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Consequences and Mitigation of Heat, Drought Stress, and Preharvest Rainfall

Markus Keller

Viticulture and Enology Program
Washington State University

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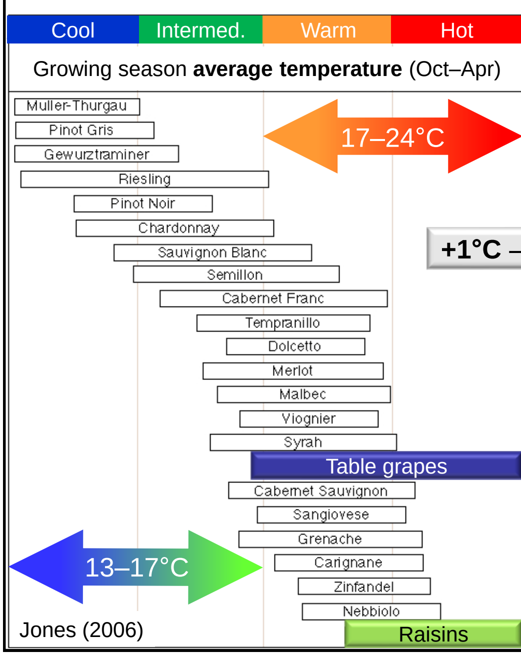
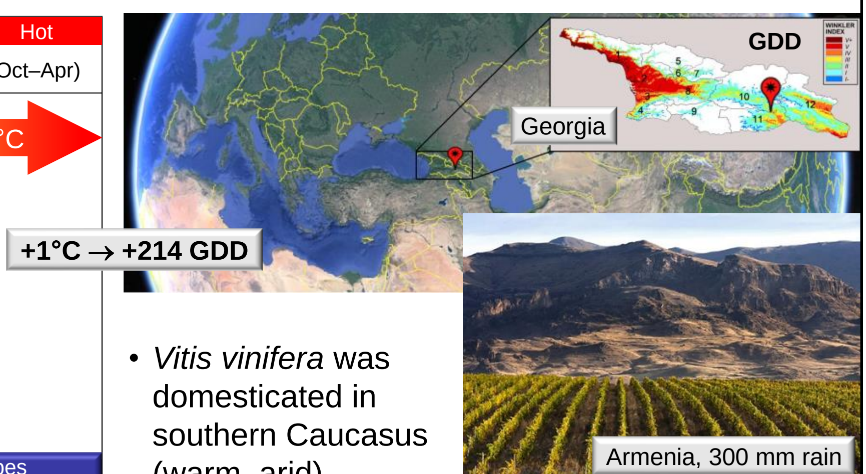
Lessons from history: Grapevines are adaptable





- *Vitis vinifera* was domesticated in southern Caucasus (warm, arid)
- Grapes (scions!) are heat and drought tolerant
- Need to exploit varietal diversity in breeding programs

Sargolzaei et al. (2021)

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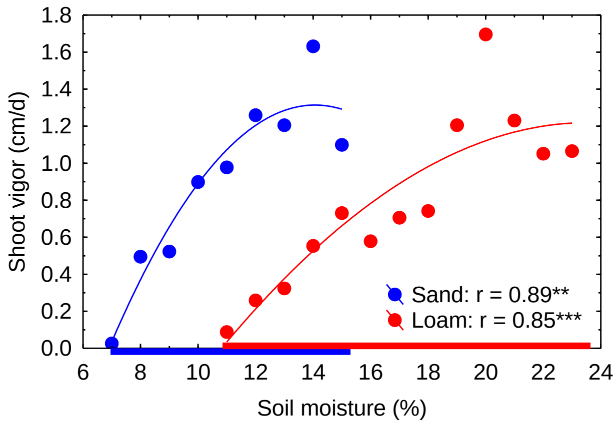
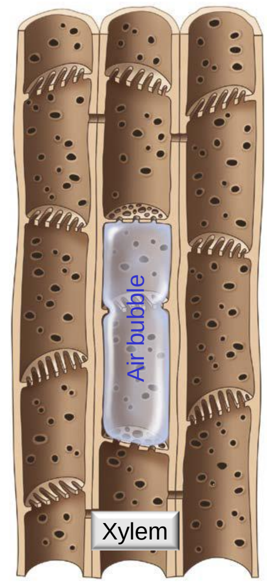
Budbreak: Drought stress compromises yield





