State: Colorado

Principal Investigator:
Ioannis S. Minas, Assistant Professor of Pomology, Dept. of Horticulture and Landscape Architecture located at Western Colorado Research Center-Orchard Mesa, Colorado State University, 3168 B ½ Rd, Grand Junction, CO 81503

Collaborators/Technical Assistance:
Davis Sterle, Emily Dowdy, Bryan Brady, Research Associates, Western Colorado Research Center-Orchard Mesa, Colorado State University, 3168 B ½ Rd, Grand Junction, CO 81503

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:** A walk-in cold room with temperature and humidity control for postharvest fruit quality analysis was installed in WCRC-OM. This cold room is currently used for postharvest quality analysis of the effect of rootstocks in tree fruit production. 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, 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 exhibit 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 5 Objectives:**

   ***Objective 1*. Evaluate the influence of rootstocks on temperate-zone fruit tree characteristics grown under varying environments using sustainable management systems.**

   2009 'Red Haven' Peach Rootstock Evaluation Trial (cooperator)
   Yields in 2017 were reduced by 30% compared to 2016 due to a post-bloom spring frost (25.5^{o}F) in the morning of April 5th. There were significant differences in tree size and yields among the rootstocks tested in this trial (see addendum). *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 two consequent years (2016 and 2017) show a trend of lower DMC in the larger tree sizes. However, because of the lighter crop in 2017 data collection on fruit quality will continue in 2018. Many plum species and hybrids such as Penta, Imperial California, Fortuna, Controller 5 and Krymsk® 1 continue to have poor growth, survival and/or yields and do not look promising as peach rootstocks even for high density systems.

2010 'Honeycrisp' Apple Rootstock Evaluation Trial (cooperator)
Yields continued to be low for this trial at the WCRC-OM site probably due to the spring frost in April 5th, 2017. B.64-194 gave the largest trees and B.71-7-22 the most dwarf. Highest yield for 2017 obtained from CG.5222 and lowest from CG.2034. Highest cumulative yield has been obtained from M.9 Pajam2 followed by CG.5222 and G.41TC. On the other hand, lowest cumulative yield has been obtained by B.71-7.22 followed by CG.2034 (**Table 3**).

2015 'Modi' Apple Organic Rootstock Evaluation Trial (cooperator)
Extremely light to no 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**).

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, KGB bush, and UFO inclined tree) using 9 rootstocks (Cass, Clare, Clinton, Gi3, Gi5, Gi12, Lake, and MxM14) with Benton as the scion. High tree mortality observed in MxM14. Trunk circumference data will be collected shortly as soon as leaves will drop off the trees.

2017 Semi-dwarf Peach Rootstock Evaluation Trial (cooperator)
The trial was established in WCRC-OM experimental orchard in May 8th, 2017. The scion cultivar was Cresthaven and the rootstocks were 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. Trunk circumference data for year 1 will be collected as soon as leaves will drop off the trees.

***Objective 4*. Better understand the impacts of biotic and abiotic stresses on scion/rootstock combinations in temperate-zone fruit trees.**

During the fall/winter season of 2016/17 an extensive cold hardiness analysis was performed on 10 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 2016/17. However only data from three time points are presented herein (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. DTA data collection continues over the fall/winter season of 2017/18 on the same rootstocks. In addition, DTA data were validated (**Table 2**) in the field based on tissue oxidative browning after the various killing frosts in late February and early March (**Figure 2**). Validation revealed DTA to be very consistent with the field damage in Lovell samples. DTA predicted damage by the frost events in February 24th, 25th and 26th and in March 1st and 7th, 2017 was ~55-60% buds killed. Field evaluation of frost damage in Lovell rootstocks shoots in March 9th, 2017 revealed a 46% live buds among the buds analyzed, consisted with DTA predicted damage (**Table 3**). Subsequently, in the same rootstocks frost damage was evaluated as fruit set after a post-bloom spring frost (25.5^{o}F) in the morning of April 5th (**Figure 4**). Controlled 7 and Krymsk®86 had the higher fruit set rates whereas Atlas had the lowest fruit set.

***Objective 5*. Enhance the sustainability of temperate fruit farming through development and distribution of research-based information utilizing *e*Xtension.**

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. Attending tree fruit growers and extension personnel (50 people) were updated on the most recent information from the NC-140 rootstock trials established in the CO site. During the fall winter season CO tree fruit growers received 24 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:

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

7. Scientific and Outreach Oral Presentations:

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).

