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Research Focus

Climate, Duration of Bloom, and the Window of Risk for Grapevine Diseases

David M. Gadoury, Robert C. Seem and Michele Moyer[1]

Department of Plant Pathology and Plant-Microbe Biology, Cornell University, NYS Agric. Exper. Station, Geneva, New York

[1] Current Affiliation: Department of Horticulture, Washington State University, Irrigated Research and Extension Center, Prosser, WA

Bloom and berry development is much more variable in warmer climates, and this variability should inform our approach to controlling major diseases.

Photos by David Gadoury

Grapevine bloom is often completed in two to three days in regions with cold winters such as New York. In contrast, in warm climates with mild winter temperatures, bloom can extend for two to three weeks. Our studies in different production regions have demonstrated that average temperatures in the three coldest months influence how well-synchronized grapevine bloom is—and therefore how quickly grape berries pass through the critical period of susceptibility to certain key fruit diseases. Berries as they develop become progressively more resistant to powdery mildew and downy mildew. Where flowering is synchronous, berries become highly resistant to powdery mildew by four weeks after bloom. However if bloom extends over several weeks, berries lagging in development remain vulnerable to infection, extending this critical window in direct proportion to the duration of bloom. Knowledge of this link between climate and synchronous bloom can be used to assess the risk of extended vulnerability and adjust management practices accordingly.

Key Concepts

- Mid-winter temperatures determine the duration of bloom and subsequent fruit development. Asynchronous bloom in regions with the warmest winters lasts up to ten times longer than bloom in regions with the coldest winters, like New York.
- Increased variability in bloom is seen within clusters, between clusters, and among shoots, vines, and cultivars.
- Powdery mildew, downy mildew and black rot all have a narrow 'window' of berry susceptibility, and fruit acquires ontogenic (age-related) resistance three to four weeks after bloom.
- Extending bloom extends fruit susceptibility, and consequently it extends the need for intensive management of disease.
- Trends towards milder winters may increase disease pressure by increasing asynchrony of bloom and berry development, with downstream effects on ripening and late-season fruit rots.

Introduction. It's not often that we think of our winters in upstate New York as an advantage for viticulture. However, as we study how grapevines grow in our region compared to regions with warmer winters, let's just say it does have certain advantages.

Since 2005, our lab has led an international effort to determine just how grapevines develop in climates with substantially different winters (**Fig. 2**). Why focus on winter? Because it emerged that winter chilling had a far greater effect upon grapevine development—and consequently the risk of certain diseases—than anyone had previously supposed. Several studies have examined temperature relationships such as the minimum chilling required to break dormancy or those influencing cold hardiness of vines. However, information about how the depth and degree of chilling can stabilize and synchronize development in grapevine was limited. To understand why this is relevant to the risk of certain diseases, we'll first need to review a phenomenon called ontogenic (or age-related) resistance.

What is ontogenic resistance? Age-related changes in a plant's susceptibility to disease, which we call *ontogenic resistance*, are a common phenomenon. Plant tissues, organs, and even whole plants can change in susceptibility to pathogens as they age and develop through phenological stages during the growing season. Substantial changes can occur over relatively short periods of time, creating critical periods of susceptibility that, once understood and quantified, can be of great relevance to forecasting epidemic development and improving the performance of disease management programs. The grape clusters in **Fig. 3** were inoculated with spores of the powdery mildew pathogen (*Erysiphe necator)* at the indicated stages of development. Notice that only the earliest inoculations resulted in severe infection.

Figure 2. In cooperation with colleagues around the world, we've been studying the relationship between climate and variability in berry development since 2005.

Photos by David Gadoury

Bloom starts the clock for the development of ontogenic resistance in grape berries. Berries are highly susceptible to powdery mildew when they first form, but within 14 days after fruit set, they begin a rapid transition to resistance, i.e., they develop ontogenic resistance. By the time a berry of *V. vinifera* 'Chardonnay' is 21 days old, it is nearly immune to infection (**Fig. 4)**.