- Dry soil in spring → No root pressure → Erratic budbreak, slow shoot growth, cluster abortion, poor fruit set → **Yield loss**
- Growth, yield maximum: Soil moisture 3–4% below field capacity
- Caution: No sap flow (bleeding) in spring → Irrigate!

Keller (2020)

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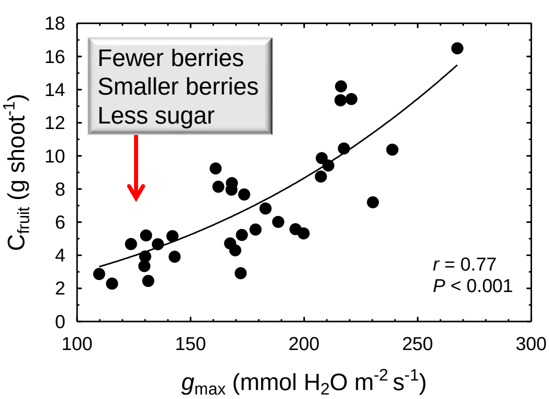
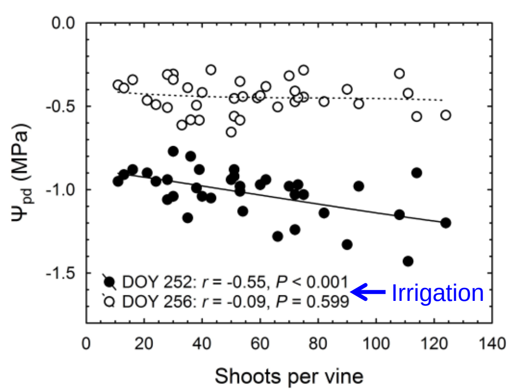
Growing season: Drought stress compromises yield





- Water stress → Water status (**Ψ**) declines (more quickly with larger canopy) → Stomata close ($\boldsymbol{g_{max}}$) → Photosynthesis declines → Less carbon for fruit (**C_{fruit}**)
- Water stress during bloom → Poor fruit set → Fewer berries
- Water stress before veraison → Smaller berries
- Water stress after veraison → Lower TSS, berry shrinkage

Yield loss

Keller et al. (2015)

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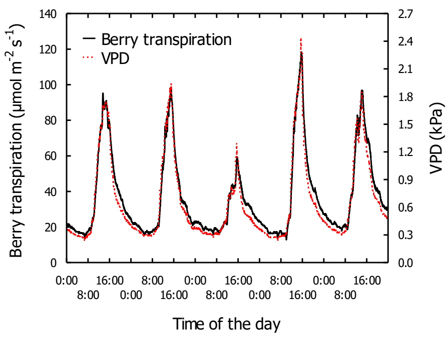
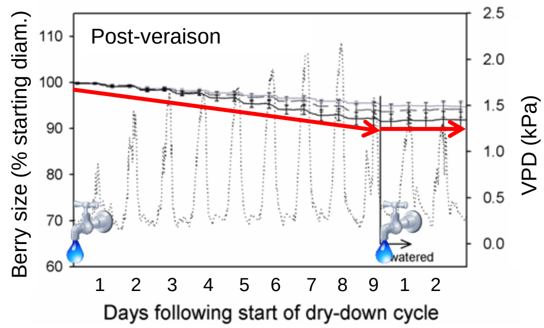
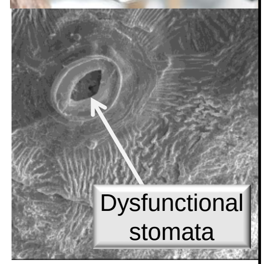
Water and heat stress: Berry dehydration