Addendum

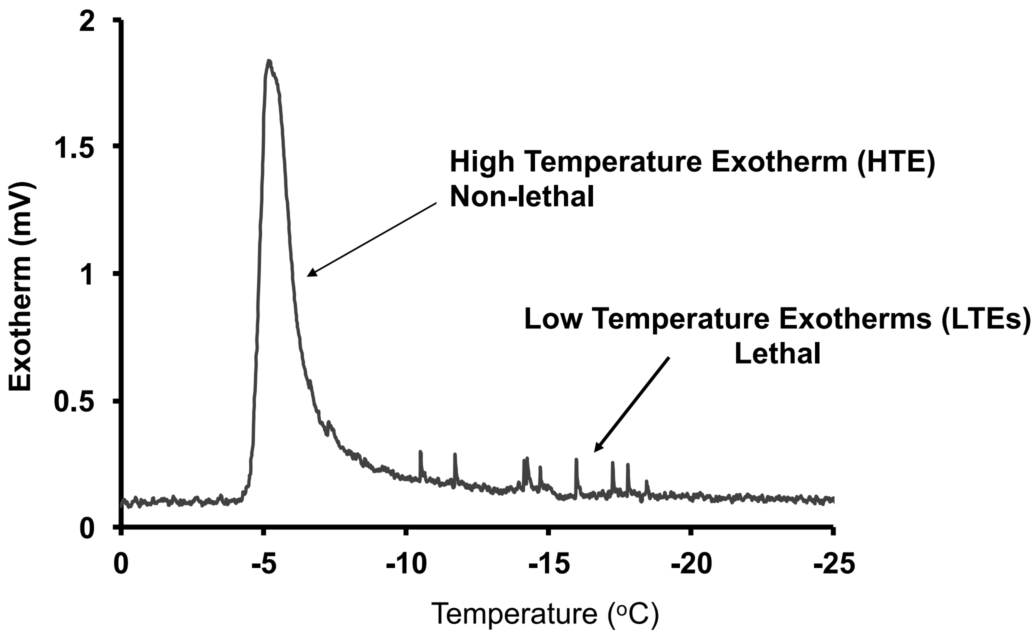


Figure 1. Differences in low temperature exotherms (LTE) for 'Red Haven' flower buds coming from trees growing at the experimental orchard at the CSU's WCRC-OM near Grand Junction, CO, on November 21, 2016. High temperature exotherms (HTEs), indicating non-lethal extracellular freezing of extracellular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

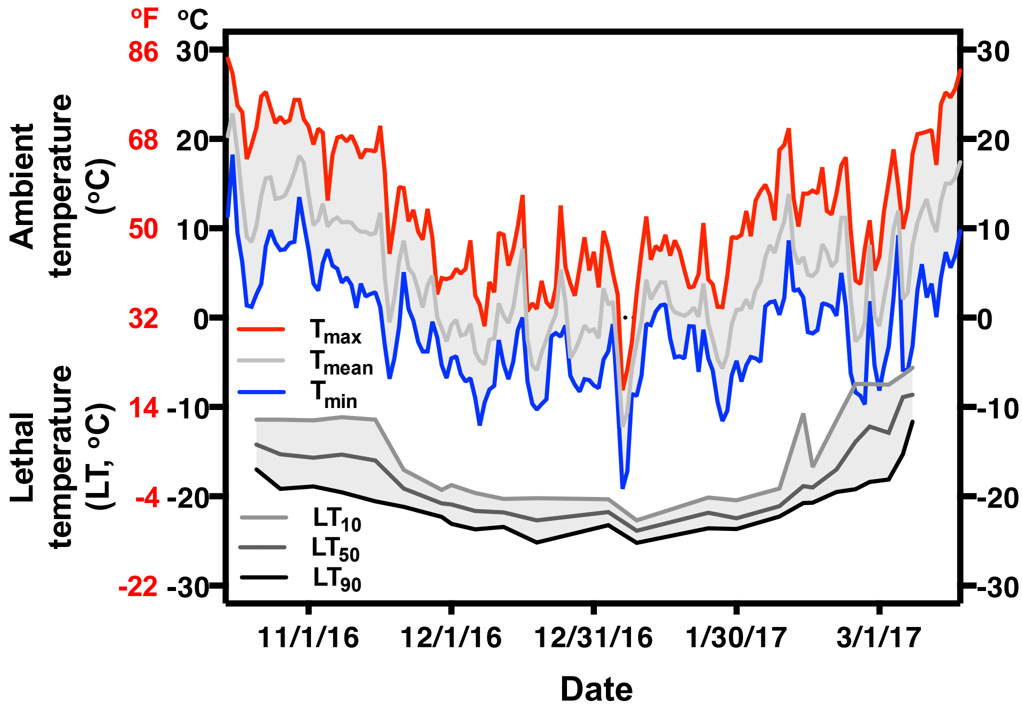


Figure 2. Seasonal patterns of temperature and cold hardiness, expressed as lethal temperature for 10, 50 and 90% of the total flower buds killed (LT_{10}, LT_{50}, LT_{90}, respectively), for peach flower buds of 'Red Haven' peaches grafted on 'Lovell' peach seedling cultivar rootstock that is planted 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 (°C) and Fahrenheit (°F) 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®, KV 010127, Krymsk®86, Lovell, Controller 7, Controller 8, Controller 5 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 near Grand Junction, Colorado.

