HORTICULTURE AND LANDSCAPE ARCHITECTURE
COLORADO STATE UNIVERSITY

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January 20, 2022

Orchard & Environmental Factors Affecting Peach Productivity & Harvest Quality

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Cold damage of floral tissues is the biggest single limitation to profitability of the Colorado tree-fruit industry

HORTICULTURE AND LANDSCAPE ARCHITECTURE
COLORADO STATE UNIVERSITY

April 14, 2020
T_{min}=-5.9°C

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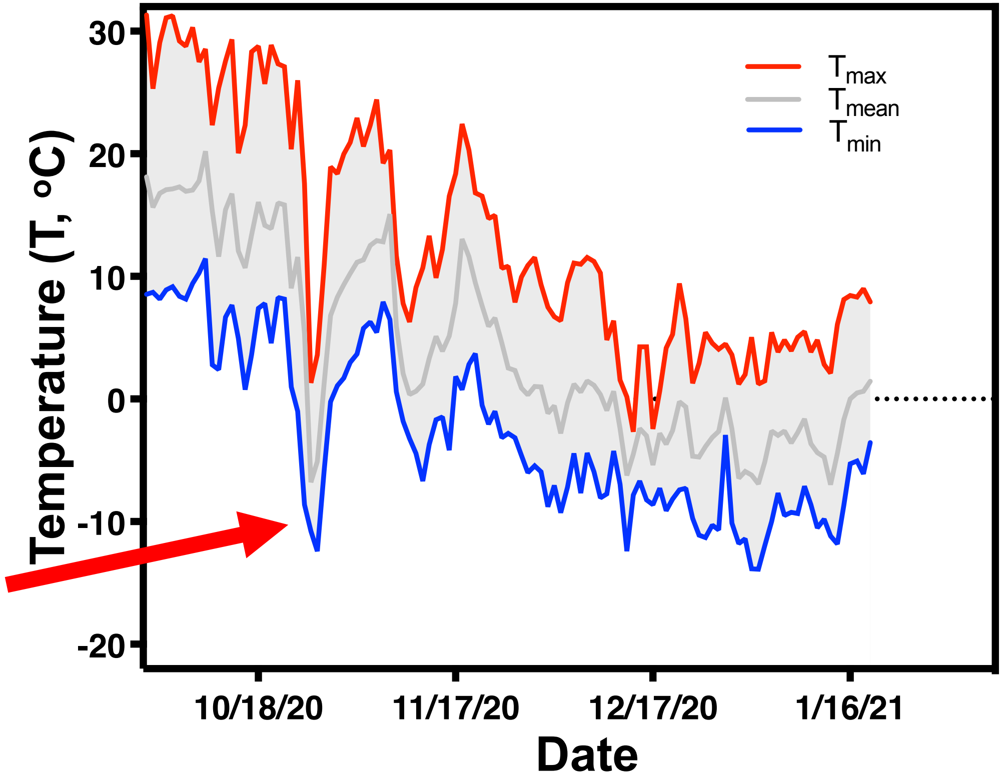
Cold damage during fall 2020



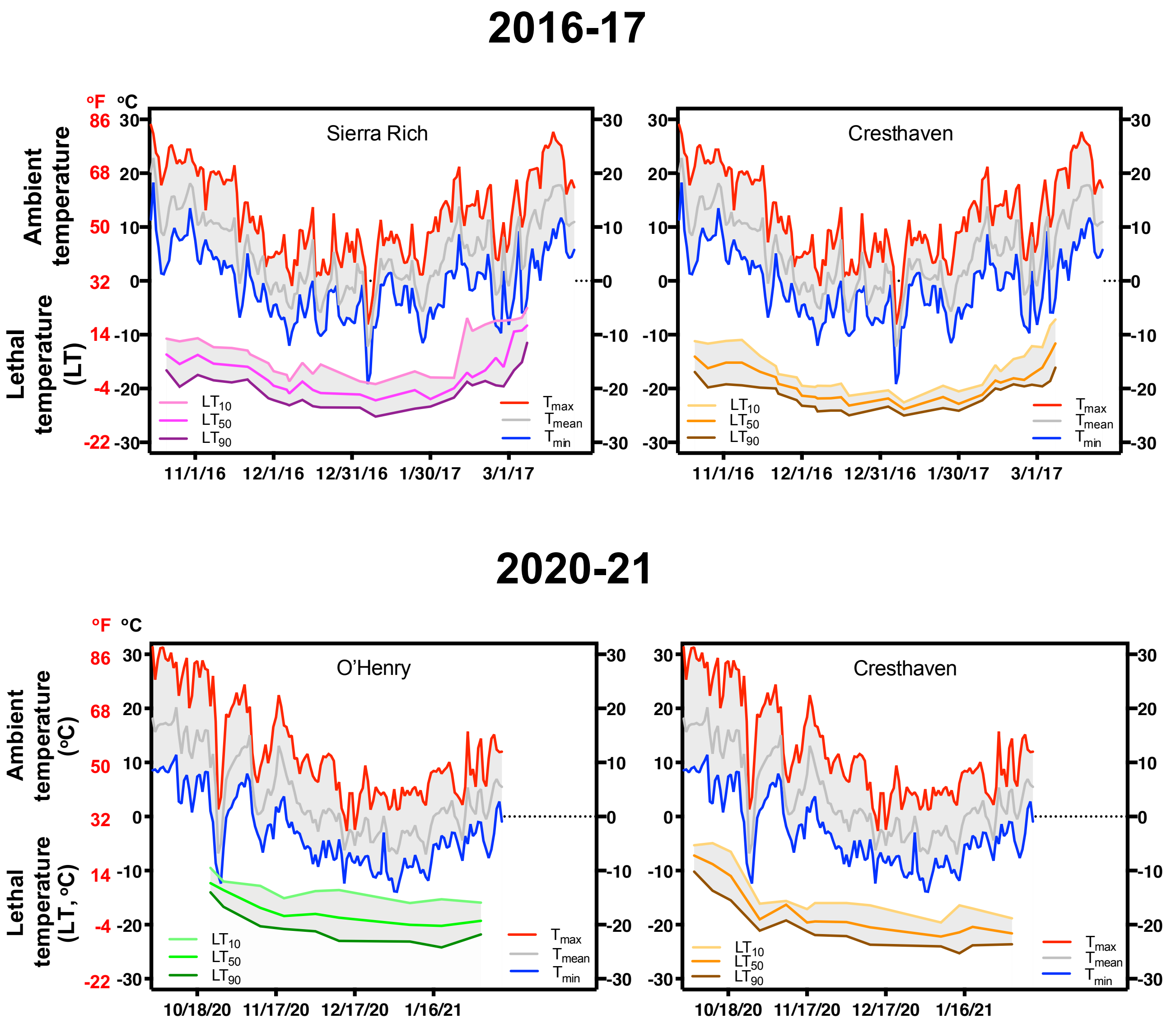
10/26/2020: -10.6°C (13°F)

10/27/2020: -12.4°C (9.7°F)

*windy nights and no inversion

Cold damage during fall 2020 - Acclimation

- Acclimation a genotype x climate x management equation
- Peach acclimation mainly related to chilling and freezing events in fall
- Most cultivars coming from cold breeding programs are very good in acclimation in response to freeze
- Cultivars coming from warm breeding programs do not respond to freeze
- No freeze signal to the plants to acclimate in fall 2020
- Vegetative vs floral tissue acclimation?



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Range of Tissue Damage

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- Trees didn't receive adequate chilling before the frost
- Cambial and xylem damage
- Potential disease (e.g. Cytospora or bacterial canker) vulnerability

*These shoots looked similar from the outside

Gummosis in Wood Damage

- Increased young shoot gummosis seen, especially in cultivars displaying woody tissue browning
- Bark cracking, often leading to gummosis

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Whole Tree Damage

Shoots, scaffolds and trees with previous cankers collapsed often

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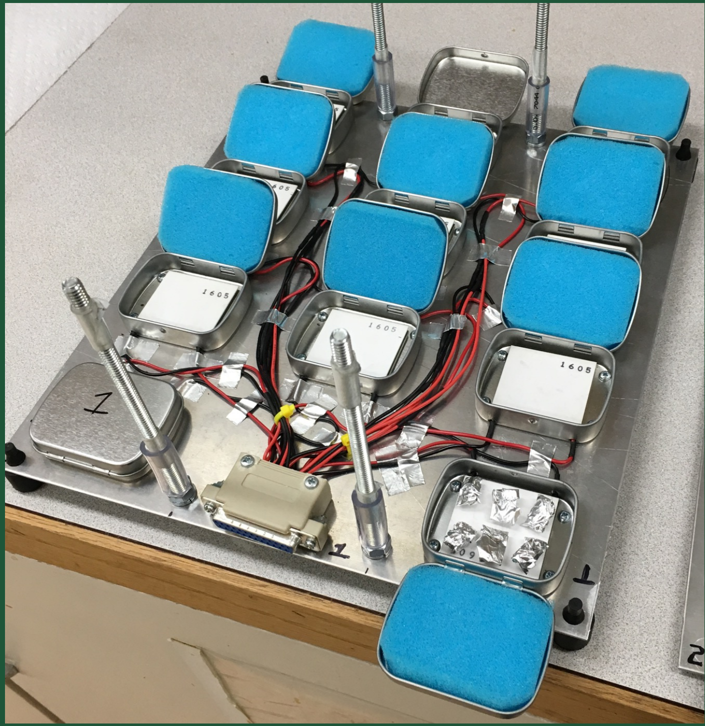
Can we develop reliable tools to determine lethal temperatures of peach floral buds precisely?

- Differential Thermal Analysis (DTA)
- Monitors difference in temperature between a sample and a reference thermocouple
- Thermoelectric modules (TEMs) detect temperature gradients (exotherms) generated by the freezing floral parts (method described by Mills et al., 2006)

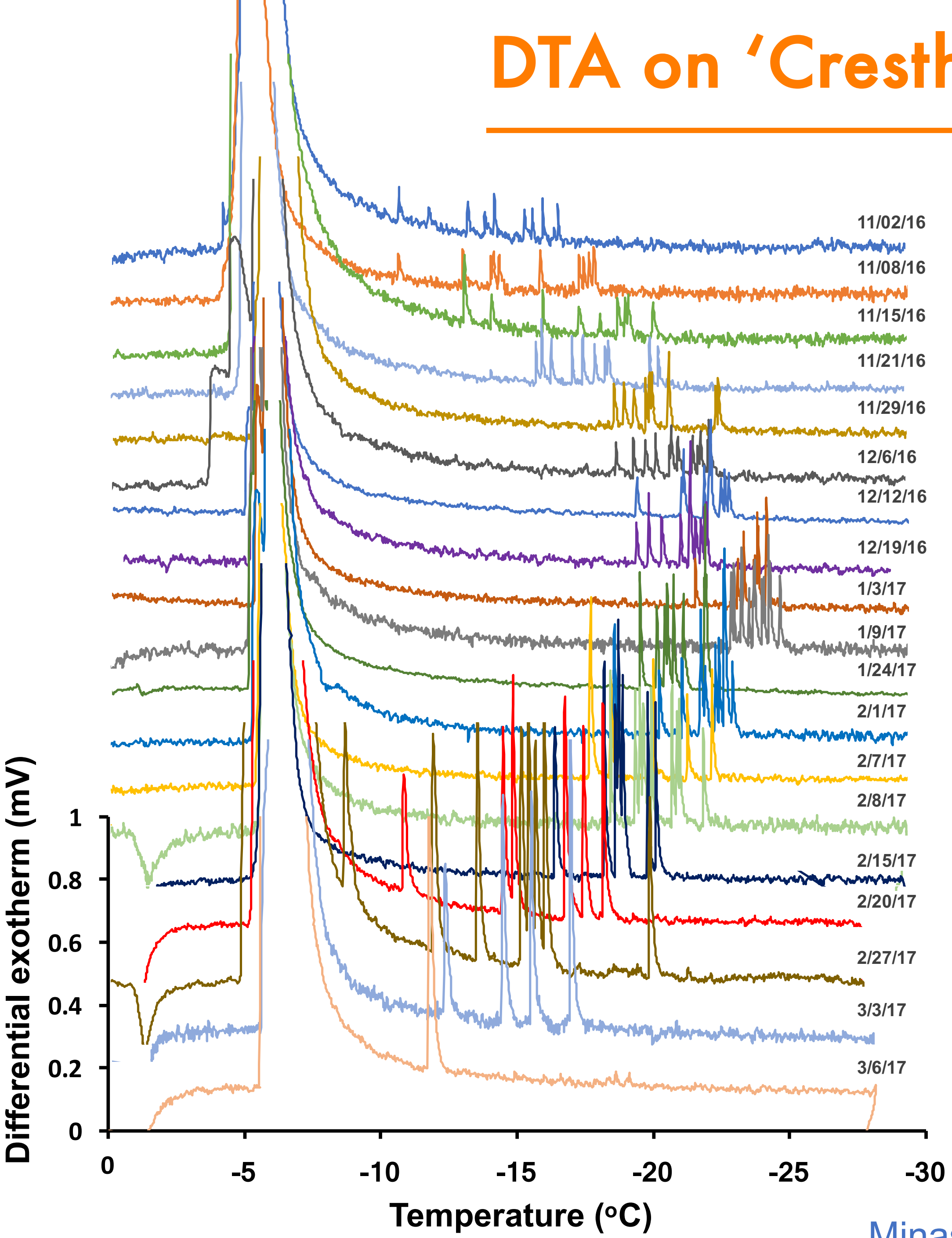
Minas & Sterle. 2020. Acta Hortic. 1281, 385-392

10-12 peach buds per TEM



10 replicated TEMs plus one reference

DTA on 'Cresthaven' floral buds



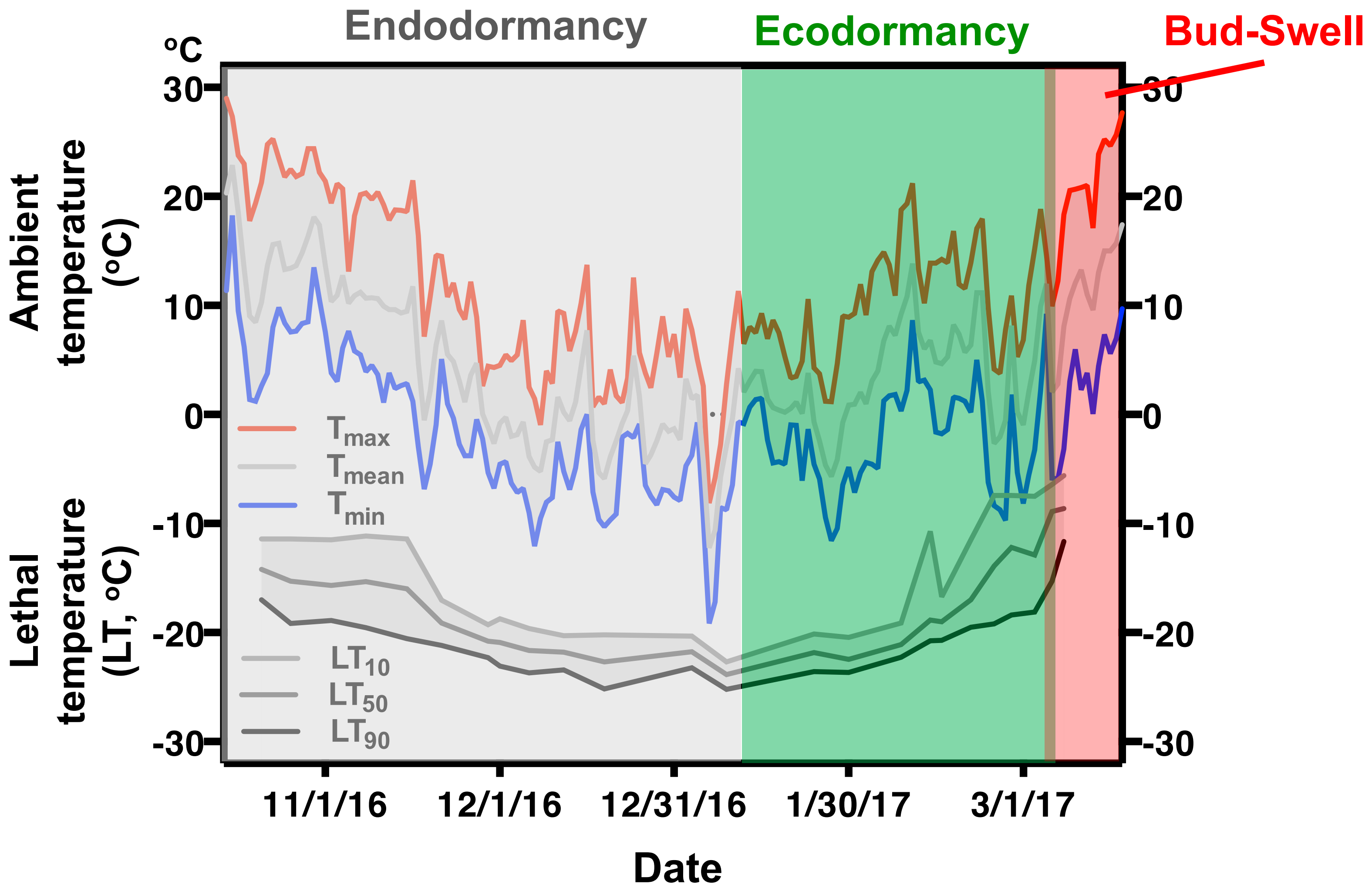
Acclimation: the gradual increase of cold hardiness
(Fall – Dec 6th, 2016)

Maximum Hardiness
(Dec 12th - Feb 1st, 2017)

De-acclimation: the decrease of cold hardiness towards bud break
(Feb 7nd - March 6rd, 2017)

Minas & Sterle. 2020. Acta Hortic. 1281, 385-392

‘Redhaven’ peach floral bud cold hardiness



Seasonal patterns of temperature and cold hardiness (expressed as lethal temperature, LT) for ‘Redhaven’ peach floral buds

Dormancy phases as described by Lang, 1987. HortScience 22, 817–820

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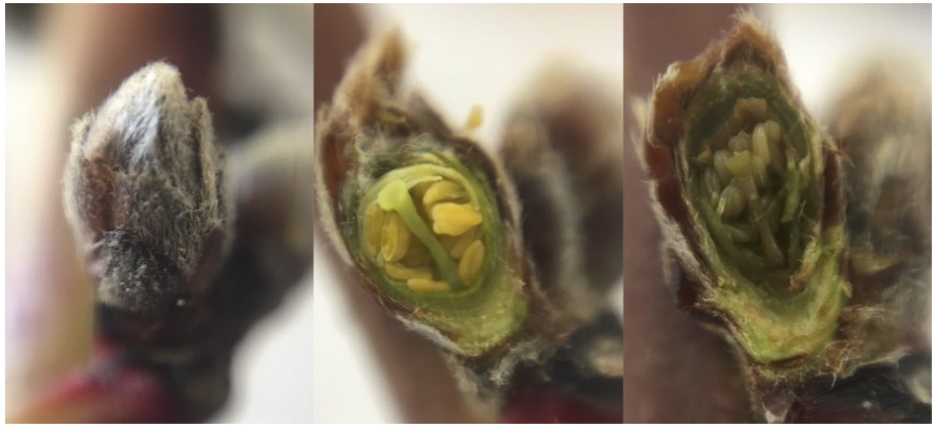
Peach bud cold hardiness monitoring updates

http://minas.agsci.colostate.edu/tree-fruit-information/cold-hardiness/

Cold Hardiness



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Peach Floral Bud Cold Hardiness Updates

Cold hardiness update 2020-21 | Chilling hours/portions | Cold hardiness updates 2019-20 | 2018-19 Updates | 2017-18 Updates | 2016-17 Updates | Critical Phenological Temperatures

