AGRICULTURAL EXPERIMENT STATION
COLORADO STATE UNIVERSITY

State: Colorado

Principal Investigator:
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Collaborators/Technical Assistance:
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1. **Impact Nugget:** The performance results of the various peach rootstocks tested under NC-140 could have a significant impact on Colorado orchard profitability.

2. **New Facilities and Equipment:** Specially constructed equipment that utilizes thermoelectric modules (TEM) and a Tenney Jr programmable freezer (-80 to +200 °C) for differential thermal analysis (DTA) to estimate cold hardiness of 'Red Haven' peach floral buds from trees grafted to different rootstocks and tested under the frame of the NC-140 rootstock trials (**Figure 1 and 2 and Table 1**) was installed in WCRC-OM.

3. **Unique Project-Related Findings:** *Prunus* hybrid rootstocks released for peach and might be suitable for replant were field screened for up to 9 years in CO. New *Prunus* hybrid rootstocks exhibited increased productivity in the poor, alkaline and calcareous western Colorado soils compared to the industry's standard, Lovell. However, early acclimation and extensive vigor should be seriously considered prior planting in CO conditions. *Prunus* hybrids might have higher risk for cold damage early in the dormant season or higher risk for *Cytospora* sp. infections due to the subsequent more intensive pruning management required in more vigorous trees.

4. **Accomplishments Related to Each of the 4 Objectives:**

   Objective 1. To evaluate the influence of rootstocks on temperate-zone fruit tree characteristics grown under varying environments and training systems using sustainable management practices.

   2009 'Red Haven' Peach Rootstock Evaluation Trial (cooperator)
   There were significant differences in tree size and yields among the rootstocks tested in this trial (see addendum, Figure 3 and 4). *Prunus* hybrids rootstocks were the most productive in CO high soil pH conditions when compared to the peach seedling rootstocks. Among peach seedling rootstock cultivars Guardian was the most productive. Non-destructive models were developed to estimate dry matter content (DMC) for Red Heaven peaches and was used to

measure the effect of the rootstock in peach fruit internal quality. Data collected in three consequent years (2016, 2017 and 2018) show a trend of lower DMC in the larger tree sizes (Figure 5). Many plum species and hybrids such as Penta, Imperial California, Fortuna and Controller 5 continue to have poor growth, survival and/or yields and do not look promising as peach rootstocks even for high density systems.

2017 Semi-dwarf Peach Rootstock Evaluation Trial (coordinator)
The trial was established in WCRC-OM experimental orchard in May 8th, 2017. The scion cultivar was Cresthaven and the rootstocks are Controller 6, 7 and 8 (UC Davis); Rootpac 20 (Densipac) and Rootpac 40 (Nanopac) from Agromillora Iberica; MP-29 (USDA-Georgia); Lovell and Guardian® (Clemson/USDA). High mortality observed in MP-29 mainly due to heavy root pruning on the nursery stock prior shipment for planting. The growth of MP-29 hasn't been resumed yet on the second season. In this second year of this trial we observed severe iron chlorosis symptoms mainly in Controller 7. Only following repeated applications of chelated-Fe we were able to bring these trees in some balance. Other rootstocks that seem to experience iron deficiency/chlorosis were: Controller 8 and Guardian. Largest trees were produced by Guardian and smallest from Controller 7. It is worthy to highlight that Controlled 6, 8 and Rootpac 20 as well as Guardian exhibited the largest increase in TCSA compared to previous years. In Table a summary overview of the 2018 collected data is provided.

2017 Benton Sweet Cherry Training Systems and Rootstocks Evaluation Trial (cooperator)
The trial was established in WCRC-OM experimental orchard in May 2nd, 2017. This trial compares 3 systems (Tall Spindle Axe, KGB bush, and Bi-UFO inclined tree) using 8 rootstocks (Cass, Clare, Clinton, Gi3, Gi5, Gi12, Lake, and MxM14) with Benton as the scion. High tree mortality observed in MxM14 trained in TSA. Trunk circumference data as well as number of lateral shoots are regularly collected within these first two establishment years. Bending the cordons of Bi-UFO on MxM14 was really challenging due to the size of the branches of such trees. In addition, and because some of the freestanding Lake trees were bending down due wind it was suggested to the group that some support should be established on TSA trees. In Table a summary overview of the 2017 collected data is provided.

