Responses to Smoke-Taint and Abiotic Stress in Vineyards

Water, Heat, and Smoke

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Vineyard Health

- 'Health' – the state of being **free** from illness or injury

Vineyard Health

- 'Health' – the state of being **free** from illness or injury
- No way to be **totally free** of health-limiting factors
- The next best option is to look for preventative options

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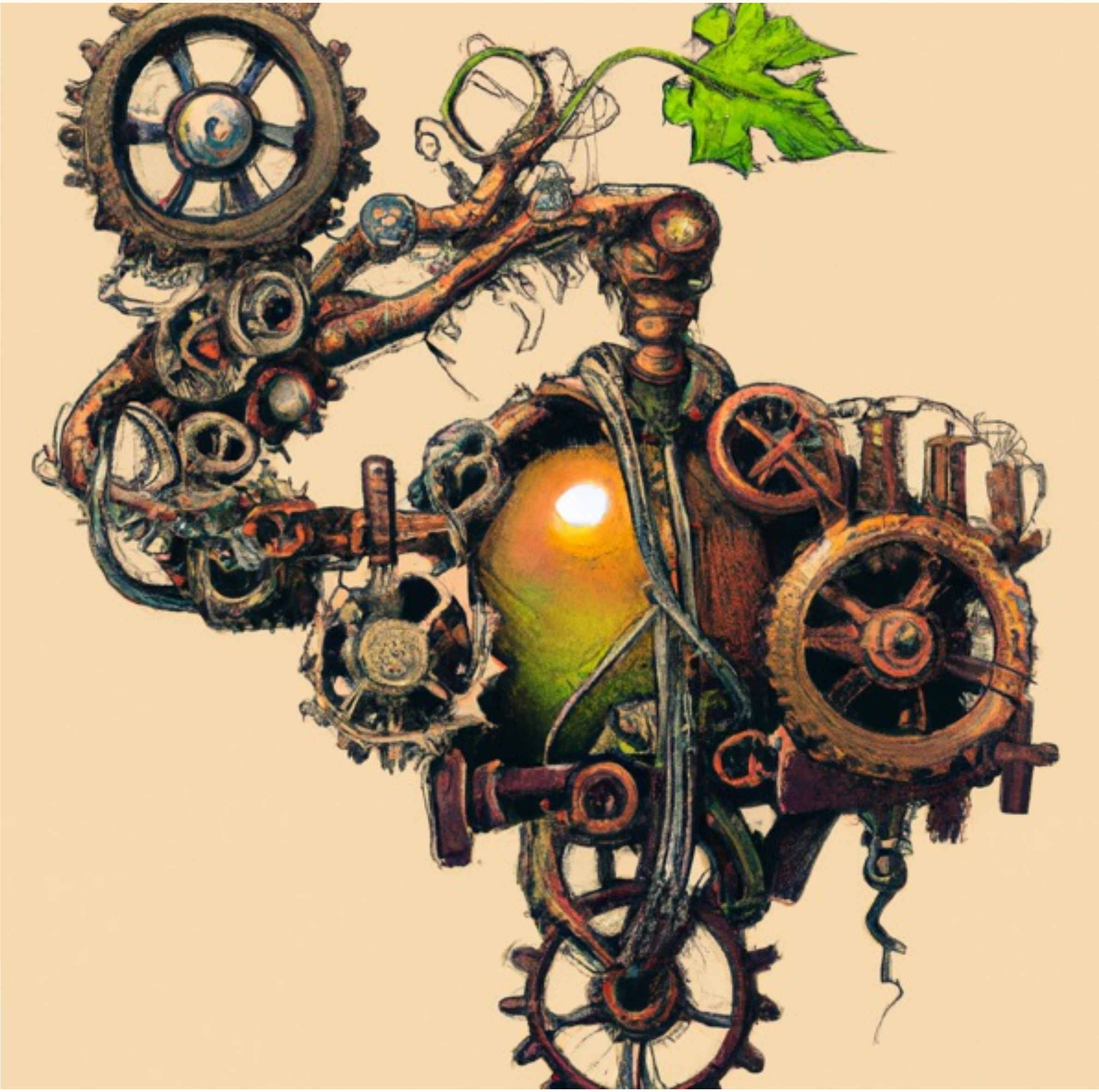
Vineyard Health

- **Vine Function ≈ Vine Health**

- Important Vine Functions
  i. Photosynthesis
  ii. Vascular system
  iii. Reproductive efficacy
  iv. Physical support



Vineyard Health

- **Photosynthesis**
  - Source = Leaves
  - Rate = Vigor & canopy size
  - Dependencies
    1. Resource availability
    2. Vascular function
    3. Minimal stressors
    4. Light availability

Photosynthesis

Requirements for Photosynthesis

- 'Clean' leaf surfaces
- Open stomata
- Light (Solar radiation)
- Water
- CO_2

Photosynthesis under Drought-Conditions

Requirements for Photosynthesis

- ‘Clean’ leaf surfaces
- ~~Open stomata~~
- Light (Solar radiation)
- ~~Water~~
- ~~CO_2~~

Photosynthesis under Heat-Conditions

Requirements for Photosynthesis

- 'Clean' leaf surfaces
- ~~Open stomata~~
- Light (too much)
- Water (maybe)
- CO_2

Photosynthesis under Smoke-Conditions

Requirements for Photosynthesis

- ~~'Clean' leaf surfaces~~
- ~~Open stomata~~
- ~~Light (Solar radiation)~~
- Water
- CO_2

Climate Concerns

- Global average temperatures have risen by at least 3 °F since the start of the 20th century
- Drought persists in the West Coast
- Extreme weather events have become more frequent
- Fire events are of primary concern

Changing Climates

- Climates are changing and impacting the factors that affect vine health.

  i. Temperatures
     - Affects all aspects of vine health

  ii. Precipitation
     - Affects all aspects of vine health

  iii. Extreme weather events
     - Heatwaves, fire, and late frost events
     - Impacts photosynthesis and reproduction

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Changing Climates

Temperatures

- Impact all living things
- Alter physiology
- Ideal range differs by species
- Range differs by cultivar too

Changing Climates

Precipitation

- Mediterranean climates with unique precipitation patterns
- Changing with the climate
- No precipitation in late-Summer
- Limits Summer diseases

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Changing Climates

Extreme weather events

- Impacts dependent on microclimates
- Existing infrastructure matters
  - Heatwaves
    - More damaging in coastal regions
  - Spring Frosts
    - More damaging inland
  - Wildfires
    - More damaging where not prepared

Heat and Drought Impacts on Grapevine Physiology

Changes in Phenological Timing

In Central Europe the impact of warming climates has been documented in Bernáth et al. 2022 (pre-print)

Between 1985 and 2018

➢ Budbreak:	5-7 days earlier
➢ Flowering:	7-10 days earlier
➢ Berry maturity:	18 days earlier
➢ Harvest:	8-10 days earlier