- Grape berries are designed to minimize transpiration (100× lower than leaves) → Poor evaporative cooling
- No stomatal control → Transpiration tracks VPD (temperature!)
- Berries are vulnerable to heat injury → **Sunburn**
- Water and/or heat stress → Berry **shrinkage**
- Postveraison irrigation may prevent but not reverse shrinkage

Zhang & Keller (2015)

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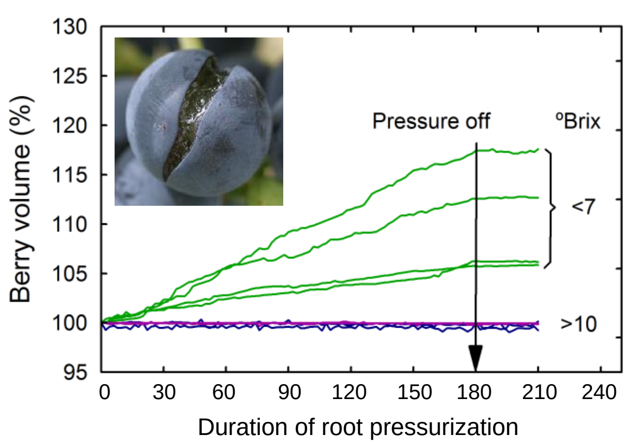
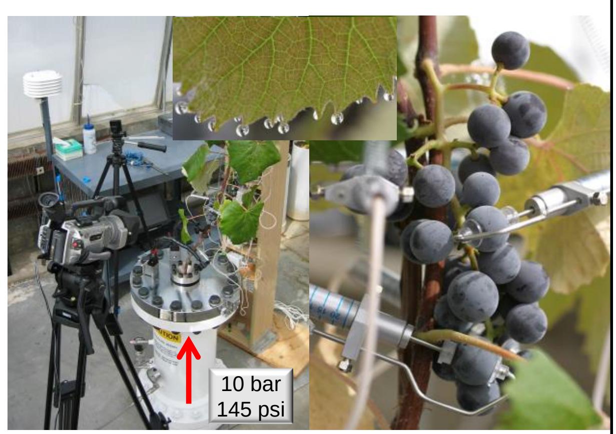
Excess water: Restrictions apply





- Excess water before veraison (<7°Brix) → Berry **expansion** but no splitting
- Excess water after veraison (>10°Brix) → No berry expansion but **splitting**
- Xylem water flow into and out of berries is reversible (pressure gradient)
- Ripening skin stiffens → Skin restricts berry expansion

Keller et al. (2015)

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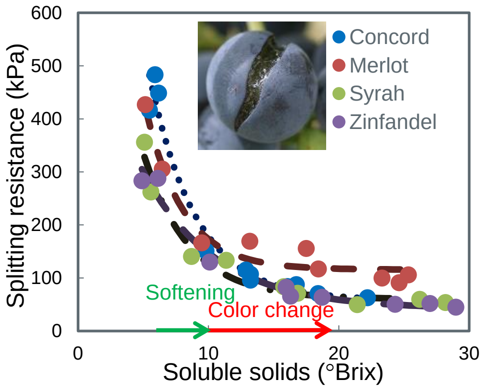
Split happens: Berry splitting due to excess water



Excess water (pre- or postharvest):

→ Berries absorb surface water (rain…)
→ Internal pressure on skin increases
→ Splitting starts from existing microcracks
→ Berries may expand or shrink (weather!)
→ Sugar may leach out during rainfall
→ Higher disease susceptibility (*Botrytis*…)

- Berry splitting resistance drops during initial berry softening
- Splitting due to rainfall, sprinkler irrigation, or high relative humidity (low berry transpiration) before or after harvest (storage, shipping)
- Preveraison drought stress → Higher splitting susceptibility
- Dehydrated berries do not split → Delay harvest after rain

