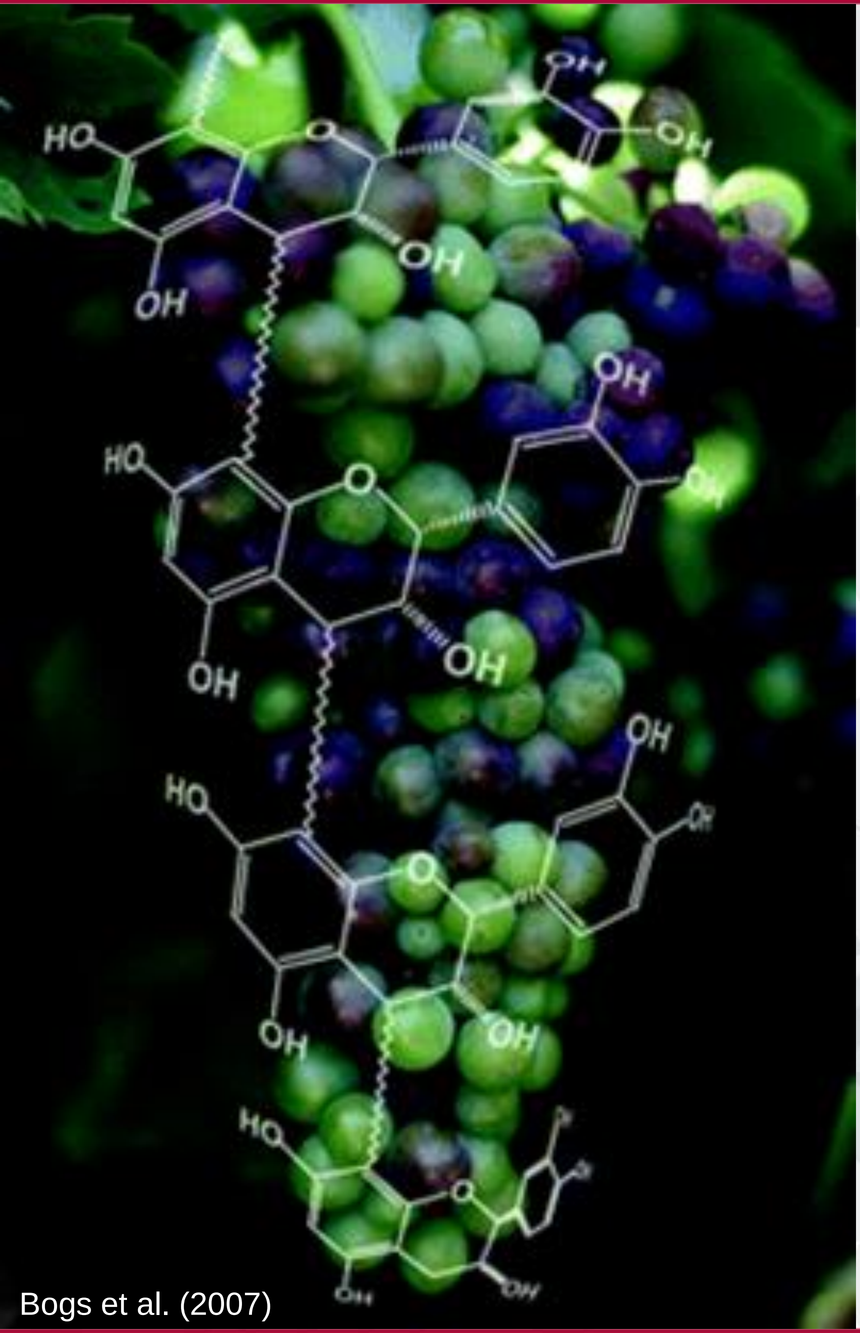


Bogs et al. (2007)

Grape Berry Ripening: Environmental Drivers and Spoilers

Markus Keller

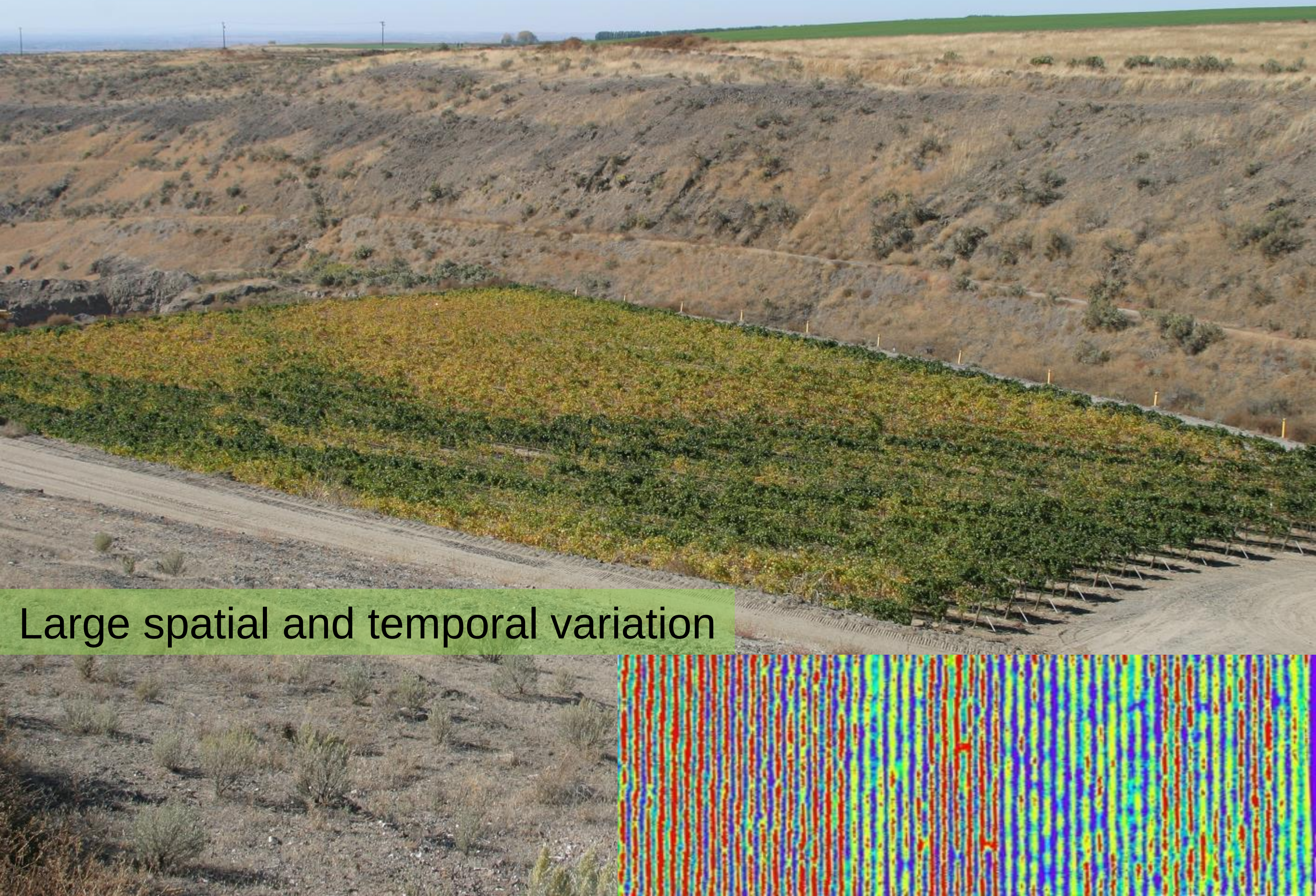
WASHINGTON STATE UNIVERSITY

Viticulture and Enology

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?

Cabernet Sauvignon

Normal ripening
25 °Brix
1-2 seeds/berry
25 mg/seed
34% seed germination

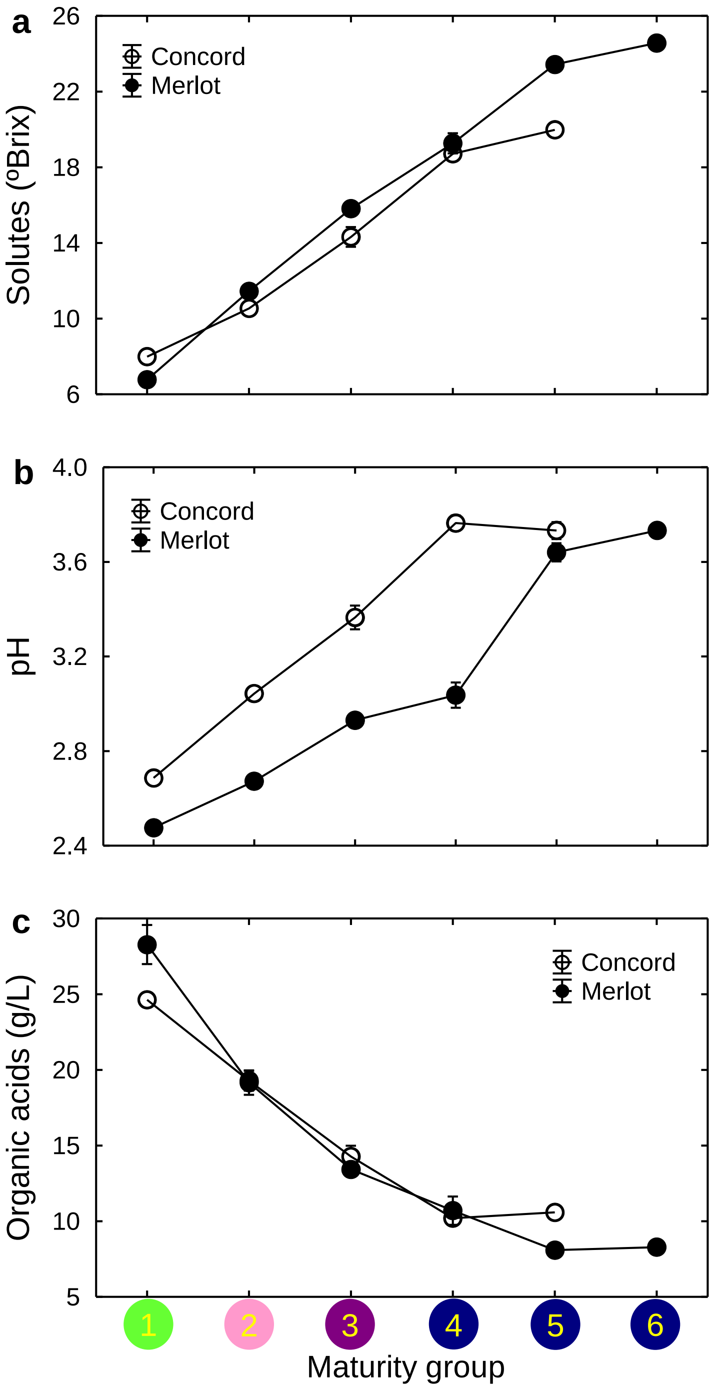
Berry shrivel disorder
14 °Brix
1-2 seeds/berry
22 mg/seed
31% seed germination