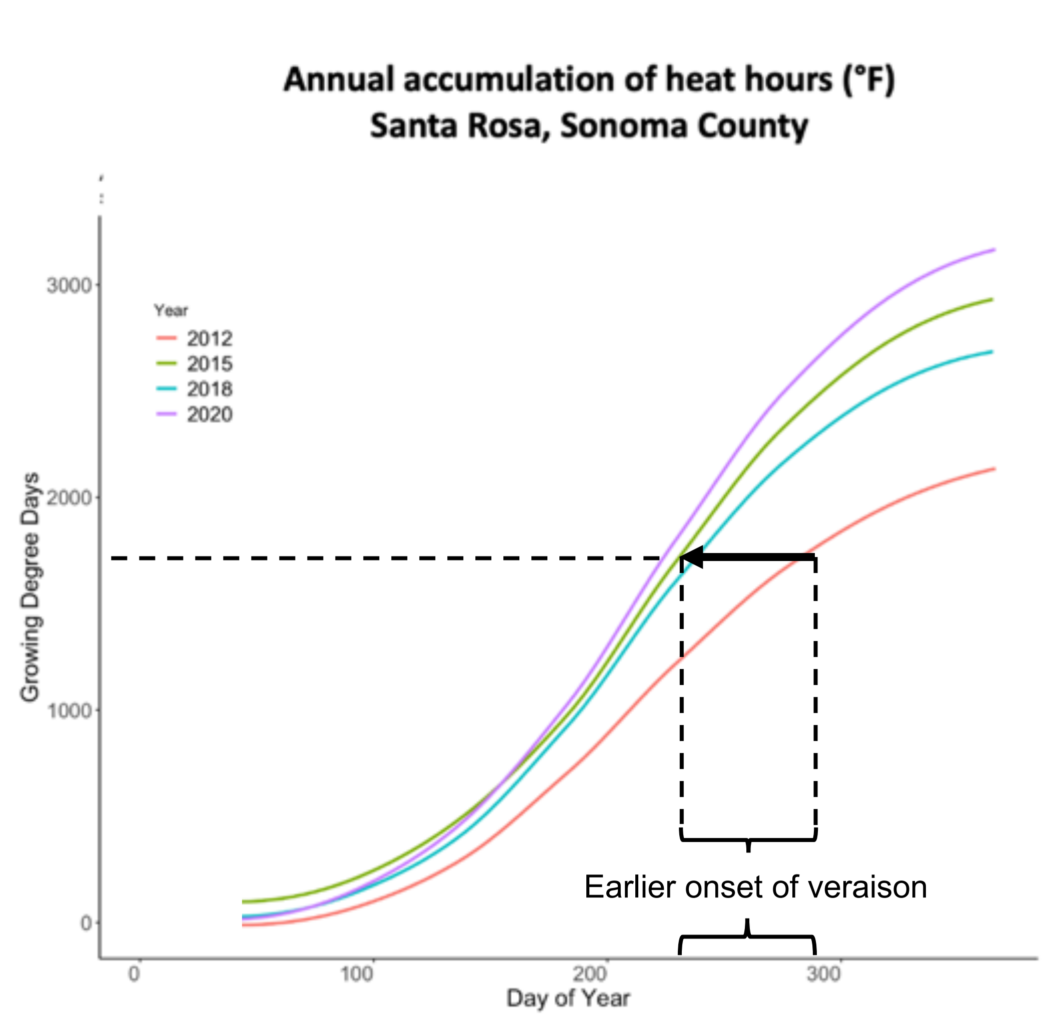
Increasing Temperatures

Temperatures rising

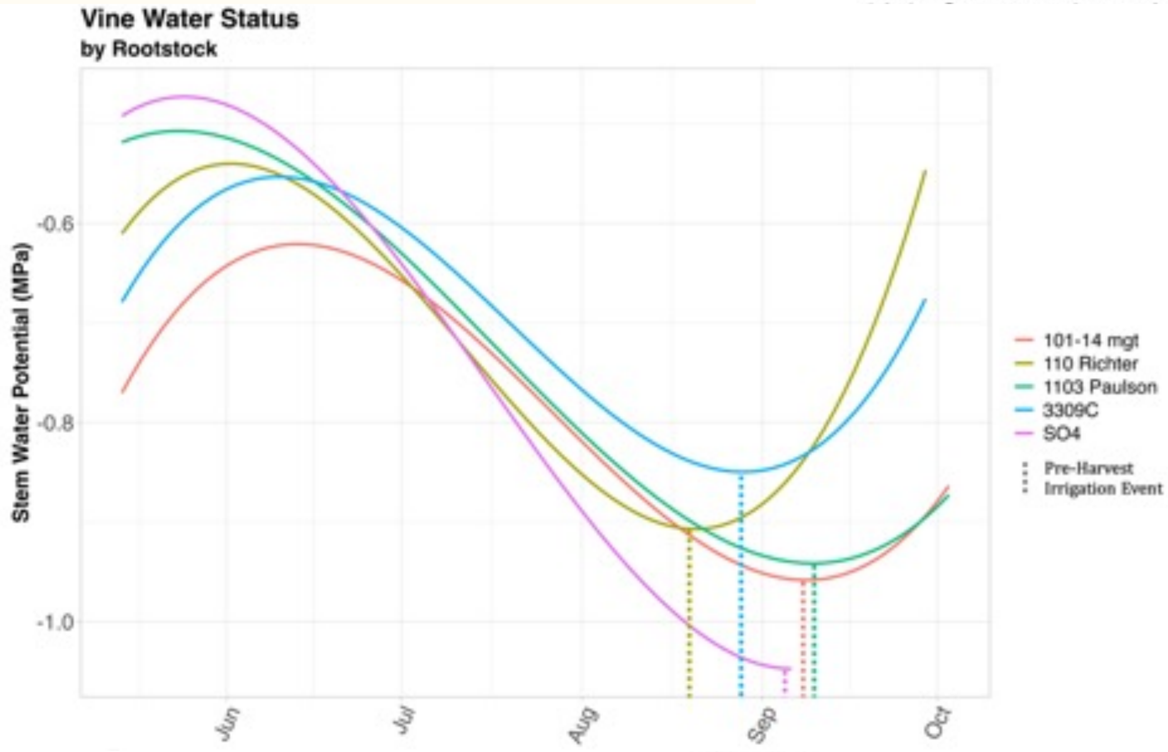
Total GDD increasing

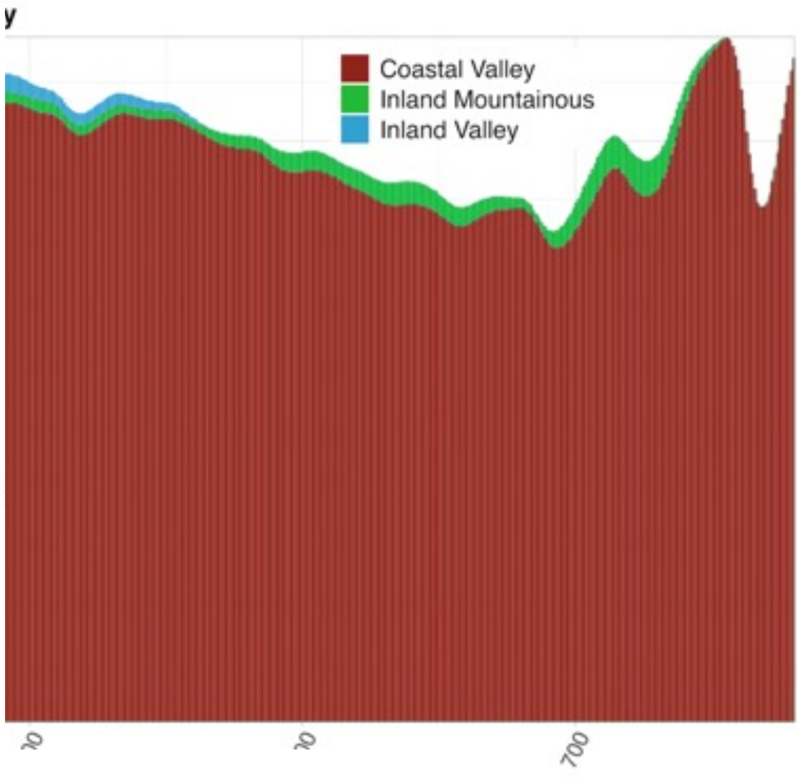
Heat hours accumulating earlier in the year

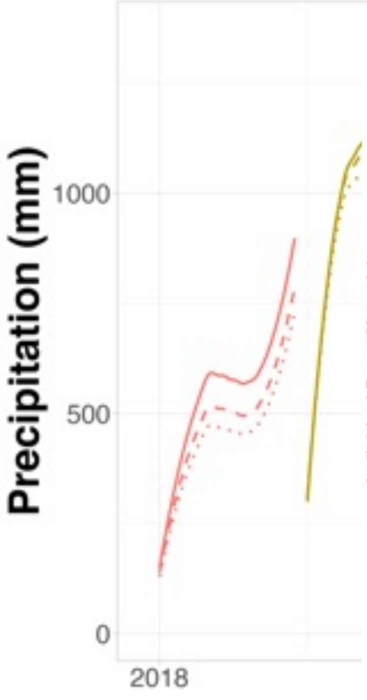
Changing phenological timing for grapes

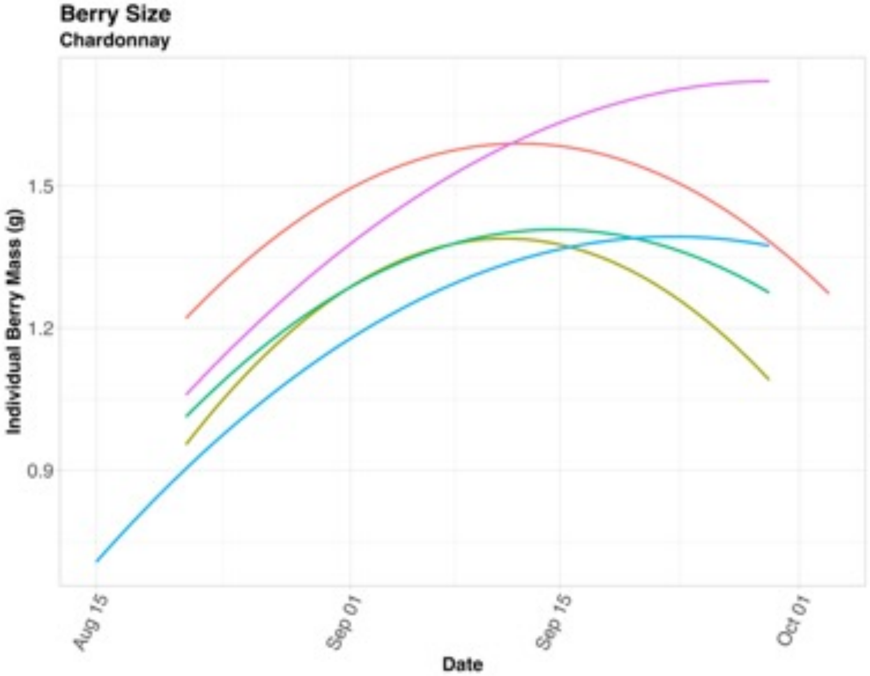


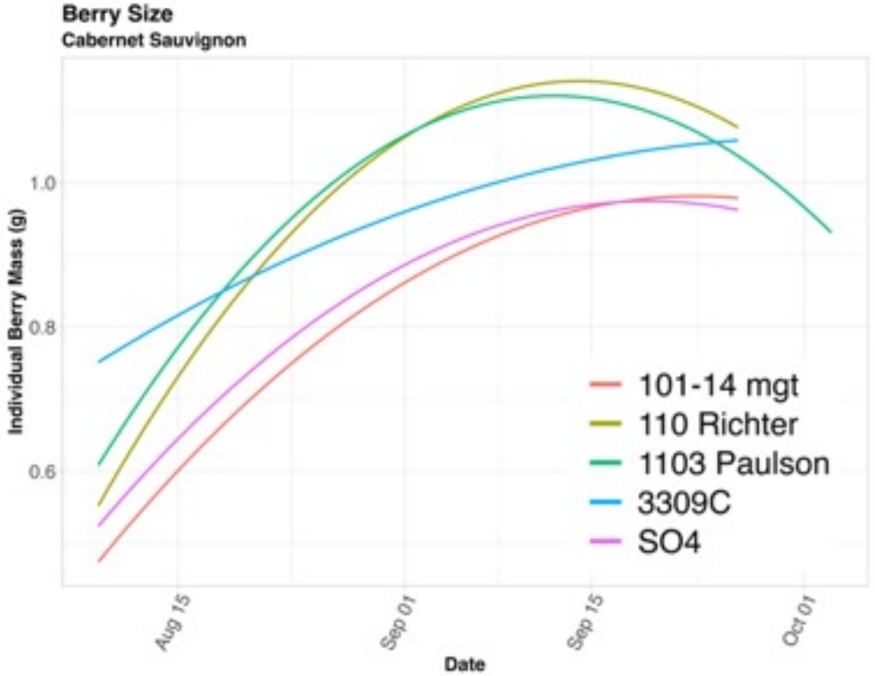
Cumulative heat accumulation in Santa Rosa, California in 2012, 2015, 2018, and 2020; linear model. (Data from https://cimis.water.ca.gov)

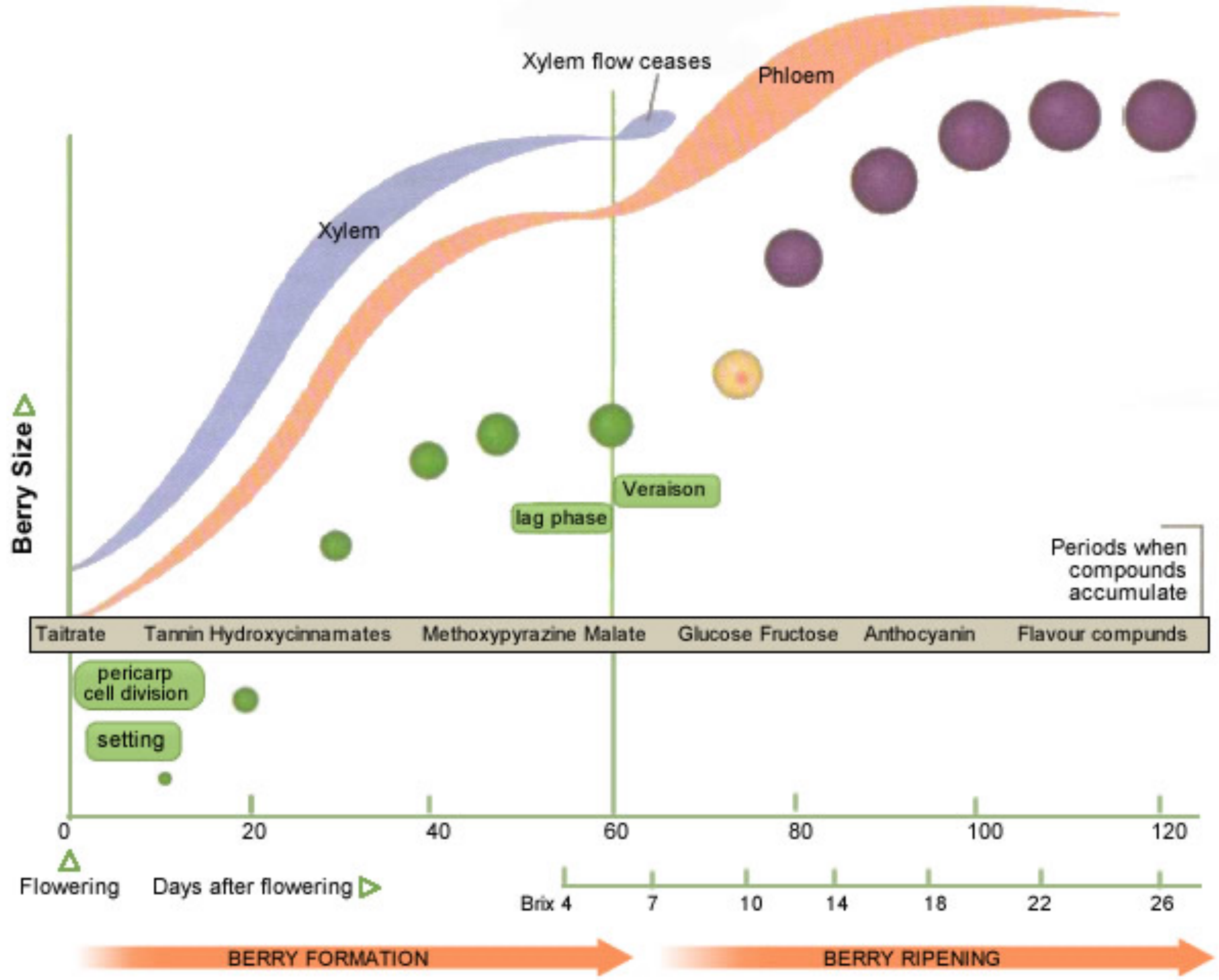

Vine Water Status
by Rootstock
Stem Water Potential (MPa)
-0.6
-0.8
-1.0
Jun
Jul
Aug
Sep
Oct
101-14 mgt
110 Richter
1103 Paulson
3309C
SO4
Pre-Harvest
Irrigation Event