Chang et al. (2019)

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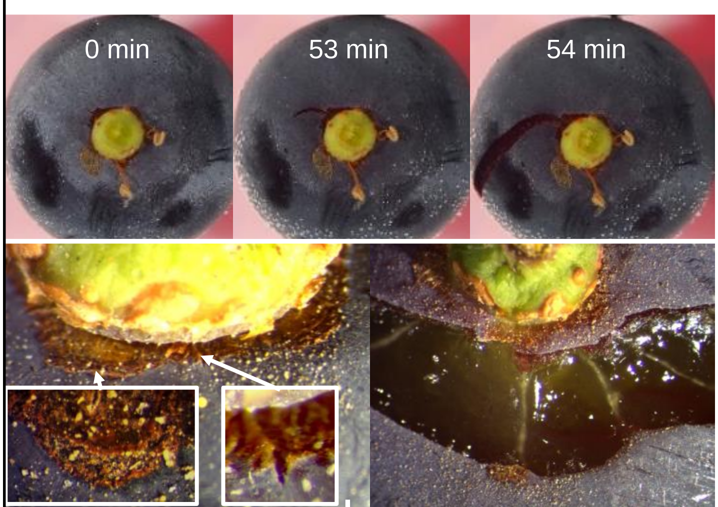
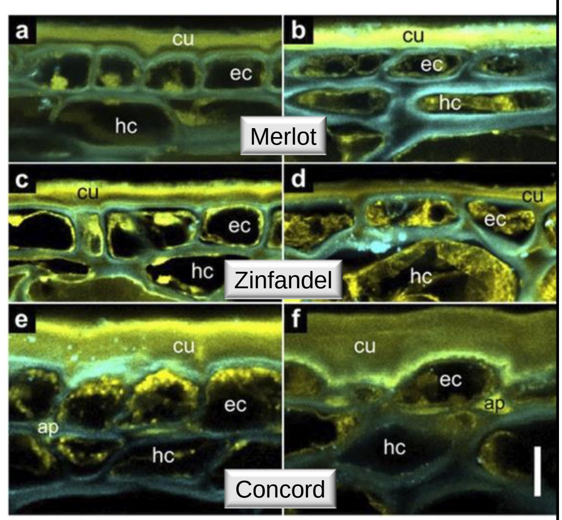
Split happens: Thick skins don't help





- Berry splitting starts from microcracks, slow initially, then sudden disaster
- Skin (cuticle) thickness is not related to splitting susceptibility

Chang and Keller (2021)

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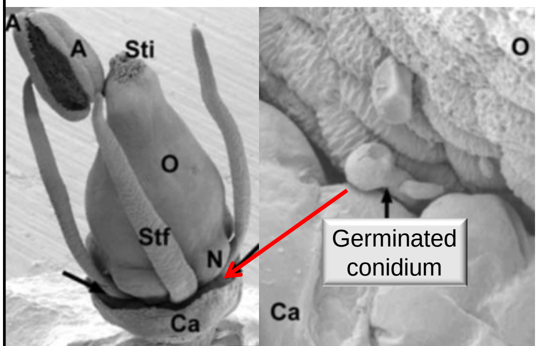
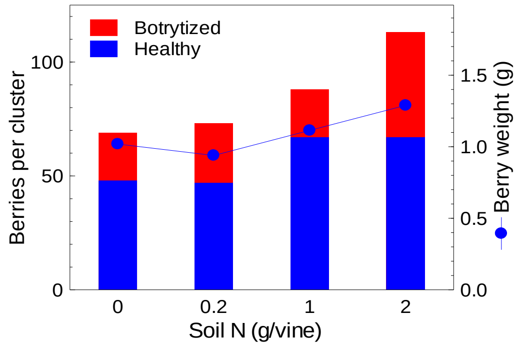
Split happens: Early *Botrytis* control required