2015 'Modi' Apple Organic Rootstock Evaluation Trial (cooperator)
A better crop observed this year in this trial mainly due to the spring frost in April 5th, 2017. Trees were most vigorous on G.890 and least vigorous on G.16, with the most precocious initial yield and largest fruit size on Liberty, followed by G.969 (**Table 4**).

Objective 4. To investigate physiological processes, biotic and abiotic stresses and scion/rootstock interactions on tree growth and productivity.
During the fall/winter season of 2017/18 we continued an extensive cold hardiness analysis was performed on 6 selected rootstocks form this trial using differential thermal analysis (DTA). DTA is a technique used to quantify cold tolerance in plants, freezing episodes called exotherms can be identified as change points, local minima or selected infection points of differential temperature. When super cooled water freezes extracellularly, the heat released is referred to as a high-temperature exotherm (HTE); extracellular freezing is considered

nonlethal. On the other hand, the freezing of intracellular water creates a similar, low-temperature exotherm (LTE) and is lethal (Figure 1). DTA analysis performed on five time points with Red Haven bud samples from selected rootstocks coming from the 2009 Peach rootstock trial during the fall/winter season of 2017/18 (see addendum **Table 1**).
DTA data revealed that *Prunus* hybrids acclimate later in fall compared to peach seedling rootstock cultivars, however among them Krymsk®86 exhibited maximum mid-winter hardiness and delayed deacclimation in late winter. DTA data collection continues over the fall/winter season of 2018/19 on the same rootstocks to comlete a three years study on such an important task.

Objective 5. To integrate and disseminate research-based information that facilitates successful stakeholder adoption of rootstock technologies
Reports, presentations that update NC140 peach, apple and cherry, rootstock research and at CSU are regularly posted on CSU Pomology web page (http://minas.agsci.colostate.edu). In addition, an annual CSU Pomology Field Day was established for first time in WCRC-OM in May 18, 2017 and was repeated the past June 2018. Attending tree fruit growers and extension personnel (50 people) were updated on the most recent information from the NC140 rootstock trials established in the CO site. A workshop 'Principles of Tree-Fruit Production' for beginner growers was organized in January 15, 2018 (33 attendees). During the 2017/2018 fall/winter/spring season CO tree fruit growers received ~25 updates of peach cold hardiness through the CSU Pomology web page (http://minas.agsci.colostate.edu).

5. Impact Statements

Colorado peach growers through the different means of outreach and extension are informed on the most recent findings of the NC-140 rootstock trials in WCRC-OM to support their decisions on proper rootstock selection for CO growing conditions.

6. Published Written Works:

Miller ST, Otto KL, Sterle D, **Minas IS**, Stewart JE. 2018. Preventive Fungicidal Control of *Cytospora leucostoma* in Peach Orchards in Colorado. *Plant Disease, https://doi.org/10.1094/PDIS-01-18-0175-RE*
https://apsjournals.apsnet.org/doi/abs/10.1094/PDIS-05-18-0801-RE

Karagiannis E, Michailidis M, Karamanoli K, Lazaridou A, **Minas IS**, Molassiotis A. 2018. Postharvest cold responses of sweet cherry fruit and stem tissues revealed by metabolomic profiling. *Plant Physiology and Biochemistry* 127, 478-484.
https://www.sciencedirect.com/science/article/abs/pii/S0981942818301876

Minas IS*, Tanou G, Molassiotis A. 2018. Environmental and orchard bases of peach fruit quality. *Invited Review article for the Special Issue: Quality and Safety of Fresh Fruits and Vegetables*. *Scientia Horticulturae*, 325, 307-322.
https://www.sciencedirect.com/science/article/pii/S0304423818300323

Karagiannis, E., Tanou, G., Samiotaki, M., Michailidis, M., Diamantidis, G., Minas, I., Molassiotis, A. (2016). Comparative Physiological and Proteomic Analysis Reveal Distinct Regulation of Peach Skin Quality Traits by Altitude. *Frontiers in plant science* **2016***, 7*, 1689. https://www.frontiersin.org/articles/10.3389/fpls.2016.01689/full