Coastal Valley
Inland Mountainous
Inland Valley
700

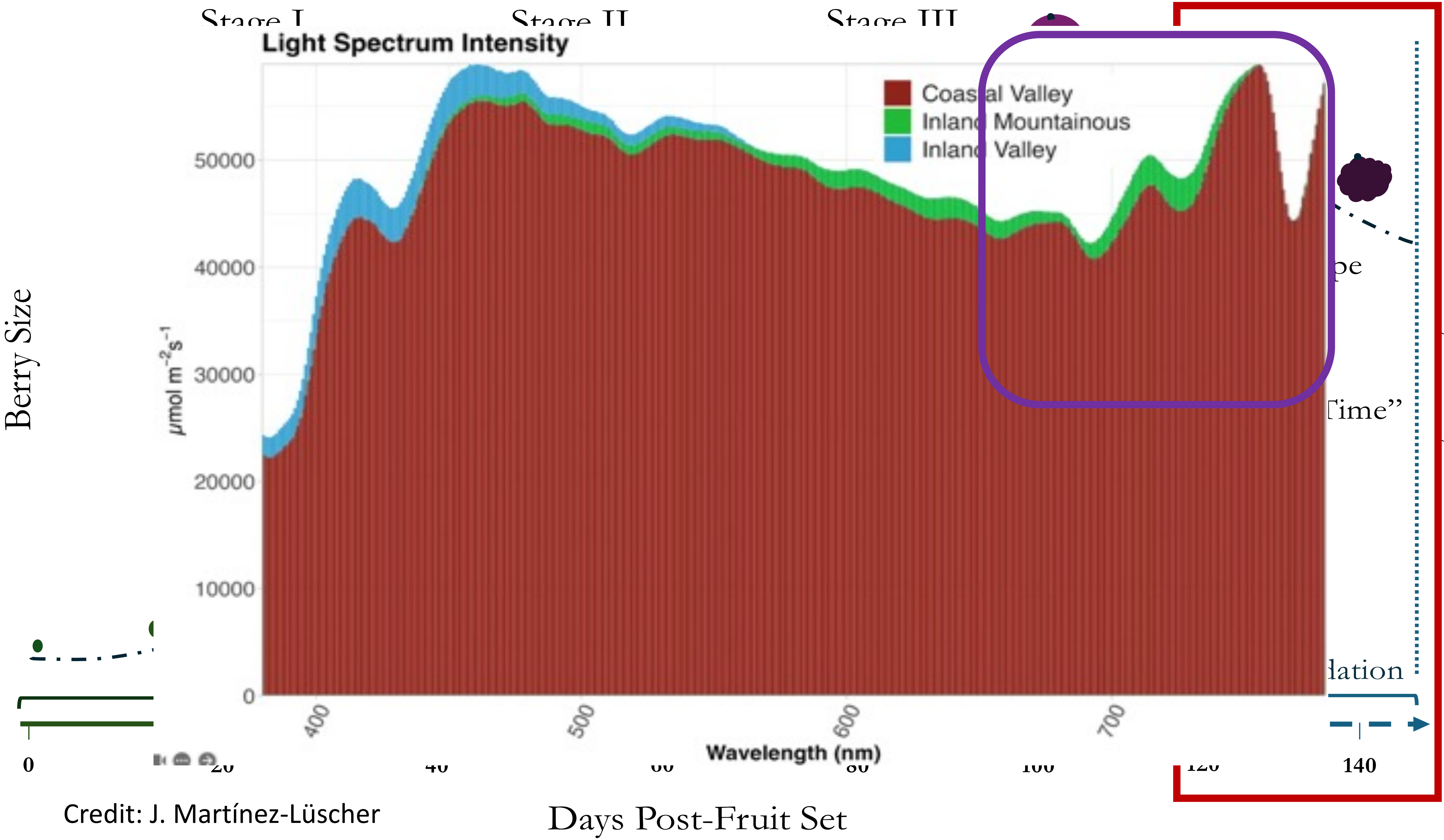

Precipitation (mm)
1000
500
0
2018


Berry Size
Chardonnay
Individual Berry Mass (g)
1.5
1.2
0.9
Aug 15
Sep 01
Sep 15
Oct 01
Date

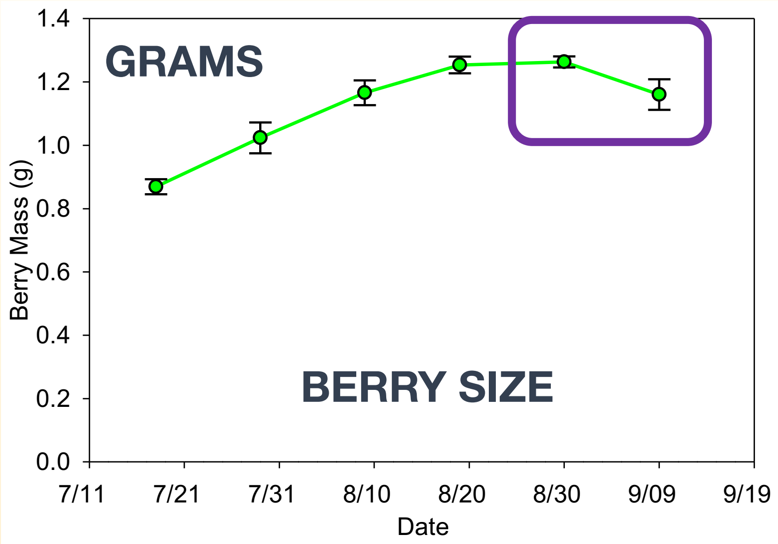

Berry Size
Cabernet Sauvignon
Individual Berry Mass (g)
1.0
0.8
0.6
Aug 15
Sep 01
Sep 15
Oct 01
Date
101-14 mgt
110 Richter
1103 Paulson
3309C
SO4

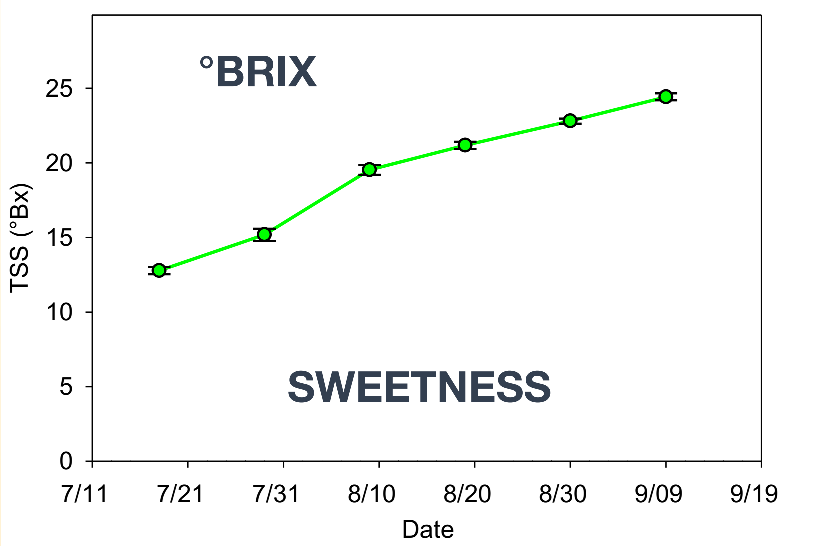


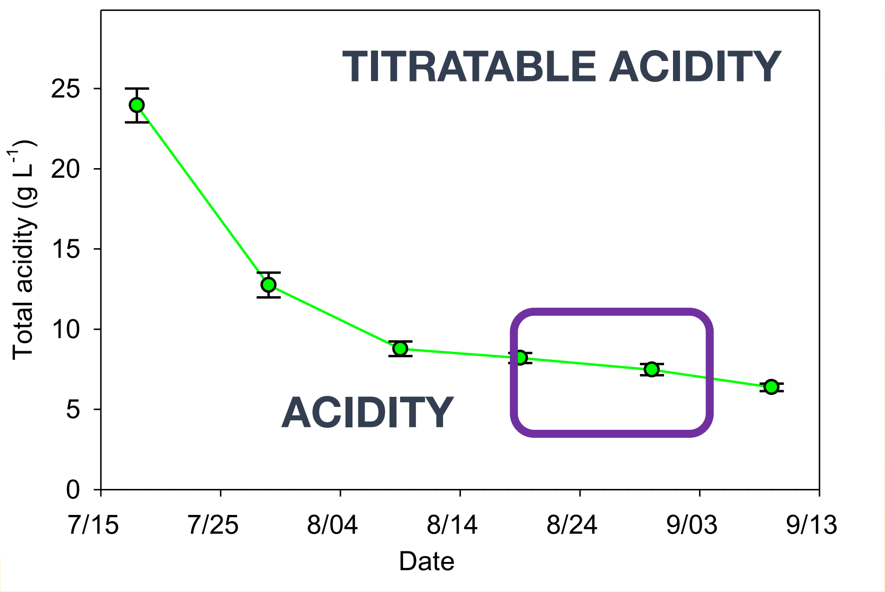
Xylem flow ceases
Phloem
Xylem
Berry Size
Veraison
lag phase
Periods when compounds accumulate
Taitrate
Tannin Hydroxycinnamates
Methoxypyrazine Malate
Glucose Fructose
Anthocyanin
Flavour compunds
pericarp cell division
setting
0
20
40
60
80
100
120
Flowering
Days after flowering
Brix 4
7
10
14
18
22
26
BERRY FORMATION
BERRY RIPENING

