Grape Berry Ripening: Environmental Drivers and Spoilers

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Bogs et al. (2007)
A winemaker’s dream

- Loose clusters
- Small berries
- Uniform composition
Nature’s reality

Large spatial and temporal variation
Grape berry: A job description

- Seed production and dispersal
- Color, aroma = Advertising
- Sugar = Ticket price

photo courtesy B. Bondada
Physiological maturity?

Maturity: State in which fruit is best suited for intended use

Hall et al. (2011)
Change happens early

- Rapid changes as berry turns from hard-green (1) to soft-blue (4):
  - Sugar: <8 → >18 °Brix
  - pH: 2.6 → 3.1 to 3.7 (cultivar!)
  - Titratable acidity: >25 → ~10 g/L
- Slow changes as berry turns ripe (5: 20-24 °Brix), and then overripe (6: >24 °Brix)
- Physiological maximum 23-25 °Brix

Keller & Shrestha (2014)
Berry size: Much ado about water

- Berry contains 70-80% water at harvest
- **Water in:** Xylem and phloem inflow
- **Water out:** Transpiration and xylem backflow
- Balance between ins and outs determines berry size (limited by skin extensibility)
- Véraison: Phloem flow ↕, xylem flow reverses → Berries less sensitive to soil moisture
Berry transpiration facilitates ripening

- Transpiration is mostly cuticular, increases with berry size, and changes with berry development
- VPD (temperature, RH) drives transpiration
- Berry transpiration discharges surplus phloem water
- Low transpiration rate → Phloem pressure release
  → Phloem unloading
  → Sugar accumulation
  → Anthocyanin accumulation
- Low VPD (low temperature, high humidity) → Slow ripening

Zhang & Keller (2015)
• Berry size is determined early → It is difficult to manipulate berry weight after véraison
• Cool spring temperatures → Small flowers → Small berries
• Water deficit before véraison → Small berries

Keller et al. (2010)  
Keller (2015)
Diluting fruit quality – really?

More water before véraison increases berry size

More water after véraison decreases berry shrinkage
-5% weight → +1 °Brix

Berry weight loss (%) Merlot (r = -0.45*) Syrah (r = -0.41*) Chardonnay (ns)

Berry weight (g) Merlot (r = 0.53**) Syrah (r = 0.43*) Chardonnay (r = 0.51*)

More water before véraison increases berry size

Post-veraison Ψstem (MPa)

Pre-veraison Ψstem (MPa)
Rainfall: Berry splitting (cracking)

Water through skin
→ Berries swell, may split
→ Sugar may leach
→ Split berries may shrink

Berry sugar (Brix)
Concord, \( r = -0.80^{***} \)
Merlot, \( r = -0.88^{***} \)

Soluble solids (Brix)

Splitting due to:
• Rainfall
• Sprinkler irrigation
• High humidity
• Preveraison drought
Water deficit impacts berry development

- Water deficit $\rightarrow g_s \rightarrow Pn \rightarrow C$ partitioned to fruit
- Water deficit before véraison $\rightarrow$ Smaller berries $\rightarrow$ Skin:juice
- Stimulation of anthocyanin biosynthesis (sugar + ABA)
- Water deficit after véraison $\rightarrow$ Less sugar, berry shrinkage

Keller et al. (2015)
Tannin variation due to water and weather; anthocyanin variation dominated by weather (more in cool vintage, less in warm vintage)

- Full-season deficit → Higher anthocyanins and tannins → More LPP
- Prevéraison deficit → Intermediate tannins
- Postvéraison deficit → No gain → Dehydration does not make berries more mature

Casassa et al. (2015)
Water deficit: It’s not just about berry size

- Water deficit → Small berries, low vigor
  → Open canopy, restricted shoot growth
  → High cluster sun-exposure
  → High light and high temperature

- Exposed berries are warm berries

Keller et al. (2016)
• Climate variation and vineyard location: By far the strongest determinants of fruit composition
• Acidity and color vary >2-fold, aroma volatiles >10-fold at similar Brix level and yield
• Temperature trumps soil moisture and crop load

Keller et al. (2004, 2005)
Temperature limits fruit ripening

No berry growth or sugar accumulation at <10°C and >40°C

Hall (2010)
Disentangling the **light** from the **heat**

- Photosynthesis
- Sugar (20-30°C)
- Acids: Tartrate (?
- Malate
- pH (?)
- K+
- Amino acids (proline, arginine)
- Phenolics: Anthocyanins (days: 30-35°C)
- Tannins (?)
- Volatiles (?): Methoxypyrazines
- Sunburn: >42°C + UV/visible light

partly from Spayd et al. (2002)
Light: Visible and UnVisible

- Photosynthesis ⊢-☉
- Sugar ⊢
- Acids: Tartrate (☉)
  - Malate ⊢
  - pH (?)
- K⁺ ⊢ (?)
- Amino acids (arginine ⊢), N ⊢
- Phenolics: Anthocyanins (color) ⊢ (visible >100 µmol m⁻²s⁻¹)
  - Flavonols (color cofactors) ⊢ ⊢ (UV-B)
  - Cinnamic acids (lignin, Brett….) ⊢ (visible)
  - Tannins (astringency) ⊢ (visible?)
- Volatiles: Norisoprenoids, monoterpenes… ⊢
  - Methoxypyrazines ⊢
- Wine sensory properties ⊢-☉
Sun exposure: More is better?

- **Sun-exposed berries:** More UV light + heating (+15°C)
- **Chardonnay, Riesling:** Sun-exposed berries with 6-8 times more flavonols and 2-4 times more flavan-3-ols (monomers, dimers, trimers, polymers) than shaded berries + Sunburn
- Smaller, open canopy → More sun-exposed fruit → More bitter and astringent phenolics → Skin contact → White wine?
Nitrogen: Moderation is a virtue

- More N $\rightarrow$ Higher yield, more lateral growth, denser canopy
- Growing shoot tips compete with fruit $\rightarrow$ Delayed ripening
- N suppresses secondary metabolism (phenolics)
- Bad recipe: Apply N fertilizer, then hedge away excess growth
- N (and S) enhance aroma precursors (volatile thiols)

Nitrogen: Interaction with light

Light drives anthocyanin accumulation, but N modulates it

Keller & Hrazdina (1998)
• Proline and PR proteins accumulate during ripening
• Water deficit → N deficit → Risk of stuck fermentation → H₂S
• N deficit → High phenolics but low aroma precursors

Wade et al. (2004)
Potassium and the pH conundrum

- Metal cations (K+, Na+), may counter the influence of organic acids by substituting for H+ \(\rightarrow\) Juice pH
- Variation in juice pH is driven by variation in both TA and K+
- Late harvest \(\rightarrow\) TA ↘, K⁺ ↗ \(\rightarrow\) pH ↗
- Crop load ↘ \(\rightarrow\) K⁺ ↗ (phloem import) \(\rightarrow\) pH ↗
- Juice pH is not very responsive to soil K⁺ (\(\rightarrow\) Malate ↗)
- Ca²⁺ and K⁺ compete for root uptake: Soil pH ↗ \(\rightarrow\) Juice pH ↗
It’s in the book

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