Autio, W, Robinson, T, Black, B, Blatt, S, Cochran, D, Cowgill, W, Lang, G, **Minas, IS**, Hampson, C, Hoover, E, Miller, D, Parra Quezada, R, Stasiak, M. Budagovsky, Geneva, Pillnitz, and Malling apple rootstocks affect 'Honeycrisp' performance over the first five years of the 2010 NC-140 Honeycrisp Apple Rootstock Trial. *Journal of American Pomological Society* **2017**, 71, 149-166. http://www.pubhort.org/aps/71/v71_n3_a3.htm

Tanou G, **Minas IS**, Scossa F, Belghazi M, Xanthopoulou A, Ganopoulos I, Madesis P, Fernie A, Molassiotis A. Exploring priming responses involved in peach fruit acclimation to cold stress. *Scientific Reports* **2017**, 7, 11358. https://www.nature.com/articles/s41598-017-11933-3

Extension fact sheets:

Stewart, J.E., Miller, S.T., Minas, I.S. 2018. Preventive Control for Cytospora Canker on Peach. Colorado State University Extension, Crop Series, Diseases, Fact Sheet No. 2.954.

7. Scientific and Outreach Oral Presentations:

Minas I.S., Sterle D., Blanco-Cipollone F. 2018. Near infrared spectroscopy can non-destructively assess the effect of rootstock, crop load and canopy position on peach fruit harvest maturity and internal quality. 30th International Horticultural Congress, ISHS, Istanbul, Turkey, August 2018.

Minas I.S., Sterle D. 2018. Differential thermal analysis sheds light on the effect of environment, cultivar, rootstock, and crop load in peach floral buds early acclimation and maximum cold hardiness. 30th International Horticultural Congress, ISHS, Istanbul, Turkey, August 2018.

Minas, I.S. NC-140 Peach & Apple Rootstock Trials Update. 2018 CSU Pomology Field Day, WCRC-OM, Grand Junction, CO, May 2017.

Minas, I.S. 2018. Understanding the environmental bases for cold hardiness and damage in peach. Invited Speaker, Idaho State Horticultural Society, Nampa, Idaho, November 2018.

Minas, I.S. 2018. Colorado Tree Fruit Research Challenges & Opportunities. Invited Speaker, Idaho State Horticultural Society, Nampa, Idaho, November 2018.

Minas, I.S. 2018. Orchard Bases of Peach Fruit Quality, Oral presentation at Western Colorado Horticultural Society 2017 Annual Meeting, Western Colorado Horticultural Society, January 19, 2017, Grand Junction, CO.

Minas, I.S. 2017. CSU Pomology Research Program Update, Oral presentation at Western Colorado Horticultural Society 2017 Annual Meeting, Western Colorado Horticultural Society, January 19, 2017, Grand Junction, CO.

Minas I.S., Sterle D., Caspari H. 2017. Understanding the environmental bases for cold hardiness and cold damage in peach floral buds using differential thermal analysis. Oral presentation at 9th International Peach Symposium, July 2-6, Bucharest, Romania.

Minas I.S., Blanco-Cipollone F. 2017. Non-destructive assessment of the effect of crop load and canopy position on peach fruit harvest maturity and internal quality using near infrared spectroscopy. Oral presentation at 9th International Peach Symposium, July 2-6, Bucharest, Romania.

Miller S.T., Otto K., Sterle D., Minas I.S., Stewart J.E. 2017. Developing strategies for managing Cytospora canker in peach orchards in Colorado. Poster presentation at 9th International Peach Symposium, July 2-6, Bucharest, Romania.

Minas, I.S, Sterle, D., Caspari, H. 2017. Differential thermal analysis to understanding the environmental bases for cold hardiness and cold damage in peach floral buds. Oral presentation at 2017 American Society for Horticultural Science (ASHS) Annual Conference, September 19-22, 2017, Waikoloa, Hawaii.

Minas, I.S. 2017. CSU Pomology Research Program Update, Oral presentation at Western Colorado Horticultural Society 2017 Annual Meeting, Western Colorado Horticultural Society, January 19, 2017, Grand Junction, CO.

Minas, I.S. NC-140 Peach & Apple Rootstock Trials Update. 2017 CSU Pomology Field Day, May 18, 2017, WCRC-OM, Grand Junction, CO.