Peach floral bud cold hardiness update #21 02_03_21

Data from the last dormant seasons (2016-2021) on peach cold hardiness, chilling accumulation & critical phenological temperatures

Effect of Rootstock on ‘Red Haven’ peach floral buds acclimation, max hardiness & deacclimation (2017-18)

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	Atlas	Bright's Hybrid-5	Guardian®	Krymsk®86	Lovell	Krymsk®1	Date
LT_{10}	-14.9	-14.9	-14.4	-13.8	-15.4	-15.4	11/6/17
	-16.6	-16.7	-17.8	-15.4	-14.9	-17.0	11/17/17
	-18.4	-16.7	-17.8	-18.6	-18.7	-17.9	11/28/17
	-18.3	-19.0	-16.9	-15.3	-19.2	-18.1	12/14/17
	-19.3	-18.2	-17.5	-21.0	-16.8	-18.3	1/4/18
	-13.8	-15.0	-12.7	-18.4	-15.3	-8.2	1/24/18
	-6.2	-7.0	-6.5	-6.5	-6.4	-6.4	2/14/18
LT_{50}	-18.1	-17.1	-18.2	-18.2	-17.2	-17.8	11/6/17
	-19.3	-19.0	-19.5	-19.4	-18.6	-19.0	11/17/17
	-19.8	-19.6	-19.6	-19.9	-20.0	-19.9	11/28/17
	-20.4	-21.1	-21.3	-21.5	-21.0	-20.2	12/14/17
	-22.6	-22.3	-22.5	-22.9	-21.5	-21.9	1/4/18
	-20.5	-22.2	-22.7	-22.6	-22.6	-21.0	1/24/18
	-17.8	-19.0	-18.2	-18.9	-19.4	-18.2	2/14/18
LT_{90}	-19.1	-18.8	-20.1	-19.8	-19.5	-19.4	11/6/17
	-20.1	-20.8	-20.2	-20.8	-20.4	-20.0	11/17/17
	-20.9	-21.2	-21.4	-20.6	-21.1	-20.9	11/28/17
	-22.1	-22.0	-22.5	-22.1	-22.4	-21.8	12/14/17
	-23.5	-23.7	-24.1	-23.9	-23.8	-21.9	1/4/18
	-23.0	-23.8	-23.7	-23.6	-23.6	-23.3	1/24/18
	-20.9	-21.4	-20.9	-21.3	-20.9	-21.0	2/14/18

NC-140

2009 NC-140 Red Haven Peach Rootstock Trial

Least hardy: Atlas and Krymsk®1
Most hardy: Guardian, Krymsk 86

Early acclimation: Guardian®, Lovell
Late acclimation: Krymsk®86, Atlas, BH-5

Late deacclimation: Krymsk®86

Cold Hardy Cultivars Evaluation Trial

More information:
Today @ 2:30 PM
CSU Showcase

David Sterle

We are using DTA to acquire large data sets in order to fully characterize the seasonal changes in hardiness across 13 peach cultivars that:

1. Cover different harvest times
2. Defend against hardiness using multiple hardiness strategies (ie. delayed bloom, earlier acclimation, or mid-winter hardiness)

California Bred Cultivars | ***Michigan Bred Cultivars***

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Notice variety of sizes and colors

Dormant Season 2020-21 Cold Hardiness Data (LT_{50})

	Galaxy Donut	New Haven	Starfire	Glowingstar	Blushingstar	O'Henry	PF-24C	PF-23	Suncrest	PF-19007	Glohaven	Red Haven	Date
Floral bud	-13.0	-12.6	-13.8	-10.8	-12.8	-12.3	-12.1	-13.4	-15.3	-12.2	-13.7	-13.6	10/23/2020
	-16.6	-14.5	-14.9		-16.0	-16.3	-14.5	-18.6	-18.3	-16.4	-17.8	-16.5	10/28/2020
		-17.9	-18.6	-17.5	-18.5	-16.9	-16.6	-19.4	-18.4	-18.5	-19.0	-18.1	11/11/2020
	-18.2	-19.8	-20.5	-19.7	-20.1	-20.4	-20.5	-21.7	-21.3	-21.3	-21.4	-21.4	12/8/2020
	-19.0	-18.8	-19.9	-17.7	-18.6	-19.0	-20.6	-21.0	-21.5	-21.0	-20.4	-20.6	12/29/2020
	-19.9	-20.2	-21.0	-20.3	-20.7	-19.9	-21.2	-21.0	-22.5	-20.8	-20.9	-22.1	1/21/2021
	-19.3	-20.5	-21.4	-22.2	-19.9	-21.4	-22.6	-20.4	-20.1	-20.2	-21.8	-22.2	2/23/2021
	-17.9	-18.4	-19.3	-18.1	-18.4	-18.6	-19.4	-19.5	-20.1	-19.1	-19.6	-20.0	Average
Bloom date	8-Apr	14-Apr	10-Apr	10-Apr	10-Apr	9-Apr	9-Apr	9-Apr	8-Apr	10-Apr	9-Apr	9-Apr	Bloom date
Mid shoot Damage	0%	20%	14%	45%	18%	52%	25%	38%	15%	48%	32%	27%	Mid shoot Damage

Tender — **Hardy**

Fail in bud acclimation before extreme freeze was associated with shoot browning

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Forcing Early Fall Acclimation Using Abscisic Acid (ABA)

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Yellowing after 5 days

ABA (PGR)

Control

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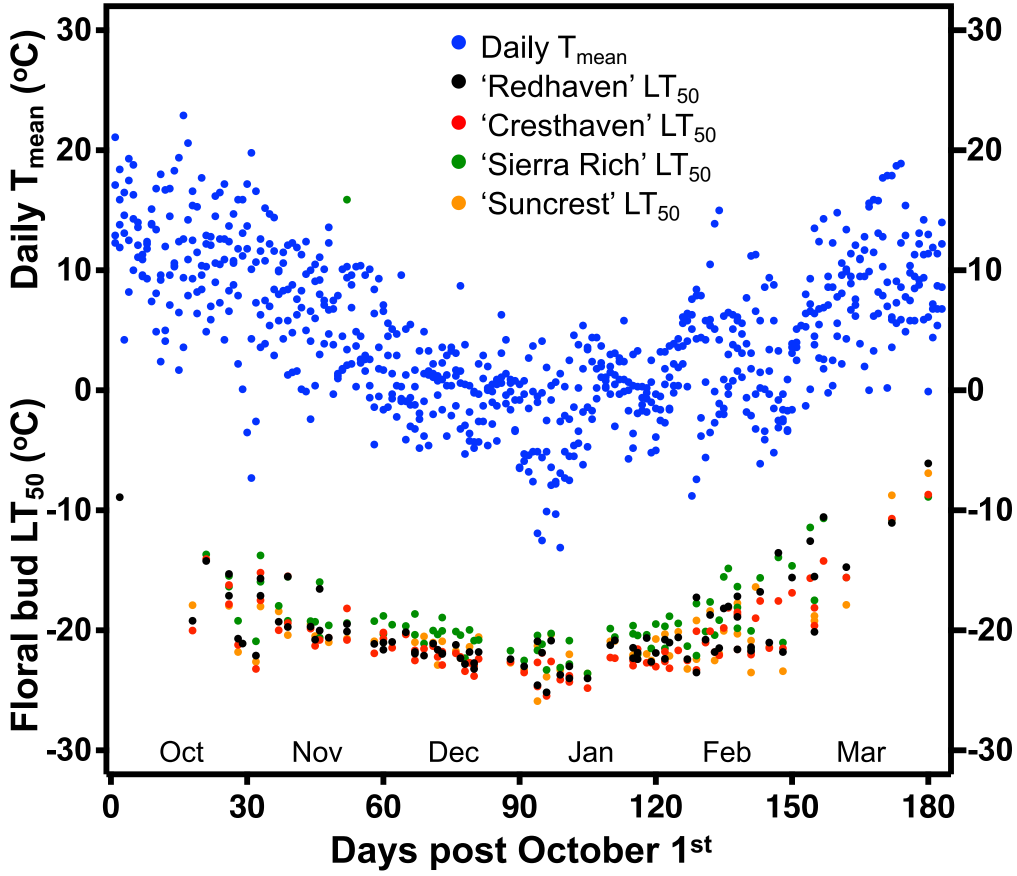
ABA Treatments Sprayed in October

- ABA stopped photosynthesis and caused leaf yellowing in 2 days and increased hardiness for the following 1 week to 2 weeks

Can we develop accurate cold hardiness prediction models based on thermal and weather data?

- DTA (LT) and weather data collected over 4 dormant seasons (2016-20)
  - ~6000 lethal events per cultivar
  - 80 time points per cultivar (each comprised of 75 LTs)
- Models were validated by randomly selected data in a ratio of 2:1 for training data to validation data
- Standard least squares with an iterative approach to compared models with different variables
- Favored models which had low error in validation with the least number of variables
- Frost control methods can only raise temps to 1-2 °C (need low error in H_c prediction)



Sterle et al., 2021. *Submitted to Environmental & Experimental Botany.*

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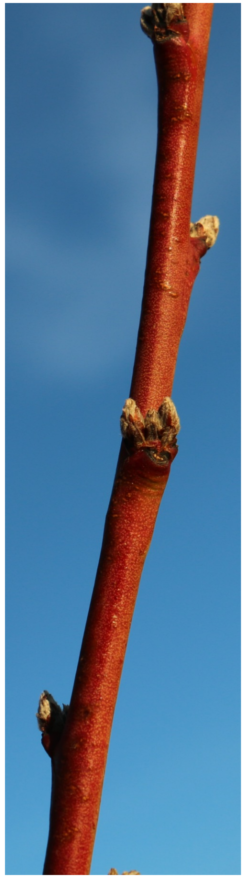
Different models for the different phases of dormancy



Endo- and ecodormancy models were created using data from predictor variables that were separated by place-holder at a point of chill satisfaction

- $T_{min,1-4}$ (recent climate history)
- Photoperiod (seasonal progression)
- Interaction: ($T_{min,1-4}$ and photoperiod)

- $T_{max,1-4}$ (recent climate history)
- GDD >0 (GDD_0, seasonal progression)
- Date post October 1st (seasonal progr.)
- Interaction : (GDD>0 x $T_{max,1-4}$)

Endodormancy — **Ecodormancy** — **Full bloom**

October — DPO_{EDB} — **Chill Satisfaction** (700 chilling hours @ 0-7 °C) — April

DPO_{EDB}, days past October that EDB was reached
EBD, endodormancy barrier
Chill Satisfaction = EDB

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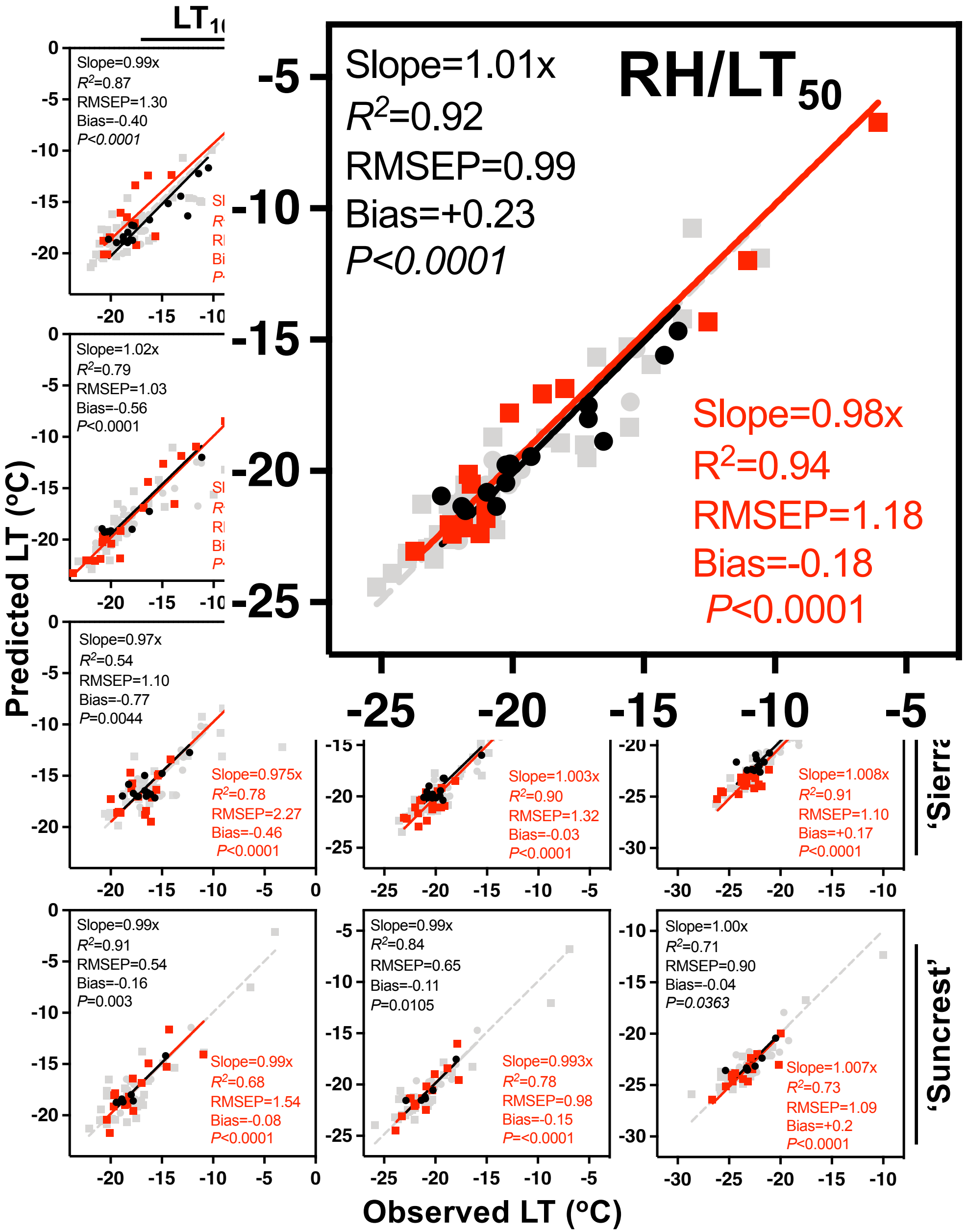
Model prediction performance



- LT_{50} + LT_{90} are predicted very accurately
- RMSEP= error (°C)
  - Low error
- Endodormancy black
- Ecodormancy red

Sterle et al., 2021. *Submitted to Environmental & Experimental Botany*

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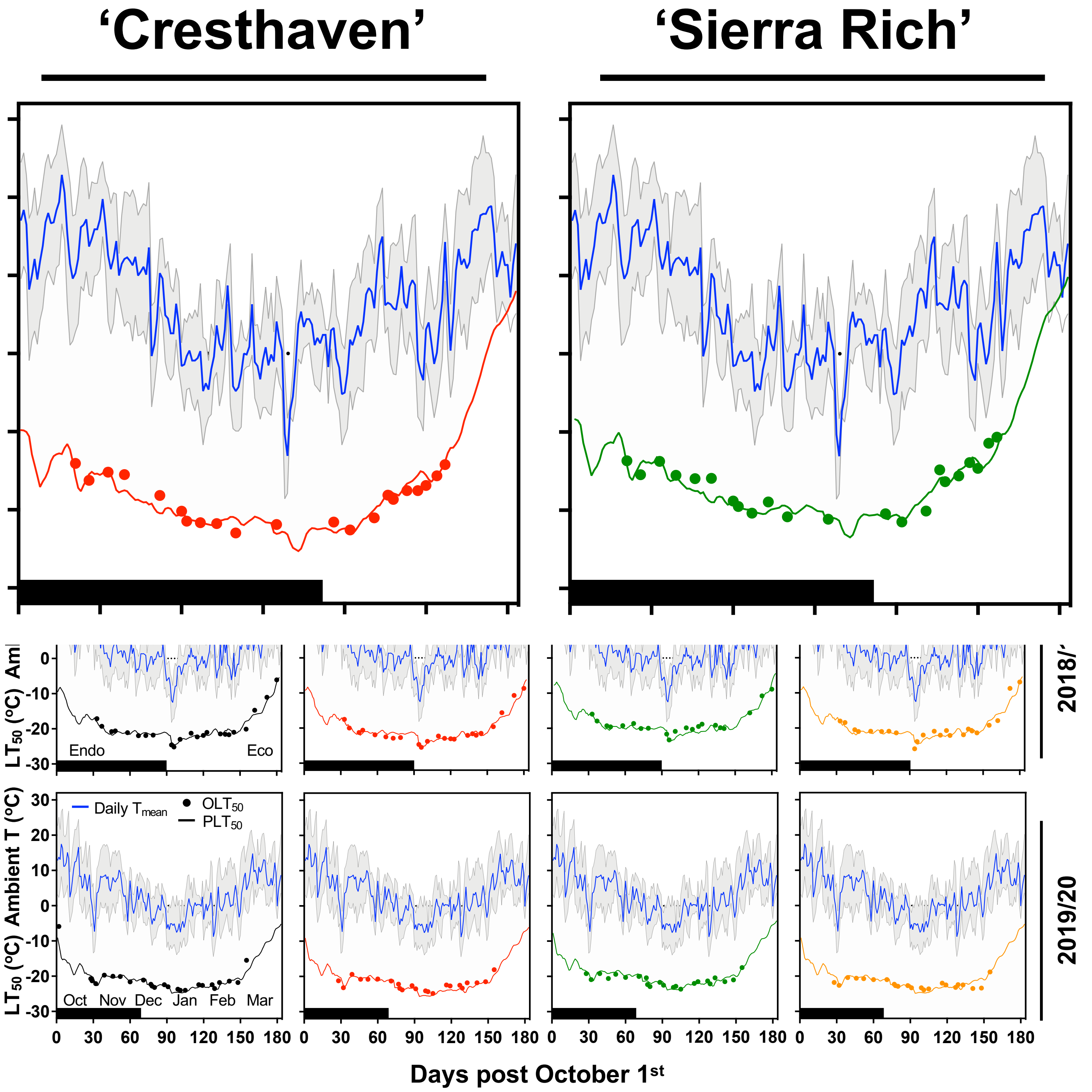
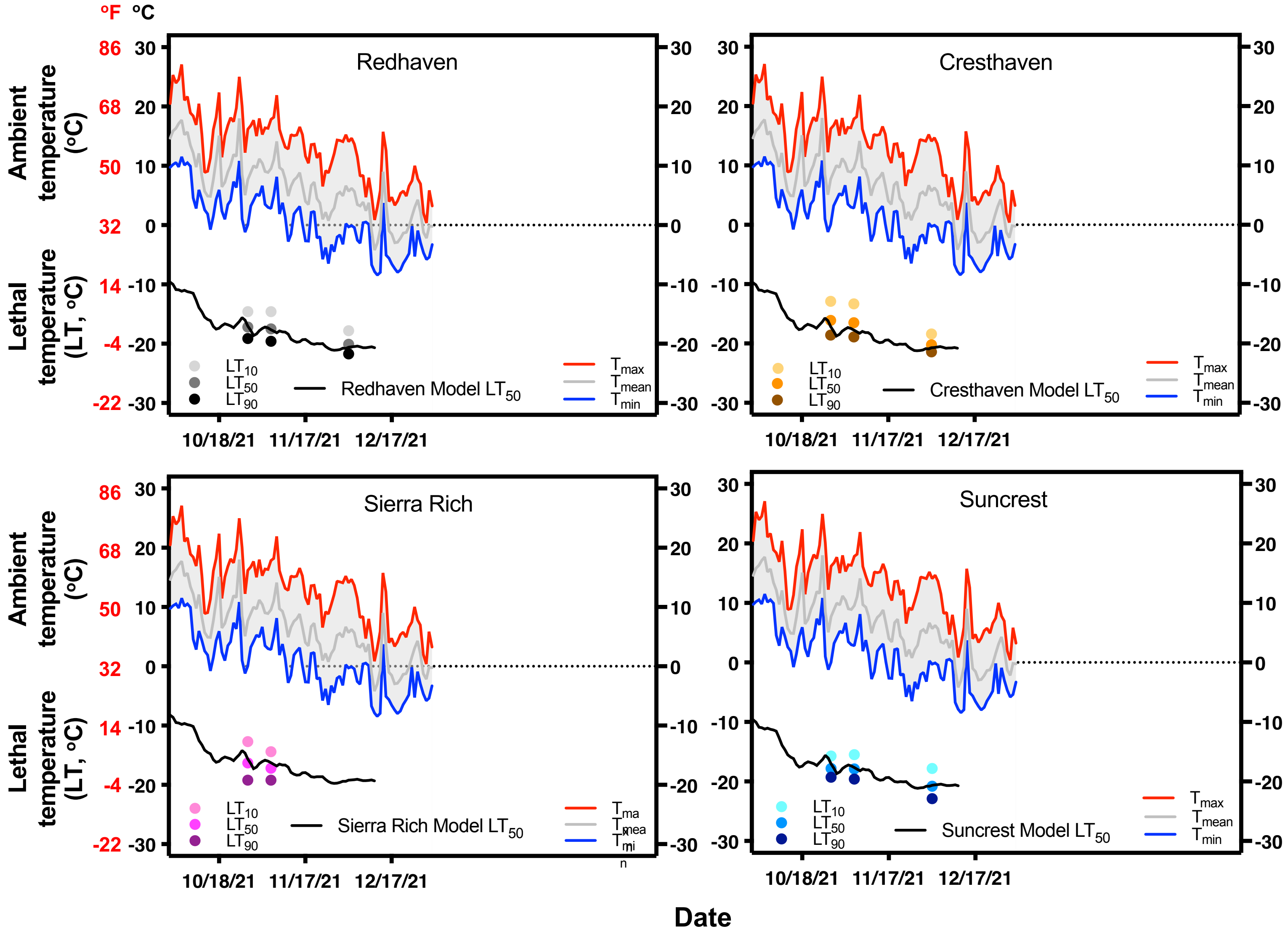
Seasonal Prediction Curves