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

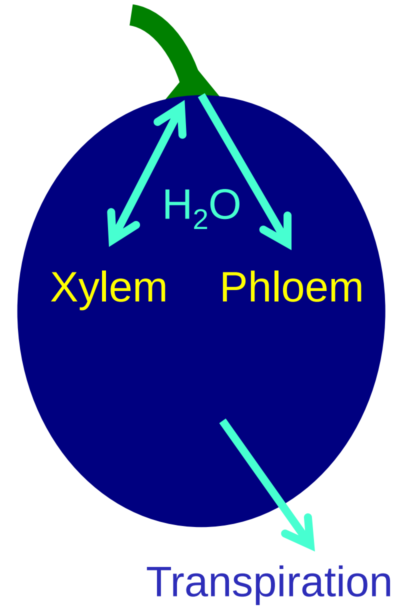


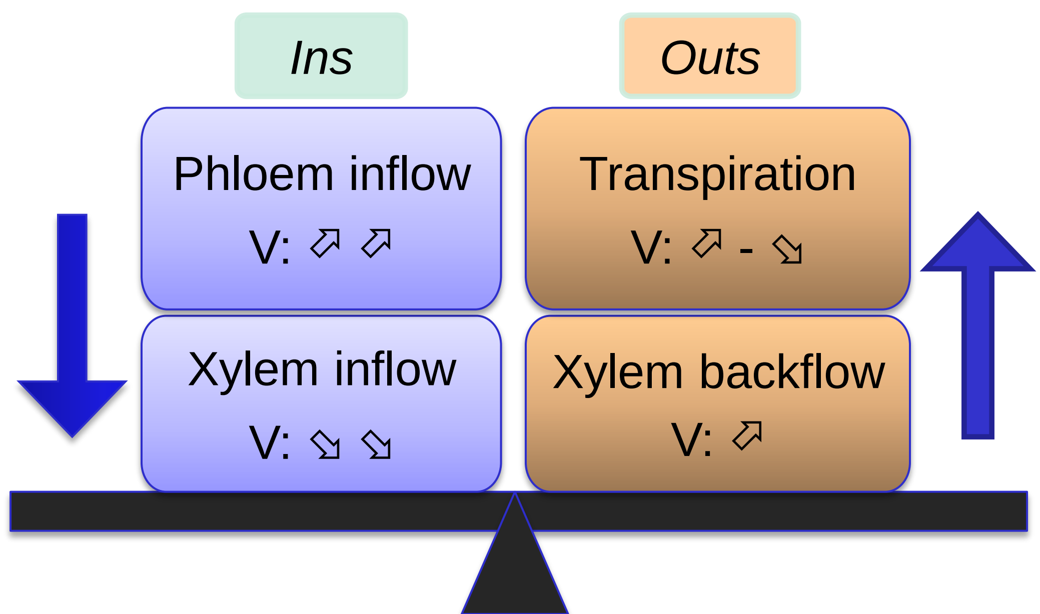
Keller & Shrestha (2014)

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

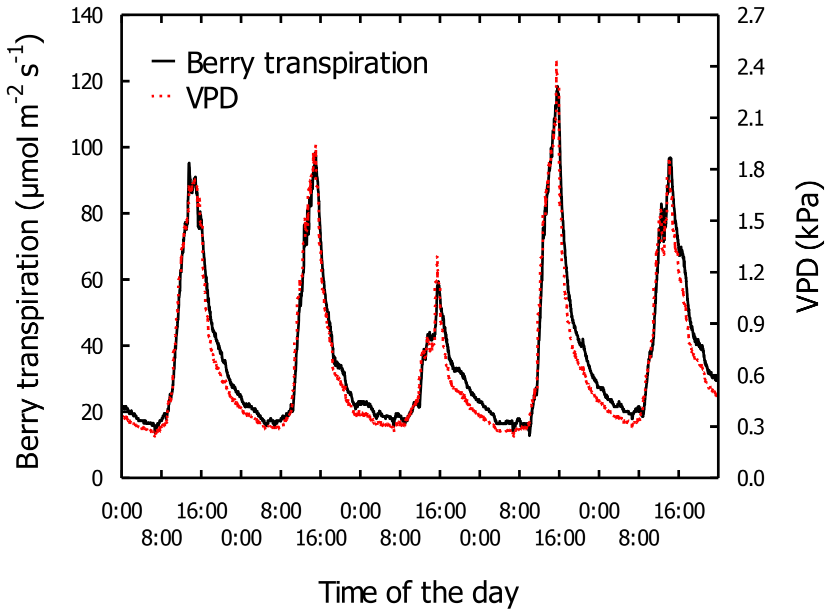
→ Phloem pressure release ⬂

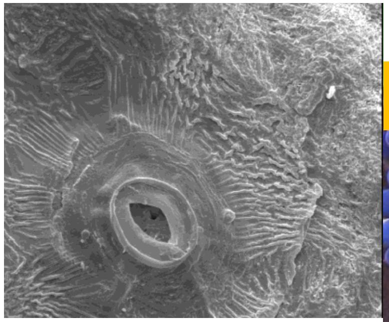
→ Phloem unloading ⬂

→ Sugar accumulation ⬂

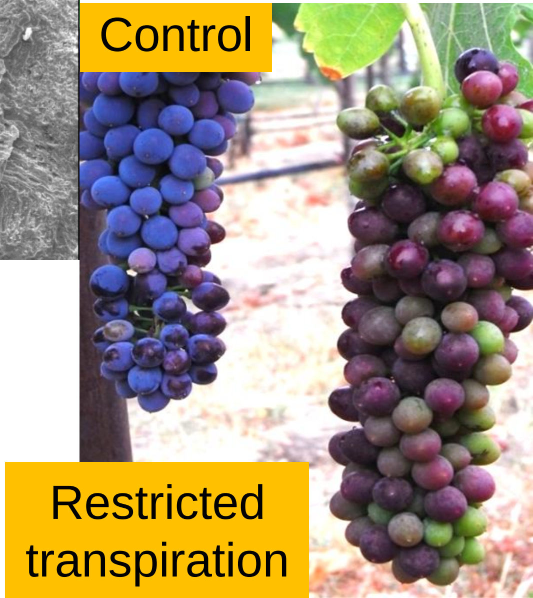
→ Anthocyanin accumulation ⬂

- Low VPD (low temperature, high humidity) → Slow ripening

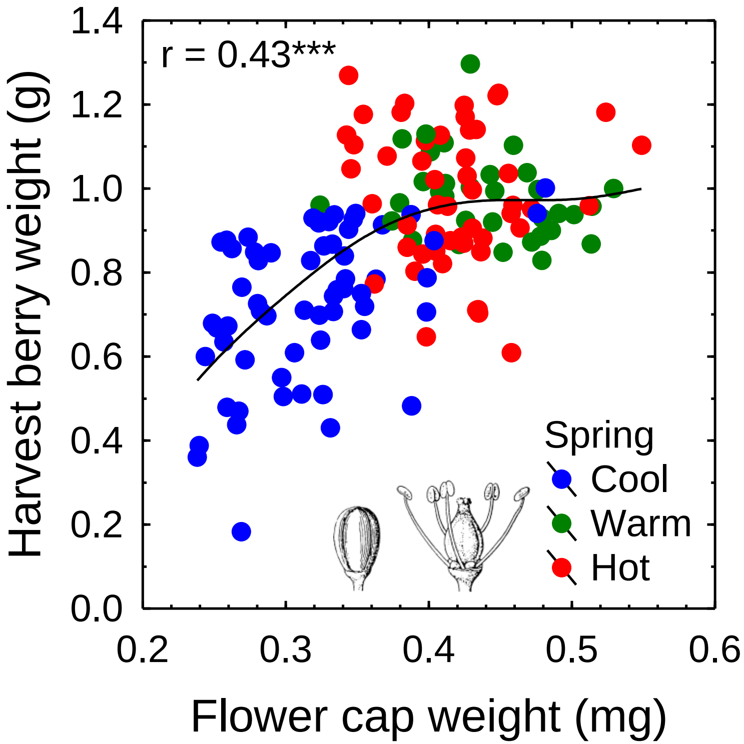


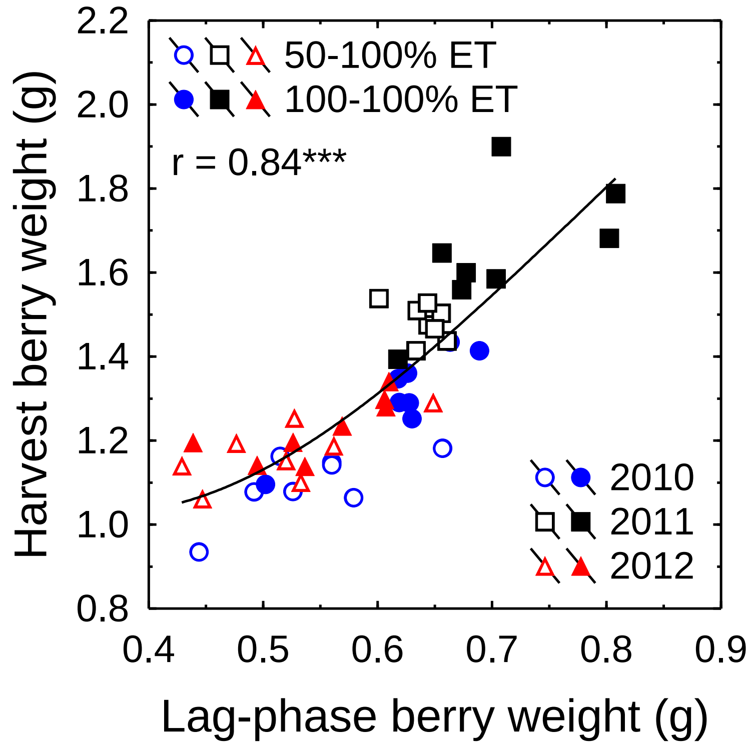


Zhang & Keller (2015)