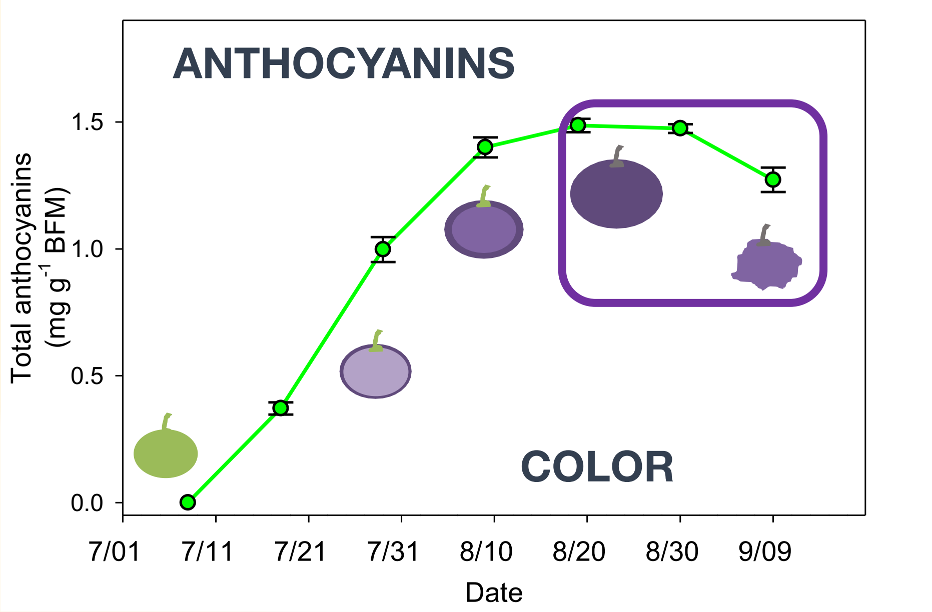


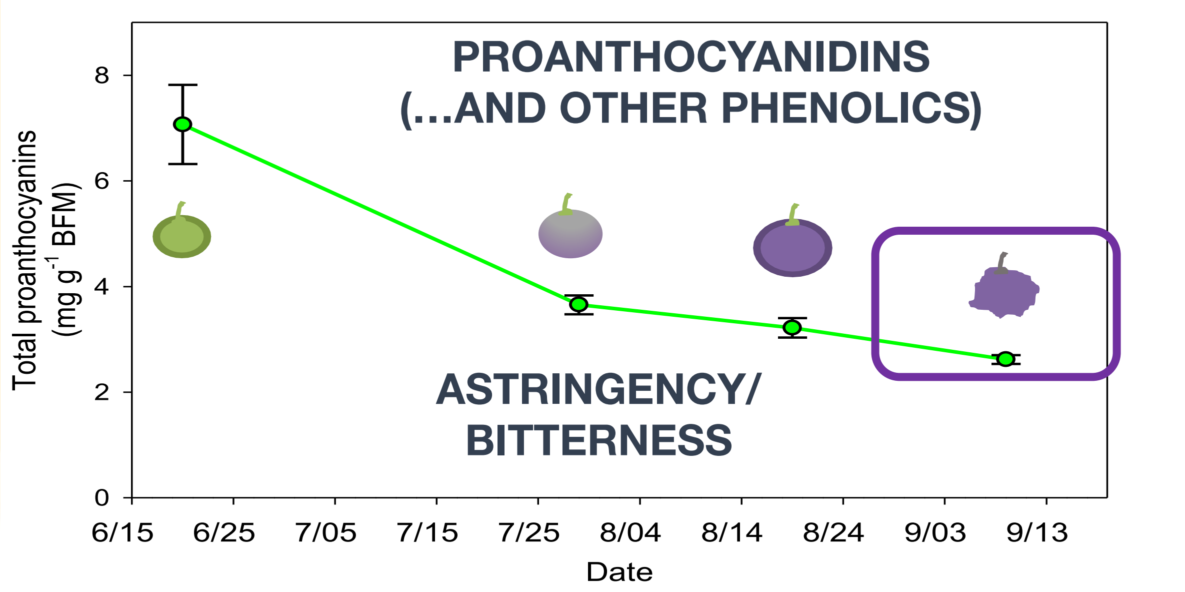
Credit: J. Martínez-Lüscher







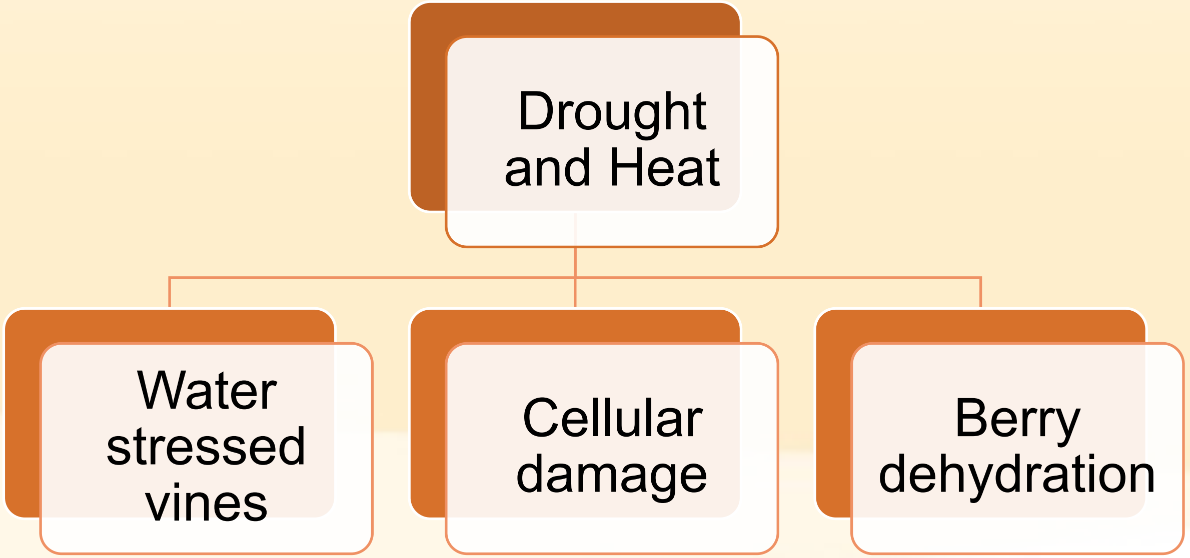


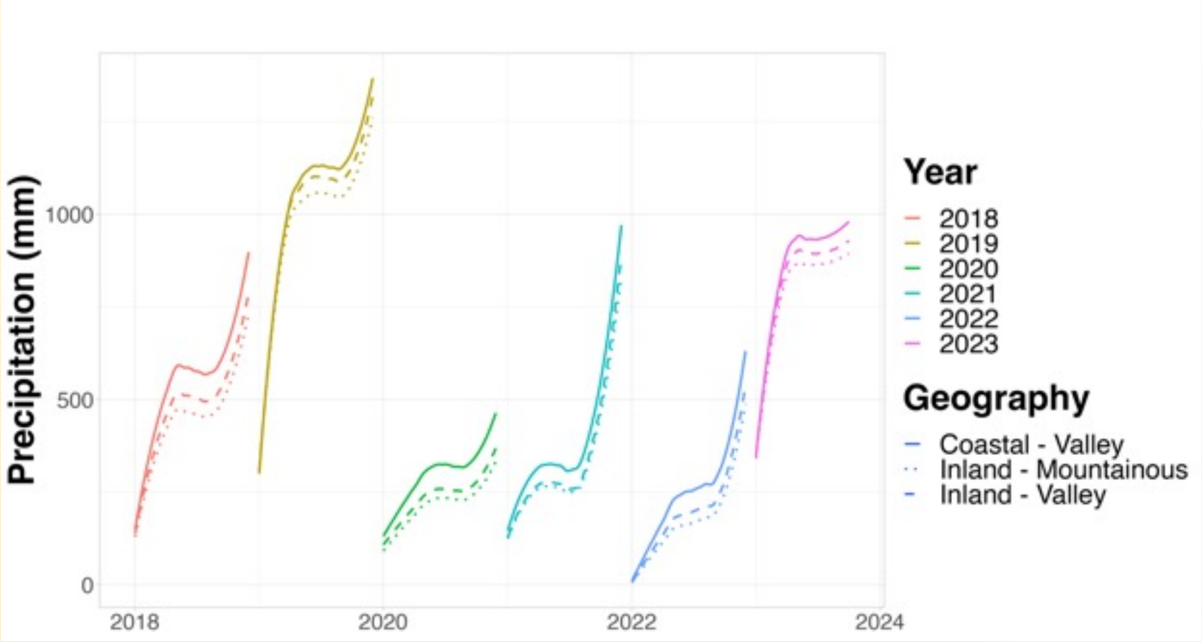


Credit: K. Kurtural

Drought

Hard to separate effects of drought from heat.





Percentage of total precipitation in Modoc County, California over six years from October to February each year since 2015. (Data from https://cimis.water.ca.gov)

Drought

Irrigation scheduling

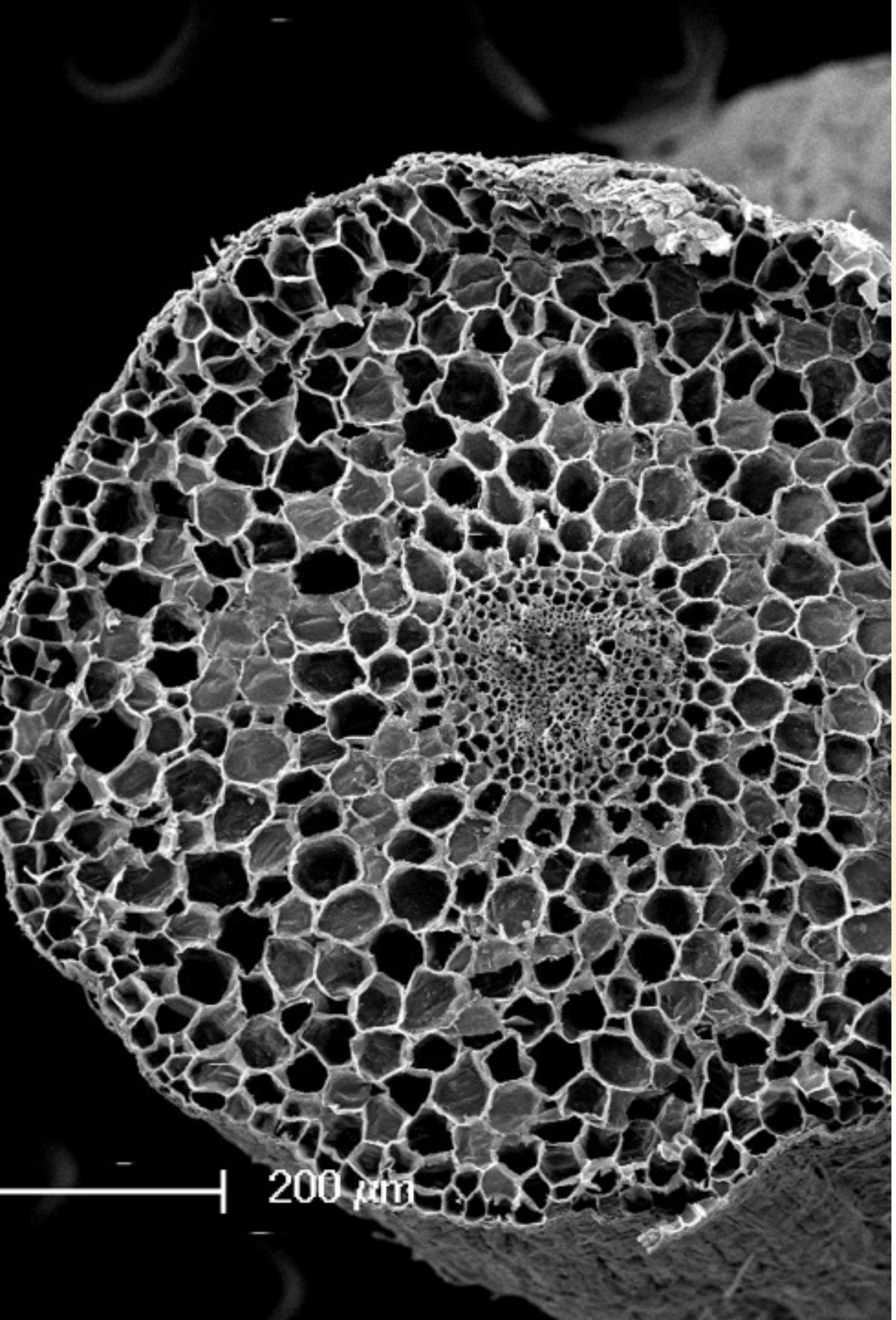
Produce a smaller canopy

Reduce labor and water costs

Reducing Irrigation

Reduce canopy management

Conserve water



Physiological impact of abiotic stressors

1. Heat stress:
   - Increases vine water demand
   - Increases vine respiration
   - Timing of heat stress can increase foliar growth
     i. Resulting in more sugars for phytophagous insect pests
2. Drought stress:
   - Can result in whole-vine oxidative stress
   - Polyphenol synthesis increases (abiotic stress response)
   - Modified morphological and phenological characteristics
     i. e.g., xylem vessel size and hydraulic conductivity

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Combined stressors: heat and drought

Changes in morphology and physiology are greater with combined stressors:

- Heat and drought in combination decrease plant growth and yields more so that each stressor individually. (10, 18)

Responses include ROS production and/or hormonal signaling (10)

Some stressors impact both the plant and the pests in the vineyard

Research into combined stress responses

Plant responses to combined stressors may be unique to the specific combination of stressors.