Sterle et al., 2021. *Submitted to Environmental & Experimental Botany*

Using Developed Models to Predict Current Cold Hardiness (2021-22)



Sterle et al., 2021. *Submitted to Environmental & Experimental Botany*

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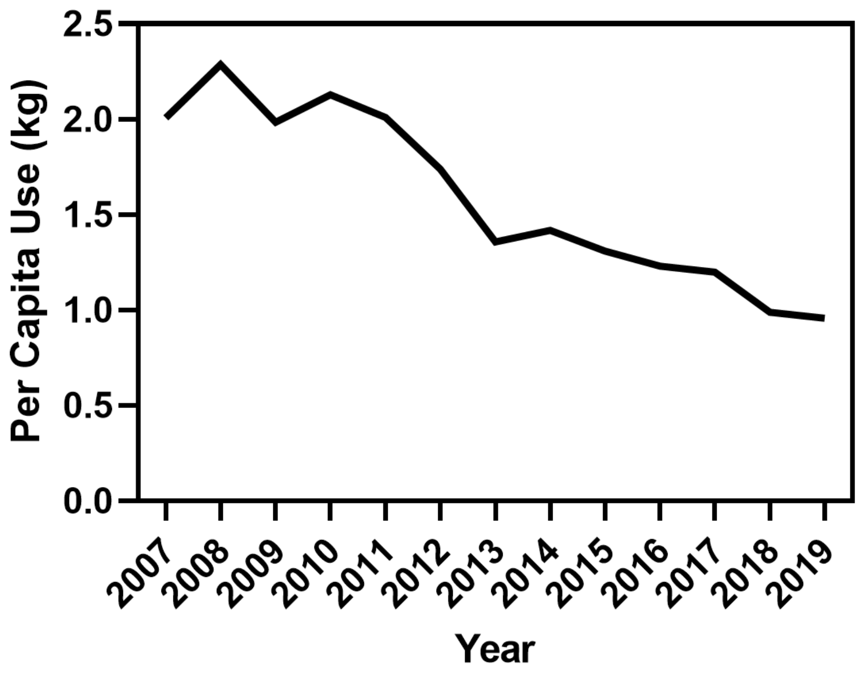
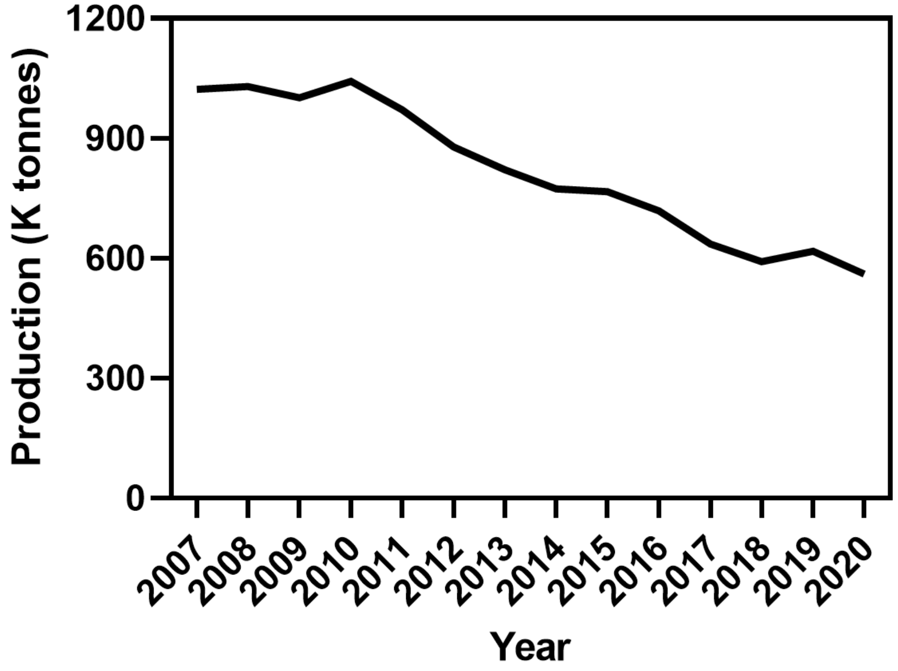
Peach per capita use in USA reduced between 2007 – 2020

- Consumption is falling
- 1.3 kg/capita in 2020



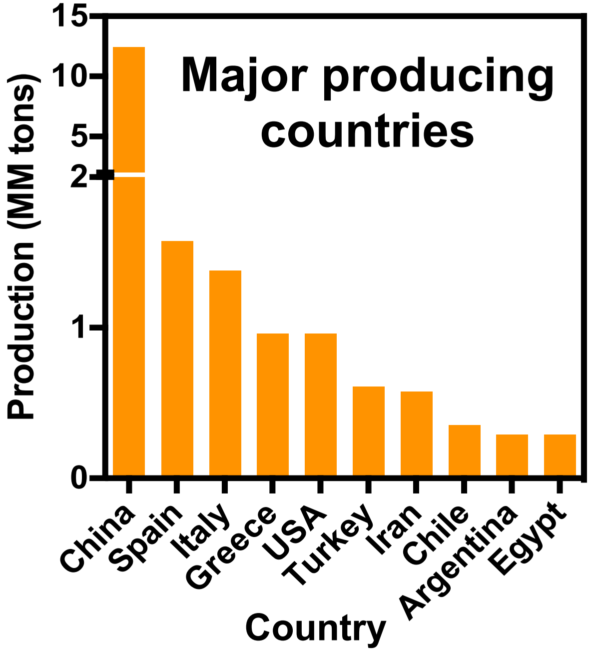
Peach and nectarine production distribution per utilization in US

- Production is falling
- Poor peach quality
- Labor costs increasing

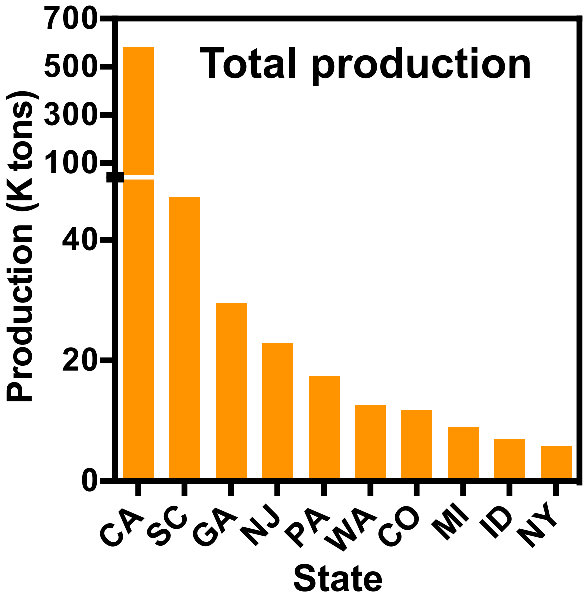


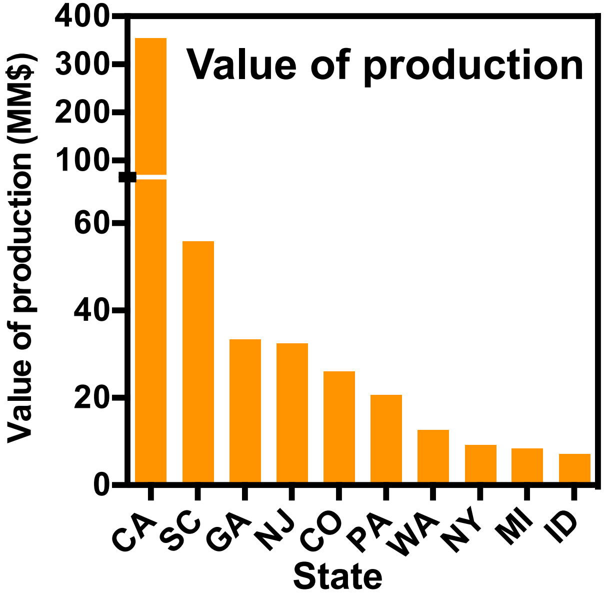
(USDA-NASS, 2017; 2019)

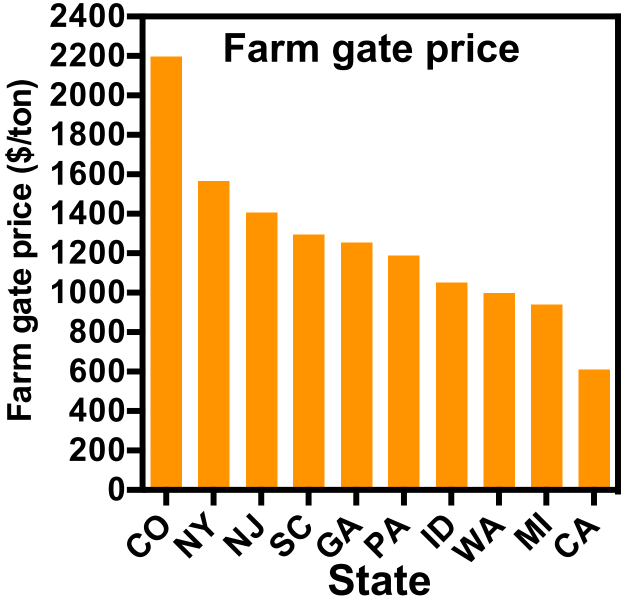
Peach & nectarine production in the world and US



Major producing states in USA*



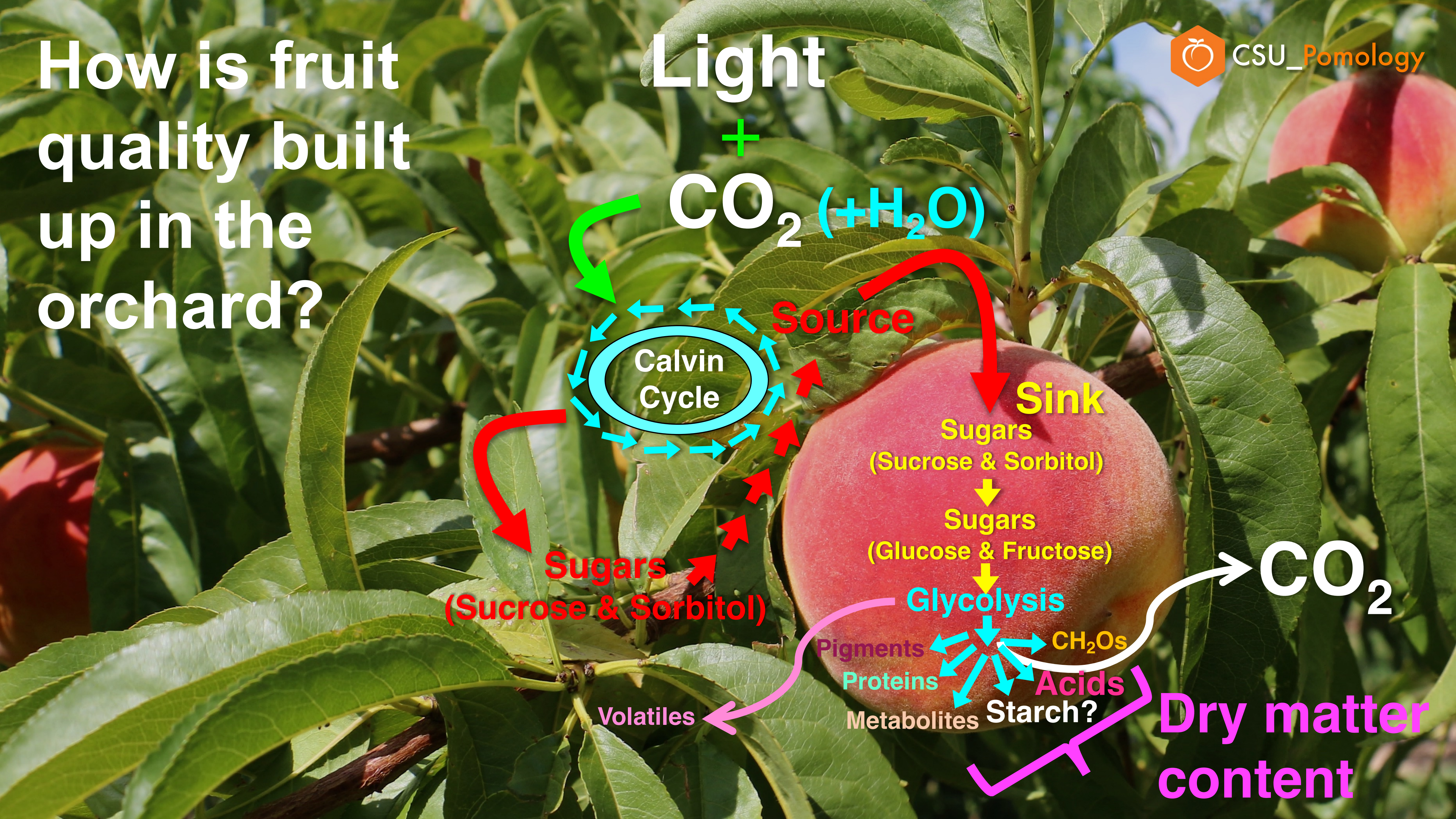




- National ‘farm gate’ avg. price = $1.2/kg
- Colorado ‘farm gate’ avg. price = $2.2/kg
    - $1 difference = ~$15 million (*quality premium*)

***Average values of 2014-17**

Source: FAO, 2019; USDA-NASS, 2019


How is fruit quality built up in the orchard?
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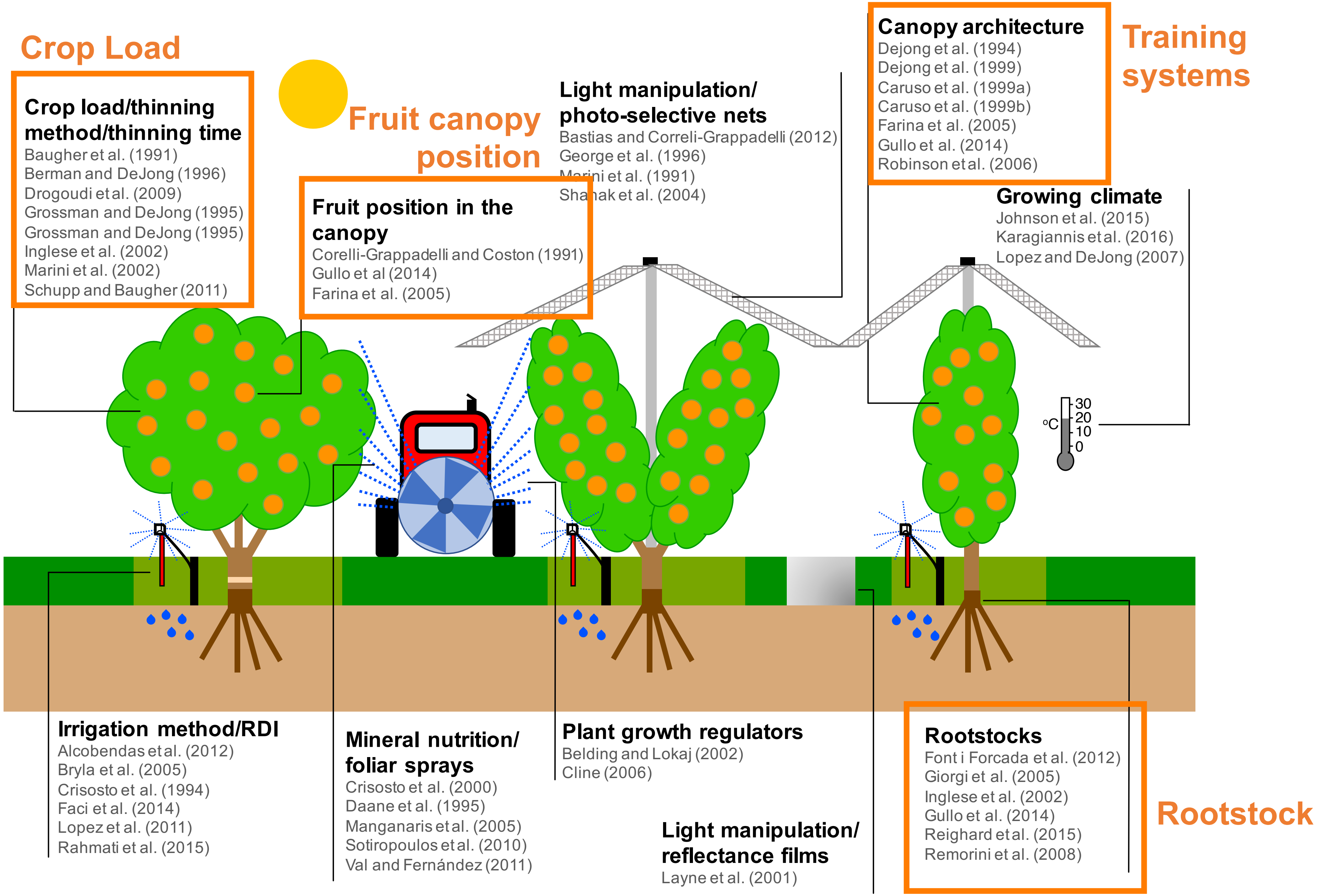
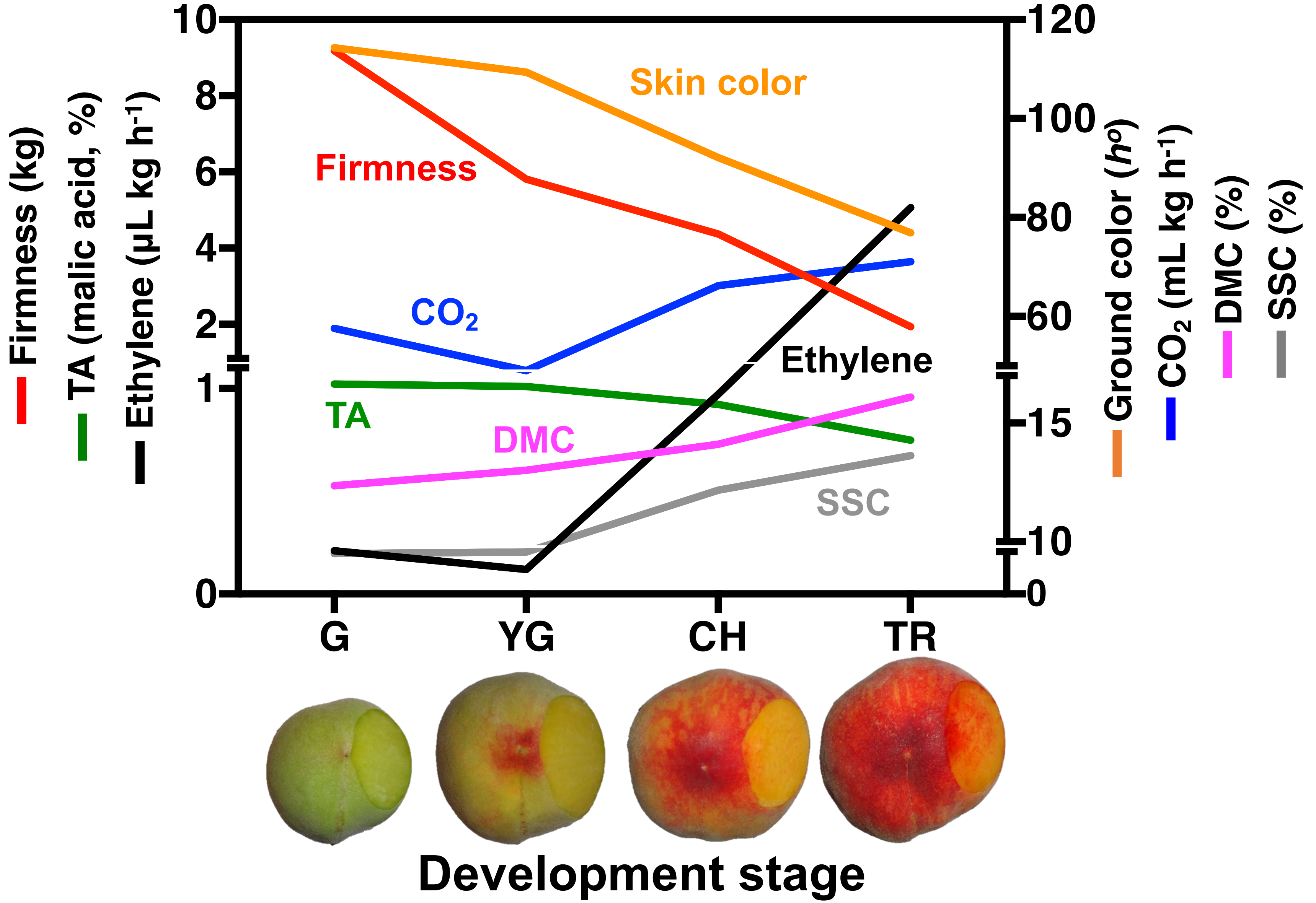
Light
+
CO_2 $(+H_2O)$
Calvin Cycle
Source
Sink
Sugars
(Sucrose & Sorbitol)
Sugars
(Glucose & Fructose)
Glycolysis
CH_2Os
Pigments
Proteins
Acids
Metabolites
Starch?
Volatiles
Sugars
(Sucrose & Sorbitol)
CO_2
Dry matter content