- *Botrytis* infects grape flowers through capfall wounds, remains latent inside berries until ripening
- Surface water (rain…) and split berries → Disease outbreaks
- Control *Botrytis* during bloom, remove dead flower debris
- High nitrogen favors *Botrytis* → Avoid high N doses at bloom
- No clear correlation between berry N and *Botrytis*

Keller et al. (2003), Viret et al. (2004)

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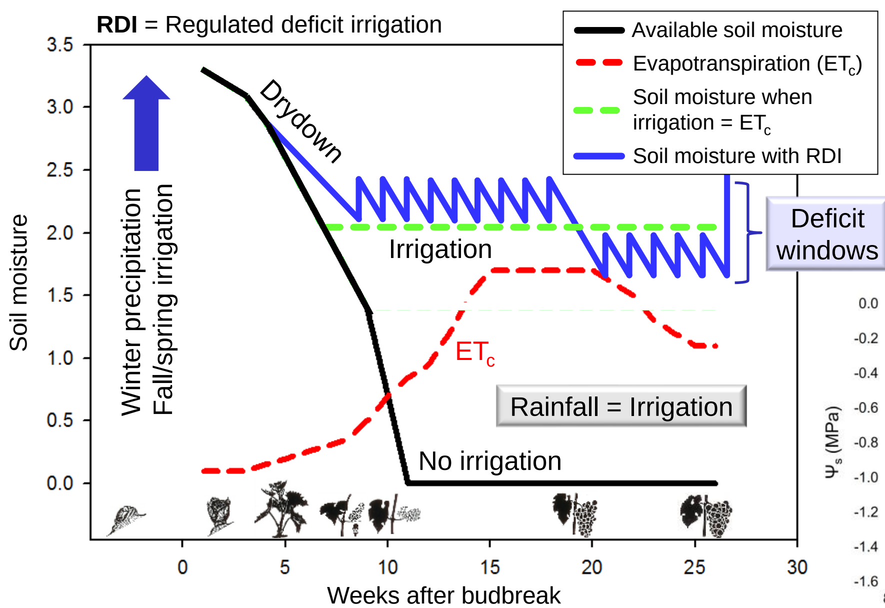
Irrigation: How to RDI for table grapes

RDI = Regulated deficit irrigation

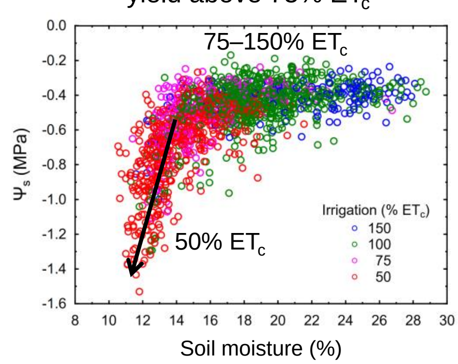


ET_c = Crop or vineyard evapotranspiration = Water evaporation from plants and soil

Ideal irrigation level:

- Preveraison: 75% ET_c
- Postveraison: 50% ET_c

- No gain in vine water status (Ψ), berry size, yield above 75% ET_c



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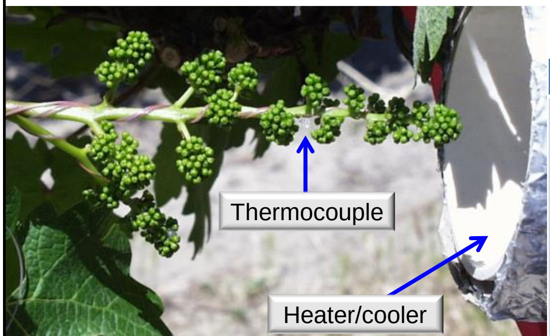
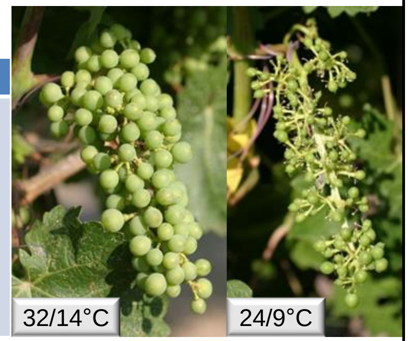
Heat stress: As bad for yield as cold spells