For disease management programs, this means that you have one great opportunity to affect the severity of fruit infection: Hit the disease hard during the crucial period of fruit susceptibility. Choose the best fungicides, get the best spray coverage, and manage the canopy to create a microclimate unfavorable to powdery mildew. All of these actions have the maximum impact when you do them during the critical period of fruit susceptibility. Con-

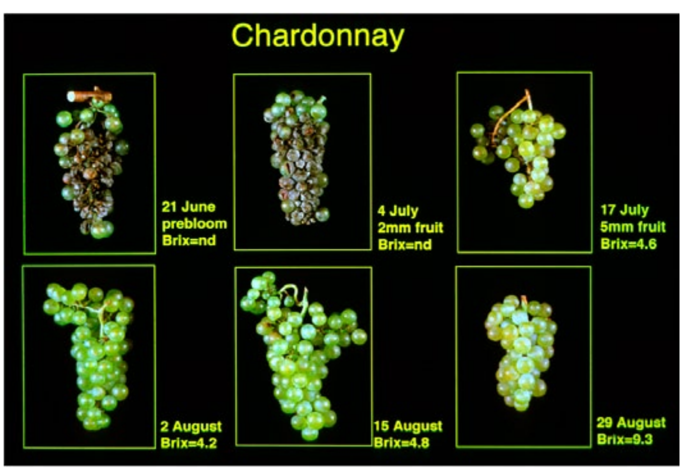

Figure 3. Chardonnay grapes were inoculated with powdery mildew spores at two-week intervals from before bloom to late August and then photographed at harvest. Notice that only the clusters inoculated at the earliest stages developed powdery mildew. Berries are nearly immune to infection by three to four weeks after bloom.

Photos by David Gadoury

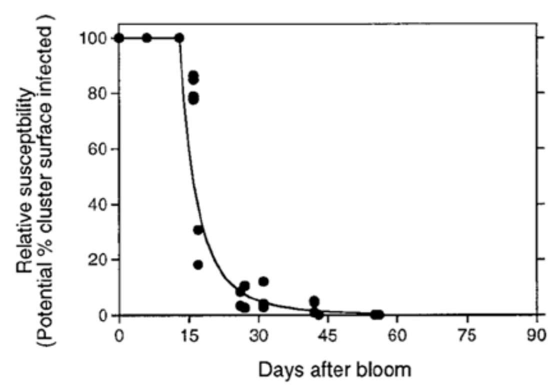

Figure 4. This graph shows the rapid loss of susceptibility to powdery mildew that begins when grape berries are about two weeks old. Susceptibility remains high at first, but it then rapidly drops and soon thereafter berries are nearly immune to new infections. This pattern applies to all V. vinifera cultivars, and it is only slightly modified for interspecific hybrids and V. labrusca cultivars.

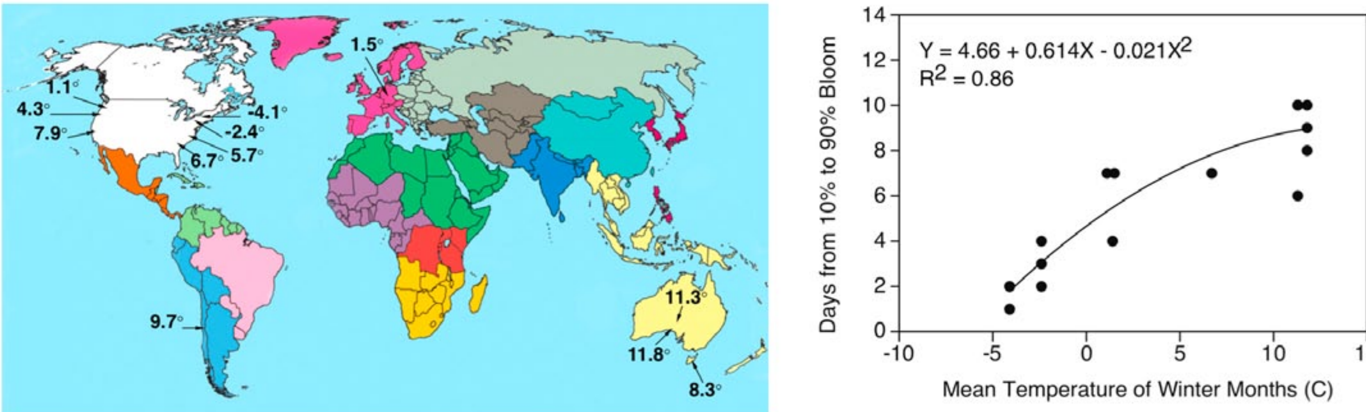

Figure 5. *Chardonnay vineyards around the world were monitored for several years to accumulate sufficient berry development and climate data to establish the relationship between the mean temperatures of the winter months (left) and the duration of bloom (right). As the mean winter temperatures increased, the average duration of bloom increased from three to four days to ten days.*