Minas, I.S, Sterle, D., Caspari, H. 2017. *Cold hardiness assessment of peach flower buds using differential thermal analysis (DTA) in western Colorado (dormant season 2016 - 17)*. CSU Pomology web page. https://minas.agsci.colostate.edu/files/2017/03/Peach-fruit-bud-cold-hardiness-update24-3_13_17.pdf

8. Fund Leveraging:

Minas, I., Grant, "Establishment of a Tree Fruit Physiology and Quality Program at Western Colorado", Western Colorado Horticultural Society, $10,000.00, Active. (start: October 1, 2016).

Minas, I., Grant, "WCRC Pomology", Colorado Apple Administrators Commission, Other, $7,414.50, Active. (start: September 5, 2016).

Jayanty, S. S., Minas, I., Bartolo, M. E., Grant, "Postharvest handling strategies for Colorado specialty crops to increase marketability and improve consumer quality", Agricultural Experiment Station, Colorado State University, $26,065.00, Active. (sub: May 12, 2016, start: September 29, 2016, end: June 30, 2018).

Stewart, J. E. (PI), Minas, I. (CoPI), Grant, “Cytospora management in peach orchards through cultural practices, cultivar selection, and stress mitigation”, Specialty Block Grants, Colorado Department of Agriculture (CDA) (2017): $91,218 (awarded: May, 2017, start: Feb 1, 2018, end: November 1, 2019).

W. Autio et al. 2018. NC140 Rootstock Research Trial Coordination. International Fruit Tree Association. $12,000 (Peach $2,000).

Addendum

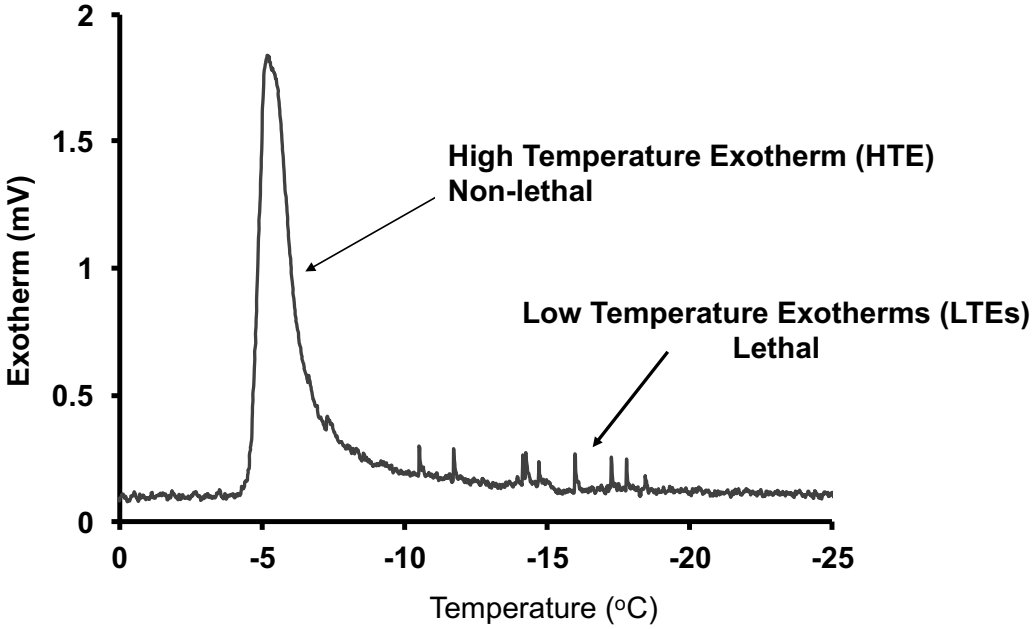

Figure 1. Differences in low temperature exotherms (LTE) for 'Red Haven' flower buds coming from trees growing at the experimental orchard at the CSU's WCRC-OM near Grand Junction, CO, on November 21, 2016. High temperature exotherms (HTEs), indicating non-lethal extracellular freezing of extracellular water, are shown to the left of the dashed vertical black line (between -5 and -8 °C). The LTEs for the two dates are shown to the right of the dashed vertical black line (below -10 °C), indicating acclimation in bud hardiness for 'Red Haven'.

