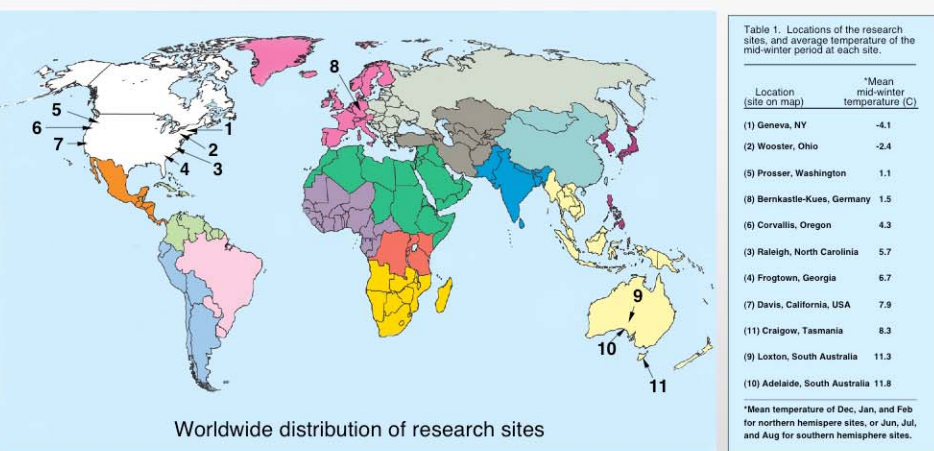


Fig. 2. Distribution of clusters in assessments of flowering.



Location (site on map)	*Mean mid-winter temperature (C)
(1) Geneva, NY	-4.1
(2) Wooster, Ohio	-2.4
(5) Prosser, Washington	1.1
(8) Bernkastle-Kues, Germany	1.5
(6) Corvallis, Oregon	4.3
(3) Raleigh, North Carolina	5.7
(4) Frogtown, Georgia	6.7
(7) Davis, California, USA	7.9
(11) Craiglow, Tasmania	8.3
(9) Loston, South Australia	11.3
(10) Adelaide, South Australia	11.8

*Mean temperature of Dec, Jan, and Feb for northern hemisphere sites, or Jan, Jul, and Aug for southern hemisphere sites.

RESULTS AND DISCUSSION

The magnitude and nature of asynchrony in bloom. In warmer climates, temporal heterogeneity in bloom was hierarchical. Variance in bloom was increased within individual clusters, between shoots at different positions on the vine, from vine to vine, and between closely-related cultivars within the same vineyards. The same forms of variation are seen in cold climates (Fig. 3A) and warm climates (Fig. 3B), but the scale of time is greatly compressed in cold climates, resulting in apparently synchronous host development.

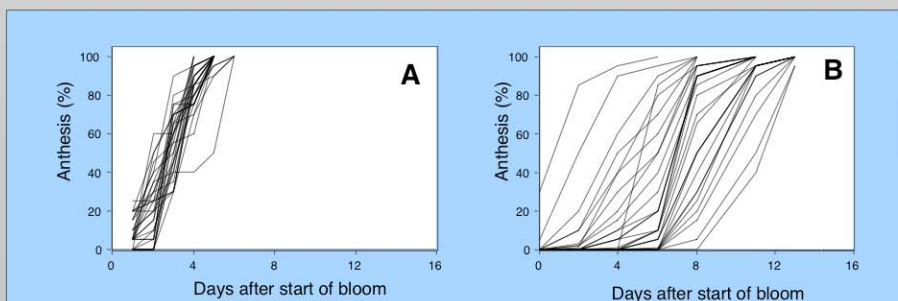


Fig. 3. Variance at the population level. Cumulative bloom of 30 individual fruit clusters on *Vitis vinifera* 'Chardonnay' in (A) Wooster, Ohio, USA, and (B) Adelaide, South Australia. Each line represents the cumulative bloom of a single cluster.

IN WARMER CLIMATES:

Asynchrony among vines increases

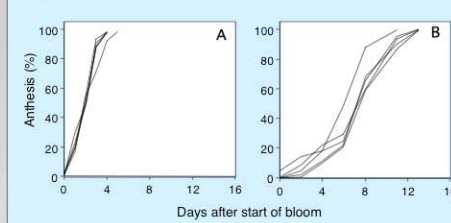
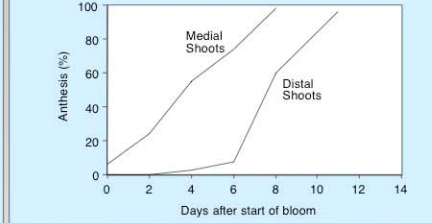


Fig. 4. Cumulative bloom of a sample of five Chardonnay vines in the cold climate (A) Wooster, Ohio, USA compared to the warm climate of (B) Adelaide, South Australia. Each line represents the cumulative bloom on a single vine.

Asynchrony between shoots increases



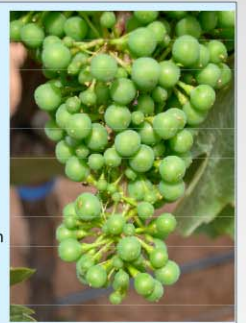
Asynchrony between basal and 2nd clusters increases



In warmer climates, a basal cluster may complete bloom more than a week before the second cluster on the same shoot. This asynchrony is reflected in subsequent developmental stages and in the acquisition of ontogenic resistance.

Asynchrony increases within a cluster

Although in cold climates, a single cluster may complete bloom in 48 hours, flowering of a single cluster is more protracted in warmer climates (see slope differences in Fig. 3A vs 3B). The resultant heterogeneous berry size is most conspicuous at 3 to 4 weeks postbloom, and is often mistakenly attributed to incomplete pollination. However, it reflects only the time of flowering (and hence time of pollination).