Photos by David Gadoury

versely, errors in rates of application, occurrence of fungicide resistance, or poor spray coverage all have profoundly bad consequences when they occur during the critical stage. Management trials have consistently shown that 80 to 90% of the reduction in the severity of fruit infection can be attributed to one or two sprays applied during this narrow window of opportunity. It's not that sprays applied at other time are unimportant, because they are. Maintenance of canopy health is important for the production of quality wines, but a healthy canopy is of little economic value if the fruit is severely infected with powdery mildew at harvest.

How is ontogenic resistance linked to climate? Ontogenic resistance is linked to climate through the effects of climate on phenology; specifically by determining how uniformly plants will grow in a particular climate. Perennial fruit crops generally undergo dormancy that requires a period of chilling before regrowth. Minimum chilling requirements of perennial fruit crops have been extensively studied with respect to minimal requirements for entry into and release from dormancy. However, beyond the minimum chilling requirement, comparatively little is known about how the degree and depth of winter chilling affects the *synchronization* of host regrowth. The warmer the winter dormancy period, the more asynchronous phenology can become. As phenology becomes more asynchronous, so does the development of ontogenic resistance. Consequently, climate can expand or contract the period of time that a host remains in a critically susceptible state (**Fig. 5**).

This dependency of the duration of bloom upon climate generally passes unnoticed unless one moves between regions with substantially different winter temperatures. For example, a viticulture text from California may speak of Chardonnay bloom lasting approximately seven to ten days as if it is the most natural thing in the world-and it is if your world is restricted to California. But Chardonnay can complete bloom in two days in New York, and it may take more than two weeks in South Australia. It may seem counter-intuitive, but grapevines take longer to complete bloom in warmer climates--a LOT longer. Remember, it's bloom that starts the clock ticking in development of ontogenic resistance. Stay in a susceptible stage for two weeks instead of two days, and spores have far more opportunities to become established on susceptible tissue. So, that's the advantage conferred by a climate with cold winters: More synchronous development means that grapes move rapidly through the critical period of susceptibility.

Many crops are affected. Less than optimal chilling can result in asynchronous host phenology and protracted periods of susceptibility to a variety of diseases in several crops, including grapevine powdery mildew (*Erysiphe necator*), grapevine downy mildew (*Plasmopara viticola*), apple scab (*Venturia inaequalis*), fire blight of apple (*Erwinia amylovora*), and brown rot of stone fruits (*Monilinia fructicola*). Any crop in which a critical window of susceptibility could be indirectly expanded through an effect of chilling upon phenological synchrony could be affected (**Fig. 6**)

Figure 6. *The depth and duration of winter cold can affect a variety of perennial fruit crops and thereby affect the length of time that fruit remains susceptible to a number of fungal pathogens.*

Grapes in particular. We know more about interactions between chilling, asynchronous phenology, the development of ontogenic resistance, and the consequent risk of disease in the European grapevine species *Vitis vinifera* than we do in any other crop. The complex structure of the vine creates a hierarchy within which we have studied phenological asynchrony between first and second clusters, among shoots at different positions on the cordons, between vines, and across a vineyard. The worldwide distribution of the crop provided us with research sites across a gradient of climates. We have also quantified ontogenic resistance for several key diseases of grapevine, including powdery mildew, downy mildew, and black rot.

Our study sites were chosen among Chardonnay and Riesling vineyards in North and South America, Europe, and Australia (**Fig. 6**). Five vines were selected at each site, and bloom (percent anthesis or "capfall") of basal and second clusters on proximal, medial, and distal shoots (**Fig. 7**) was monitored every one to three days during bloom from 2004 to 2012.