Pre-harvest factors affecting peach fruit quality



Reviewed by Minas et al., 2018. Scientia Horticulturae 235, 307–322

Quality changes during 'June Gold' peach fruit development & ripening on-tree



Fruit quality and maturity assessment methods are destructive and labor intensive

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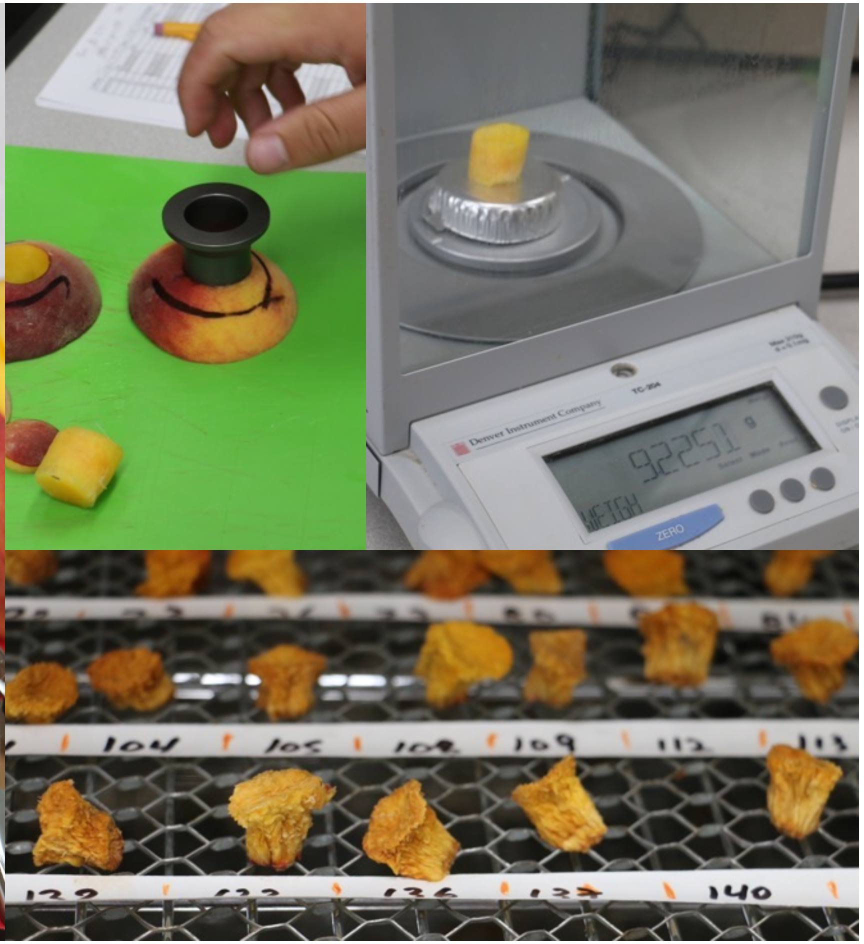
Flesh Firmness (FF)
'maturity' &
'shipment/storage potential'

Soluble Solids Concentration (SSC)
'sweetness'

Dry Matter Content (DMC)
'sweetness' &
'consumer acceptance'



Development of non-destructive technologies to estimate internal fruit quality

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Handheld non-destructive sensors to estimate internal fruit quality and maturity in the field

✓ **Analysis of larger fruit volumes to understand the effect of pre-harvest factors**

F-750 Produce Quality Meter
Near-Infrared Spectroscopy (NIR)

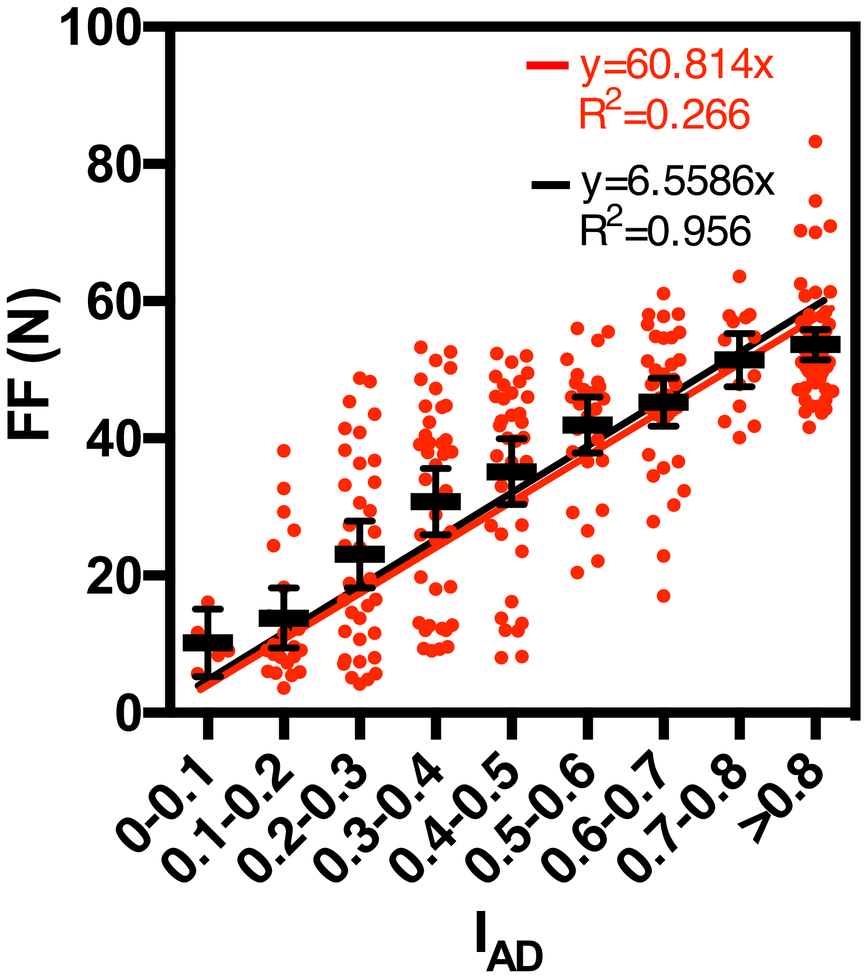
DA-meter
Vis/NIR

- "Open" type instrument (on-site calibration)
- **DMC and SSC at 729-935 nm**
- Three online measurements at the same time (2 displayed)

- **Costa et al., 2009**
- "Closed" type instrument (calibrated at the factory)
- **Index of Absorbance Difference (I_{AD})**
- **$I_{AD}=A_{670nm}-A_{720nm}$ (chlorophyll content)**
- **Fruit physiological maturity**

I_{AD} correlates with FF in 'Sierra Rich' peach only when I_{AD} values are plotted in clusters *(but describes physiological maturity better)*

FF



I_{AD}

(Minas et al., 2021)

Accurate non-destructive prediction of peach fruit internal quality and physiological maturity with a single scan using Vis-NIRS

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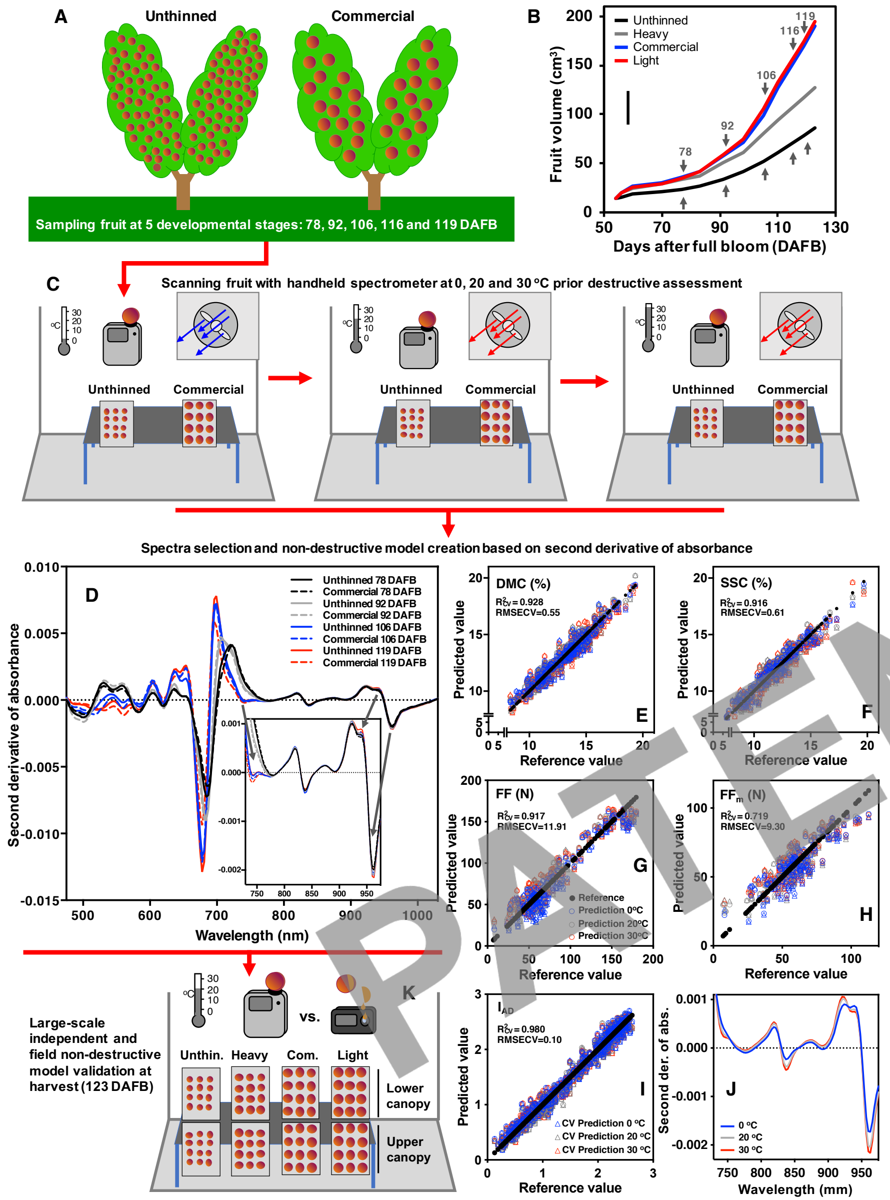
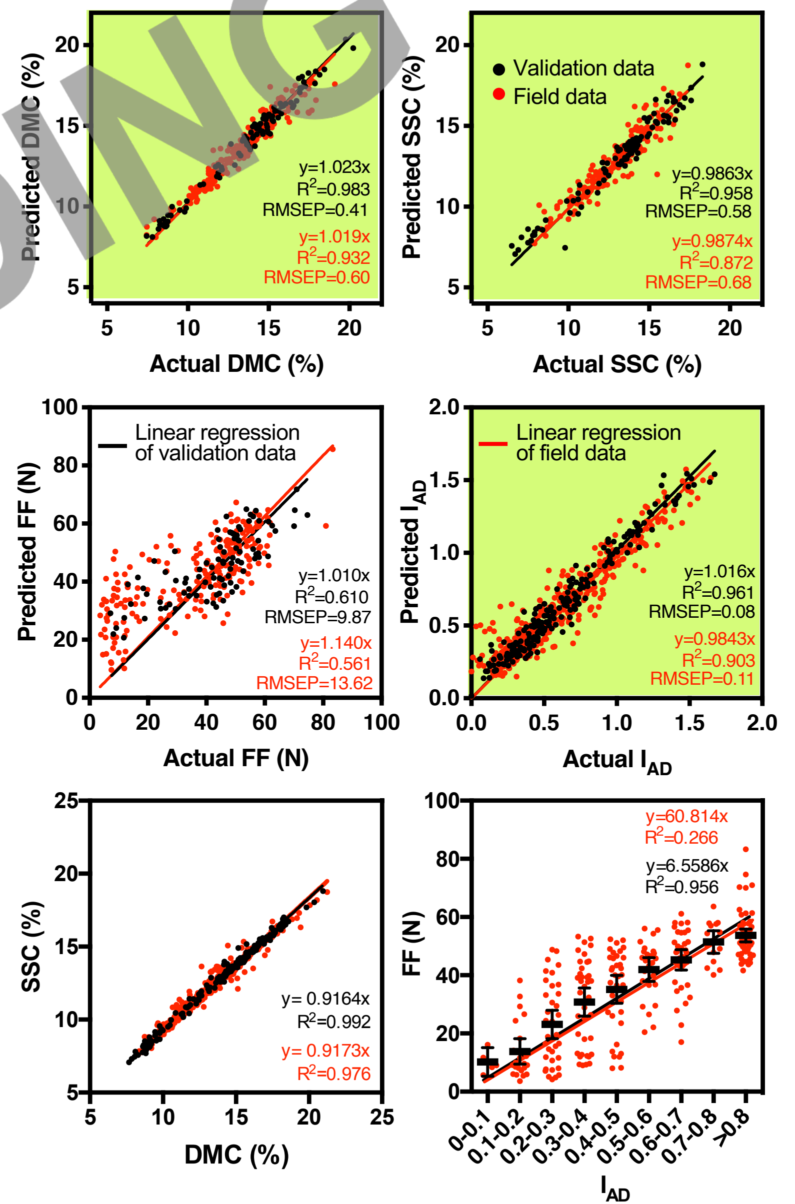


- Novel Vis-NIRS calibration protocol resulted in accurate regression models of peach quality and maturity
- DMC, SSC and I_{AD} can be predicted with a single scan to assess the true orchard impact on peach quality
- A novel concept device can assess peach quality and maturity during fruit growth, development and at harvest in the field and during postharvest
- This calibration protocol and concept device can enhance NIRS utilization across tree fruit supply chain

Minas et al, 2021. Accurate non-destructive prediction of peach fruit internal quality and physiological maturity with a single scan using near infrared spectroscopy. Food Chemistry 335, 127626.