- e.g., drought and *Xylella fastidiosa*

Research on phytotoxic metabolite biosynthesis in response to changing environmental conditions

Combined stressors may be thought of as a third-type of stress beyond biotic and abiotic

Response Strategies

Heat and Drought in Vineyards

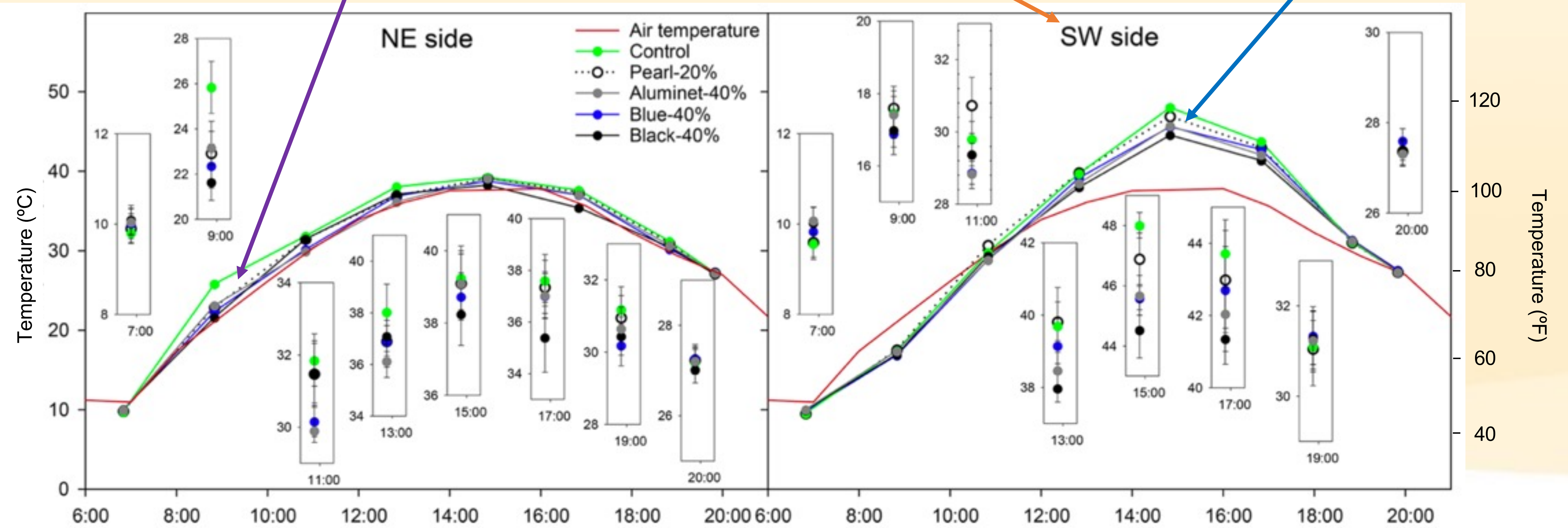
Increasing Temperatures

Shade netting

Very effective when either side is in direct sunlight

Impact last longer on the more exposed side of the canopy

Can be up to **5 ºF cooler** under the canopy [2]



Cabernet Sauvignon fruit zone air temperatures measured under different colored shade nets in Oakville, CA in July 2016 (figure from Martínez-Lüscher et al. 2017)

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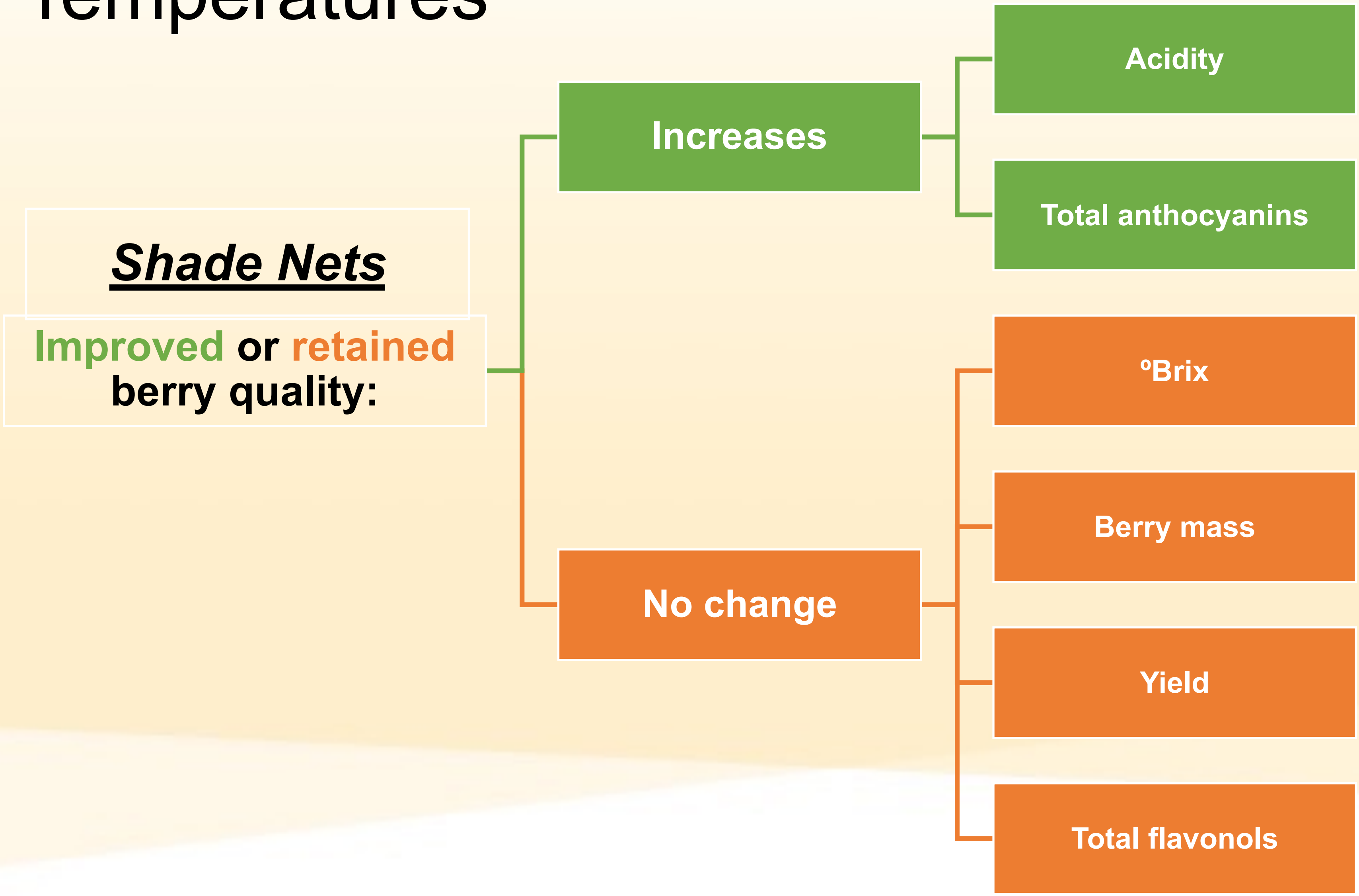
Increasing Temperatures

Shade netting



Increasing Temperatures

No shade netting

a

Shade netting

b

c

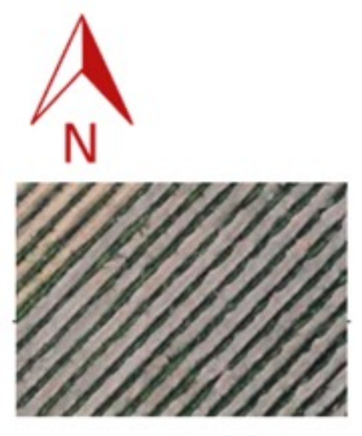
Left to Right: (a) no shade net applied; (b) example of black shade net applied following fruit set; (c) resulting cluster protected by shade net; all images were taken on the same day in Oakville, CA in August 2017.

Increasing Temperatures

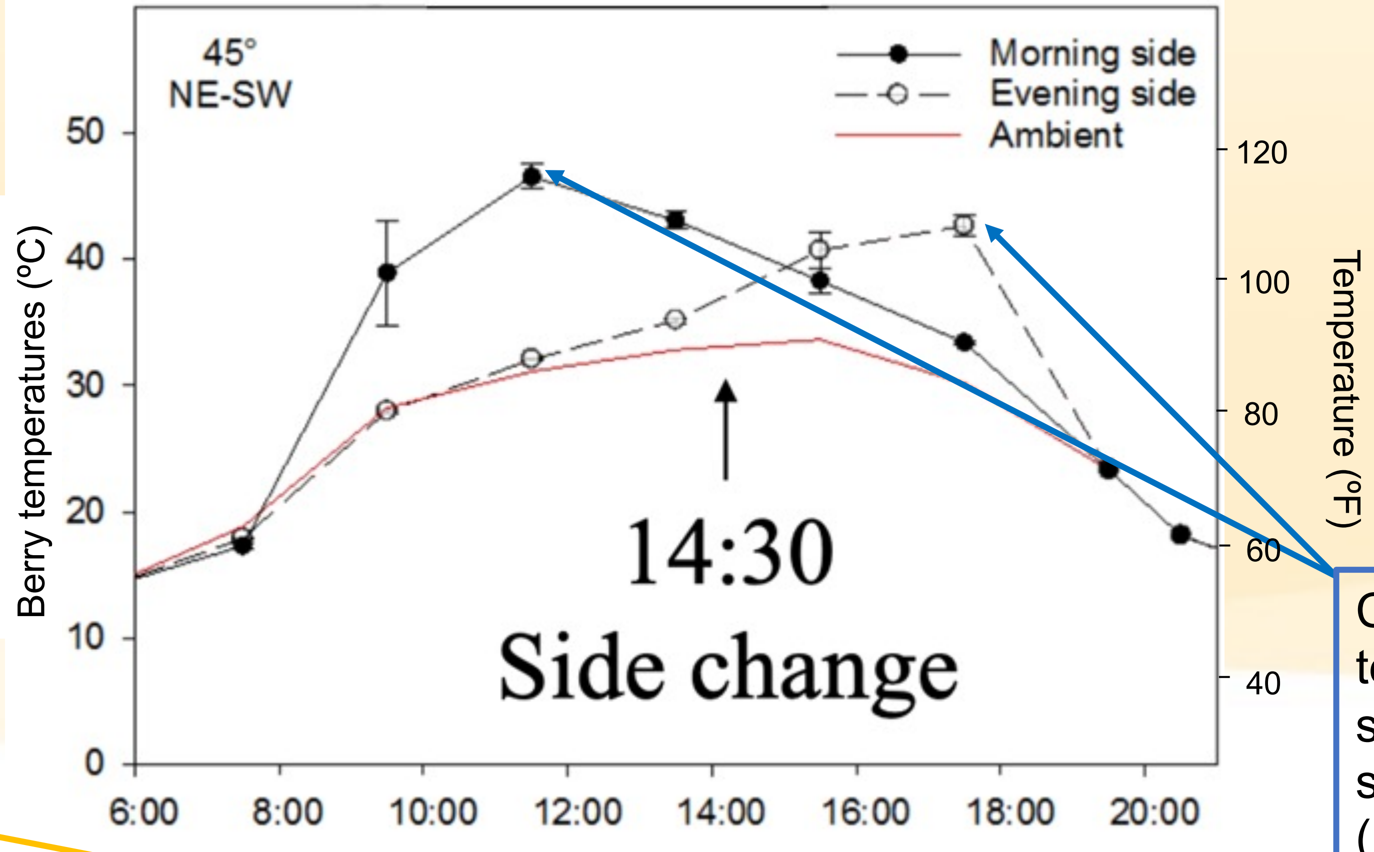
Row orientation

- Important for daily light and heat distribution on both sides of canopy
- Northeast - Southwest