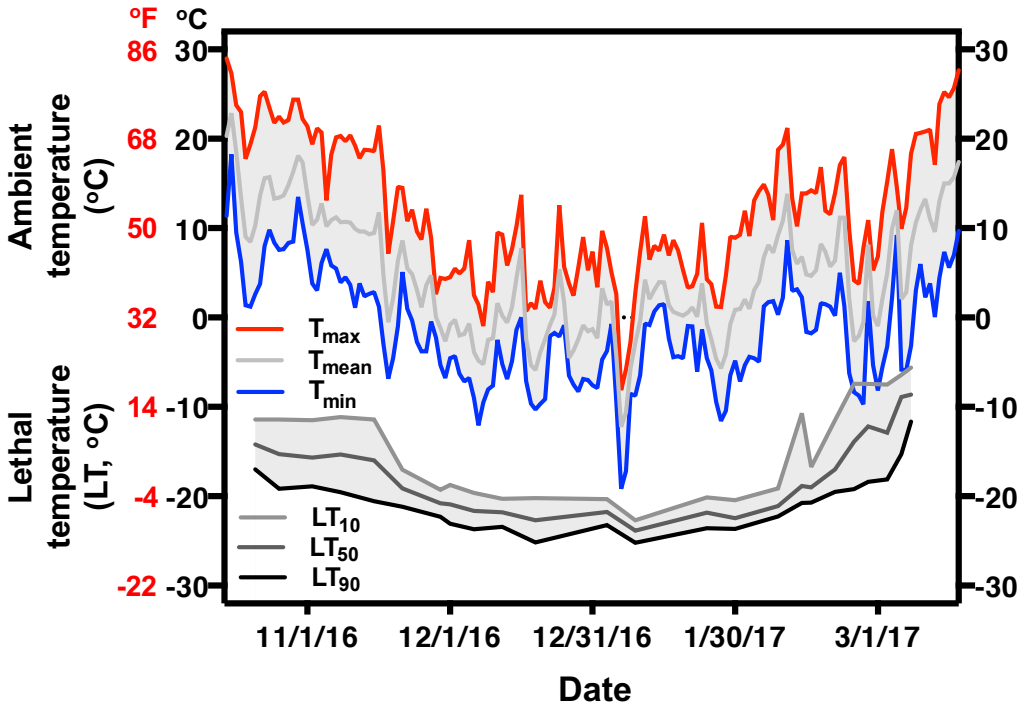

Figure 2. Seasonal patterns of temperature and cold hardiness, expressed as lethal temperature for 10, 50 and 90% of the total flower buds killed (LT_{10}, LT_{50}, LT_{90}, respectively), for peach flower buds of 'Red Haven' peaches grafted on 'Lovell' peach seedling cultivar rootstock that is planted within the *NC-140 2009 'Red Haven' Peach Rootstock Evaluation Trial*. Daily maximum, mean, and minimum temperatures recorded at the CSU Western Colorado Research Center at Orchard Mesa near Grand Junction, CO, 2016/17*.
*Temperature data for various locations within the Grand Valley can be found at: http://www.winecolorado.org/colorado-grape-growing/weather-station-network./
Meteorological data from other locations throughout Colorado may also be available from the Colorado Agricultural Meteorological network - CoAgMet.

Table 1. Lethal temperatures (LT) in Celsius (ºC) for 10 (LT_{10}), 50 (LT_{50}) and 90% (LT_{90}) flower buds killed, for 'Red Haven' peaches grafted on Atlas, Bright's Hybrid-5, Guardian®, Krymsk®86, Lovell, and Krymsk®1 rootstocks. All the above rootstocks were planted within the *NC-140 2009 'Red Haven' Peach Rootstock Evaluation Trial* in the experimental orchard of the Colorado State University's WCRC-OM, Grand Junction, CO.