		°C			**°F**		
Date	**Cultivar**	**LT_{10}**	**LT_{50}**	**LT_{90}**	**LT_{10}**	**LT_{5}**	**LT_{90}**
11/15/16	Atlas	-10.7	-16.9	-18.8	12.8	1.6	-1.8
	Bright's Hybrid-5	-11.4	-17.9	-18.8	11.4	-0.2	-1.8
	Guardian®	-12.6	-15.8	-19.6	9.3	3.6	-3.3
	KV 010127	-12.5	-16.0	-19.0	9.6	3.3	-2.3
	Krymsk®86	-9.4	-16.5	-19.6	15.1	2.4	-3.2
	Lovell	-14.3	-17.5	-21.3	6.3	0.6	-6.3
	Controller 7 (HBOK32)	-13.5	-17.6	-20.2	7.8	0.3	-4.3
	Controller 8 (HBOK10)	n/a	n/a	n/a	n/a	n/a	n/a
	Controller 5	-12.7	-17.2	-20.5	9.1	1.0	-4.8
	Krymsk®1	-11.7	-15.7	-19.4	11.0	3.8	-2.9
12/13/16	Atlas	-19.2	-21.0	-22.3	-2.6	-5.7	-8.1
	Bright's Hybrid-5	-19.3	-21.9	-22.7	-2.8	-7.5	-8.9
	Guardian®	-17.6	-21.5	-22.7	0.3	-6.8	-8.9
	KV 010127	-20.8	-21.8	-22.6	-5.4	-7.3	-8.6
	Krymsk®86	-19.8	-22.2	-23.2	-3.7	-8.0	-9.7
	Lovell	-19.5	-21.8	-22.7	-3.2	-7.2	-8.8
	Controller 7 (HBOK32)	-19.6	-21.9	-22.6	-3.3	-7.3	-8.8
	Controller 8 (HBOK10)	-19.4	-21.8	-23.2	-3.0	-7.3	-9.8
	Controller 5	-17.6	-21.2	-22.7	0.3	-6.2	-8.8
	Krymsk®1	-18.5	-21.4	-22.8	-1.4	-6.5	-9.1
1/23/17	Atlas	-17.9	-21.0	-22.1	-0.1	-5.8	-7.7
	Bright's Hybrid-5	-19.2	-21.1	-22.0	-2.5	-5.9	-7.7
	Guardian®	-16.1	-21.5	-22.3	3.1	-6.7	-8.1
	KV 010127	-20.1	-21.7	-22.4	-4.2	-7.1	-8.3
	Krymsk®86	-19.2	-21.3	-22.5	-2.5	-6.4	-8.4
	Lovell	-20.5	-21.7	-22.4	-4.9	-7.0	-8.4
	Controller 7 (HBOK32)	-20.1	-21.5	-22.4	-4.2	-6.6	-8.3
	Controller 8 (HBOK10)	-19.6	-21.4	-22.4	-3.2	-6.6	-8.3
	Controller 5	-17.6	-21.7	-22.4	0.2	-7.1	-8.2
	Krymsk®1	-17.7	-21.5	-22.4	0.2	-6.6	-8.3

Table 2. Percentage of live 'Red haven' floral buds in March 9th, 2017 on trees grafted on selected rootstocks planted within the *NC-140 2009 'Red Haven' Peach Rootstock Evaluation Trial* in the experimental orchard of the Colorado State University's WCRC-OM near Grand Junction, Colorado. Results from Lovell rootstock were used for validation of the DTA predicted frost damage in February 24th, 25th and 26th and March 1st and 7th (**Figure 2**).