More equal distribution of daily solar radiation
NE - SW



NE - Morning ← → SW - Evening



Both sides of canopy receive **similar hours of direct sunlight**

Cluster temperatures similar on both sides of canopy (**110 to 120 ºF**)

Image credit: "*Vineyard Design spacing and trellis selection*" – Johann Martinez (UC ANR presentation 2019)

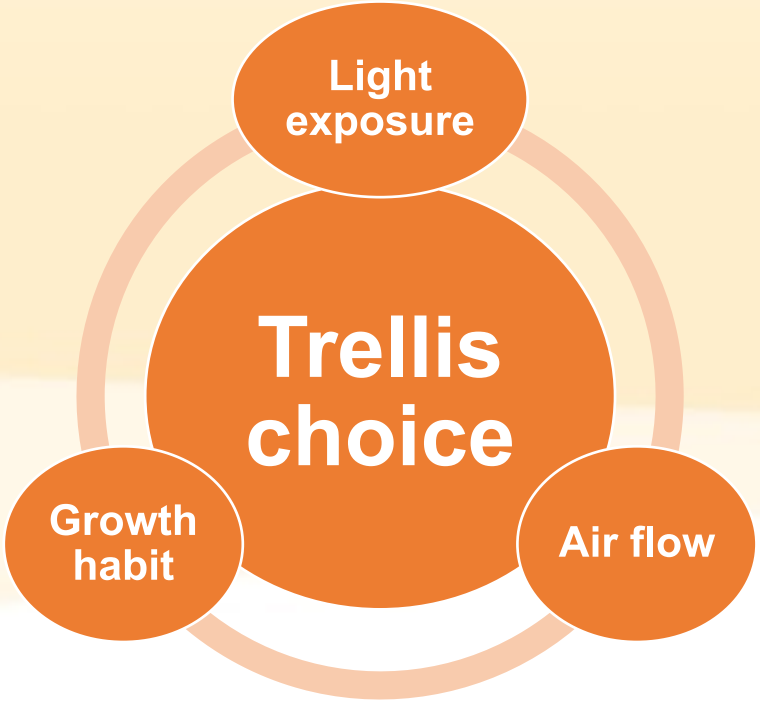
Increasing Temperatures

Canopy management and Trellis type

Trellis type:

Greatly influences incidence of exposed fruit

(e.g., VSP vs. CA Sprawl)



Vertical shoot positioned

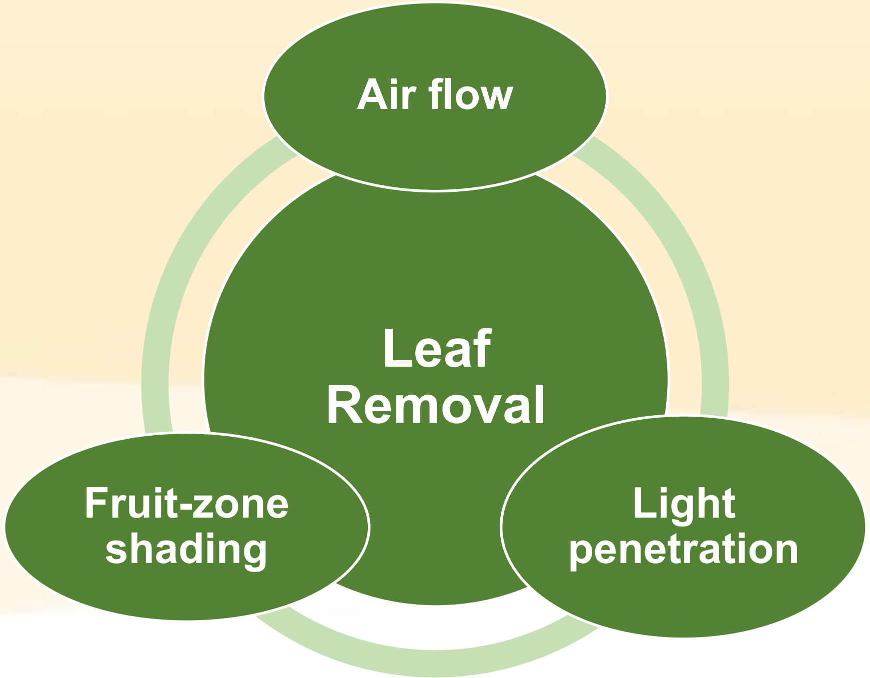
CA sprawl

Increasing Temperatures

Canopy management and Trellis type

Leaf removal:

Can achieve similar results as shade nets with additional benefits

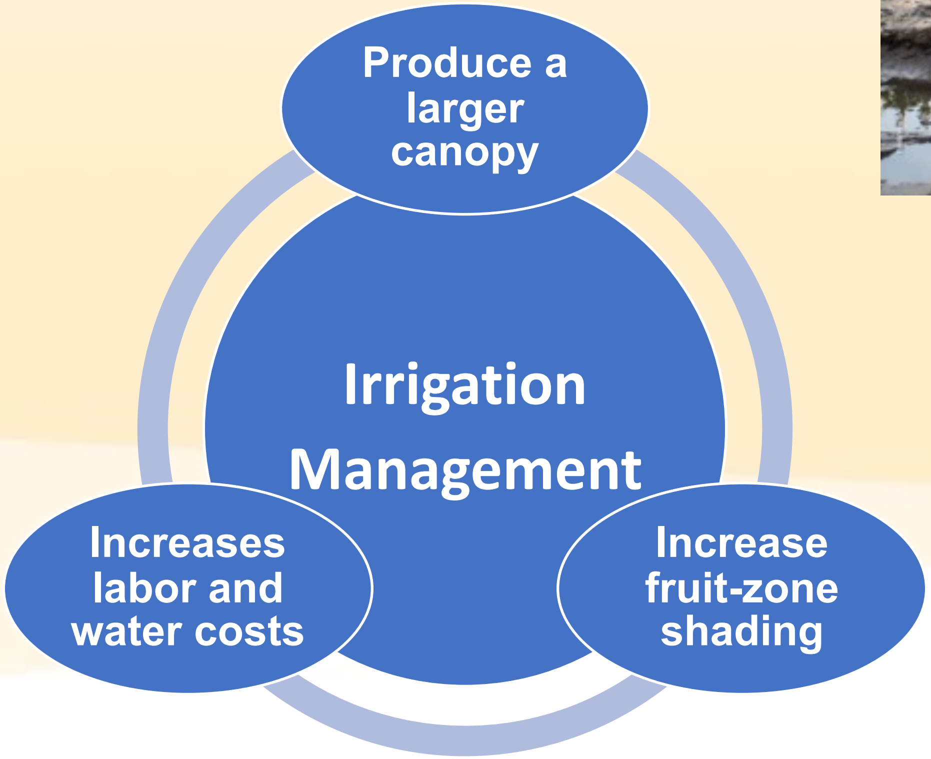


Excessive leaf removal; Oakville, CA - 2017
(*photo courtesy of Dr. Runze Yu, Asst. Prof CSU Fresno*)