Temperature and water limit berry size



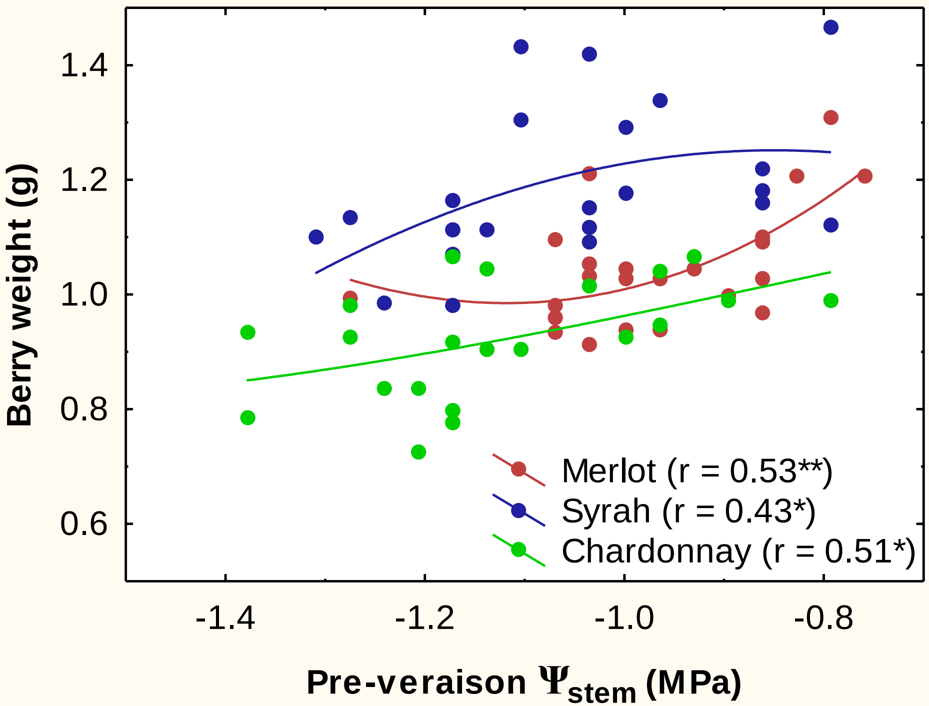


- Berry size is determined early → It is difficult to manipulate berry weight after véraison
- Cool spring temperatures → Small flowers → Small berries
- Water deficit <u>before</u> véraison → Small berries

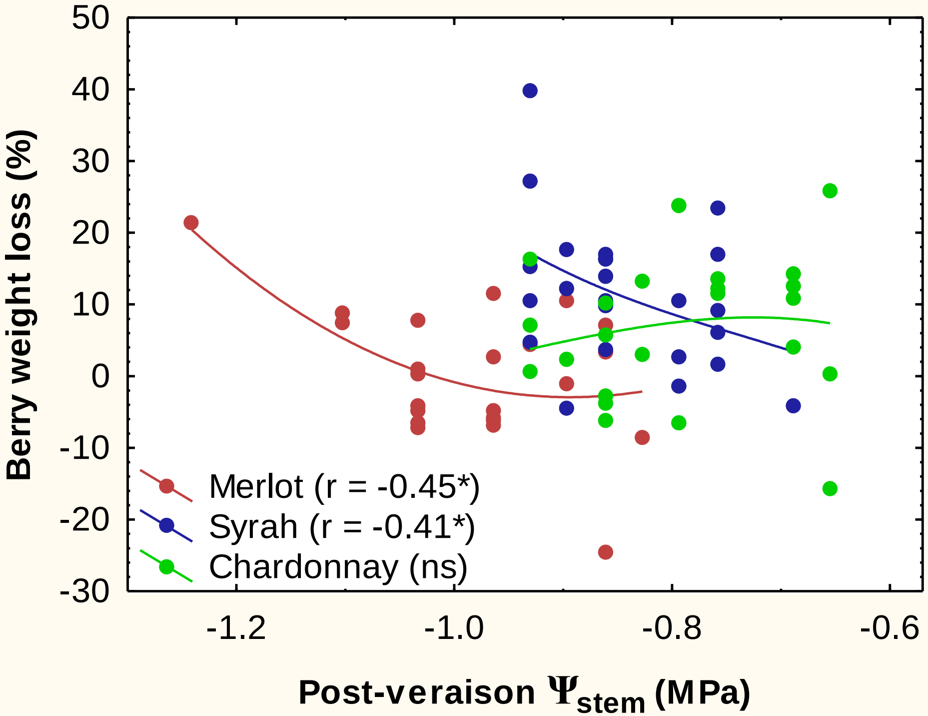
Keller et al. (2010)

Keller (2015)

Diluting fruit quality – really?