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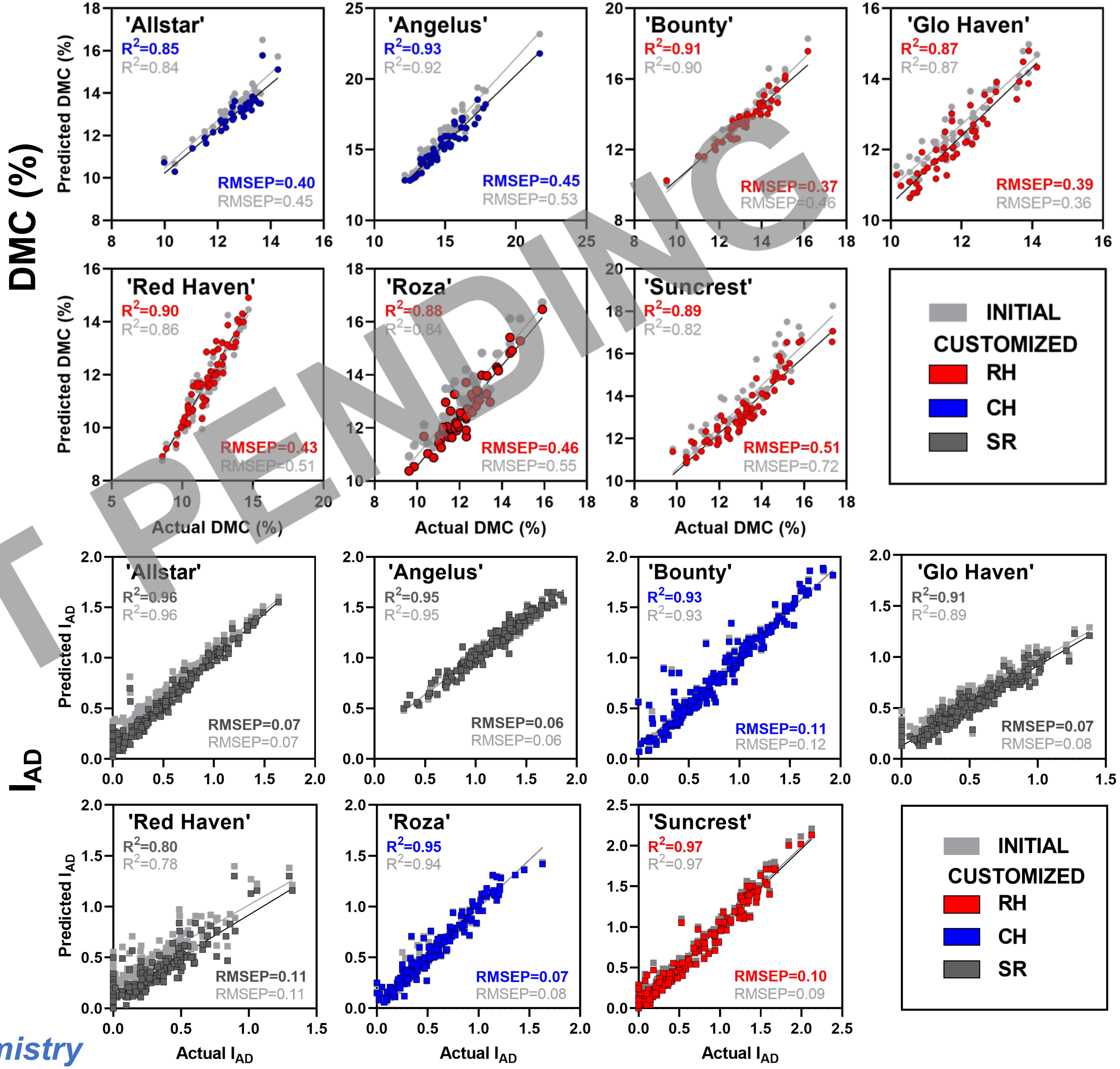
Technology Readiness Level: 5

Proof of concept-real world demonstration stage

Developed models of the concept device are showing strong performance with multiple peach cultivars



Anthony et al, 2022. *Submitted in Food Chemistry*

Cultivar Evaluation: 13 Cultivars of variable harvest date assessed for quality at three ripeness stages in 2021

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‘Redhaven’

‘Galaxy’*

‘Newhaven’

‘Starfire’

‘Glohaven’

‘PF-19’

‘Suncrest’

‘Glowingstar’

‘Blushingstar’*

‘PF-23’

‘PF-24C’

‘Angelus’

‘O’Henry’

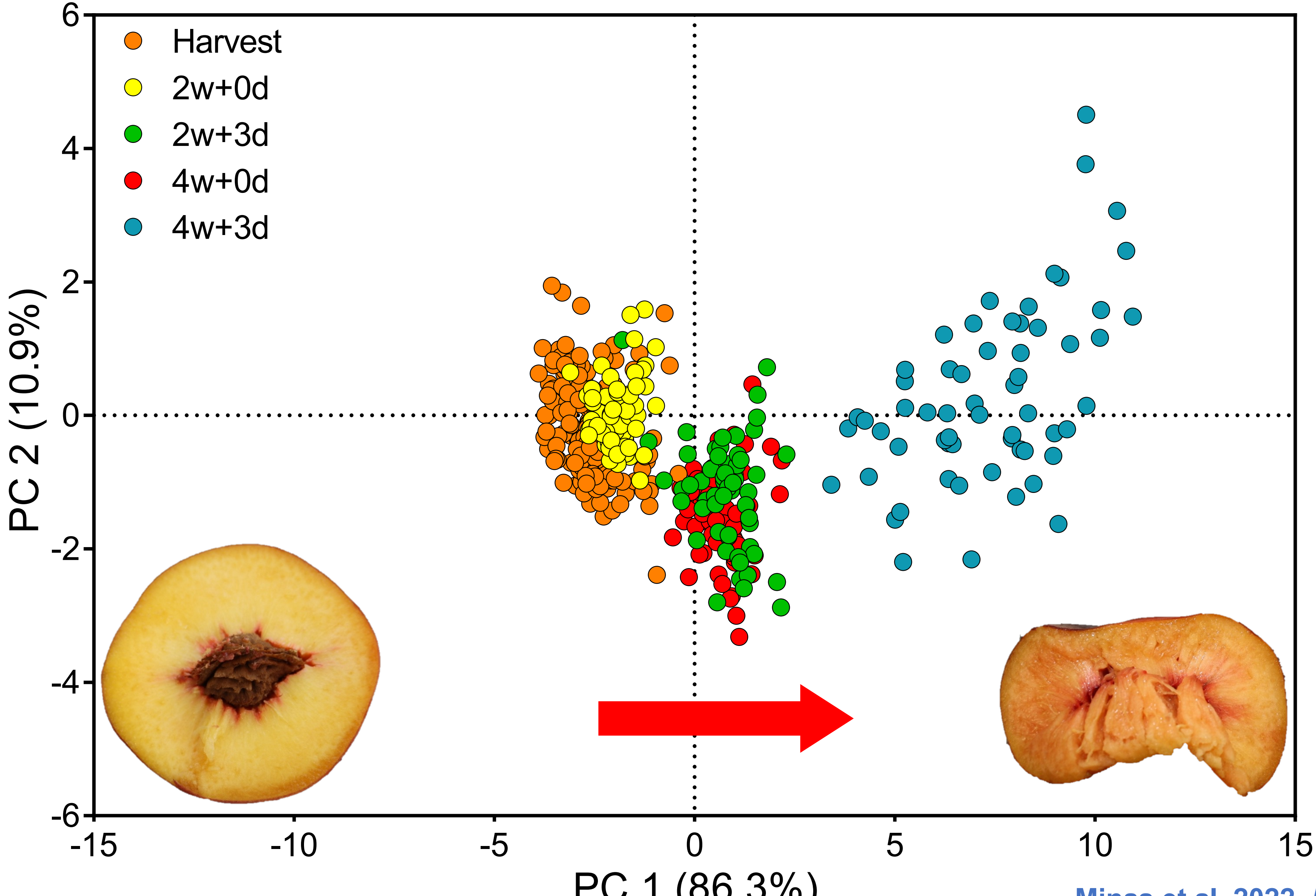
Today @ 2:30 PM – CSU Showcase

Jake Pott

Pott et al, 2022. *In preparation*

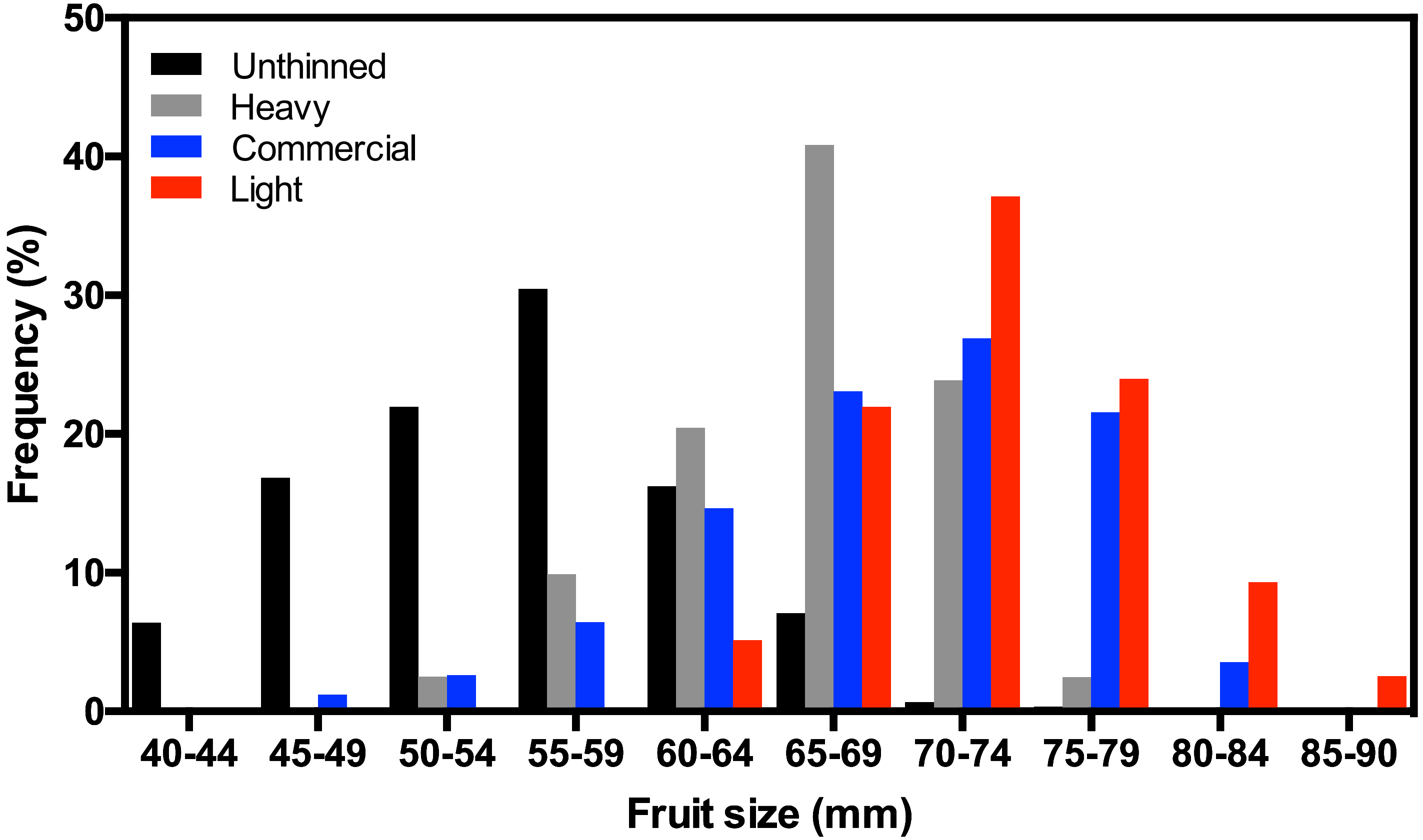
*white flesh

Use of NIR spectral data to predict chilling injury (CI) symptoms development that damage consumer quality



Minas et al, 2022. *In preparation*

Effect of crop load on ‘Sierra Rich’ peach fruit size at harvest



Unthinned Heavy Commercial Light

(Minas et al., 2021)

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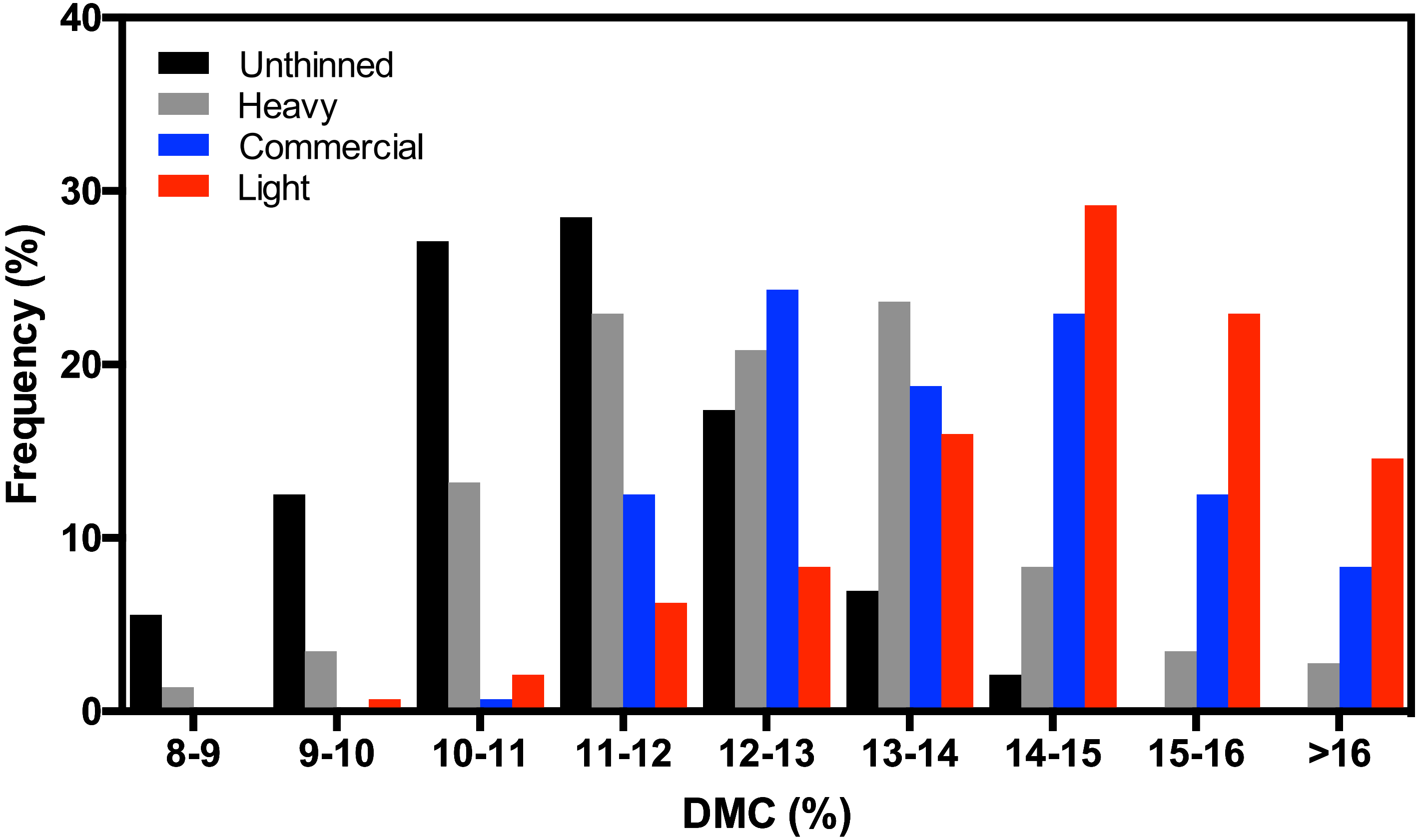
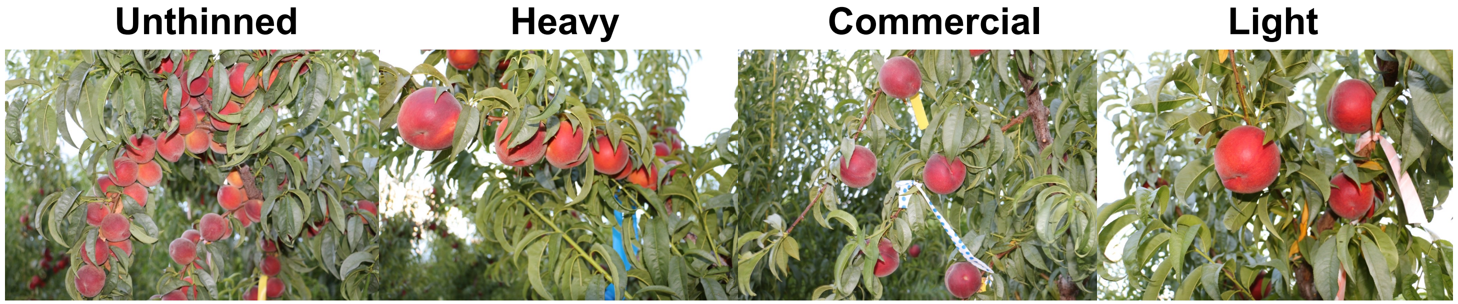
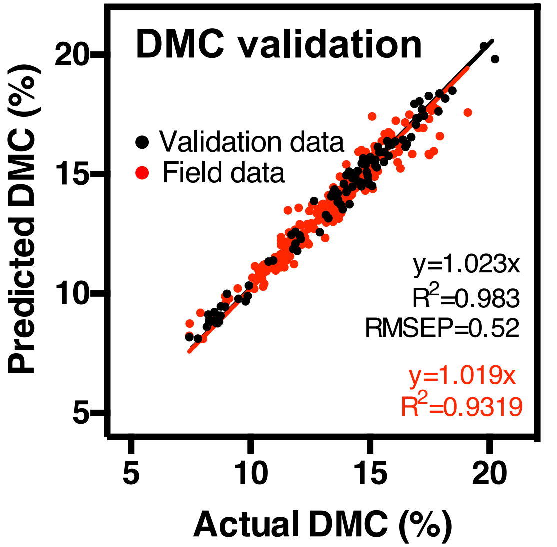
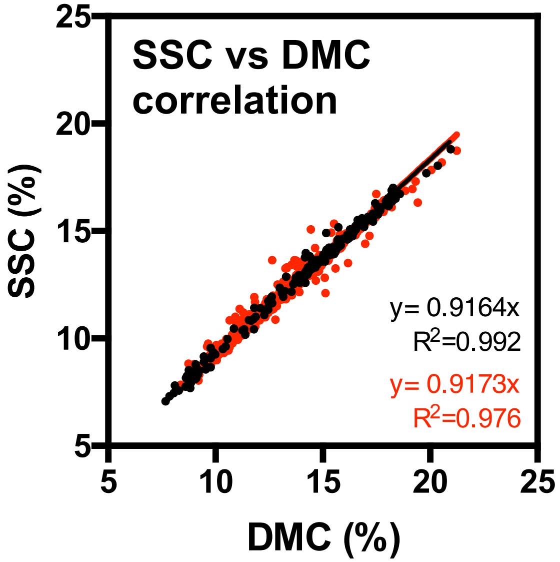
Effect of crop load on ‘Sierra Rich’ peach DMC at harvest as predicted by NIR









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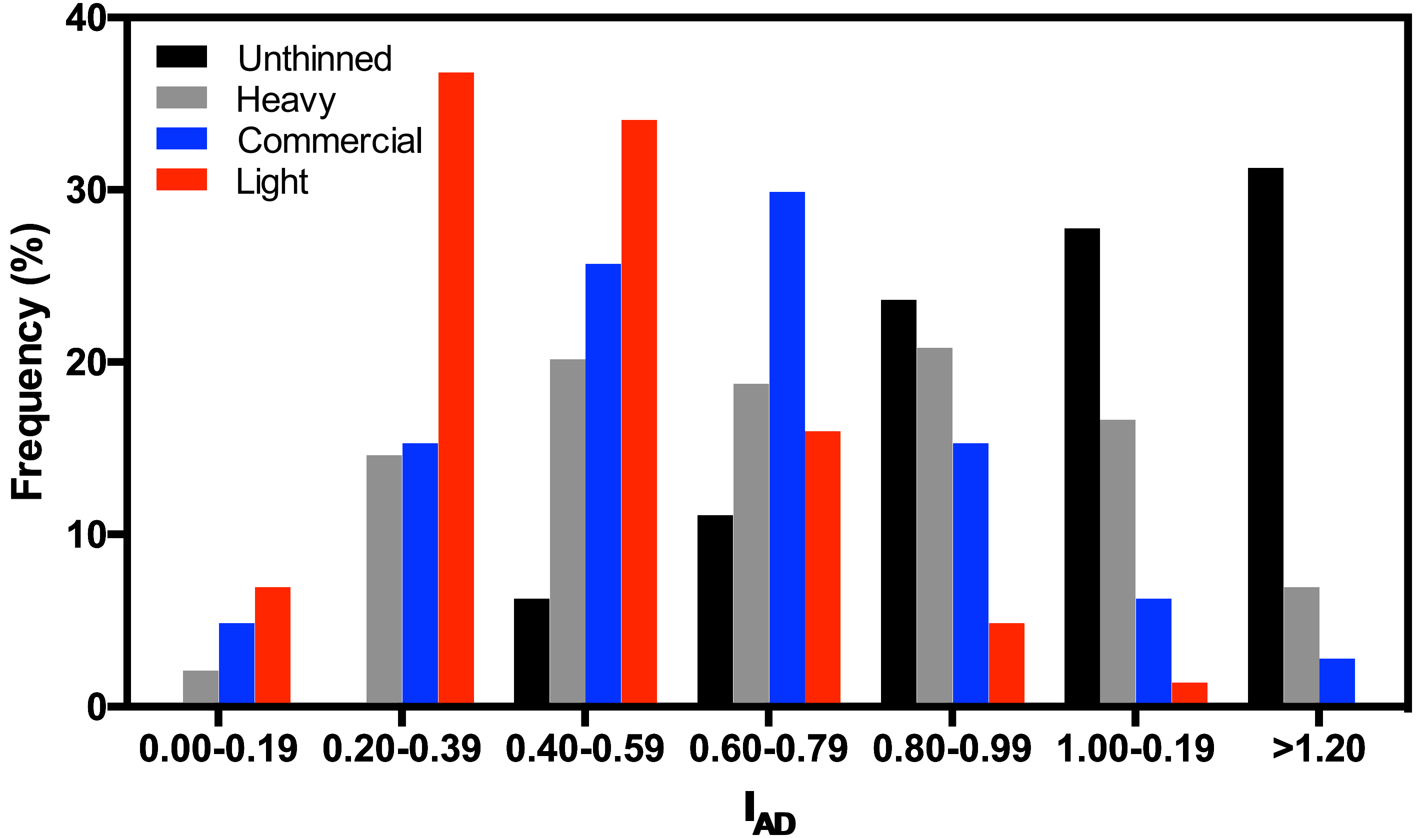
(Minas et al., 2021)