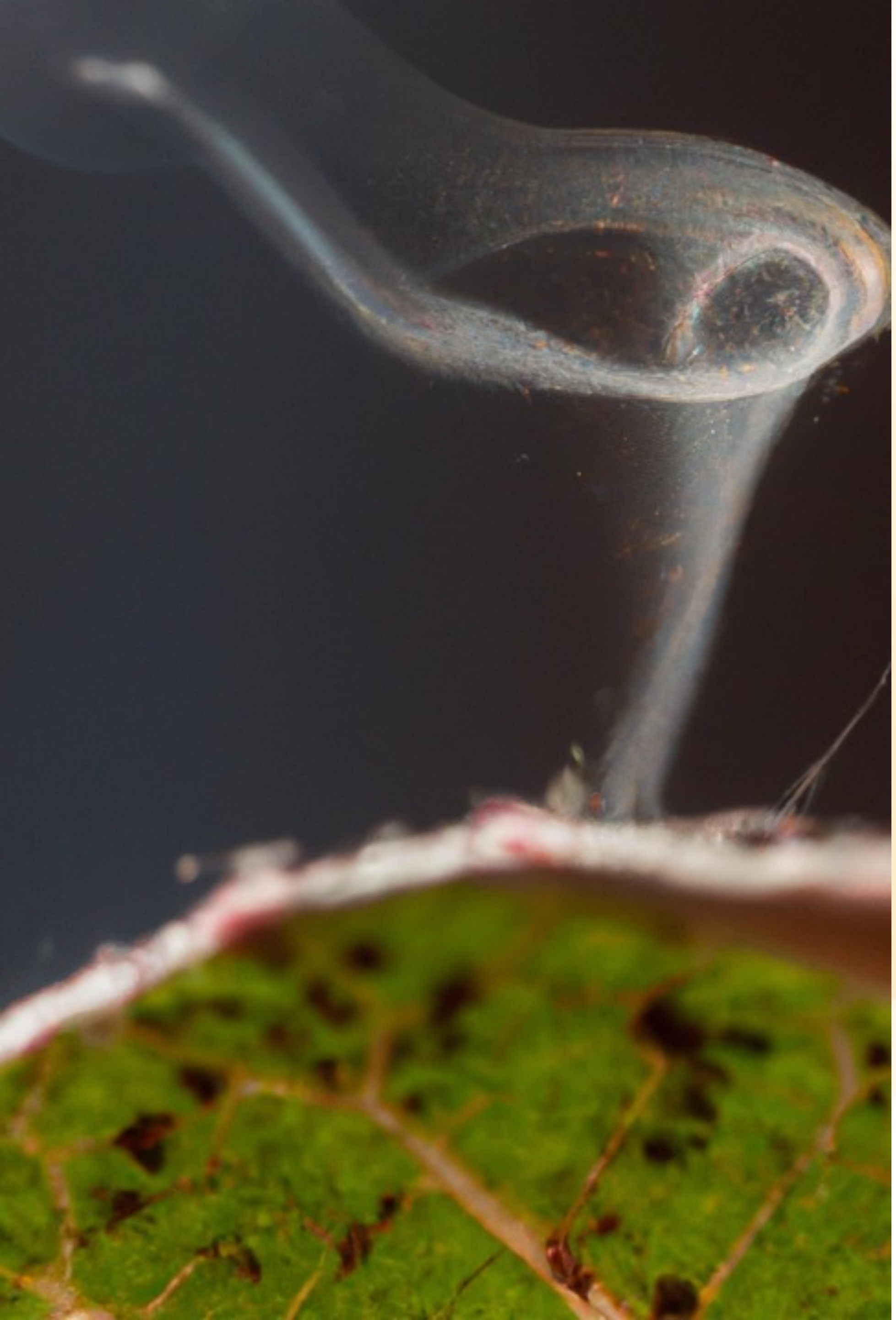
Increasing Temperatures

Irrigation scheduling

Developing a canopy



Smoke Impacts on Grapevine Physiology



Effects of smoke on gas-exchange & photosynthesis

Three parameters of photosynthesis affected by smoke exposure

1. Stomatal Conductance (g_s)
2. CO_2 assimilation rates
3. Intercellular CO_2 levels

However, reductions in these functions are short term

Plants can acclimate to the smoke-exposure within 24 - 48 hours

Gilbert and Ripley 2022

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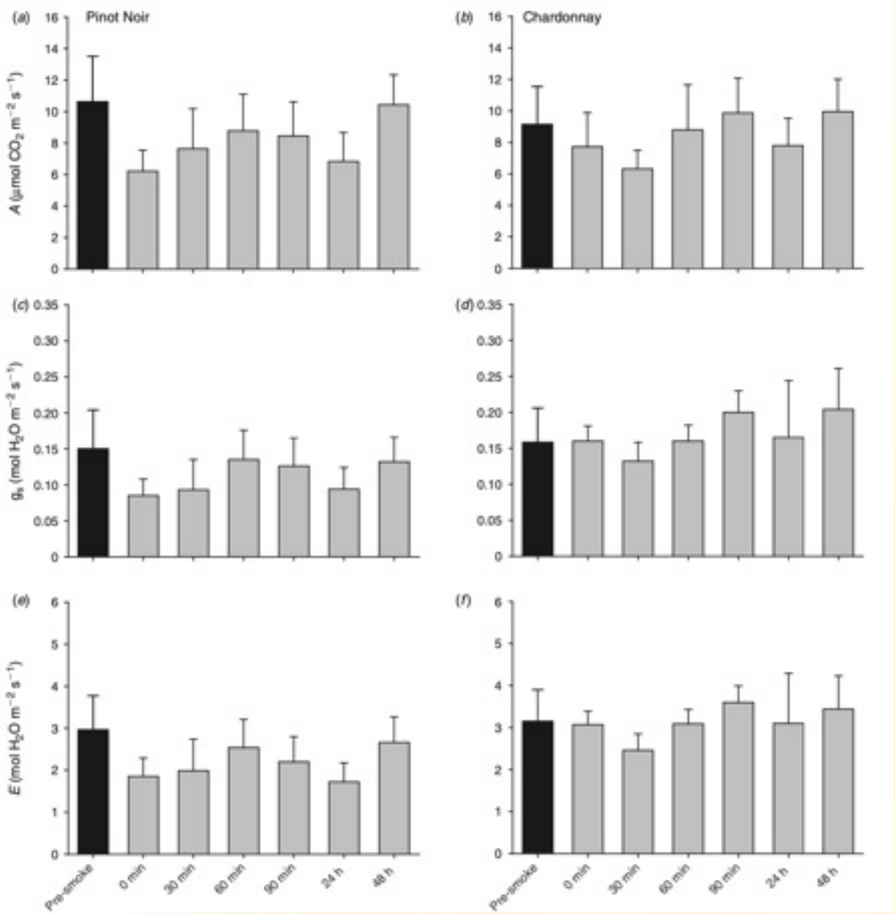
Effects of smoke on gas-exchange & photosynthesis

Fuel type matters for the short-term responses observed in gas exchange

- Research has observed a difference in grapevine stomatal conductance impacts depending if smoke comes from Coast Live Oak or Eucalyptus species (Bell et al. 2013)

Overall, the impacts of smoke *by itself* on gas exchange and photosynthesis are transitory and can be self-corrected by the vine



Bell et al. 2013

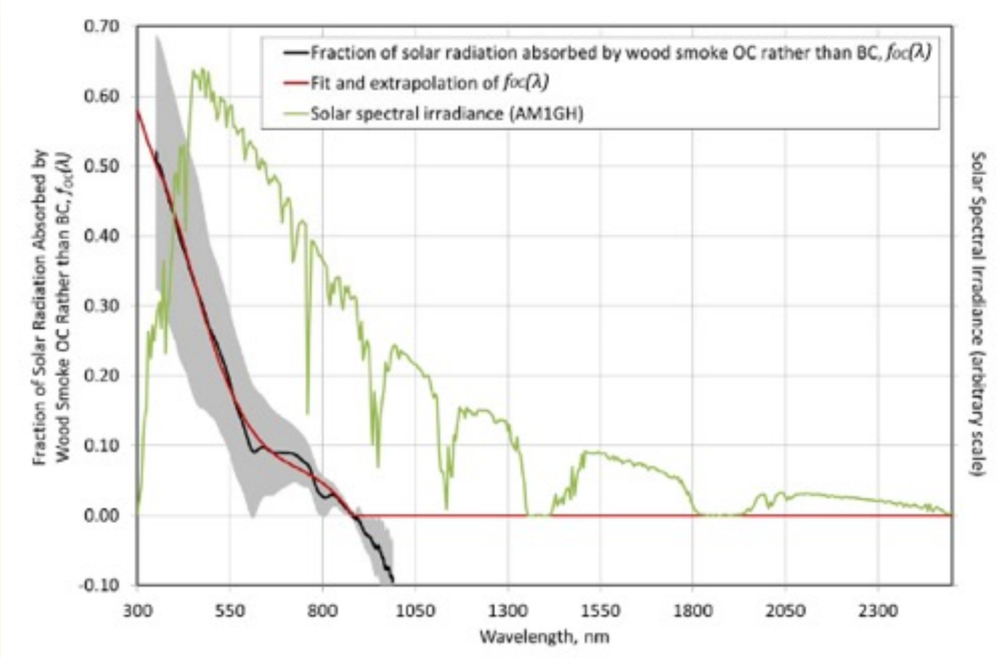
Effect of smoke on light-availability

While smoke itself may not have a significant impact on photosynthesis, particulate matter from smoke can

Wood smoke has been shown to absorb solar radiation with specific spectral selectivity (Kirchstetter and Thatcher 2012)

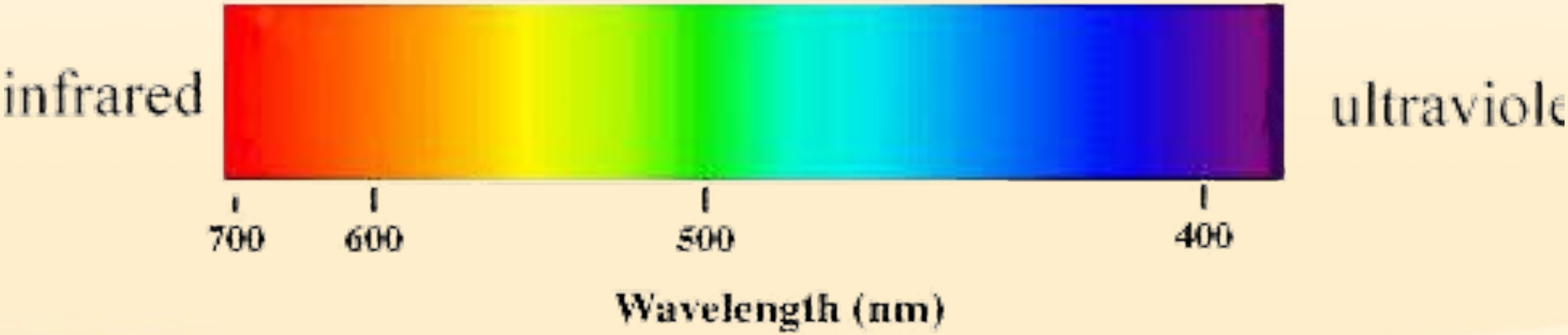
- Ultraviolet to visible spectrum absorption

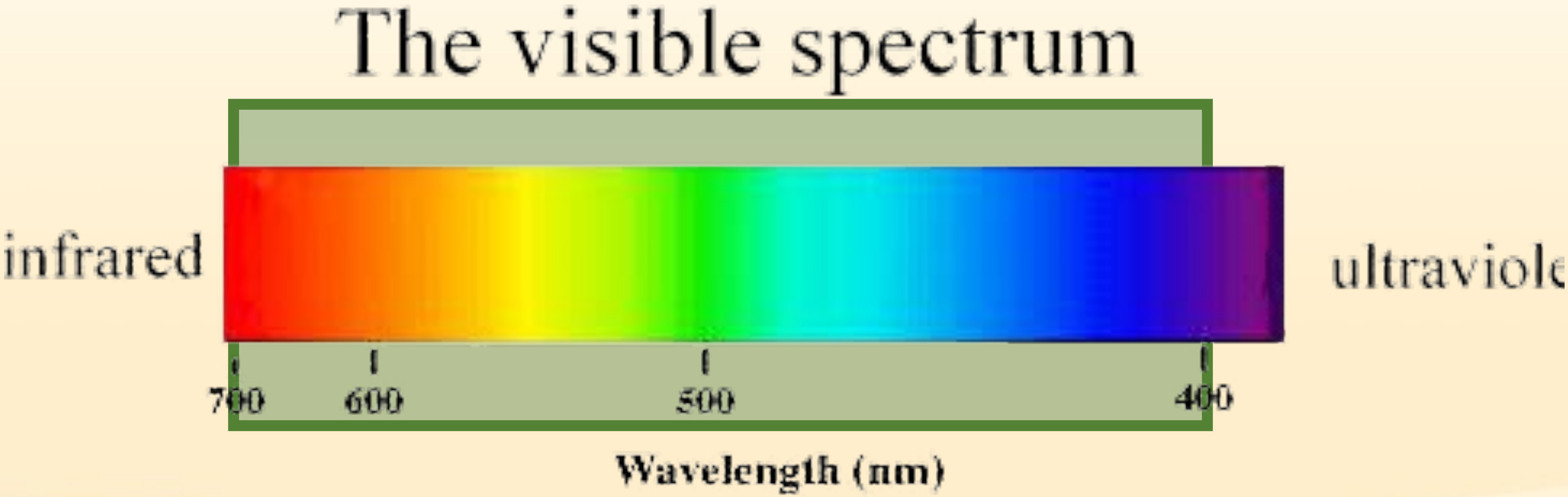
Up to a 50% reduction in UV-light and Visible-light