Asynchrony between cultivars increases

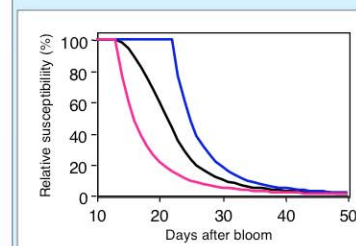


Differences between cultivars in the time of bloom are magnified in warmer climates. Chardonnay (left) blooms only 2-4 days before Pinot Noir (right) in the cold climate of New York, but may be offset by up to 2 weeks in warmer climates.

How is increased asynchrony related to increased severity of disease?

Synchronous host development in cold climates compresses heterogeneity in phenology and creates a single cohort which acquires ontogenic resistance synchronously. Warmer climates create multiple, successively-aged cohorts, which acquire ontogenic resistance successively. In the case of a disease such as black rot, where fruit acquire ontogenic resistance over a period of several weeks (Fig. 1C), expanding the bloom period from 2 days to 2 weeks adds relatively little time to the broad window of critical host susceptibility. However, in the case of powdery mildew and downy mildew (Fig. 1A and 1B), or any other disease in which the host acquires ontogenic resistance in a relatively brief period, this can more than double the time during which fruit are highly susceptible to infection.

Adapting models of synchronous development of ontogenic resistance for climate-based asynchrony



A number of approaches can be suggested. In the example at left, we created a hypothetical population of 10 cohorts of fruit clusters, each offset in age by 1 day (similar to the distribution seen in Fig. 3B). Each cohort then acquired ontogenic resistance to powdery mildew at the rate predicted by the equation shown in Fig. 1A. The acquisition of ontogenic resistance by the population was estimated as the mean susceptibility of all cohorts on any given day after the start of bloom in the first (oldest) cohort.

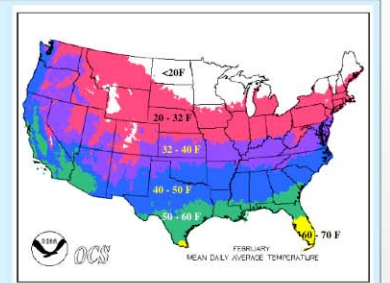
The left curve shows the development of ontogenic resistance by the first cohort, and is identical to that observed under synchronous bloom (Fig. 1A). The central curve shows the mean susceptibility of the hypothetical population in which 10% of the population initiates blooms on 10 successive days. The right curve shows the development of ontogenic resistance by the last (youngest) cohort.

A perhaps simplistic, but reasonable assumption would be that the increased duration of susceptibility, and increased area under the curve could result in an equivalent increase of disease severity, selection for fungicide resistance, loss of crop, or all of the foregoing.

Climate databases for development and deployment of forecasting systems

The climate data necessary for model development and deployment for many areas of the world are available (in most cases at no cost) from a number of sources, including:

- NOAA (National Oceanic and Atmospheric Administration) <http://www.ncdc.noaa.gov/oa/climate/stationlocator.html>
- WorldClimate WWW.Worldclimate.com
- World Meteorological Organisation <http://www.worldweather.org/>



CONCLUSIONS

- Duration and variability of bloom appear to be related to mid-winter temperatures.
- Phenological heterogeneity in warm climates may reflect satisfaction of minimal chilling requirements to break dormancy, but less than the chilling required for synchronous host growth.
- Asynchrony of grapevine development in warmer climates is seen at multiple levels: within individual clusters, within shoots, between shoots, between vines, and between cultivars.
- Asynchronous host development has the greatest potential to impact severity of those diseases in which the acquisition of ontogenic resistance is most rapid under synchronous host development.
- Models of ontogenic resistance should be adjusted for climate before testing or deployment. The increased efficacy of control observed in cold climates due to consideration of ontogenic resistance is more likely to be realized in warmer climates if models are adapted to reflect asynchronous host growth.
- Asynchronous development of deciduous perennial hosts in warmer climates is a general phenomenon, and may have important effects in diverse pathosystems (e.g., *Erwinia amylovora* and *Malus/Pyrus*, *Monilinia fructicola* and *Prunus*, and *Venturia inaequalis* and *Malus*).

ACKNOWLEDGMENTS

The authors are especially grateful to the many cooperators around the world who assisted in collecting the data on grapevine bloom and weather, including Michael Ellis, Ohio State University; Michael Maixner, Biologische Bundesanstalt; Peter A. Magarey, SARDI Loxton Research Centre; Katherine Stevenson, University of Georgia; Turner Sutton, North Carolina State University; Katherine Evans, University of Tasmania; Jay W. Pscheidt, Oregon State University; Ian Dry, CSIRO Horticulture Unit, University of Adelaide; W. Doug Gubler, University of California; Megan M. Kennelly, Cornell University; and Gary Grove, Washington State University.

REFERENCES

- Gadoury, D.M., Seem, R.C., Ficke, A., and Wilcox, W.F. 2003. Ontogenic resistance to powdery mildew in grape berries. *Phytopathology* 93:547-555.
- Hoffman, L.E., Wilcox, W.F., Gadoury, D.M., and Seem, R.C. 2002. Influence of grape berry age on susceptibility to *Guignardia bidwellii* and its incubation period length. *Phytopathology* 92:1068-1076.
- Kennelly, M.M., Seem, R.C., Gadoury, D.M., Wilcox, W.F., and Magarey, P.A. 2002. Refinement of DMCast, a predictor of grapevine downy mildew. pp 36-37 in: Proc. 4th Int. Workshop on Grapevine Downy and Powdery Mildew, Napa, California, 30 Sept. - 4 Oct., 2002. UC Davis Press. 88 pp.