More water **before** véraison increases berry size

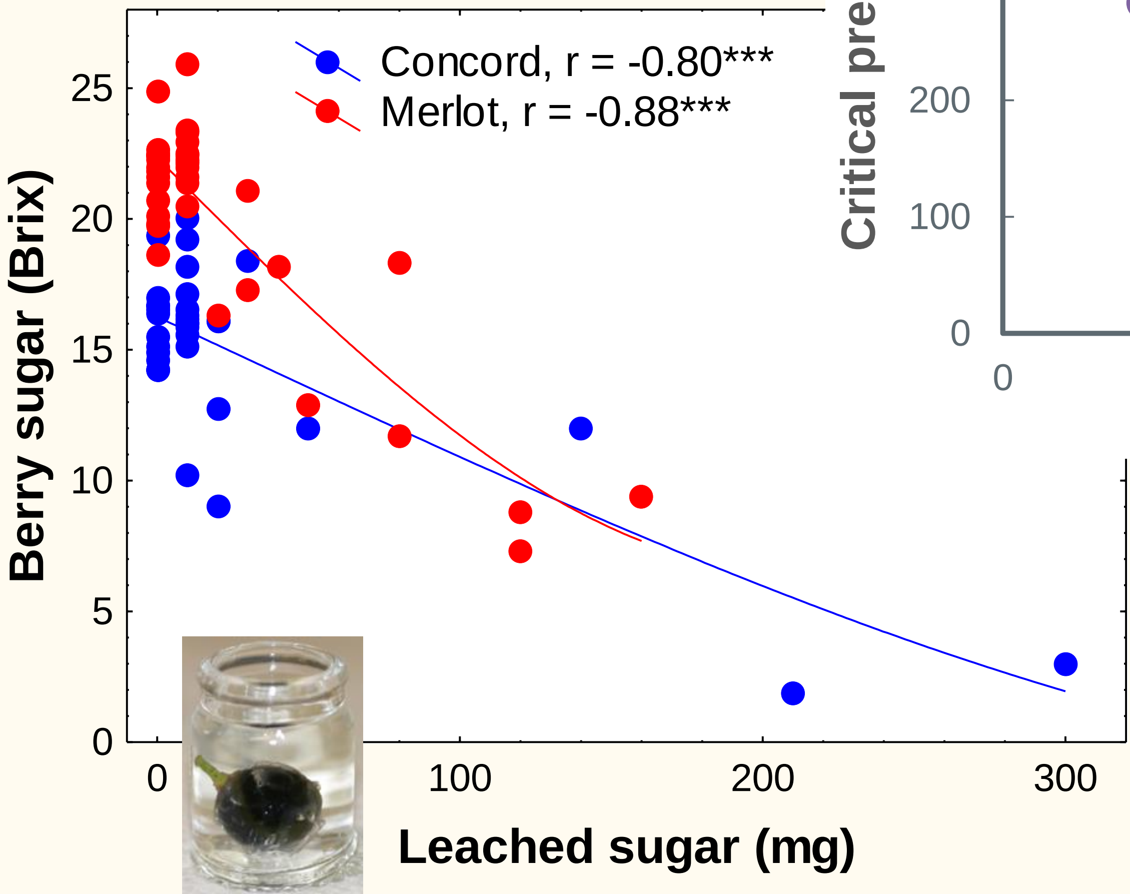


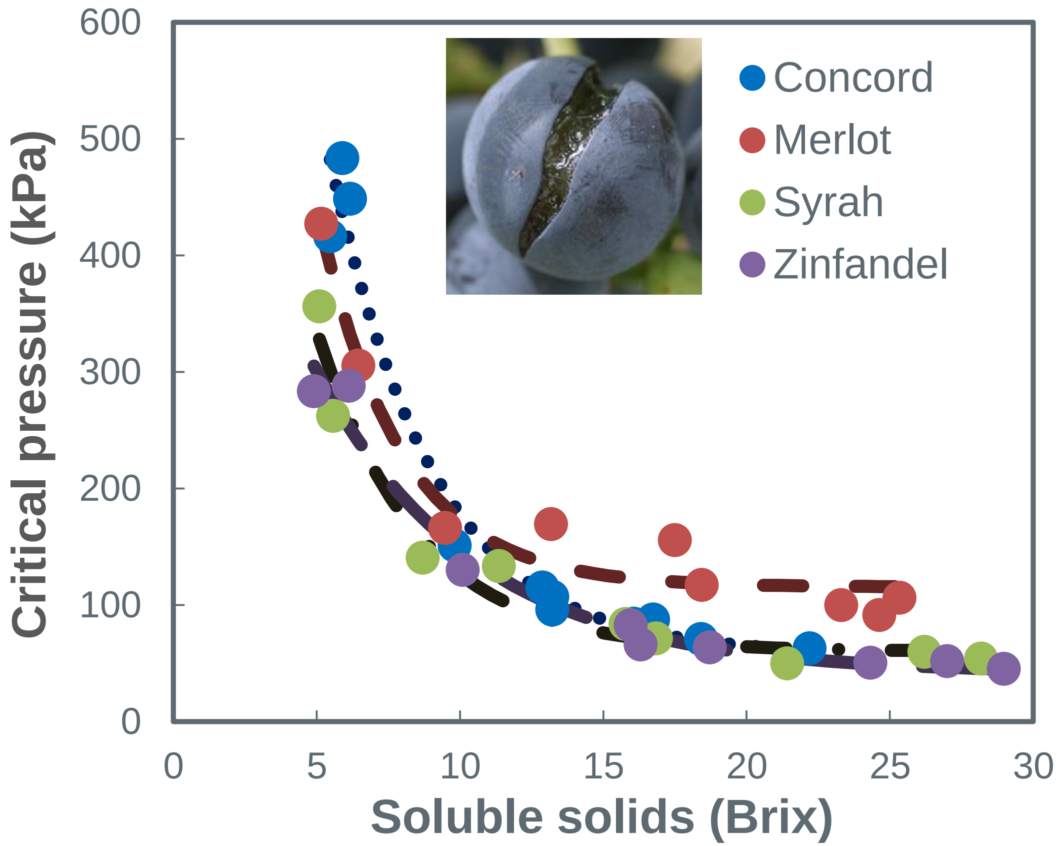
More water **after** véraison decreases berry shrinkage

-5% weight → +1 °Brix

Rainfall: Berry splitting (cracking)

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

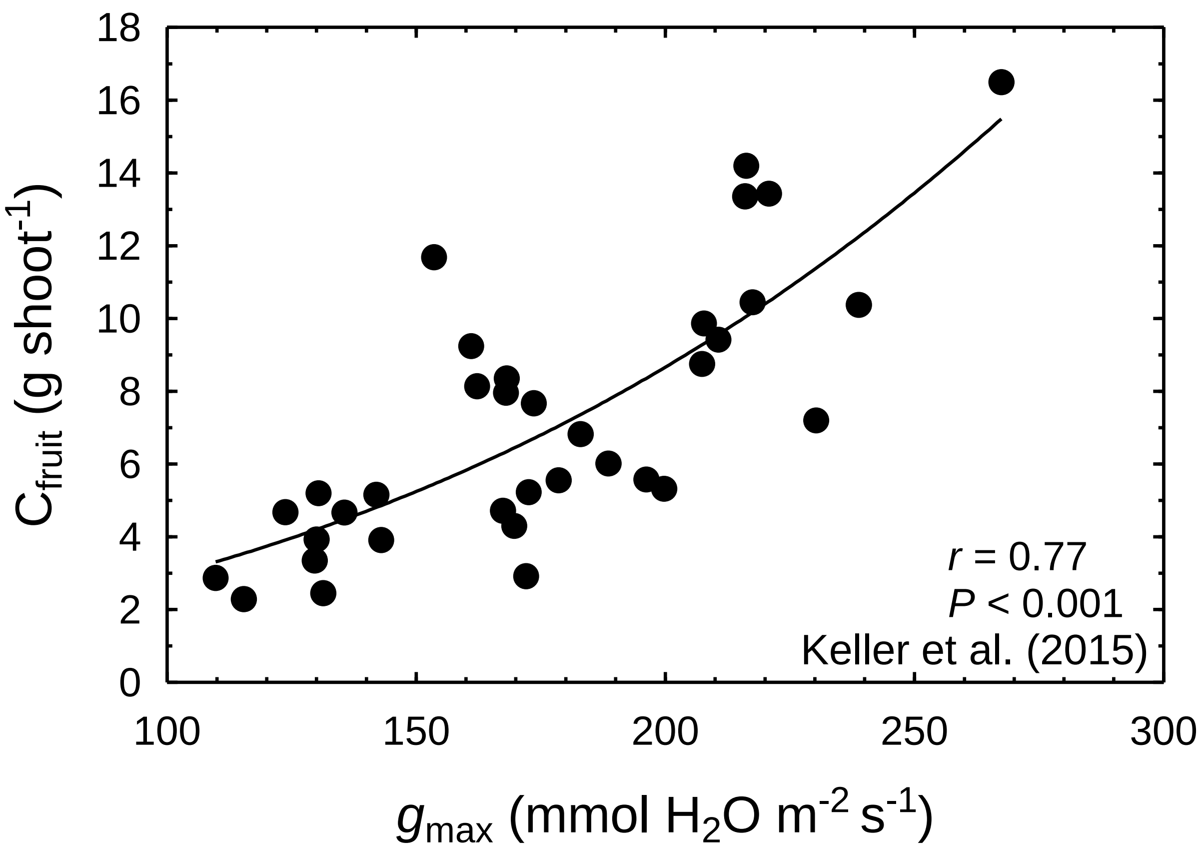




Splitting due to:

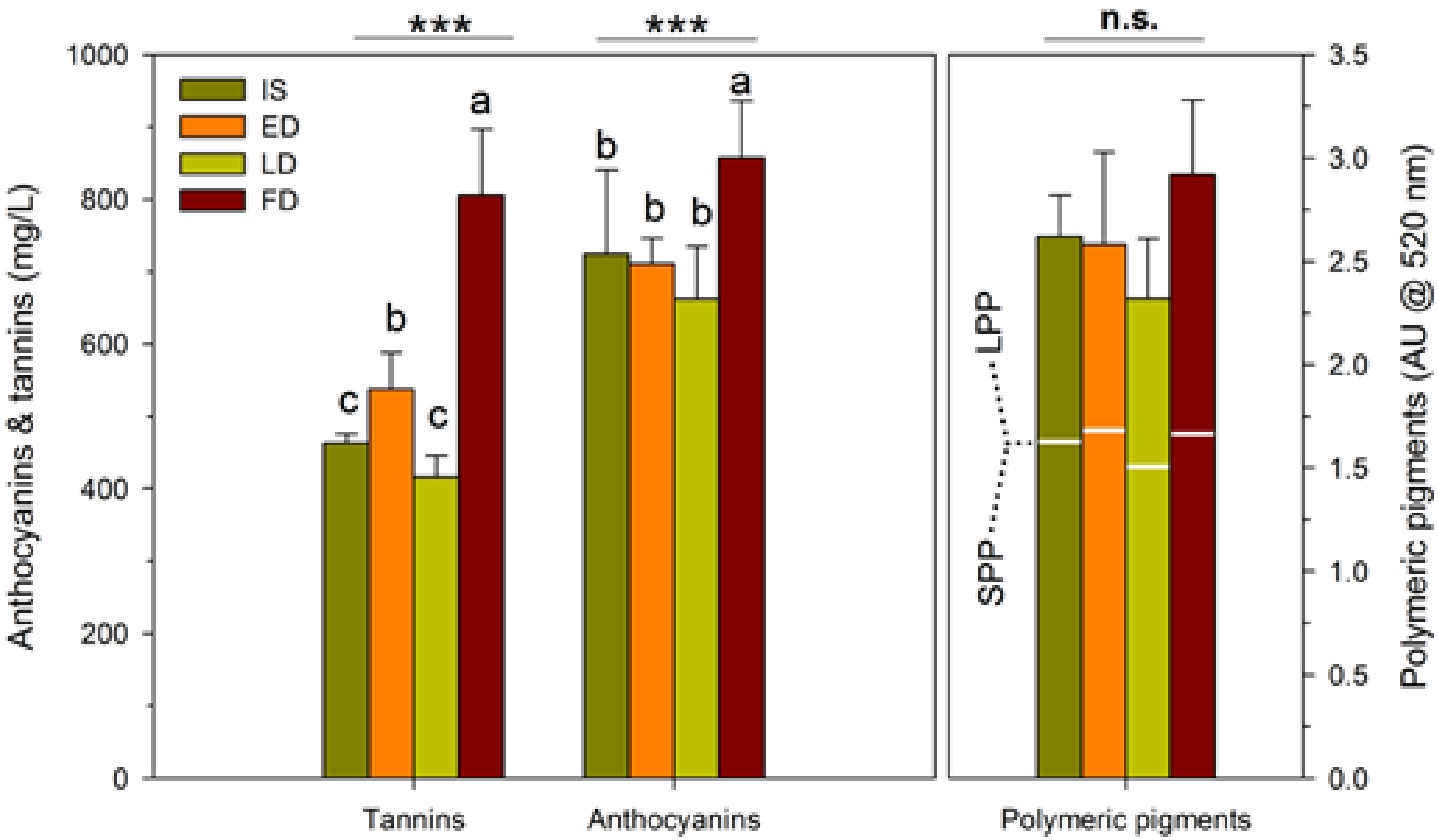
- Rainfall
- Sprinkler irrigation
- High humidity
- Preveraison drought

Water deficit impacts berry development



- Water deficit → g_s ⬂ → Pn ⬂ → C partitioned to fruit ⬂
- Water deficit <u>before</u> véraison → Smaller berries → Skin:juice ⬀
- Stimulation of anthocyanin biosynthesis (sugar + ABA)
- Water deficit <u>after</u> véraison → Less sugar, berry shrinkage