Effect of crop load on 'Sierra Rich' peach maturity at harvest assessed non-destructively with I_{AD} (DA-meter)



Light Commercial Heavy Unthinned

(Minas et al., 2021)

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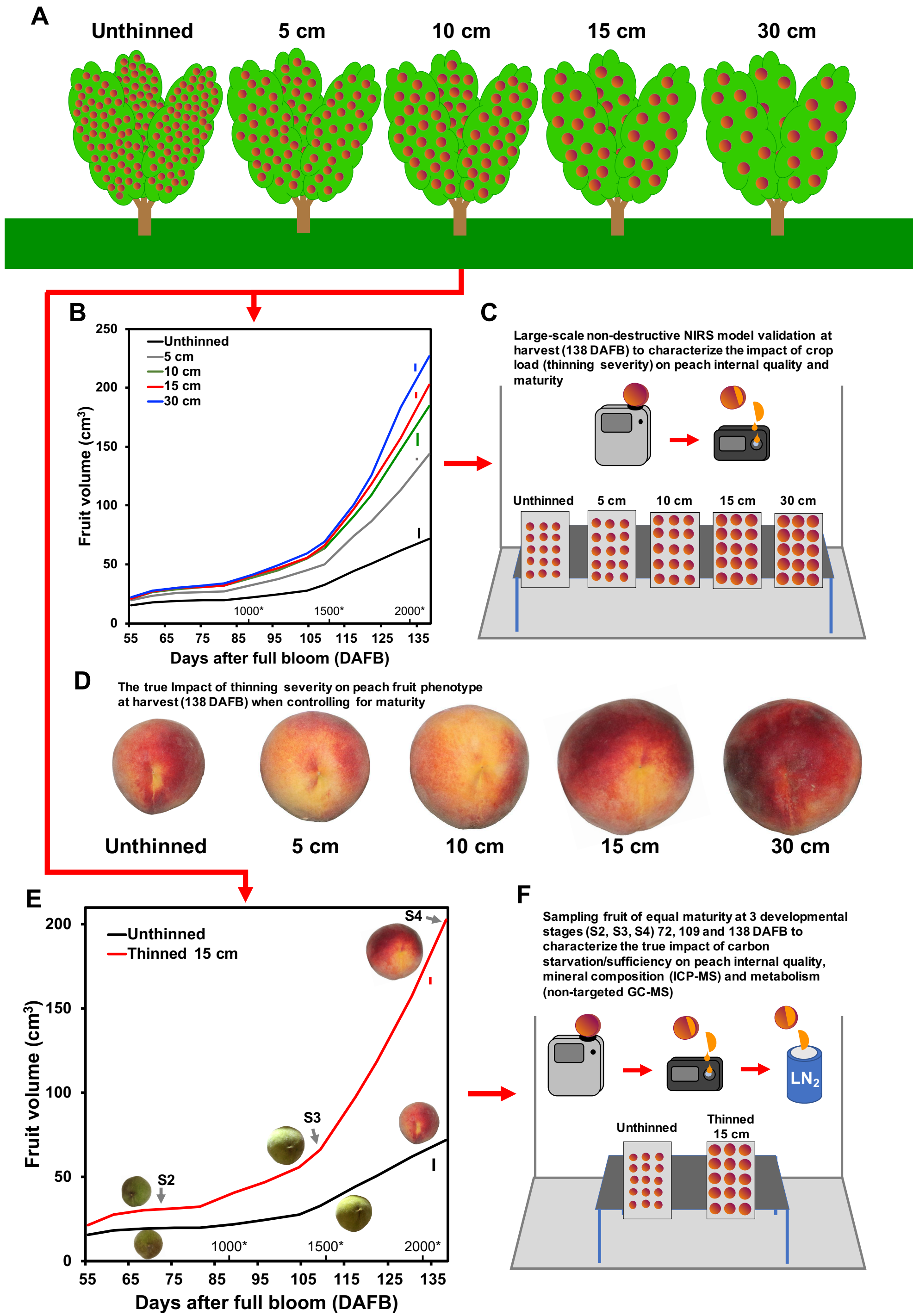
Effect of Thinning Severity and Carbon Competition on Peach Fruit Quality Development

(@ equal maturity)

- **Two distinct thinning severities** selected for in depth quality analysis and non-targeted metabolomic profiling:
  - Thinned (15 cm) – Carbon Sufficient
  - Unthinned – Carbon Starved
- At each dev. stage, **maturity was equal** between thinning treatments
- Fruit from the **thinned** (carbon sufficient) treatment **revealed superior fruit quality at harvest** (S4), when compared to the unthinned (carbon starvation) treatment



Anthony et al., (2020). Early metabolic priming under differing carbon sufficiency conditions influences peach fruit quality development. Plant Physiology and Biochemistry, DOI: 10.1016/j.plaphy.2020.11.004

Early metabolic priming under differing carbon sufficiency conditions influences peach fruit quality development

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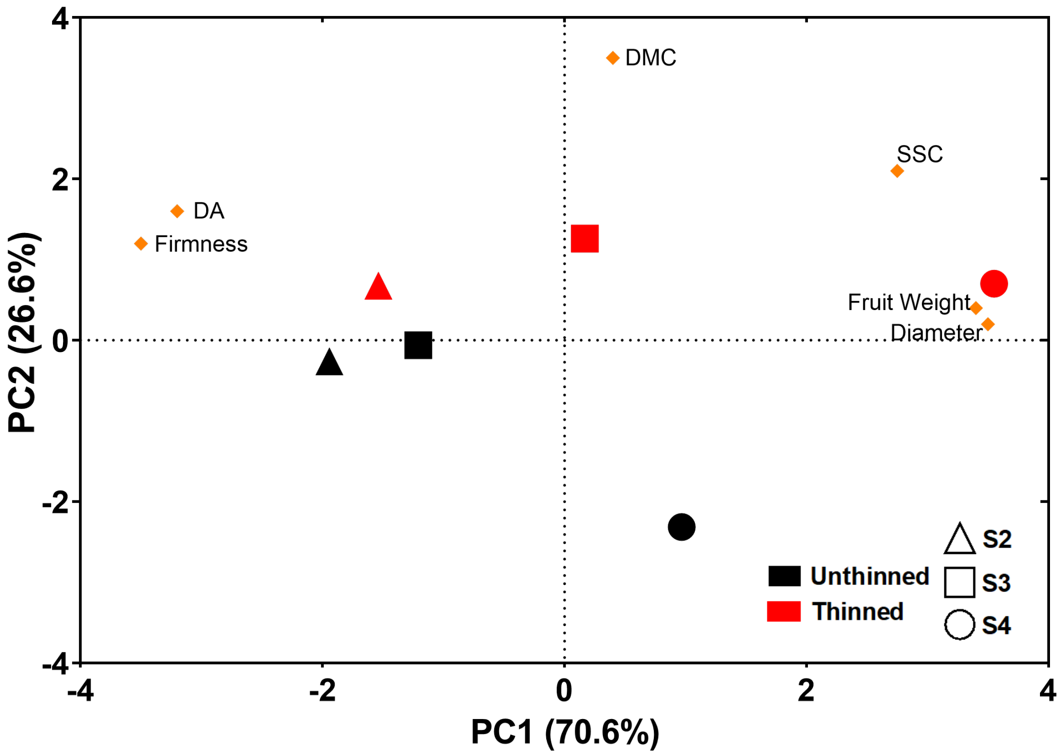
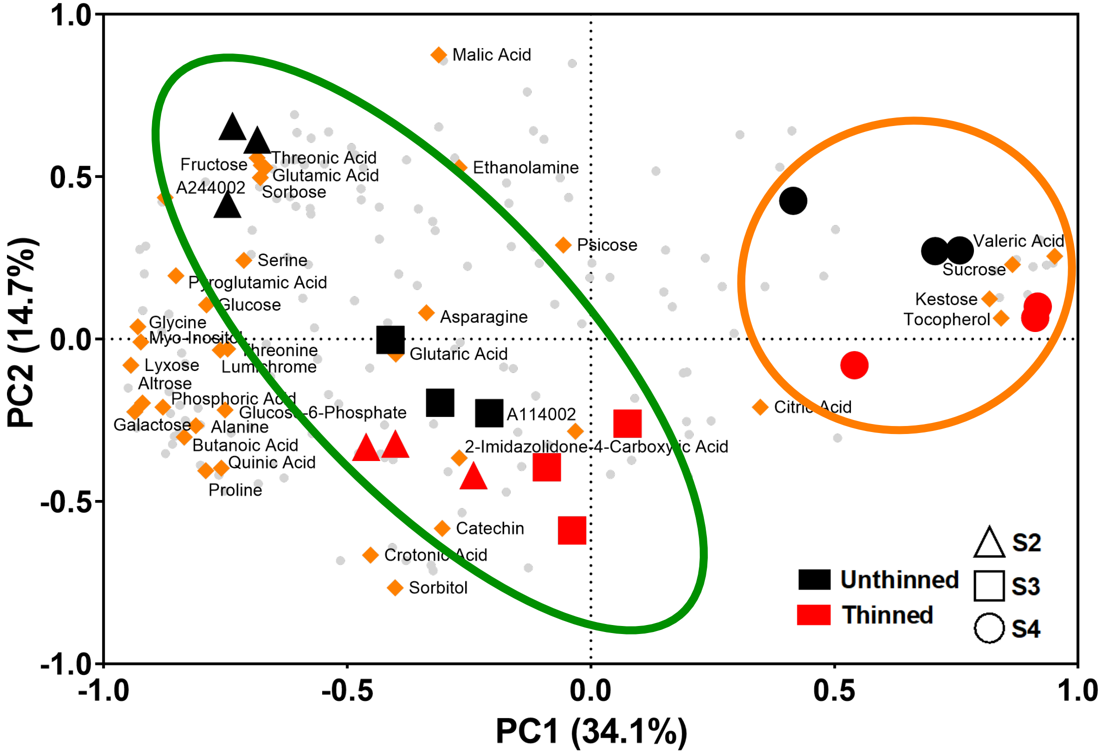
Fruit Quality



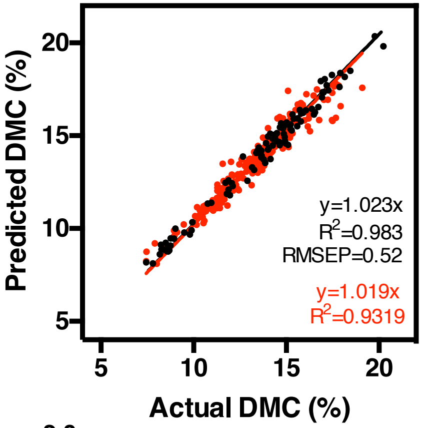
Metabolism

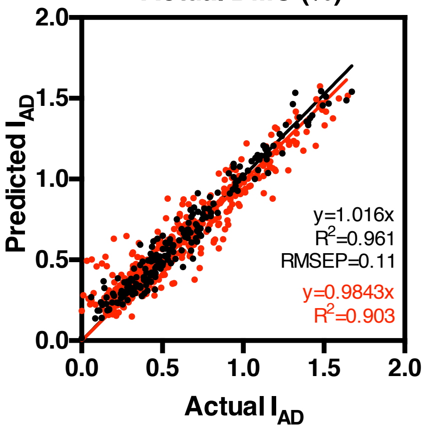


- Quality and **phenotypic differences were minimal at S2,** but vastly different at S4 (left)
- **Metabolic differences were vast at S2**, while profiles at S4 were similar (right)
- Many metabolites associated with the **primary metabolism shift according to development process**
- **Catechin** was **positively** related to **quality** parameters, DMC and SSC

(Anthony et al., 2020)

Effect of fruit position in the canopy on 'Sierra Rich' peach internal quality at harvest
(@ equal maturity)

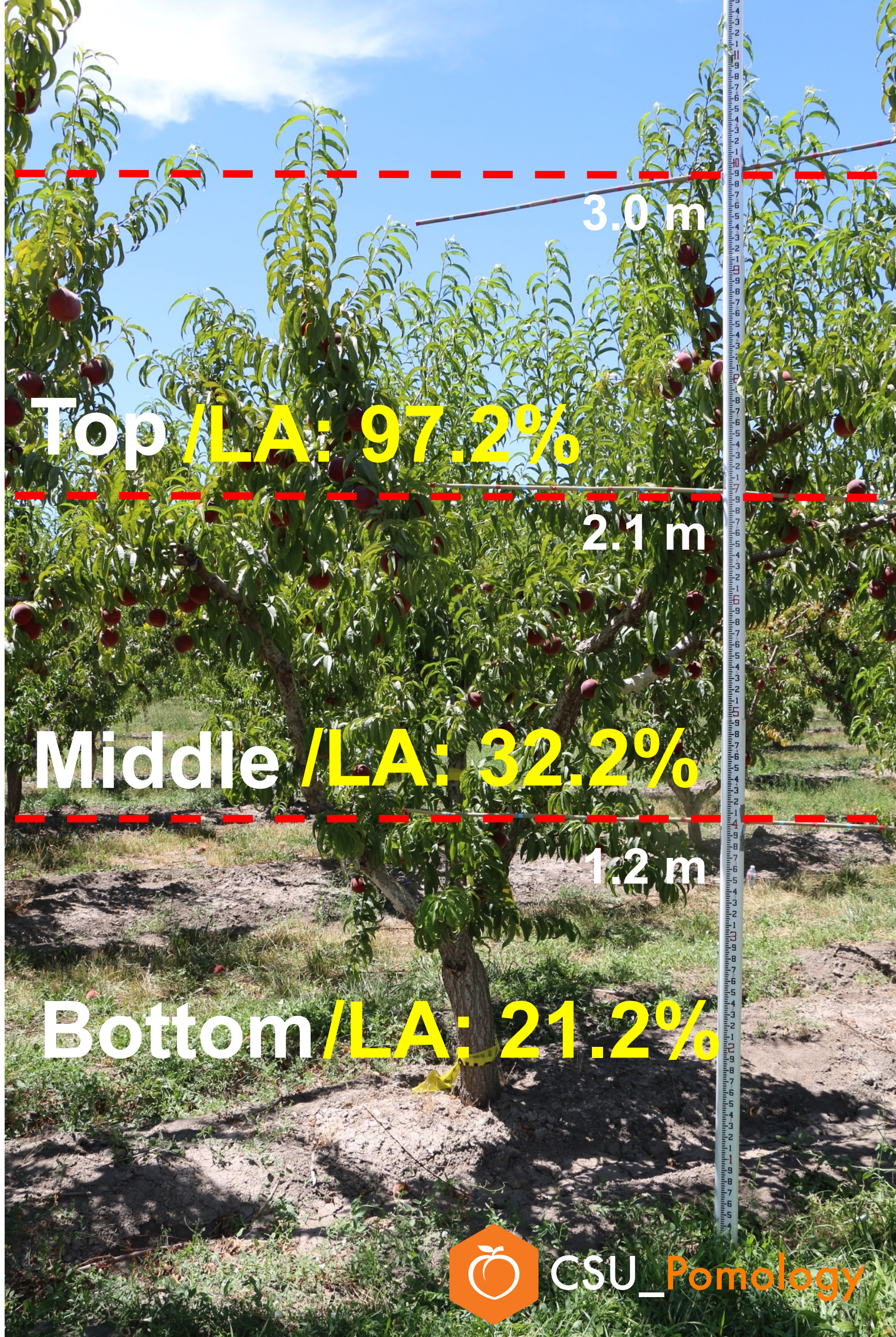




I_{AD}: 0.69
DMC (%):13.1

I_{AD}: 0.71
DMC (%):12.2

I_{AD}: 0.71
DMC (%):12.4

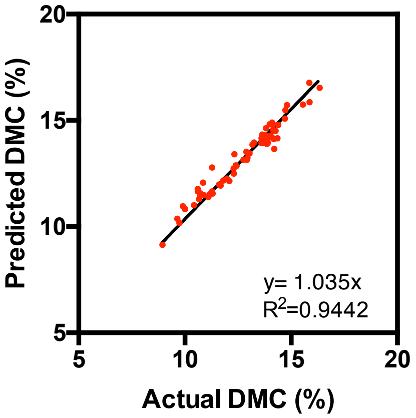


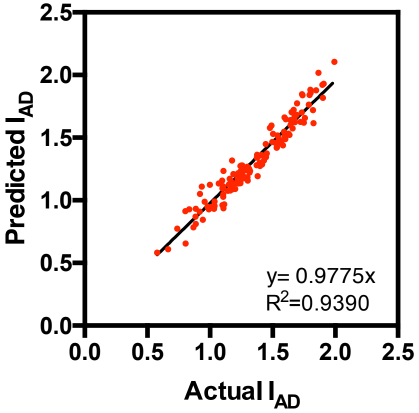
- **No significant differences** across canopy positions
- **Low vigor** = uniform light

Anthony et al., 2021. *Environmental & Experimental Botany*

*LA= Light Availability

Effect of fruit position in the canopy on ‘Cresthaven’ peach internal quality at harvest *(@ equal maturity)*