The magnitude and nature of asynchronous bloom. The duration of bloom at the various sites was highly correlated with the mean temperature of the winter months (**Fig. 5,** December, January and February in the northern hemisphere and June, July, and August in the southern hemisphere). Degree day accumulation during bloom was equivalent among sites and years, and it did not explain the observed differences in the duration of bloom. Bloom was completed in as little as little two days at the site with the coldest winter (Geneva, New York, USA), but bloom lasted more than two weeks at the site with the warmest winter (Adelaide, South Australia).

Once ontogenic resistance has been quantified under conditions of synchronous phenology, and the relationship between climate and phenology has been likewise quantified, the two can be integrated to produce a forecast of risk for a variety of climate scenarios.

Projections of the impact of climate change upon disease have generally focused upon host and pathogen effects during the growing season. Our results and analysis indicate that substantial effects occur across existing winter temperature gradients. Effects of similar magnitude could be reasonably projected to occur in vineyards if climate change brings warmer winters to historically cool climate areas.

Variability in bloom duration. In warmer climates, the variation in the duration of 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 (**Figs 8-12**). The same forms of variation are seen in cold climates (**Fig. 8A and 12A**) and warm climates (**Fig. 8B and 12B**), but the scale of time is greatly compressed in cold climates, resulting in relatively synchronous host development.

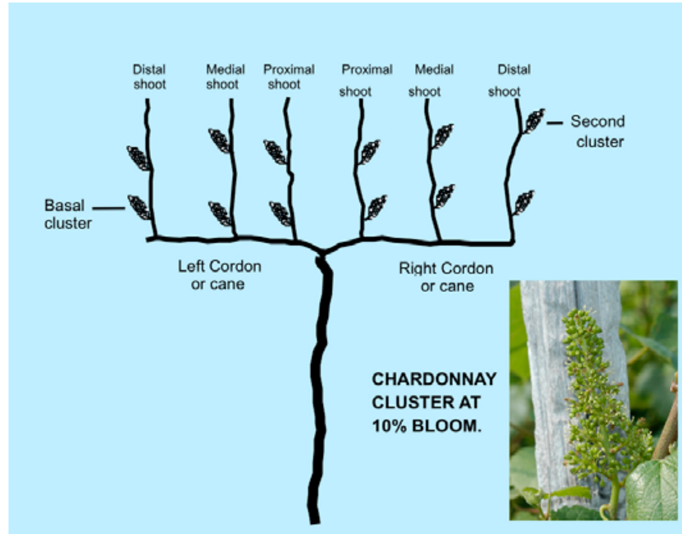

Figure 7. *We selected and tagged flower clusters from vines spaced along a transect across our research sites. On each vine, we followed bloom on basal and second clusters on shoots in different positions on the cordon. By frequent examination of the same clusters, we could reconstruct the duration of bloom.*

Downstream effects on ripening, late season diseases, and fruit quality. Asynchronous emergence from dormancy is the root cause of protracted flowering, and it sets the stage for asynchronous maturation. In the case of wine grapes, asynchronous ripening could affect diseases that occur late in the growing season (**Fig. 13**), such as bunch rot (*Botrytis cinerea*). Uneven ripening can also complicate the determination of optimal harvest dates in premium wine production.

We tracked the accumulation of soluble solids in Chardonnay vineyards that differed in the duration of bloom. Sugar accumulation in berries is a key factor related to fruit maturity as well as risk of bunch rot. Variability in sugar accumulation across a vineyard was directly proportional to the observed degree of asynchrony of bloom. Of course, sugar accumulation is notoriously variable in clusters at certain phases during berry maturation in any climate, and sugar accumulation is just one indicator of berry maturity. Nonetheless, we found that the period of high variability in brix was proportionally longer when bloom lasted longer. The ultimate impact of this upon juice and wine quality is still unknown and is a subject of our continuing work. However, it would require some degree of wishful thinking to assume that this variability in berry maturity, once established by asynchronous bloom, just goes away because we can no longer detect it in an assessment of brix.