	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**

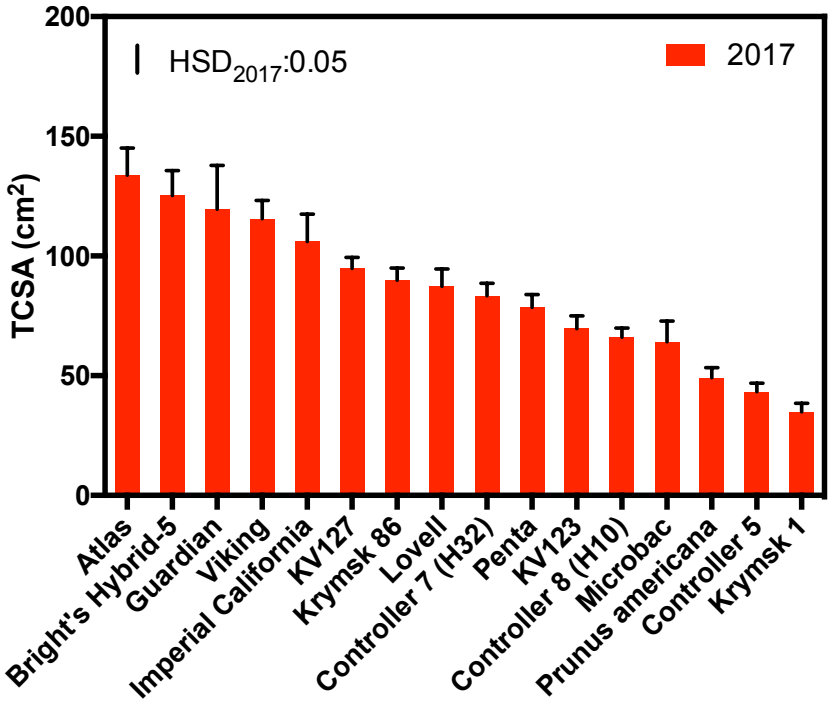

Figure 3. Trunk cross sectional area (TCSA, 2017) data of the 2009 Red Haven peach rootstock evaluation trial. Rootstocks are presented from left (large) to right (dwarf) based on tree size.

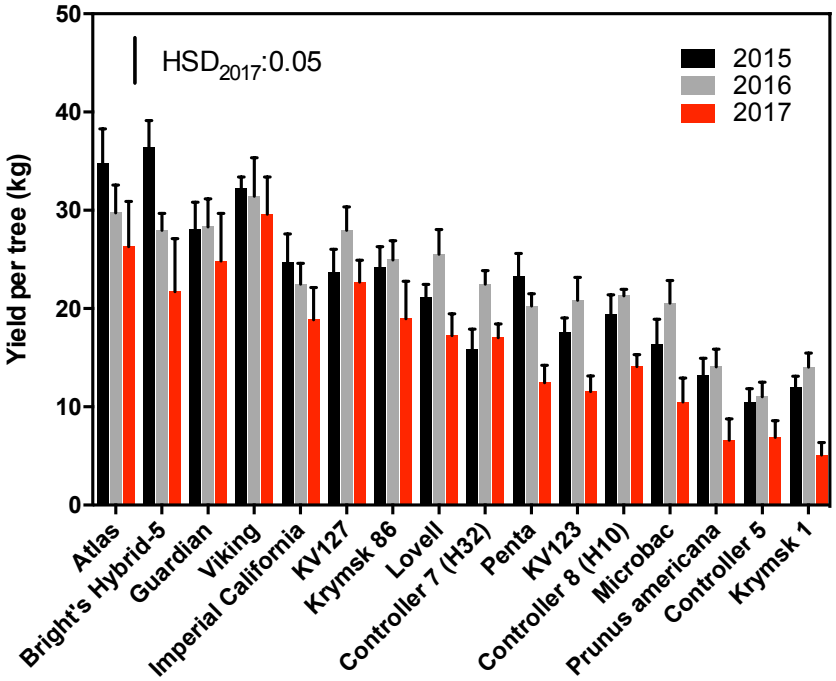

Figure 4. Yield per tree (2017) data of the 2009 Red Haven peach rootstock evaluation trial. Rootstocks are presented from left (large) to right (dwarf) based on tree size.