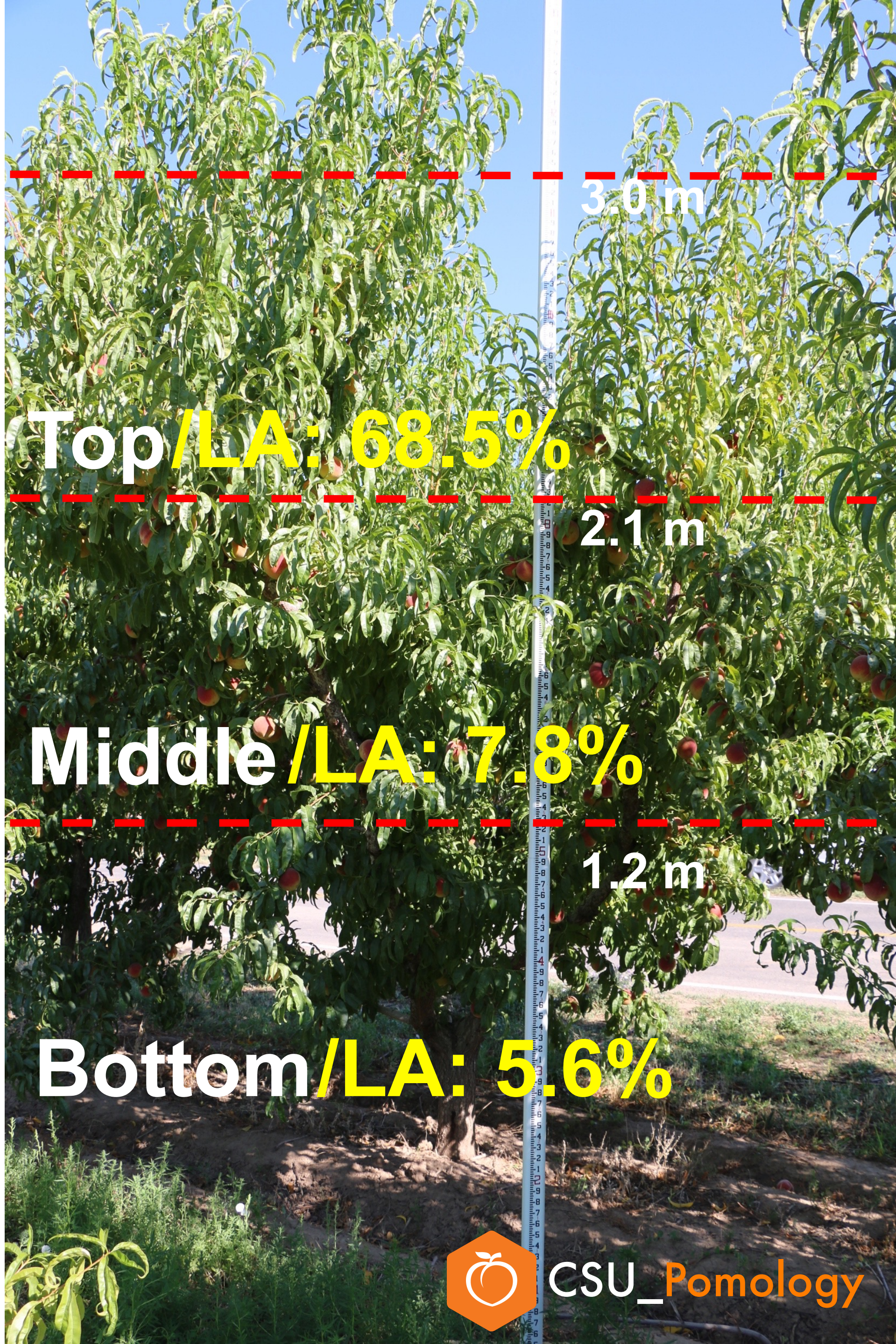




I_{AD}: 1.05
DMC (%):13.0* a

I_{AD}: 1.07
DMC (%):11.7* b

I_{AD}: 1.08
DMC (%):10.9* c



- ***Significant differences** across canopy positions
- **High vigor** = non-uniform light

*LA= Light Availability

Anthony et al., 2021. *Environmental & Experimental Botany*

Impact of cultivar x canopy position on peach mesocarp and exocarp primary metabolism (GC-MS) at harvest

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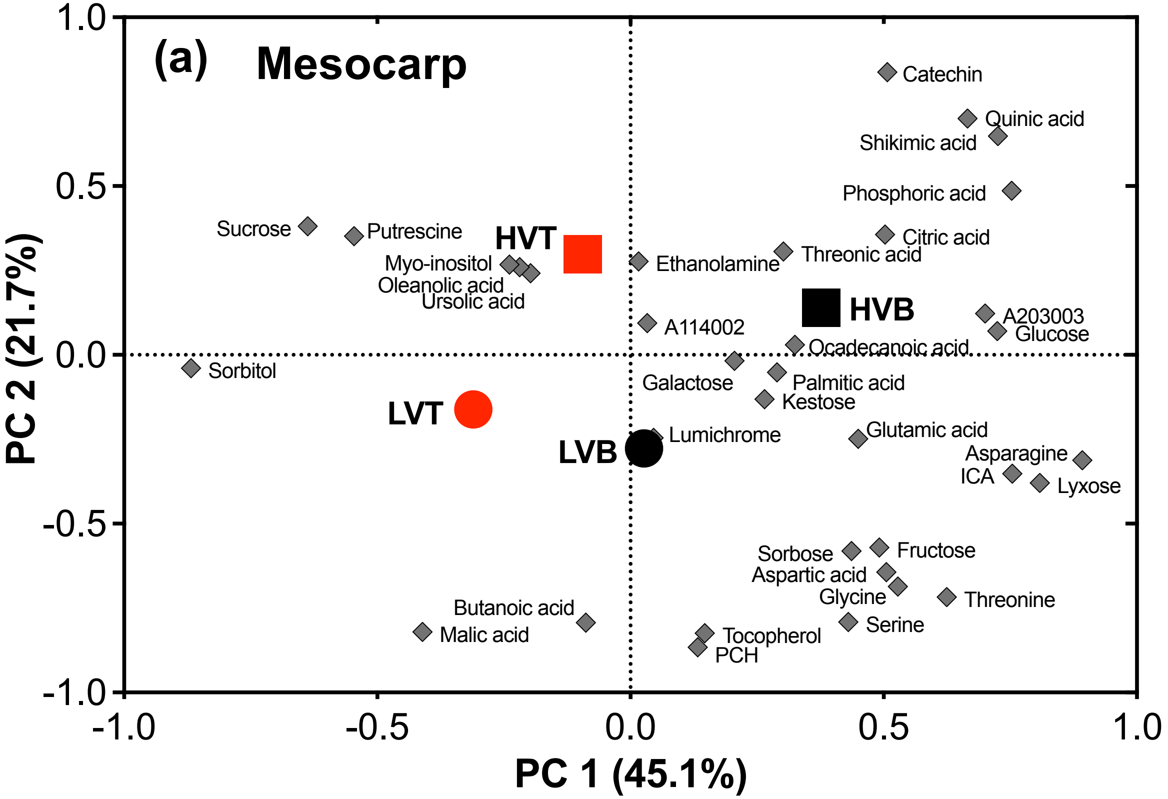
35 annotated metabolites across all samples

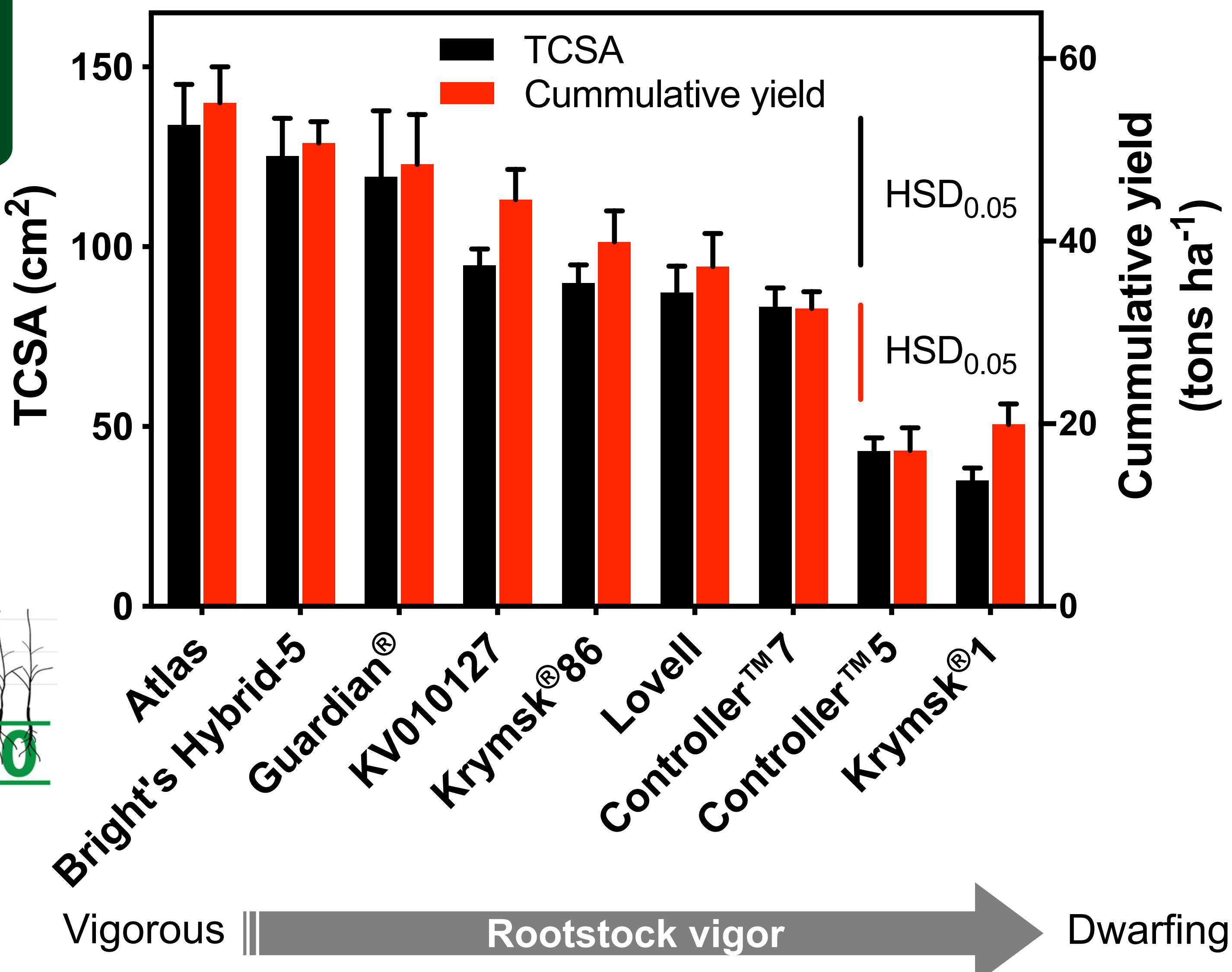


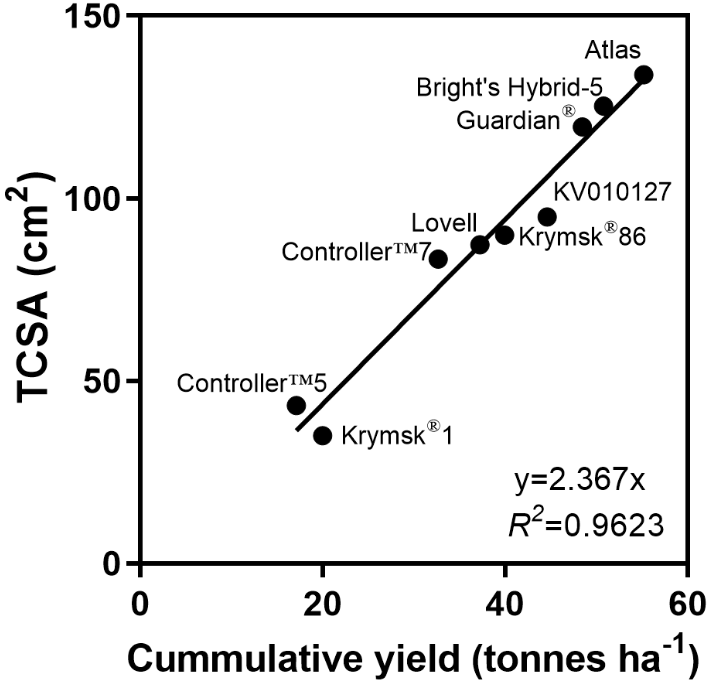
- **Minimal/similar variation** across positions in each cultivar (vigor context) in mesocarp
- **Mesocarp less affected by environment**, due to protection from exocarp and is heavily regulated by development (i.e., maturity)
- **Exocarp metabolite profiles more distinct in HV**, due to less uniform light conditions

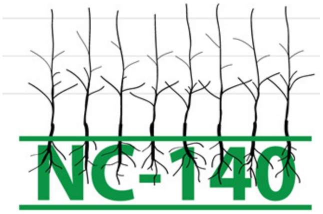
Anthony et al., 2021. *Environmental & Experimental Botany*

X INTERNATIONAL PEACH SYMPOSIUM

Effect of rootstock on ‘Redhaven’ tree size and cumulative yield (2009-2017)







2009 NC-140 ‘Red Haven’ Peach Rootstock Trial

Minas et al., 2021. *In preparation*

Influence of rootstocks on peach fruit internal quality

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NC-140

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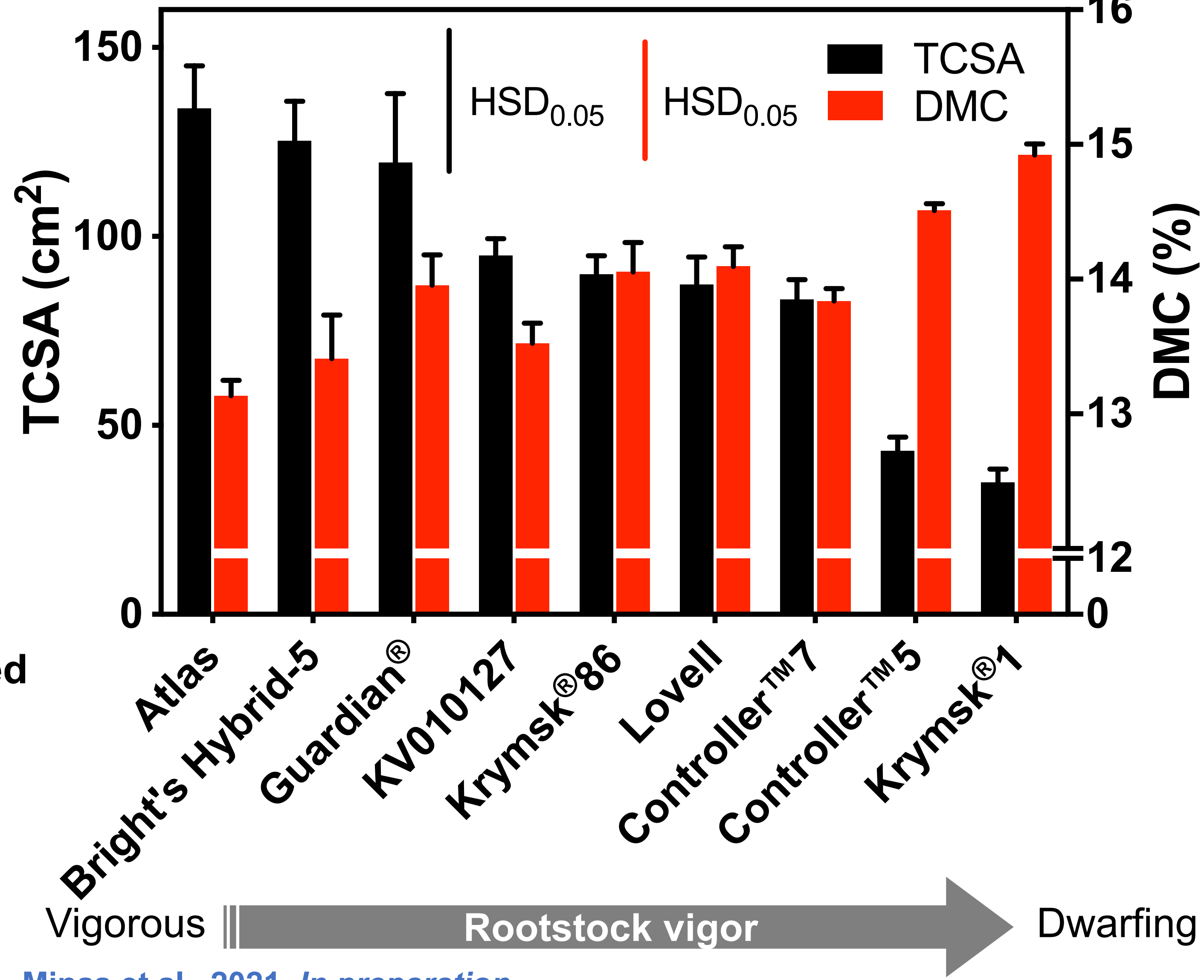
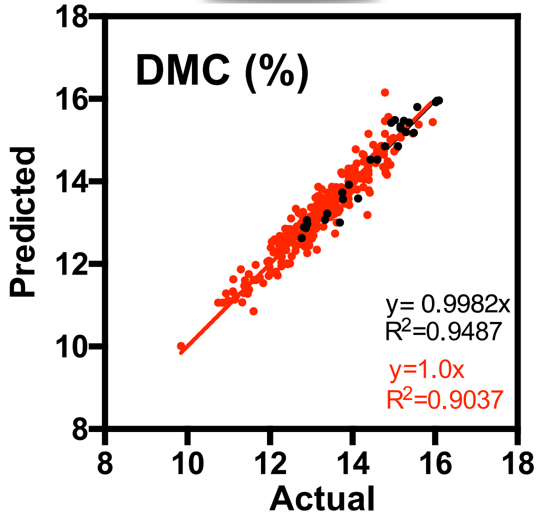
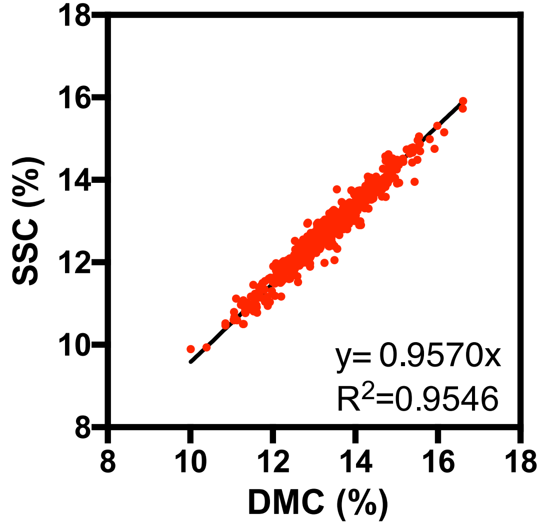
Rootstocks influence 'Redhaven' peach productivity and dry matter content (DMC) - 2016-18

(@equal maturity & crop load)