Implications for disease management. New York has just experienced one of the mildest winters on record. As a result, the time required to progress from 10% to 90% bloom lasted seven days compared to our long-term average of two to three days. Fortunately, our weather during

Asynchrony among vines increases

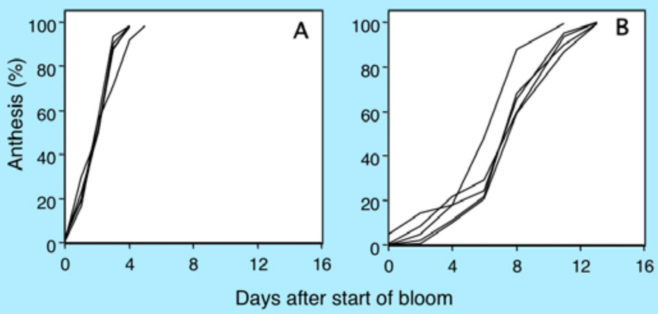

Fig. 8. Cumulative bloom of a sample of five Chardonnay vines in the cold climate (A) Wooster, Ohio, USA compared to the warm climate of (B) Adelaide, South Australia. Each line represents the cumulative bloom on a single vine.

Asynchrony between shoots increases

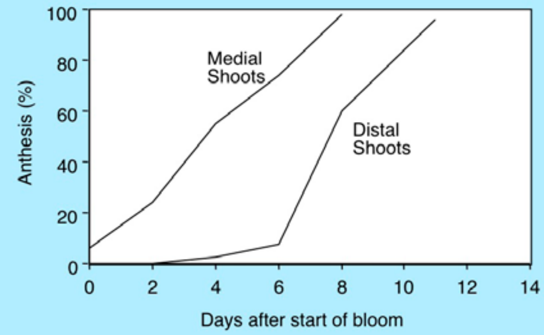

Fig. 9. Cumulative bloom of basal clusters on medial compared to distal shoots of Chardonnay vines in Adelaide, South Australia, 2002. In cold climates, clusters on these shoots bloom synchronously (see Fig. 12A).

Asynchrony between basal and 2nd clusters increases

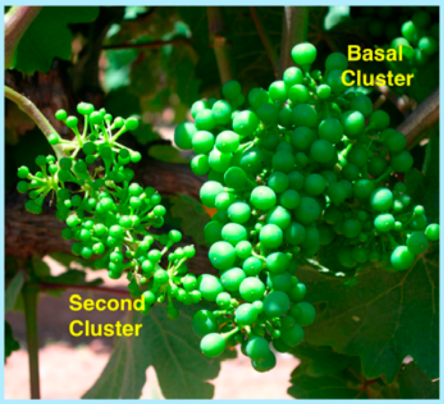

Fig. 10. In warmer climates, a basal cluster may complete bloom more than a week before the second cluster on the same shoot. This asynchrony is reflected in subsequent developmental stages and in the acquisition of ontogenic resistance.

Asynchrony increases within a cluster

Fig. 11. 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 12A vs 12B). 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 at the population level