Cabernet Sauvignon

T_{max}/T_{min} (°C)	32/14	24/9
Bloom time (d)	10	24
Fruit set (%)	31	20
Berries/cluster	126	81
Berry wt (g)	1.0	0.8
Cluster wt (g)	130	70
TSS (Brix)	24.8	23.6
TA (g/L)	5.3	7.1
pH	3.63	3.41



- Pollination success and fertilization increase from 10°C to 30°C
- Temperatures <15°C and >40°C inhibit pollen germination and pollen tube growth → Low **fruit set**, live green ovaries ("shot berries"), inflorescence necrosis
- Carryover effect: Low cluster initiation/differentiation → Low **bud fruitfulness**
- Temperatures <15°C and >35°C reduce cell division → Small **berry size**

Keller et al. (2022)

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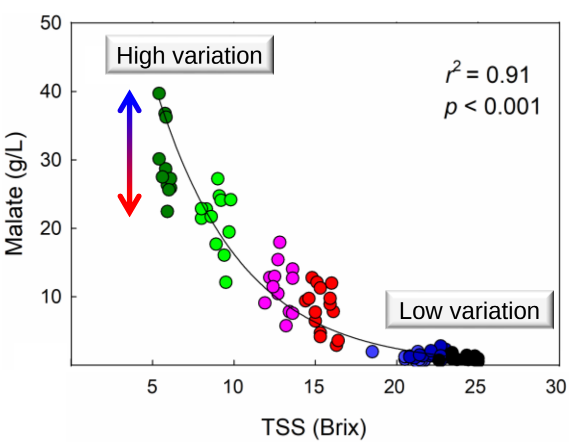
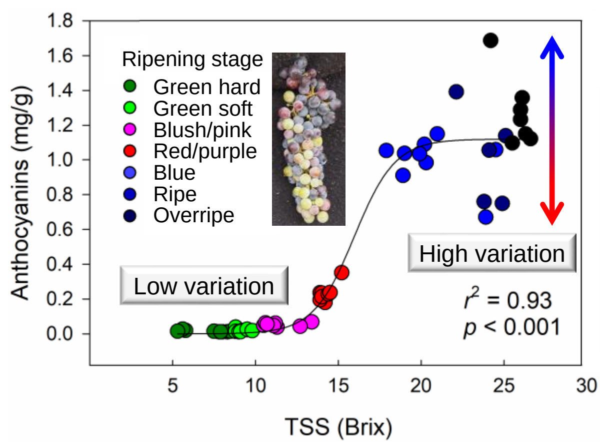
Heat stress: Ripening decoupling?





- **Acidity:** Early **malate** breakdown is driven by ripening and environment
- **Red color:** Early **anthocyanin** accumulation is driven by **sugar** accumulation
  Late **anthocyanin** accumulation/degradation is driven by environment
- More heat (>35°C) → Lower acidity and less color

Hernández-Montes et al. (2021)

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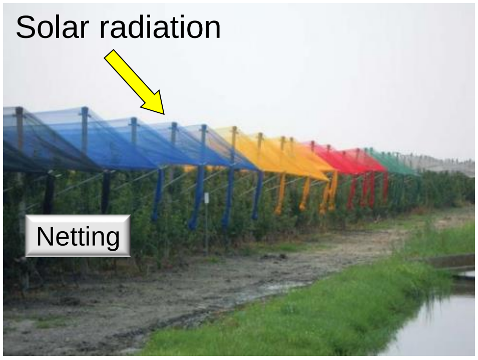
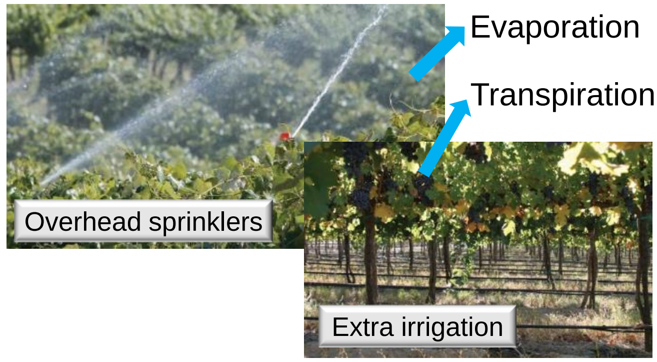
Mitigating heat stress: Dealing with excess solar energy