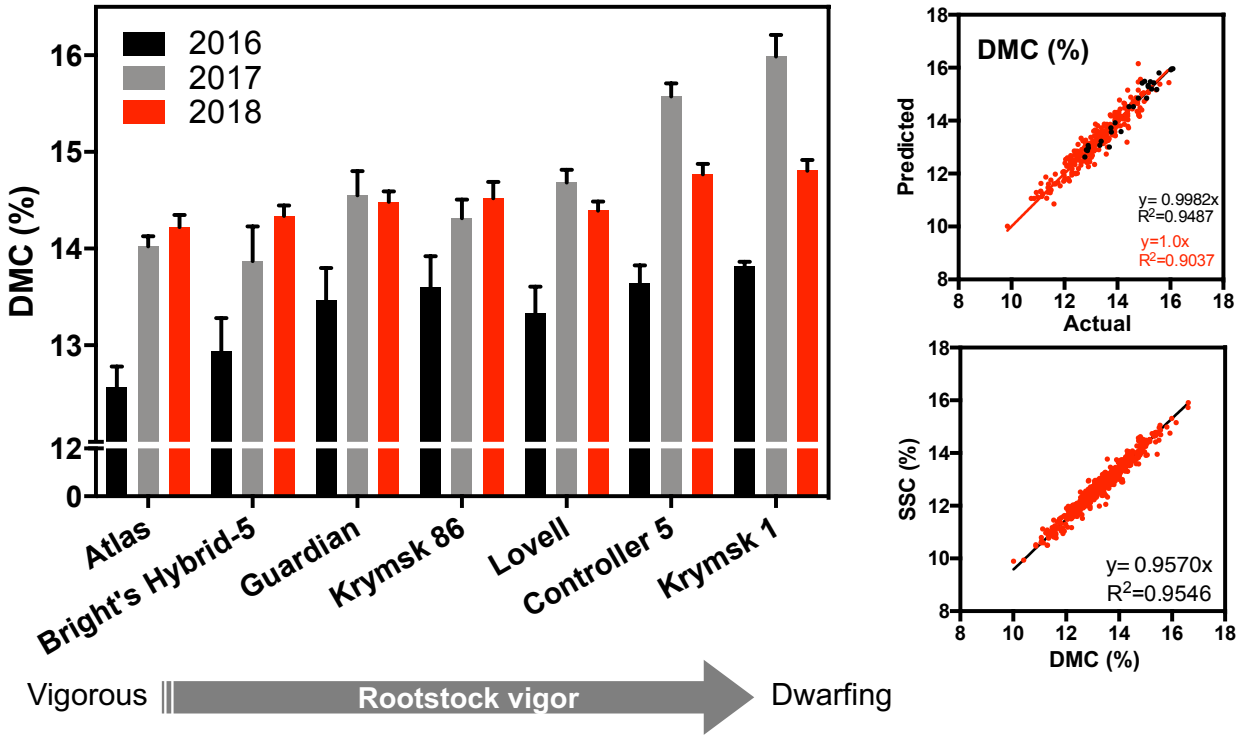

Figure 5. Validation data of the non-destructive models created to estimate internal fruit quality of 'Red Haven' peaches (A). Effect of rootstock on 'Red Haven' peach internal fruit quality estimated as dry matter content (DMC) in 2016, 2017 and 2018. Rootstocks are presented from left (large) to right (dwarf) based on tree size.

Table 2. Survival, trunk cross-sectional area (TCSA) in fall 2017 and 2018, number of root suckers and percentage of chlorotic trees for the *2017 NC140 Peach Semi-Dwarf Rootstock Evaluation Trial* in WCRC-OM, Grand Junction CO (2018).

Rootstock	Survival (%)	% Size of Lovell	TCSA (cm^2) fall 2017	TCSA (cm^2) fall 2018	TCSA increase	Suckers	% of chlorotic trees*
Controller™ 6	90	93.2	1.1	7.9	6.8	0.0	16.7
Controller™ 7	95	30.1	1.3	2.6	1.3	0.4	100.0
Controller™ 8	95	120.4	1.7	10.2	8.5	0.0	52.6
MP-29	83	56.1	2.7	4.8	2.1	0.0	6.7
Rootpac® 20	100	126.4	2.7	10.7	8.0	3.3	31.6
Rootpac® 40	73	80.0	1.6	6.8	5.2	0.4	0.0
Guardian®	95	158.8	3.3	13.5	10.2	0.5	60.0
Lovell	80	100	2.2	8.5	6.3	3.5	31.2
Estimated HSD			0.6	1.7		0.7	

**Spring 2018.*

Mean separation in columns by Tuckey's HSD (P=0.05). HSD was calculated based on the number of observations per mean.

Table 3. Survival, trunk cross-sectional area (TCSA) at planting and in fall of 2017, tree height at planting, extension of the leader during the growing season of 2017 as well as the number and the length of lateral shoots for the tall spindle axe (TSA) trees of the *2017 NC-140 'Benton' Sweet Cherry Rootstock x Training Systems Trial* in WCRC-OM, Grand Junction CO (2017).