Wine and water deficit: Timing matters

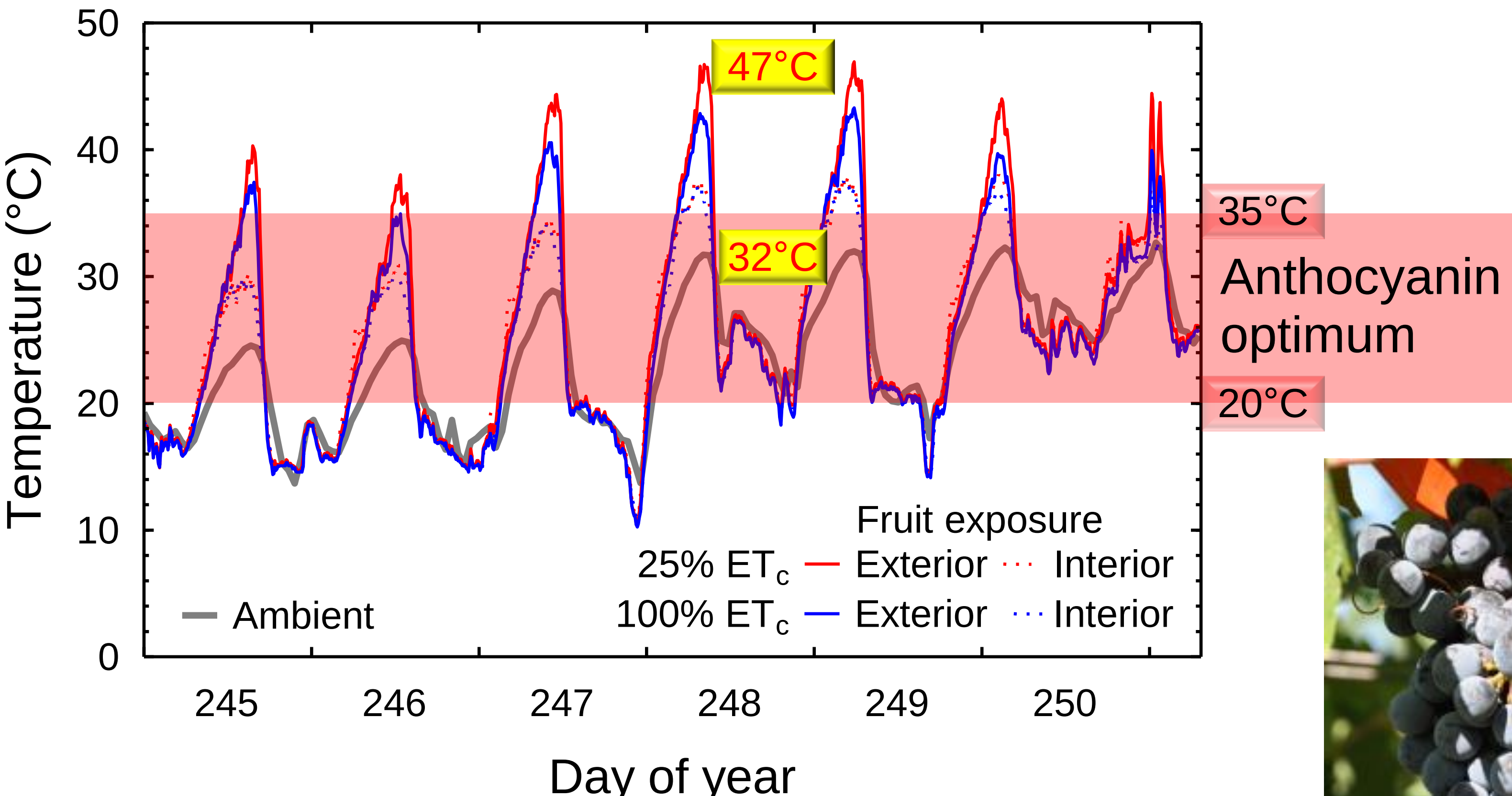


- Tannin variation due to water and weather; anthocyanin variation dominated by weather (more in cool vintage, less in warm vintage)
- Full-season deficit → Higher anthocyanins and tannins → More LPP
- Prevéraison deficit → Intermediate tannins
- Postvéraison deficit → No gain

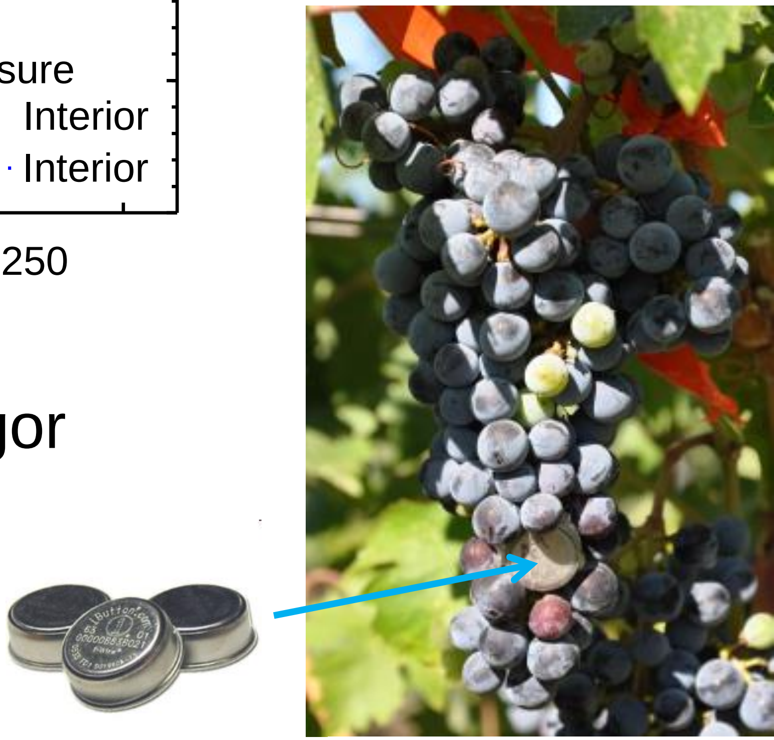
→ Dehydration does not make berries more mature

Casassa et al. (2015)

Water deficit: It's not just about berry size

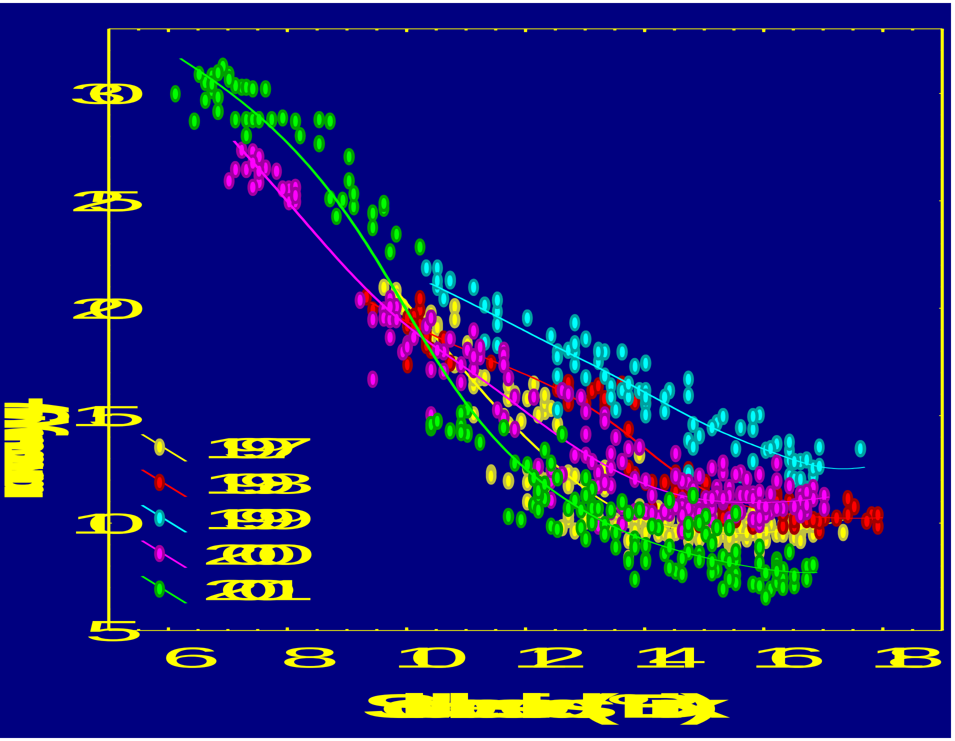


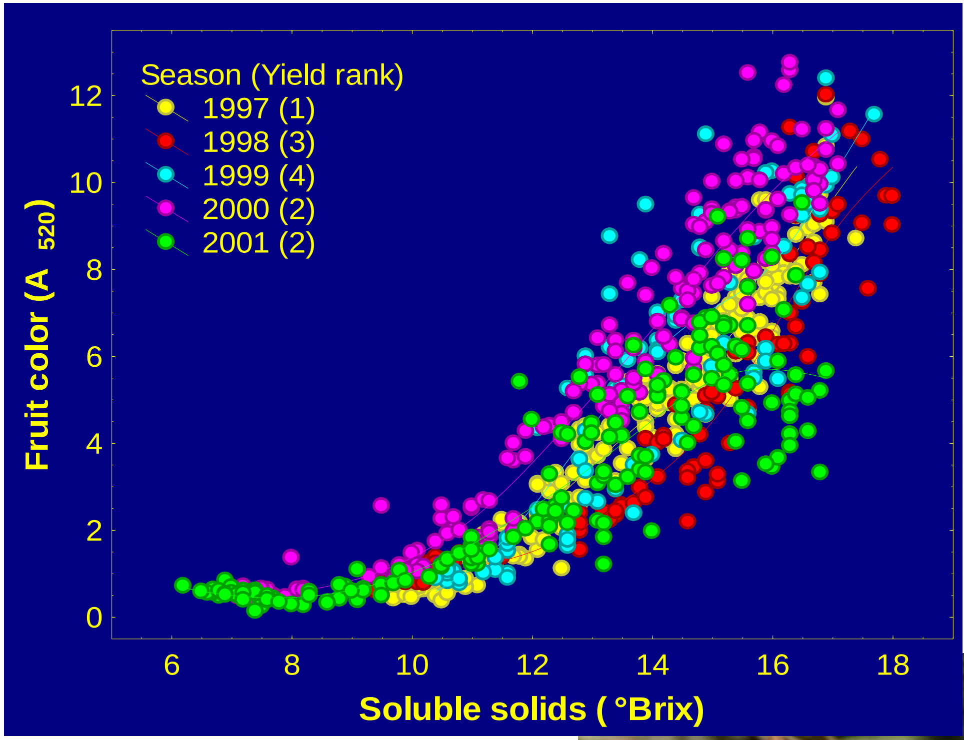
- Water deficit → Small berries, low vigor
  - → Open canopy, restricted shoot growth
  - → High cluster sun-exposure
  - → High light and high temperature
- Exposed berries are warm berries