Block



- Less light → Lower photosynthesis
- Heat trapping
- Not flexible
- Expensive (~$30,000/ha)

Remove



- More water → Deficit irrigation?
- Disease incidence?
- Vigor?
- Berry splitting?

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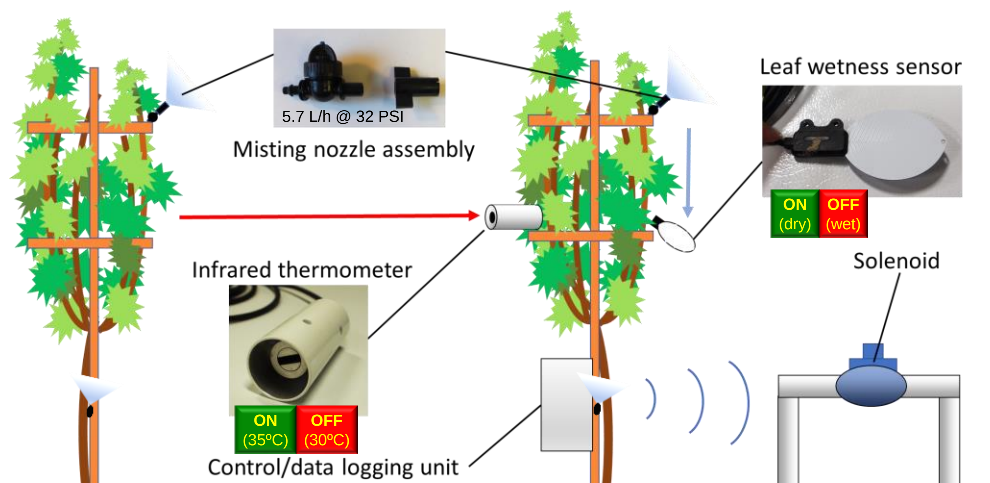
Mitigating heat stress: Mist-type evaporative cooling



- Misting nozzles on drip tube attached to foliage wire or irrigation wire, feedback control maintains temperature, avoids leaf wetness and water runoff
- Canopy temperature maintained around 30–35°C during heatwaves, no effect on disease incidence, yield, TSS, methoxypyrazines, but higher TA and lower pH and tannins

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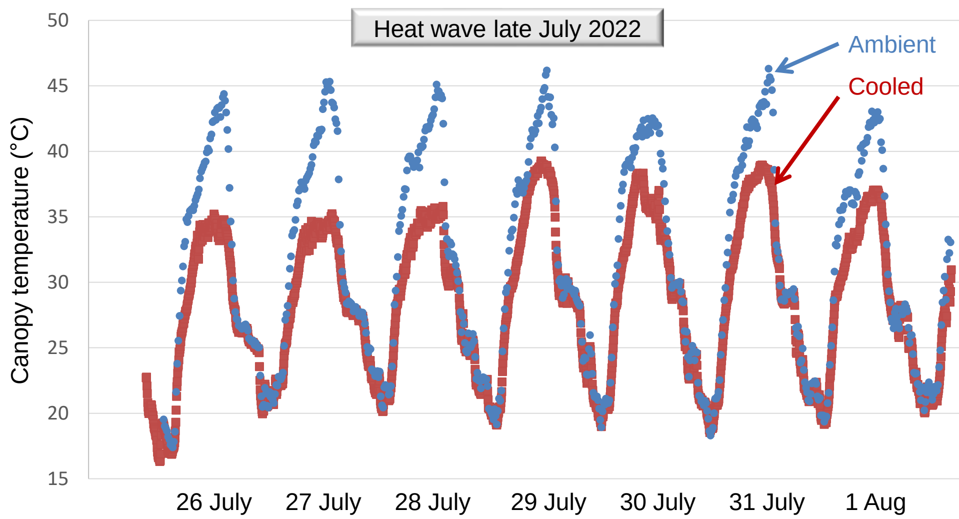
Mitigating heat stress by canopy/fruit zone cooling