Rootstock	Survival (%)	% Size of MxM14	TCSA (cm^2) at planting	Tree height (cm) at planting	TCSA (cm^2) at fall	New growth (cm)	Lateral shoots (no.)	Length of lateral shoots (cm)
Cass	83	40.7	1.2	87.3	1.9	24.0	3.5	9.0
Clare	100	45.5	1.0	82.4	1.6	34.3	3.5	19.0
Clinton	83	69.4	0.9	71.4	2.5	76.1	2.9	33.3
Lake	92	61.5	1.5	101.0	2.2	33.0	3.1	18.6
MxM14	33	100	2.9	130.1	3.6	51.5	3.3	20.8
Gi3	83	57.9	1.0	93.7	2.1	31.1	4.0	14.4
Gi5	83	79.8	1.4	108.0	2.8	41.9	3.6	26.8
Gi12	80	69.1	0.8	75.8	2.5	44.5	4.5	26.5
Estimated HSD			0.3*	11.0	0.8	31.5	1.6	12.1

Mean separation in columns by Tuckey's HSD (P=0.05). HSD was calculated based on the number of observations per mean.

Table 4. Survival, trunk cross-sectional area (TCSA) at planting and in fall of 2017, tree height at planting for the bi-UFO Trees of the *2017 NC-140 'Benton' Sweet Cherry Rootstock x Training Systems Trial* in WCRC-OM, Grand Junction CO (2017).

Rootstock	Survival (%)	% Size of MxM14	TCSA (cm^2) at planting	Tree height (cm) at planting	TCSA (cm^2) at fall
Cass	100	36.5	1.2	87.7	1.9
Clare	100	34.6	0.9	86.5	1.8
Clinton	92	47.8	0.9	70.1	2.5
Lake	92	43.1	1.2	92.9	2.2
MxM14	42	100.0	3.3	137.9	5.2
Gi3	75	43.5	0.9	84.3	2.2
Gi5	100	49.5	1.2	101.7	2.6
Gi12	90	59.6	1.4	102.0	3.1
Estimated HSD			0.3	14.0	0.6

Mean separation in columns by Tuckey's HSD (P=0.05). HSD was calculated based on the number of observations per mean.

Table 5. Survival, trunk cross-sectional area (TCSA) at planting and in fall of 2017, tree height at planting for the KGB trees of the *2017 NC-140 'Benton' Sweet Cherry Rootstock x Training Systems Trial* in WCRC-OM, Grand Junction CO (2017).

Rootstock	Survival (%)	% Size of MxM14	TCSA (cm^2) at planting	Tree height (cm) at planting	TCSA (cm^2) at fall
Cass	100	40.8	1.1	83.0	1.7
Clare	100	44.6	0.9	83.1	1.9
Clinton	100	50.2	1.0	74.1	2.1
Lake	92	60.1	1.2	89.7	2.6
MxM14	67	100.0	3.2	137.5	4.2
Gi3	100	51.7	0.8	84.9	2.2
Gi5	100	79.0	1.2	96.3	3.4
Gi12	89	71.9	1.2	83.1	3.1
Estimated HSD			0.6	13.2	0.9

Mean separation in columns by Tuckey's HSD (P=0.05). HSD was calculated based on the number of observations per mean.

Table 4. Tree and yield characteristics in 2017 of Modi® apple trees in the 2015 NC-140 Organic Apple rootstock trial at the CSU's WCRC-OM, Grand Junction, CO.

Rootstock	TCSA (2017, cm^2)	Fruit no (2017)	Yield per tree (2017, kg)
G.11	4.0	1.2	0.1
G.16	1.7	0.2	0.0
G.202	5.3	0.8	0.1
G.214	2.1	0.1	0.0
G.222	1.8	0.0	0.0
G.30	4.0	1.3	0.2
G.41	3.8	0.9	0.5
G.890	5.8	1.3	0.2
G.935	4.0	1.8	0.2
G.969	3.5	2.8	0.3
Liberty	3.4	4.8	0.5
M9T337	4.5	1.7	0.2
Estimated HSD	0.6*	0.3	1.4

*Mean separation in columns by Tuckey's HSD (P=0.05). HSD was calculated based on the number of observations per mean.