Keller et al. (2016)

Weather causes vintage variation

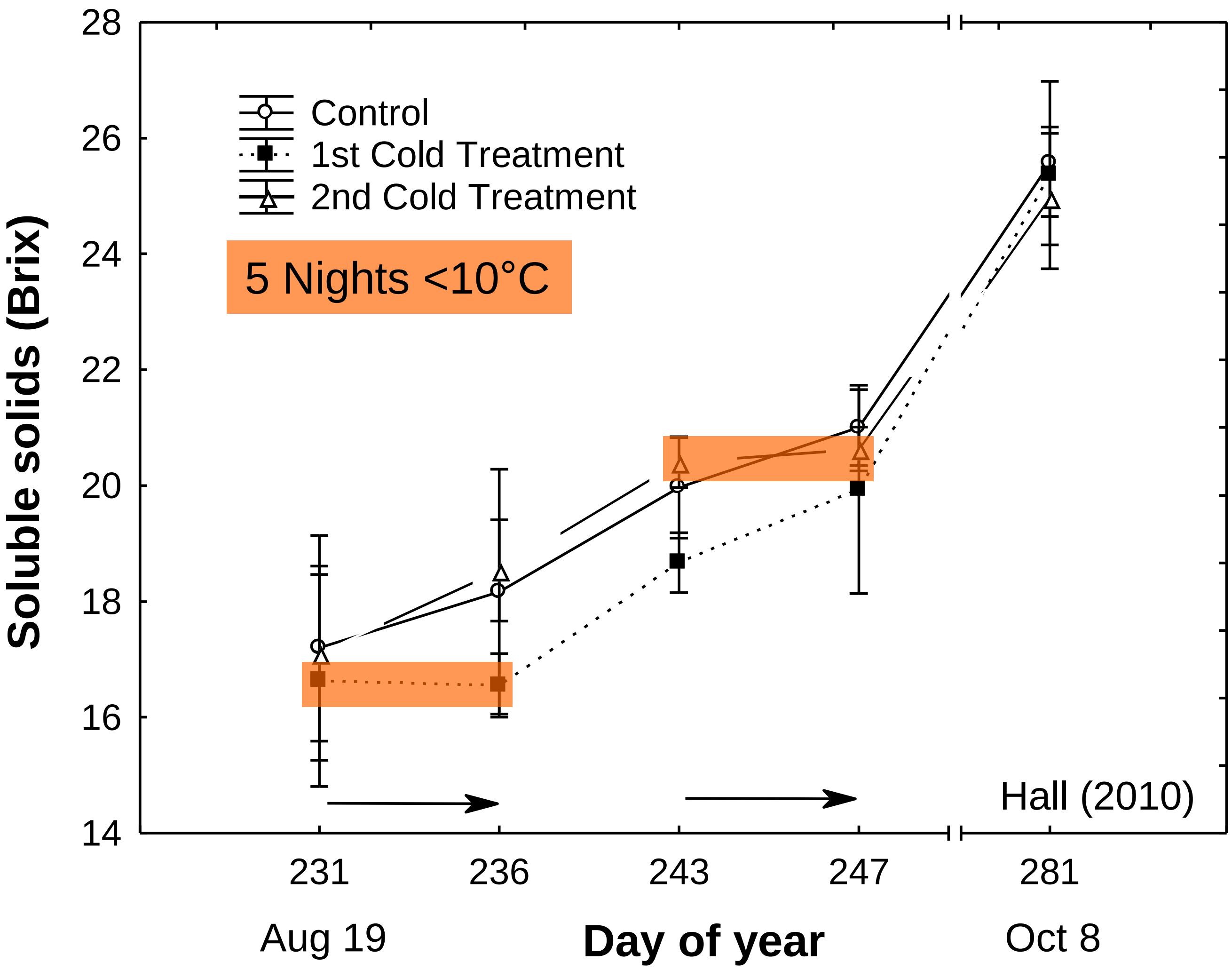




- Climate variation and vineyard location: By far the strongest determinants of fruit composition
- Acidity and color vary >2-fold, aroma volatiles >10-fold at similar Brix level and yield
- Temperature trumps soil moisture and crop load

Keller et al. (2004, 2005)

Temperature limits fruit ripening



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

Temperature: West Side Story

Disentangling the light from the heat

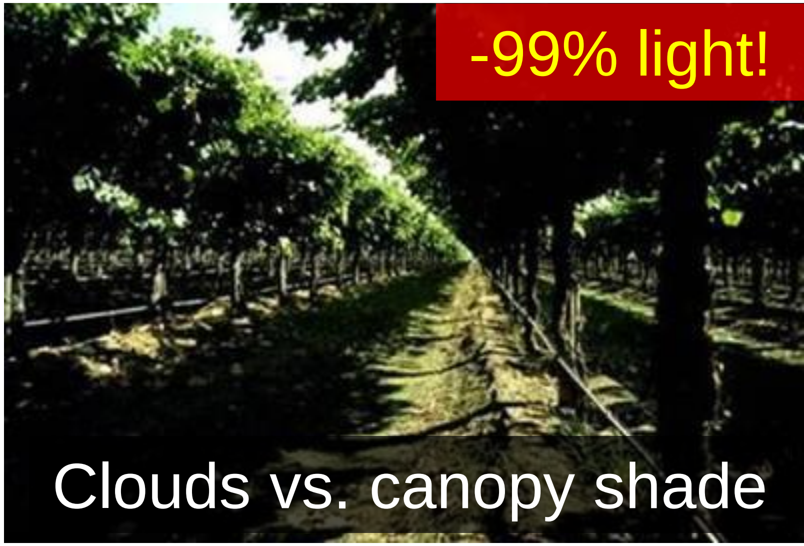
- Photosynthesis ⬀-⬂
- Sugar (⬀-⬂) (20-30°C)
- Acids: Tartrate (⬀?)
  - Malate ⬂⬂
- K^+ ⬀

} pH (?)

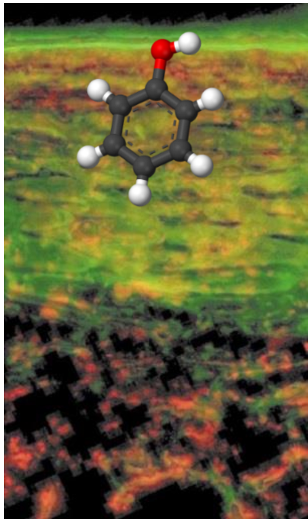
- Amino acids (proline, arginine) ⬀
- Phenolics: Anthocyanins ⬀-⬂ (days: 30-35°C)
  - Tannins (⬀?)
- Volatiles (?): Methoxypyrazines ⬂
- Sunburn: >42°C + UV/visible light

partly from Spayd et al. (2002)

Light: Visible and UnVisible

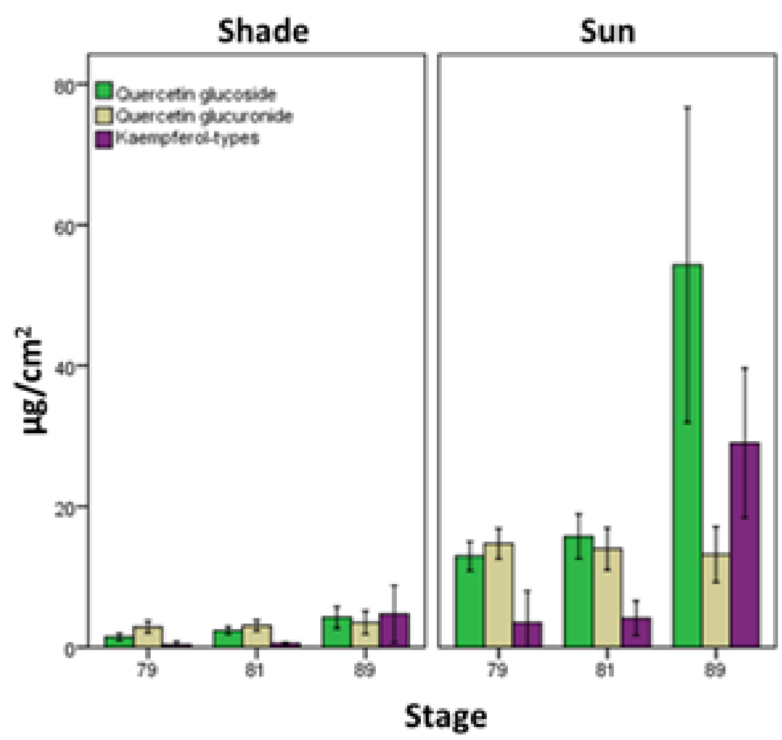


- Photosynthesis ⬀-⬂
- Sugar ⬀
- Acids: Tartrate (⬀)
  Malate ⬂ } pH (?)
- K^+ ⬂(?)
- Amino acids (arginine ⬂), N ⬀
- Phenolics: Anthocyanins (color) ⬀ (visible >100 µmol $m^{-2}s^{-1}$)
  Flavonols (color cofactors) ⬀⬀ (UV-B)
  Cinnamic acids (lignin, Brett…) ⬀ (visible)
  Tannins (astringency) ⬀ (visible?)
- Volatiles: Norisoprenoids, monoterpenes… ⬀
  Methoxypyrazines ⬂
- Wine sensory properties ⬀-⬂