- **5–10°C** reduction in canopy (fruit zone) temperature during July 2022 heatwave
- Water use ~1 mm/day (10 m^3/ha)

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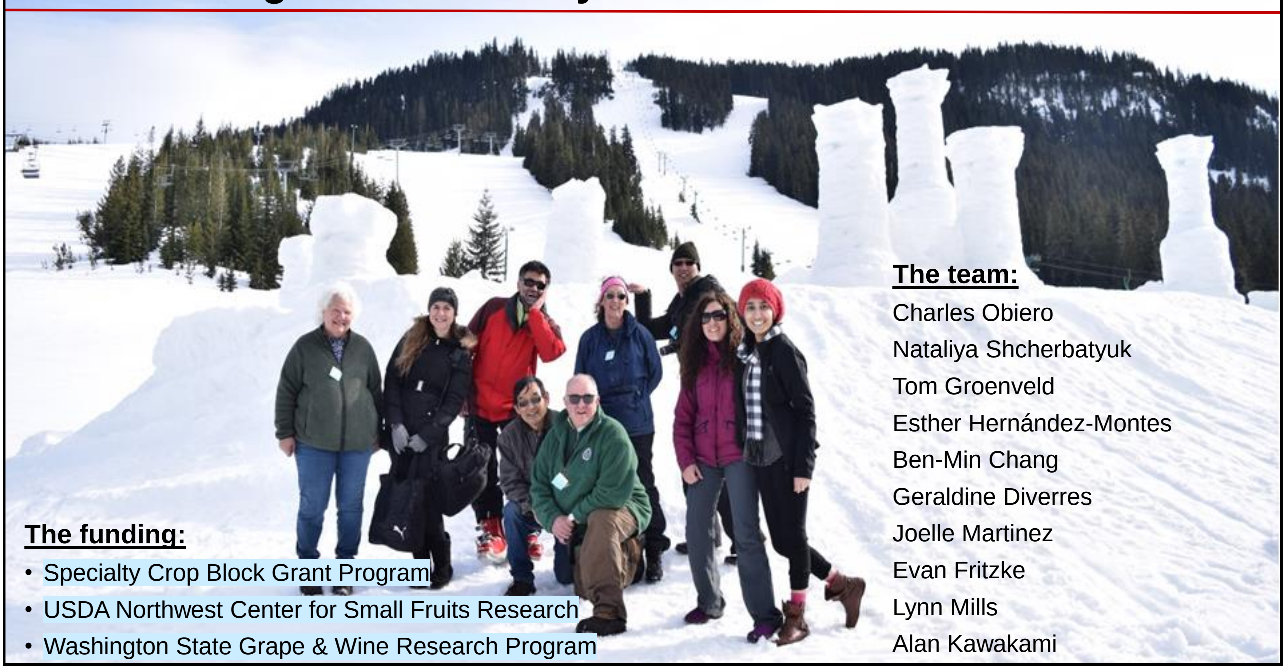
Acknowledgments: Thank you!



The team:

Charles Obiero
Nataliya Shcherbatyuk
Tom Groenveld
Esther Hernández-Montes
Ben-Min Chang
Geraldine Diverres
Joelle Martinez
Evan Fritzke
Lynn Mills
Alan Kawakami

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