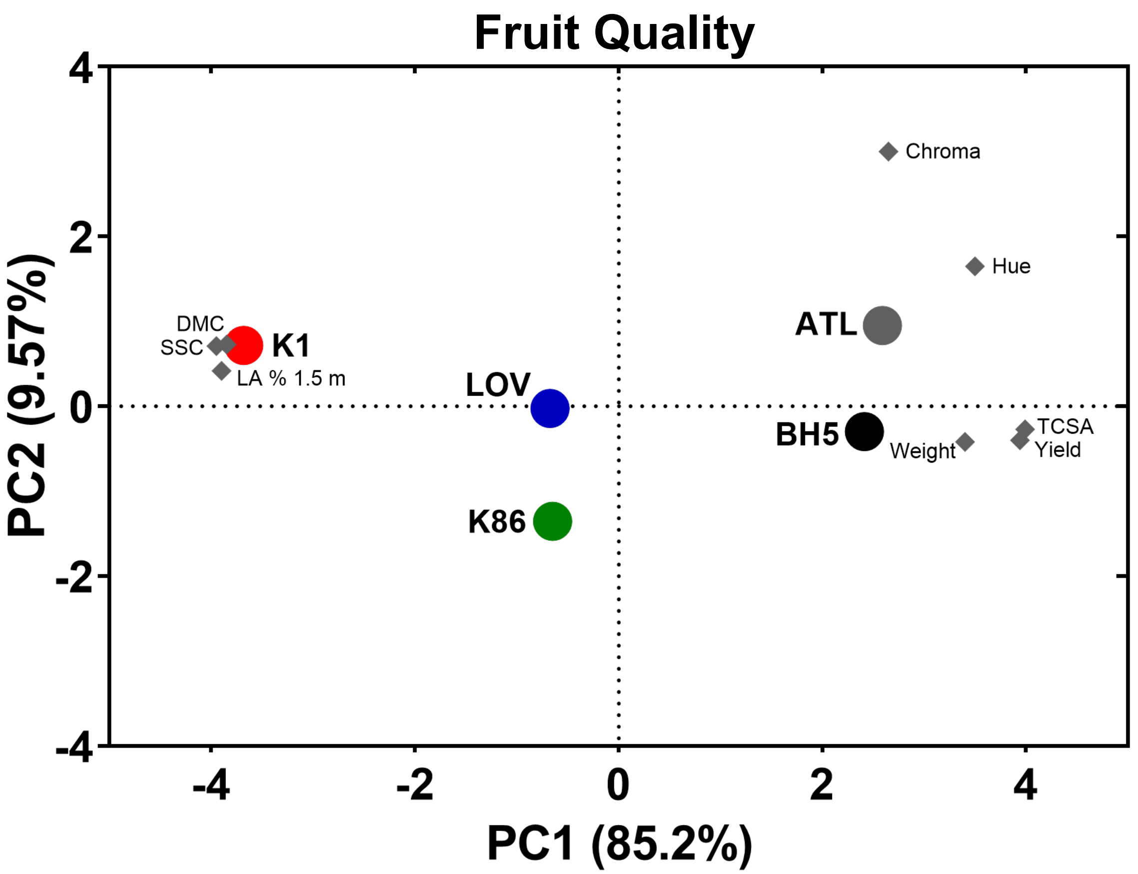


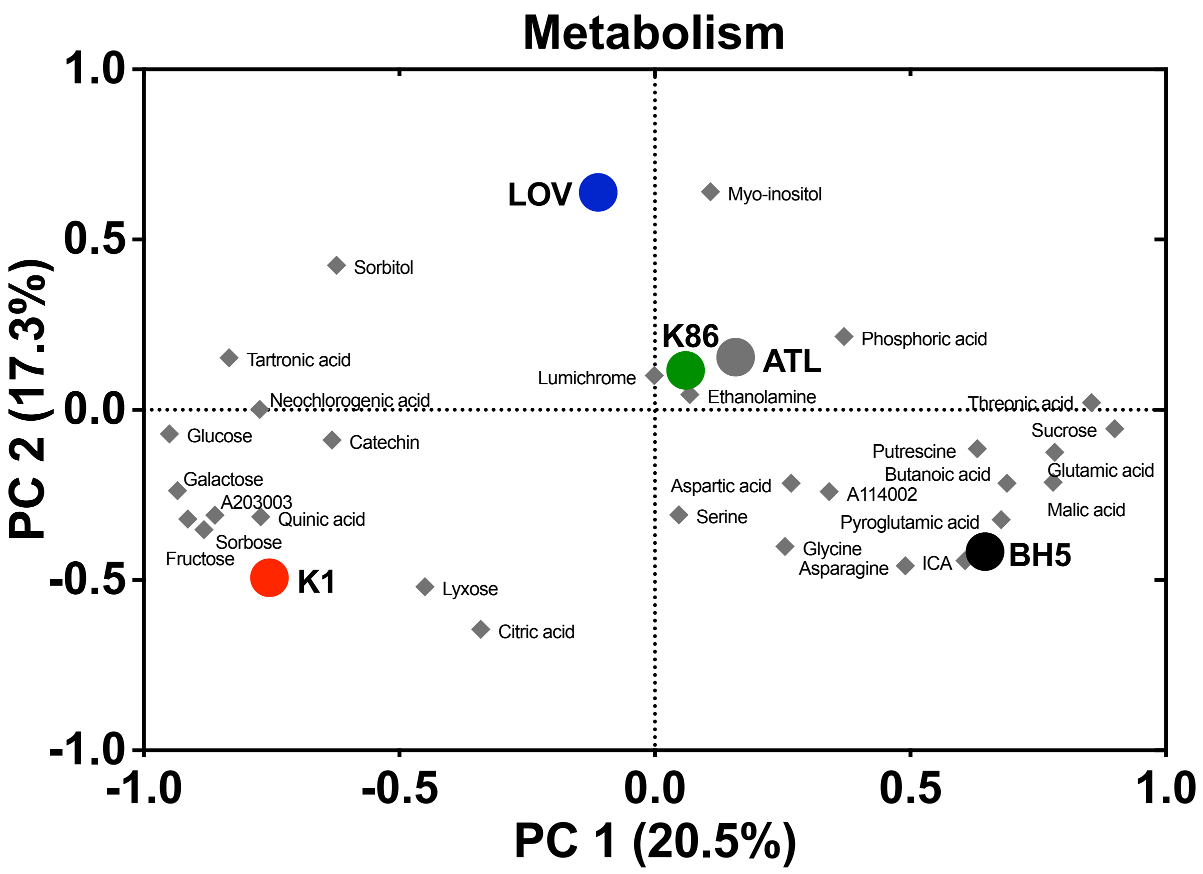


2009 NC-140 'Red Haven' Peach Rootstock Trial

Minas et al., 2021. *In preparation*

Rootstock vigor and light availability highly correlated with internal fruit quality and caused swifts to primary metabolites (GC-MS)





Dwarfing **Rootstock vigor** Vigorous

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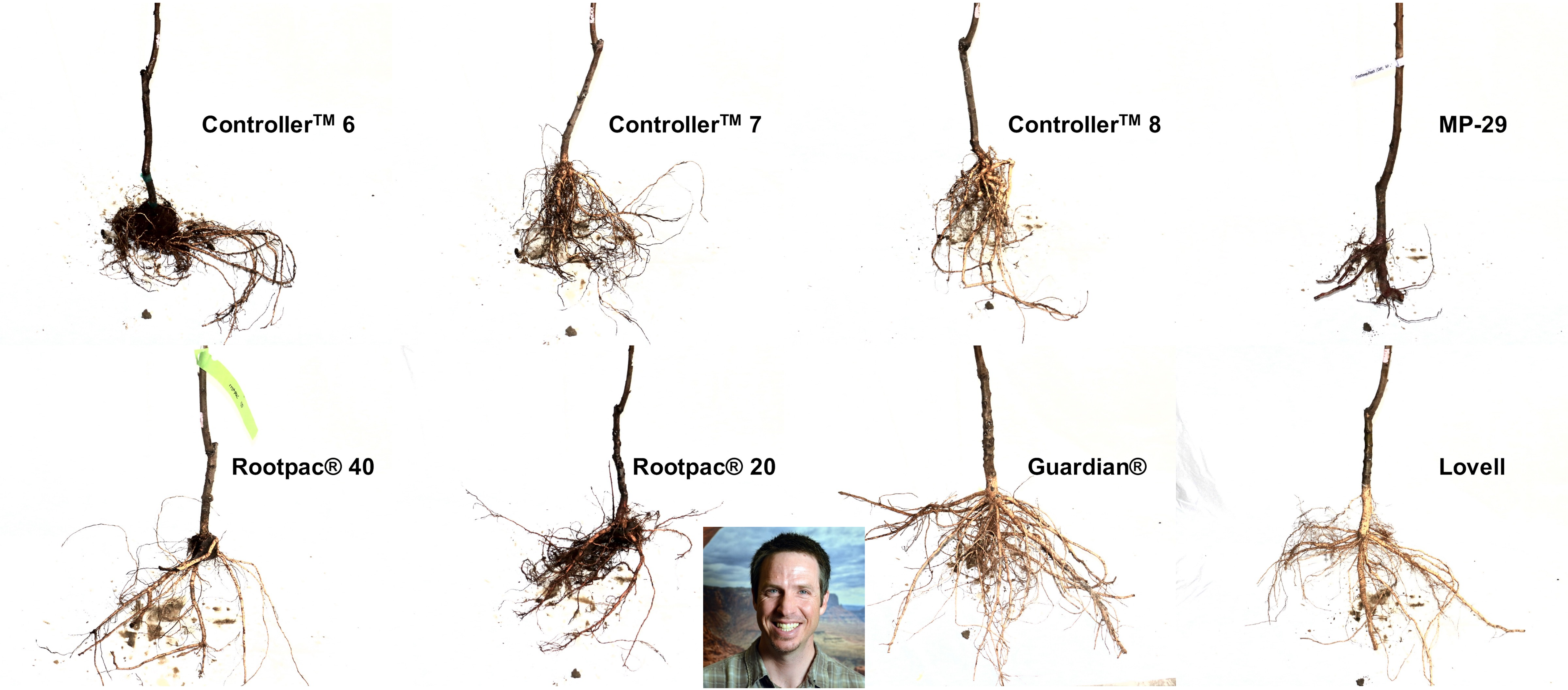
Pieper et al., 2021. *In preparation*

The 2017 NC-140 Cresthaven Semi-Dwarf Peach Rootstock Trial



Jeff Pieper

NC-140 CSU_Pomology

Today @ 2:30 PM – CSU Showcase

Good Fruit Grower, February 1st, 2018

Training Systems Trial: 2016 – 2021

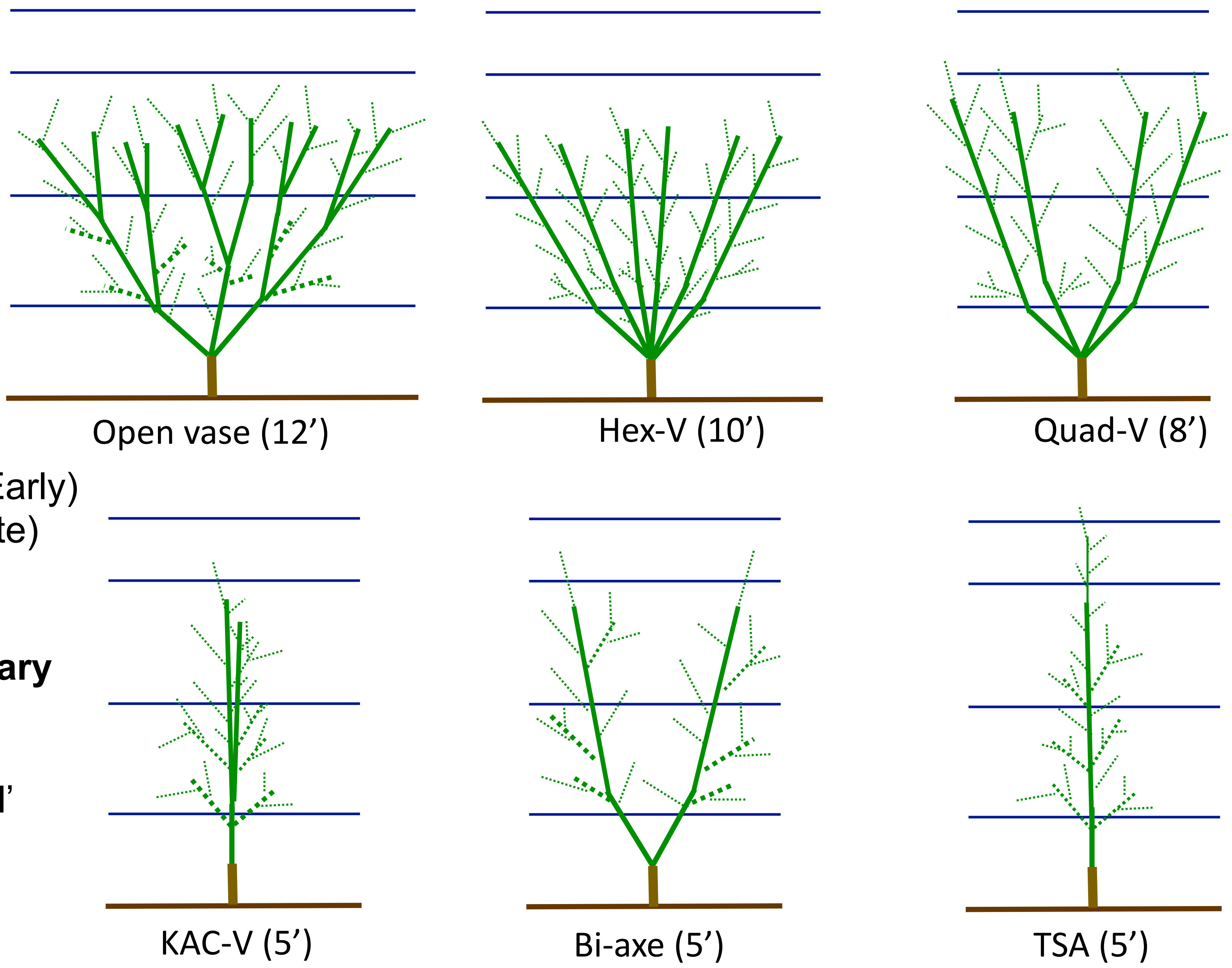
Today @ 2:30 PM
CSU Showcase

Brendon Anthony

Planted: May, 2016
Cultivars x Rootstocks:
- Red Haven x St. Julien (Early)
- O'Henry x Krymsk 86 (Late)

CDA funded project starting January 2020: 'Management strategies to maximize Colorado peach orchards productivity and fruit quality potential'
PI: Minas

COLORADO
Department of Agriculture



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Training Systems: Before and after dormant pruning in ‘O’Henry’ on ‘Krymsk®86’ in 2019

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Open vase	Hex-V	Quad-V	KAC-V	Bi-Axis	TSA

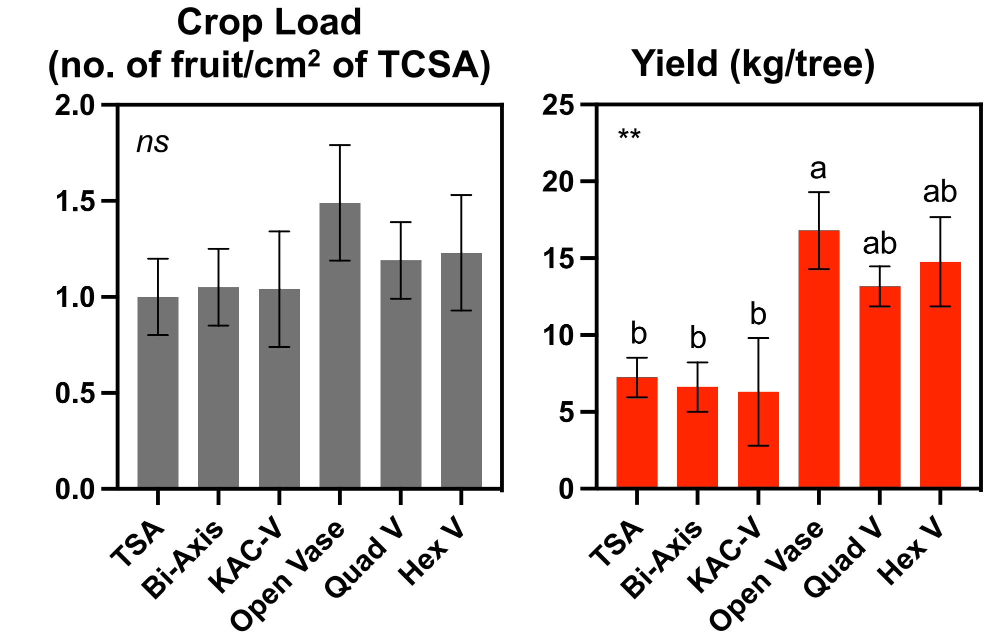
Before

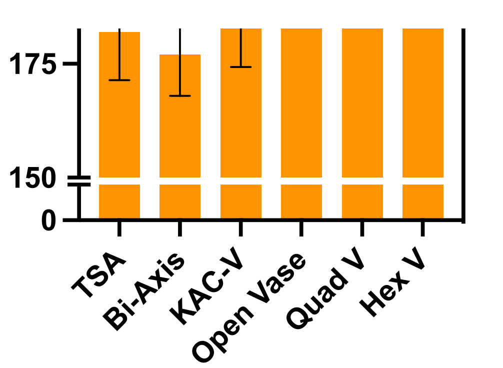
After

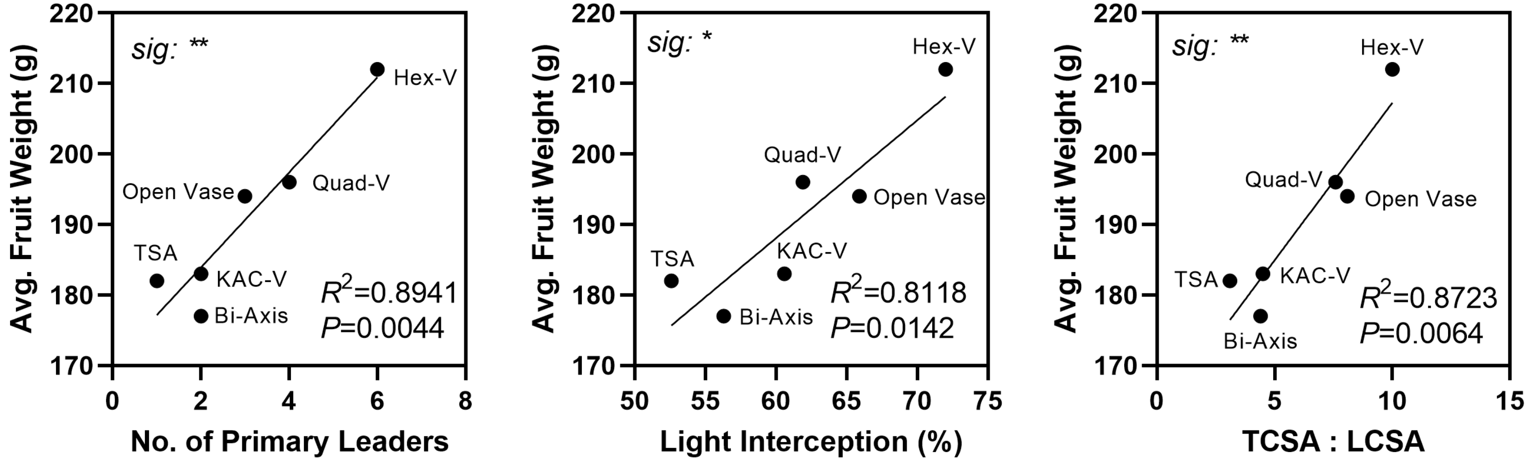
Recently Published: Anthony, B.M. and Minas, I.S., 2021. *Optimizing Peach Tree Canopy Architecture for Efficient Light Use, Increased Productivity and Improved Fruit Quality.* Agronomy, 11(10), p.1961. DOI: https://doi.org/10.3390/agronomy11101961

Training Systems: Light, vigor diffusion & FW in ‘Redhaven’ 2

- Crop loads were set to equal levels
- Yield increased with increased canopy size; fruit weight in RH was highest in Hex-V
- Fruit weight increased with increased scaffold number, light interception and vigor diffusion factor (TCSA:LCSA)
- Hex-V intercepted an optimal amount of light (~70%) and demonstrated optimal diffusion factor (TCSA:LCSA)=~10
- **Hypothesis:** Fruit size related to light and vigor diffusion; crop loads were n.s.
- At least one more crop to confirm hypothesis







Today @ 2:30 PM
CSU Showcase

Brendon Anthony

Anthony et al, 2022. *In preparation*

Developing the Next Generation 2D Peach Orchard

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7 Rootstocks: Krymsk®86, Hansen, Guardian®, Lovell, Controller™6, Rootpac®40, Rootpac ®20

4 Training Systems: SSA (single leader, 3’), Bi-axe-U (wide crotch, 6’), Bi-axe-V (narrow crotch, 6’), Quad-axe (bi-cordon with 4 uprights, 8’)

SSA (3’ x 11’, 1320 trees/acre)

Bi-axe-U (6' x 11', 660 trees/acre)

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Quad-axe (8’ x 11’, 495 trees/acre)

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Questions?

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Stakeholder Support & Collaboration:

Western Colorado Horticultural Society

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