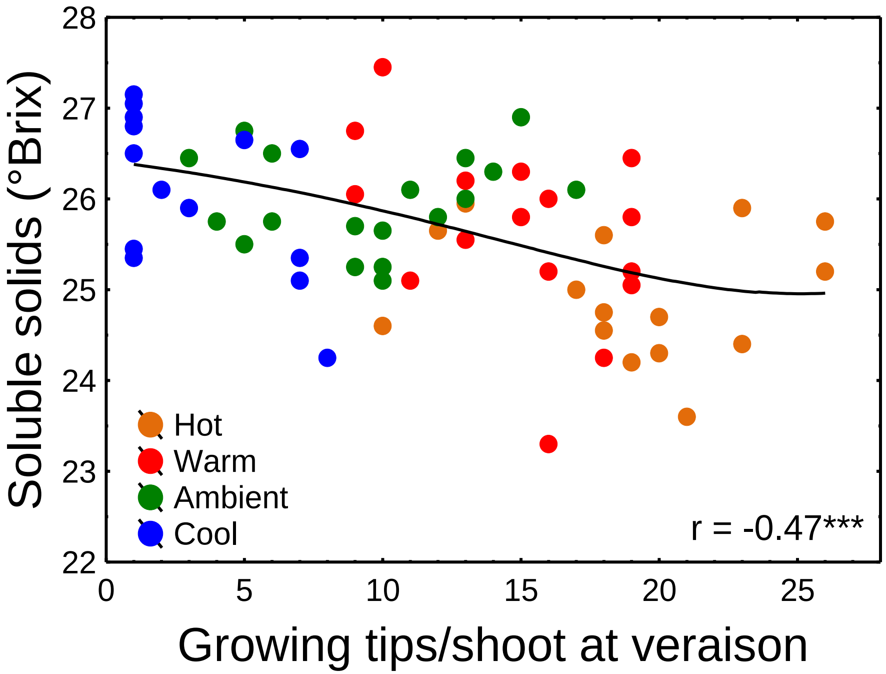


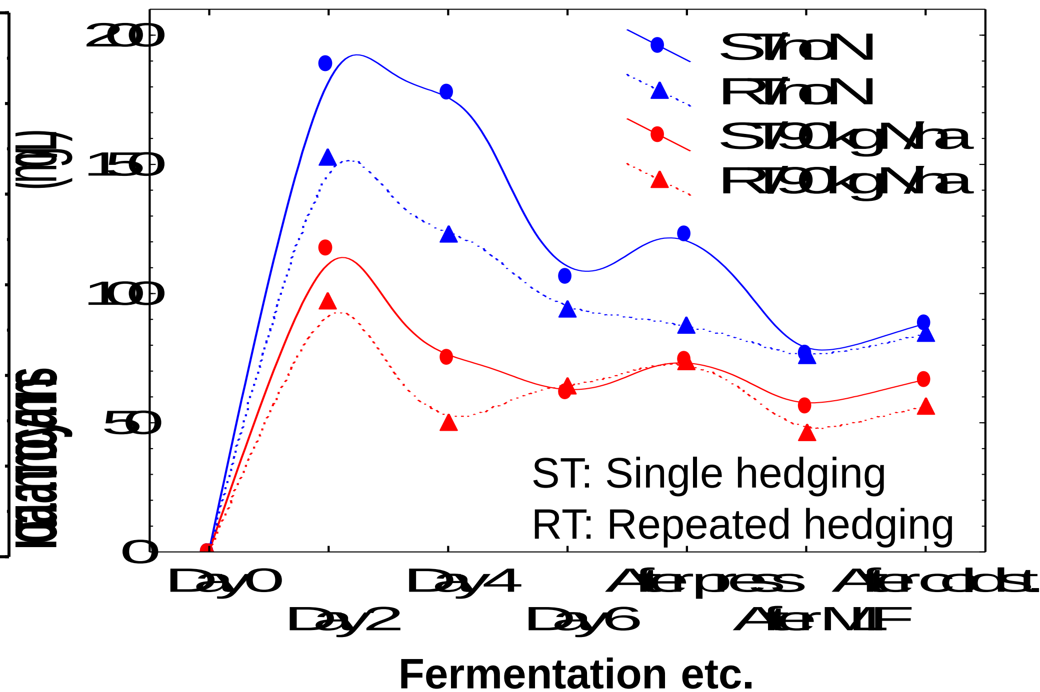
Sun exposure: More is better?

- Sun-exposed berries: More UV light + heating (+15ºC)
- **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

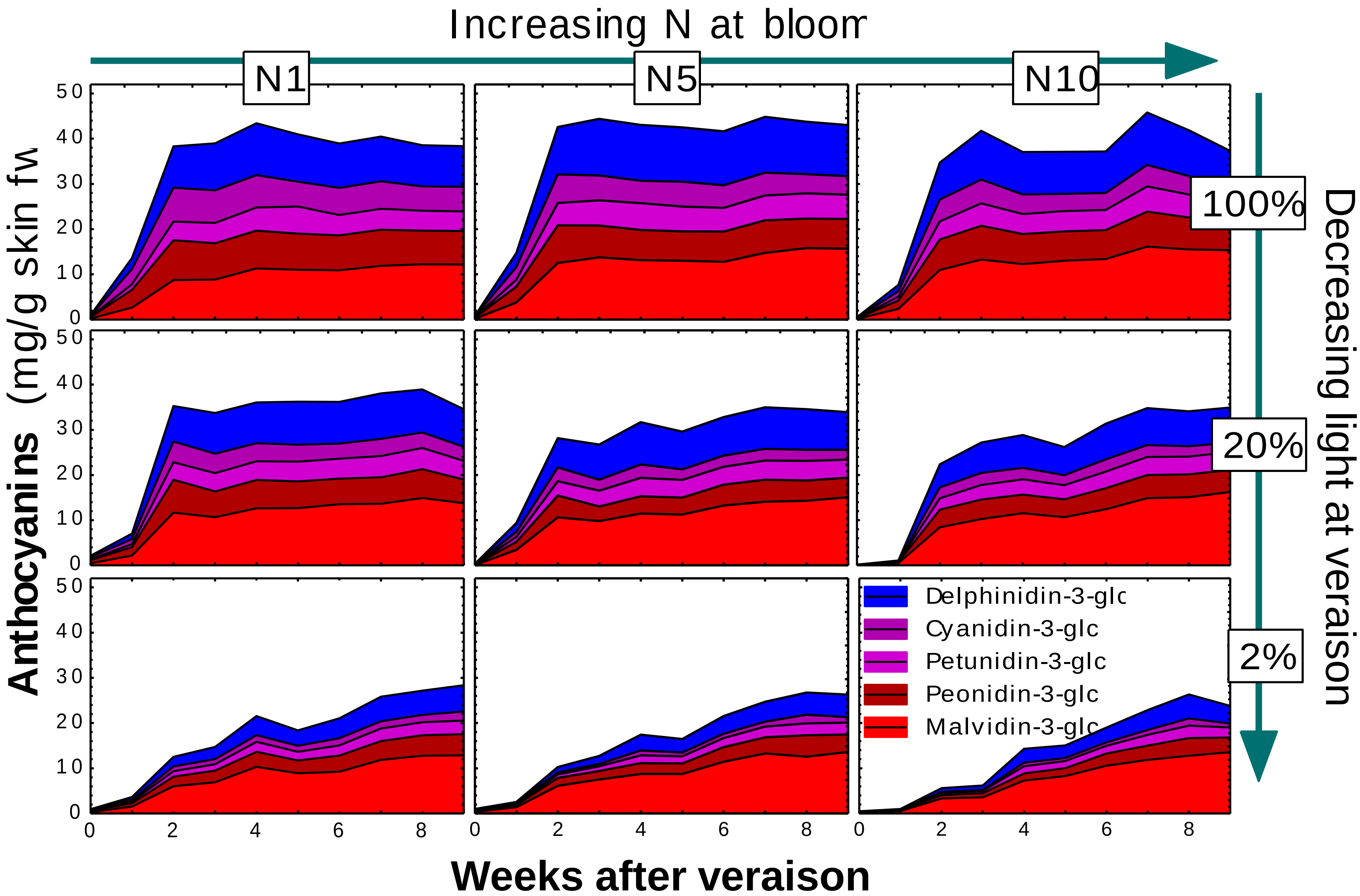




Keller et al. (1999, 2001, 2010)

- More N → Higher yield, more lateral growth, denser canopy
- Growing shoot tips compete with fruit → 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)