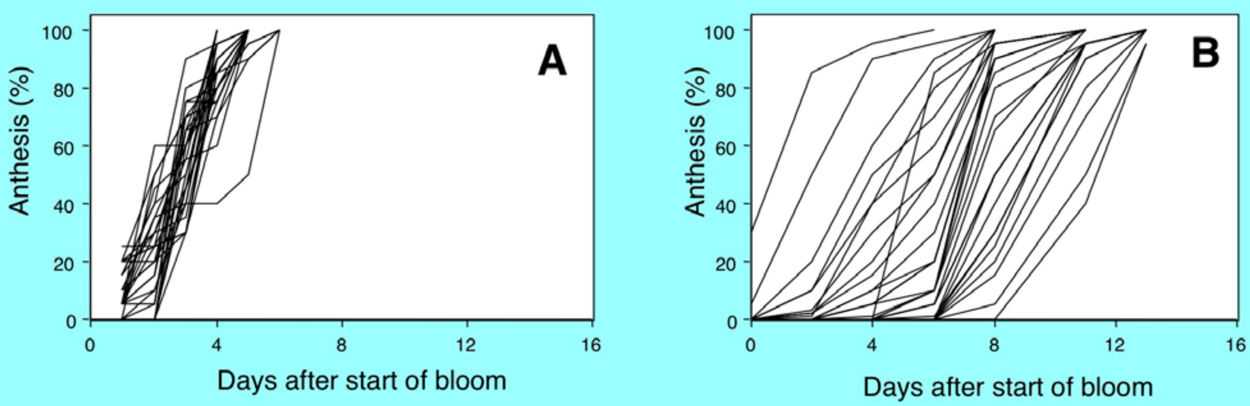

Fig. 12. Cumulative bloom of 30 individual fruit clusters on *Vitis vinifera* 'Chardonnay' in (**A**) Wooster, Ohio, USA,and (**B**) Adelaide, South Australia. Each line represents the cumulative bloom of a single cluster.

this period was not highly conducive to the major fungal pathogens, so we dodged the bullet. If this is an indicator of a long-term climatic trend, we may not always be so fortunate. The prospects are not bleak, as we know a great deal about the major diseases and impacts of climate based upon recent research, and there is much that can be done to mitigate any increased risk of disease. Producers should take every opportunity to incorporate what we already know.

First, canopy management for optimal sun exposure, air circulation, and spray coverage can greatly reduce powdery mildew development post-infection . Our prior research on ontogenic resistance has precisely delimited the time when you get the most bang for your buck from fungicides directed at suppression of fruit infection. Most of the suppression of disease on fruit is due to a few critical sprays applied during the period of maximal susceptibility. Do everything right during this period, and you'll achieve the best possible outcome. Be especially diligent regarding (i) selection of materials for high efficacy, (ii) sprayer calibration and use of an adequate volume of water, and (iii) adoption of an effective anti-resistance strategy during high risk periods. We've recently developed an advisory system that can provide some advance warning of "boom and bust" years for projected severity of powdery mildew. Keep apprised of what this model is saying about how the current year is shaping up with respect to the risk of powdery mildew. So far, it's been very accurate.

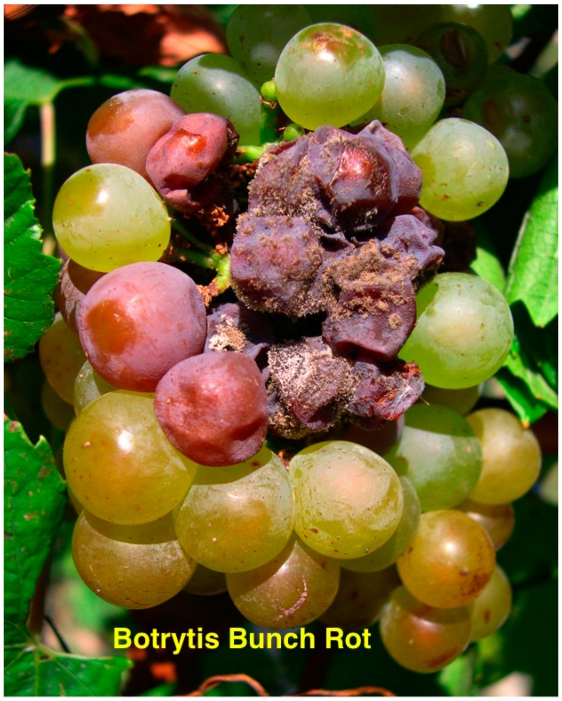

Figure 13. *Bunch rot is a late-season disease that could also be affected by asynchronous development if latent infections occur during protracted bloom, or if harvest was delayed to offset delayed maturity due to protracted bloom.*

Photos by David Gadoury

Additional Reading:

Moyer, M, D. Gadoury, and R. Seem. 2011. Variable Eastern Weather Influences Powdery Mildew Severity. **Research Focus 2011-2, Appellation Cornell** Issue 6, April 2011. Cornell University, Ithaca, NY

Austin, C. and W. Wilcox. 2010. Heat and UV Radiation from Sunlight Exposure Inhibit Powdery Mildew. Research Focus 2010-2, Appellation Cornell Issue 2, May 2010**.** Cornell University, Ithaca, NY.

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David Gadoury is a Senior Research Associate in the department of Plant Pathology and Plant Microbe Biology at Cornell's New York State Agricultural Experiment Station in Geneva.

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