Kirchstetter and Thatcher 2012

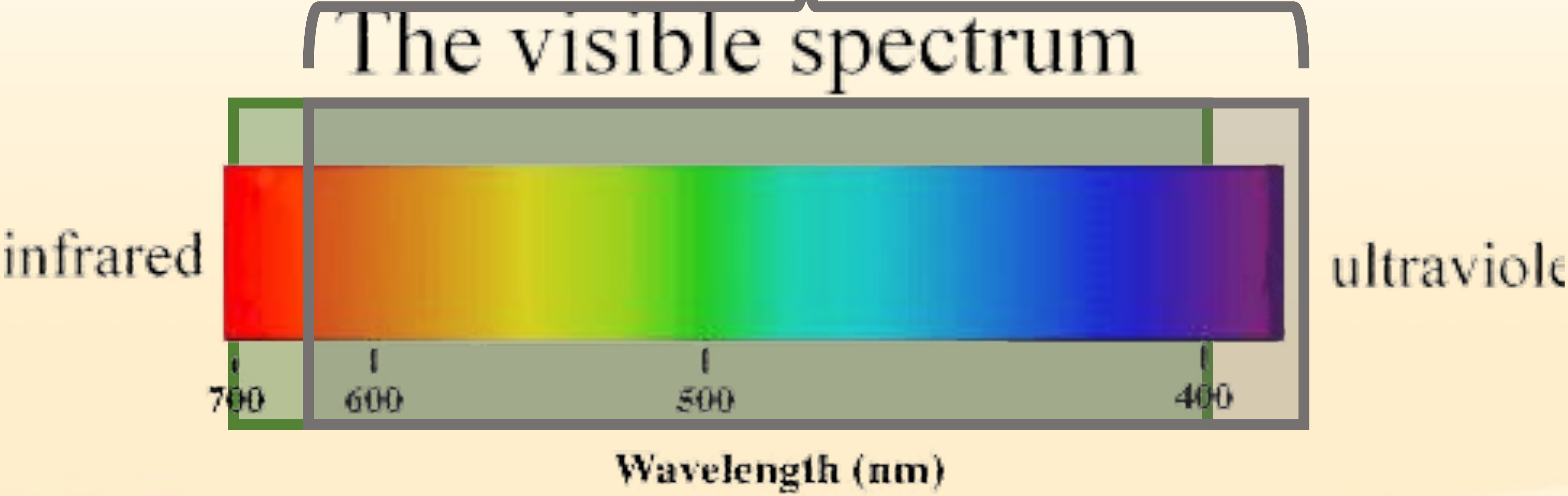
The visible spectrum





Photosynthesis

Wavelengths reduced from wildfire smoke



Photosynthesis

Effect of smoke on surface temperatures

Because wood smoke preferentially filters light in the UV and Visible spectrums

- **Most Infrared light makes it down to the surface**

Most of the heat-imparting effects of solar radiation come from the Infrared spectrum

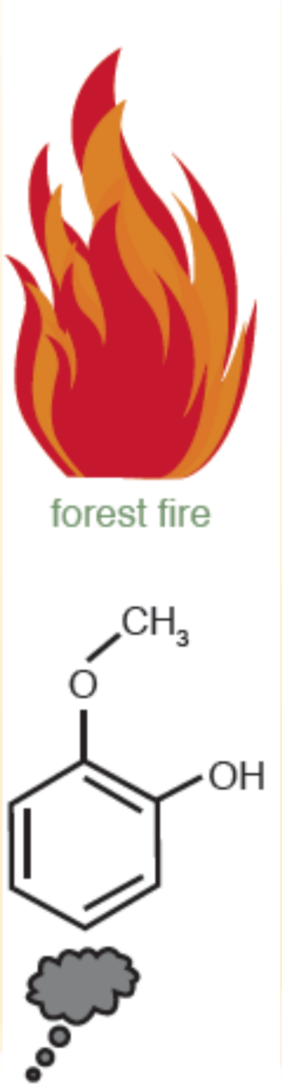
There is **little to no decrease in surface temperatures** under high-instances of smoke particulate matter

Tarasova et al. 1999

Effects of Smoke on Fruit

Volatile phenols

- Smoke derived compounds associated with burning vegetation.
- Absorbed through the skin of ripening grapes and accumulate by binding to sugars
- Bound by a native grape enzyme: glycosyltransferase
- Results in Phenolic Diglycosides

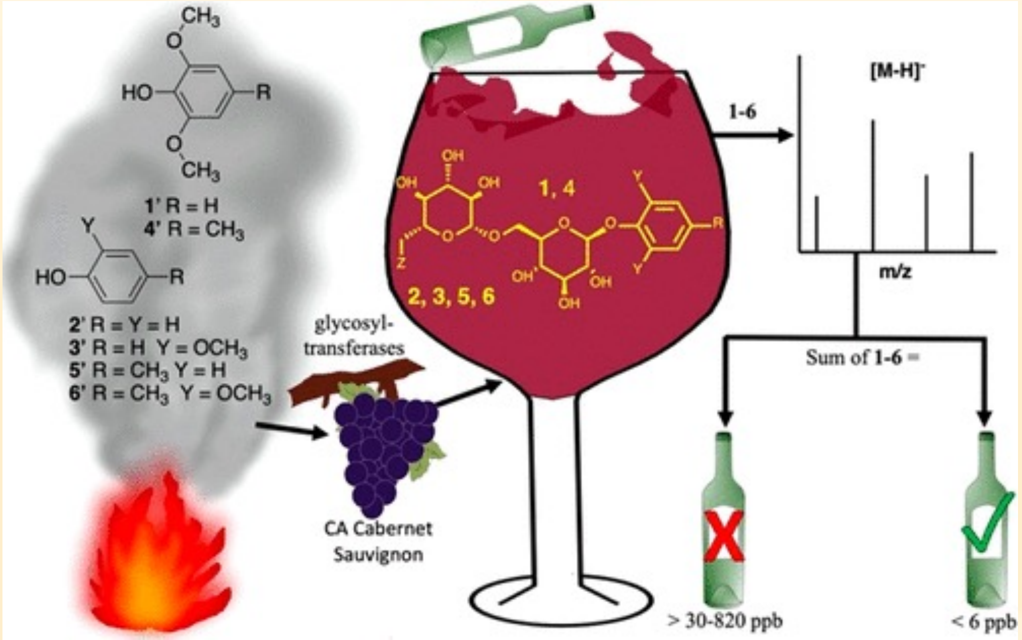


Härtl and Schwab 2018 (Article)

Effects of Smoke on Fruit

Phenolic Diglycosides

- A **nonvolatile compound** (volatile phenols bound to sugars)
- Stable compound while bottle aging (sticks around)
- Cannot be smelled or tasted while still in bound form
- Can be **released by enzymes during fermentation or in the mouth**



Crews et al. 2022

Preventative Management Strategies

Forests

Proper forest management can reduce the risk of smoke damage

If you have forests on your property try to:

- Reduce fuel loads on the forest floor
- Remove dead and dying trees
- Keep a solid canopy and understory shrubs

Like grapevines, other plants can bind volatile phenols

Forests can be used as a 'smoke-break' and bind the volatile phenols before they reach your grapes

Particulate clay barriers – Kaolin

Foliar application of kaolin can reduce the concentration of volatile phenols in smoke-exposed fruits (van der Hulst et al. 2019)

Efficacy depends on the rate of kaolin application and extent of coverage

Some results are inconclusive, but this may work as a preventative measure (Szeto et al. 2022)

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Biofilms

Fungal pathogen sprays applied 1 week before smoke exposure may help prevent accumulation of volatile phenols in nearly-mature grapes

Artificial grape cuticle (Favell et al. 2019)

Canopy Management

Leaf removal (Ristic et al. 2013)

- Post-smoke exposure
  - Decreased intensity of smoke characters in wines relative to controls
- Pre-smoke exposure
  - Exposed grapes and increased smoke taint intensity in wines

Similar effect to the ‘Forest Canopy Barrier’ concept

Volatile phenols will bind to the leaf as well as the fruit; serves as a barrier against smoke before contact with the fruit

Fabrics

Activated Carbon Fabrics (Wilkinson et al. 2022)

- Have been tested as a protectant against volatile phenols in grapes
- Activated carbon is commonly used in water and air filtration
- These trap volatile phenols well
- However, wrapping each cluster in a bag made of activated carbon may be prohibitively costly to the grower

Response Strategies

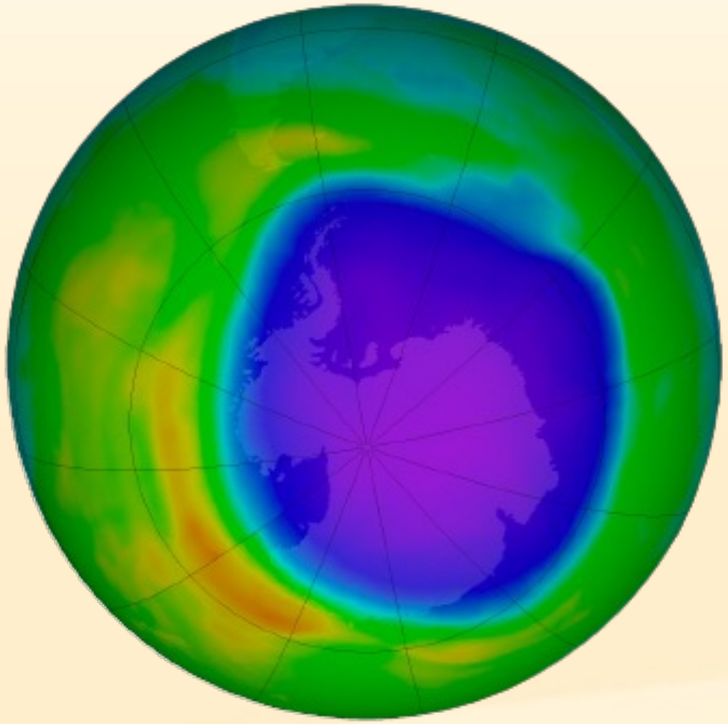
Fire and Smoke in Vineyards

Ozone (O_3) Treatments

Researchers are examining exposure to **gaseous ozone** (O_3) to mitigate the intensity of smoke taint in affected grapes

At 1ppm O_3 exposure for 24 hours one experiment saw a significant decrease in volatile phenols and phenol glycoside concentrations (Modesti et al. 2021)

Decreases in sensory perception of smoke taint in wine were also observed in this study



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Remote Sensing - Contamination Detection

Fuentes et al. 2019

- Non-invasive detection of smoke contamination in grapevine canopies **in-field.**
- Using a machine-learning model to identify **predictable changes in stomatal conductance** (g_s)
- Second method to identify levels of phenolic diglycosides in fruit and wine using **near-infrared spectroscopy (NIR)**
- Data can be collected with **drones** and is up to **96% accurate**

Artificial Intelligence - Contamination Detection

Fuentes et al. 2020

- Sensor data can be **monitored by AI** to identify signs of smoke contamination using the remote sensing methods.

- Further development of an **‘electronic nose’** to identify volatile phenols and gases in wines and vineyards.

Other processes out there

Mirabelli-Montan et al. 2021

1. Cold-maceration
   - Doesn't eliminate smoke taint, but may reduce perceived intensity of the smoke characters
2. Minimizing extraction from skins (shorter maceration times)
3. Yeast selection
   - Doesn't eliminate smoke taint, but may reduce perceived intensity of the smoke characters (some organoleptic properties mask smoke taint attributes)
4. Oak chips or Tannins – again, mask and not remove smoke
5. Centrifuge of wine – not sure this one works or how it would

Filtration

- Filtration using a highly selective membrane targeting phenolic diglycosides
- Unproven, but possible
- May require specialized enzyme to break the bonds of the phenolic diglycosides to the sugars of the must
  - Otherwise, the filter will remove necessary compounds like tannins and flavan-3-ols as well; whatever is bound to the phenolic diglycosides

Needs more testing before recommending

Summary

1. Climate change is unpredictable
2. Smoke exposure has short-term impacts on photosynthesis and gas exchange in vines
3. Binding of volatile phenols as phenolic diglycosides makes the smoke characteristics stable in the fruit
4. Mitigation is possible with emerging response-management strategies

Thank You

Sources

You can find the sources for this presentation at:

1. https://ucanr.edu/sites/chenlab
2. Speaker Presentations
3. "Other Presentations" (end of page)

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