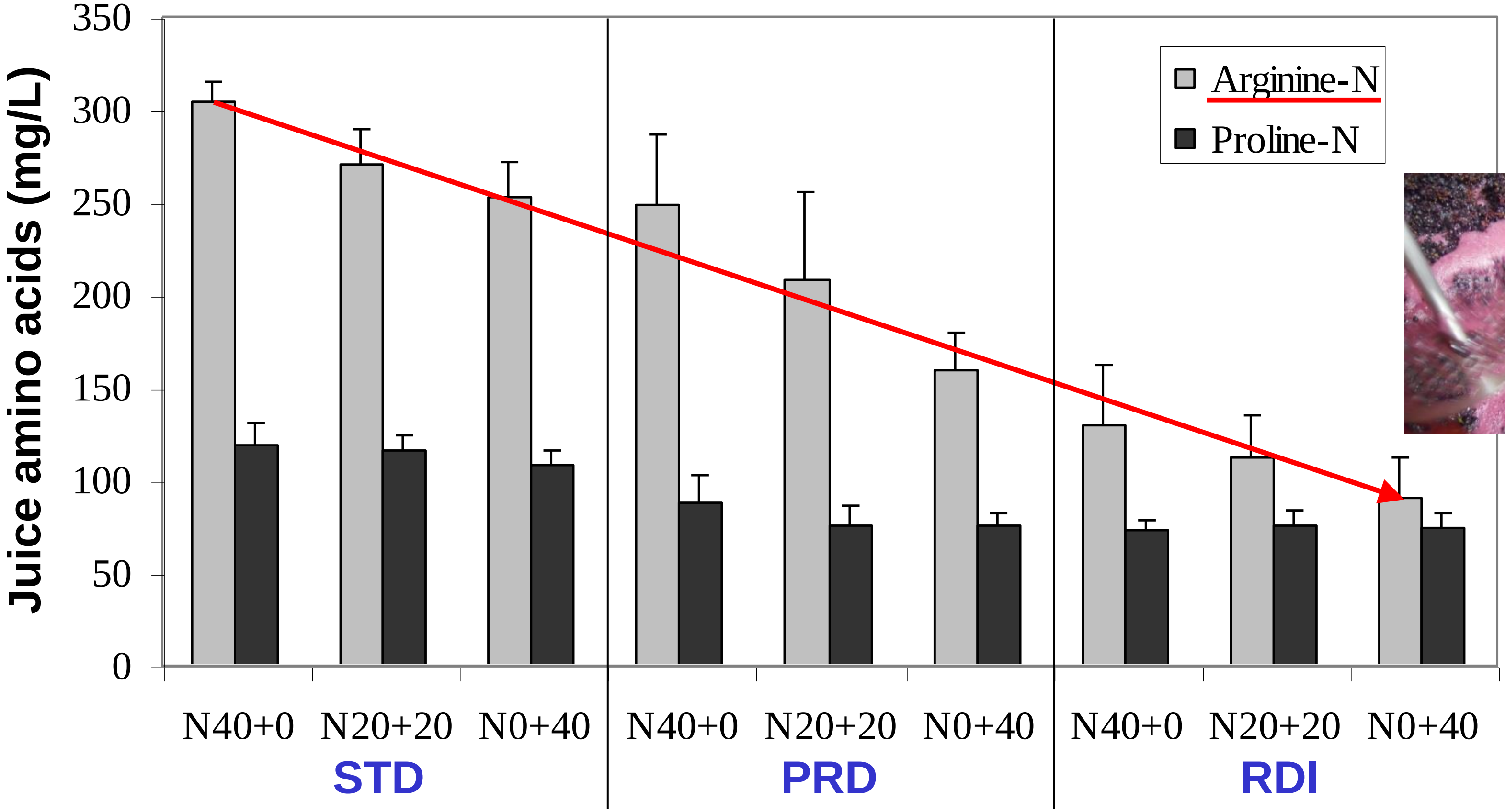
Nitrogen: Interaction with light



Light drives anthocyanin accumulation, but N modulates it

Keller & Hrazdina (1998)

Nitrogen: Yeast cannot live by sugar alone

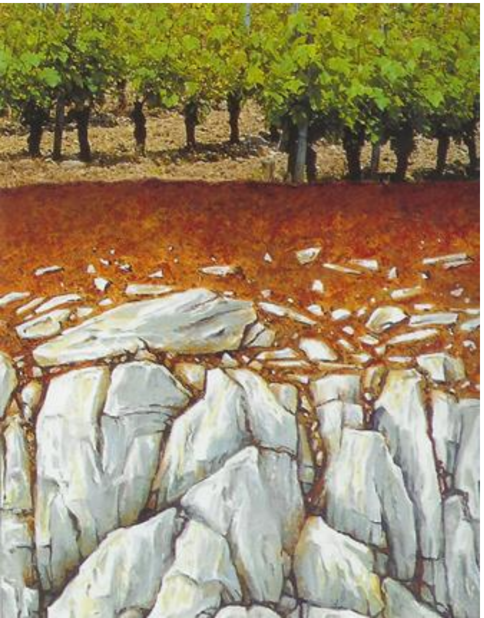


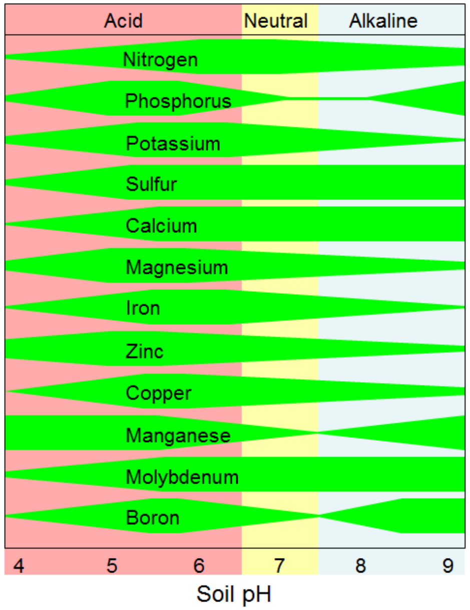
- Proline and PR proteins accumulate during ripening
- Water deficit → N deficit → Risk of stuck fermentation → H_2S
- N deficit → High phenolics but low aroma precursors

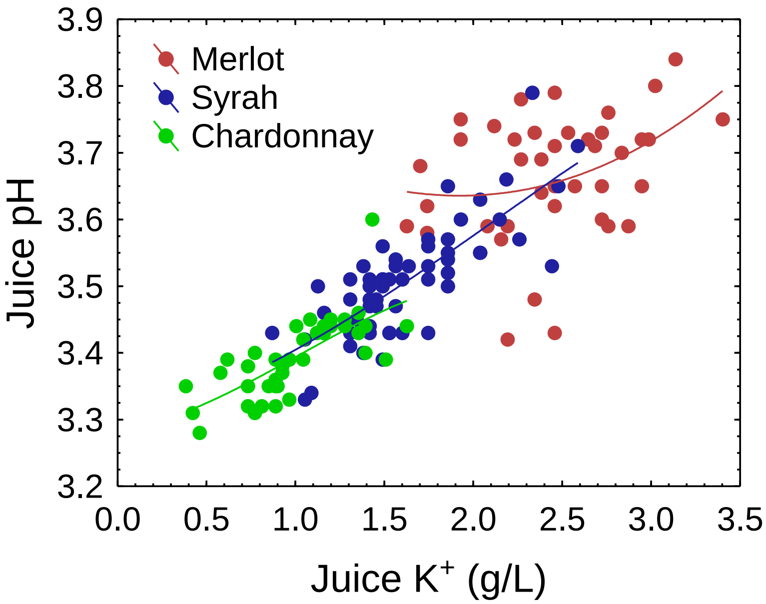
Wade et al. (2004)

Potassium and the pH conundrum

- Metal cations (K^+, Na^+), may counter the influence of organic acids by substituting for H^+ → Juice pH ⬀
- Variation in juice pH is driven by variation in both TA and K^+
- Late harvest → TA ⬂, K^+ ⬀ → pH ⬀
- Crop load ⬂ → K^+ ⬀ (phloem import) → pH ⬀
- Juice pH is not very responsive to soil K^+ (→ Malate ⬀)
- Ca^{2+} and K^+ compete for root uptake: Soil pH ⬀ → Juice pH ⬂







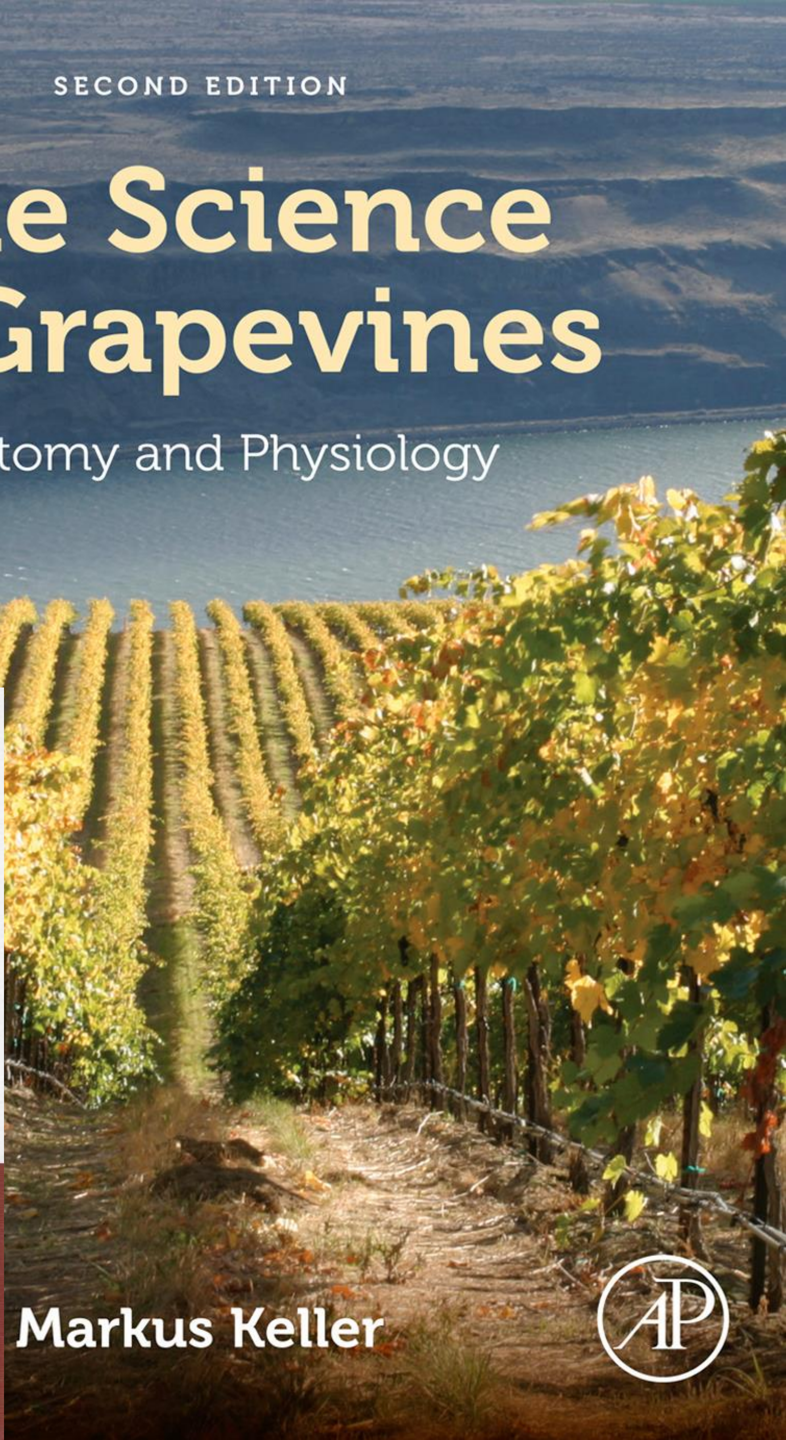
It’s in the book

Second Edition

2015

Academic Press (Elsevier)

Amazon



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