Rootstock	Percentage of live buds in March 9th, 2017
Atlas	65%
Bright's Hybrid-5	73%
Guardian®	67%
KV 010127	65%
Krymsk®86	67%
Lovell	46%
Controller 7 (HBOK32)	54%
Controller 5	60%
Krymsk®1	38%

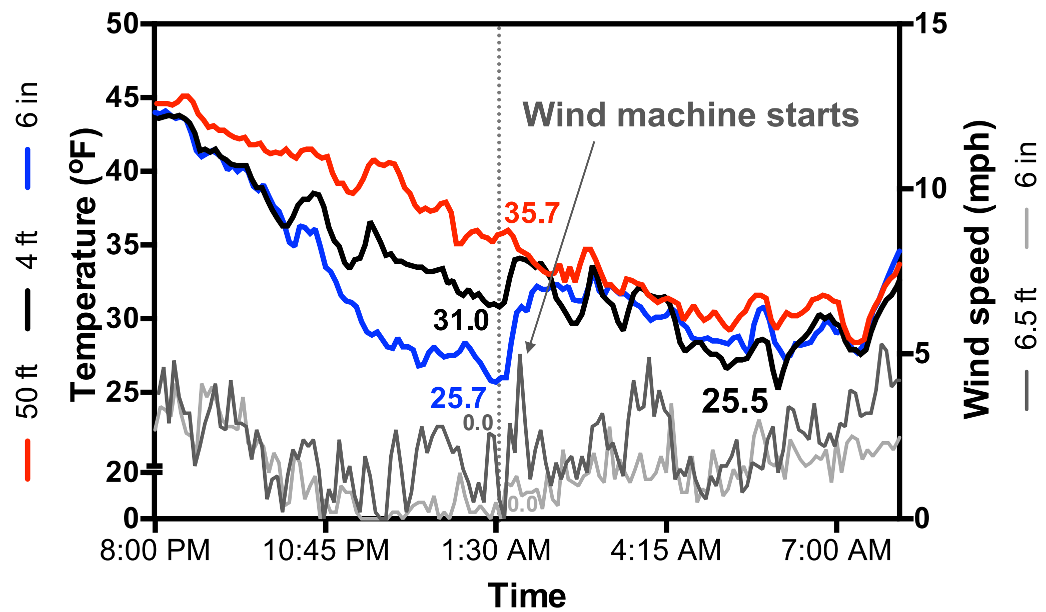


Figure 3. Inversion monitoring in WCRC-OM. Temperature (°F) and wind speed (mph) changes during the night of April 4th to April 5th, 2017 at three (50 feet, 4 feet and 6 inches) and two (6.5 feet and 6 inches) different heights, respectively, in WCRC-OM. With the grey arrow is indicated the time that wind machine was ignited.

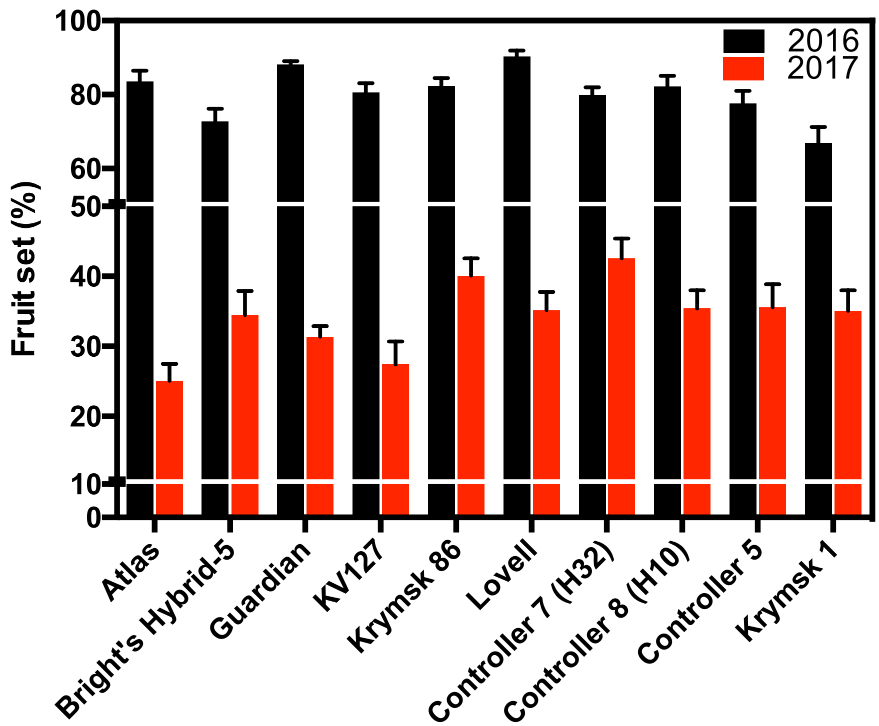


Figure 4. Fruit set in selected rootstocks from the 2009 Red Haven peach rootstock trial block in 2016 and 2017. In 2017 fruit set was significantly reduced compared to 2016 due to the post-bloom spring frost in April 5th.

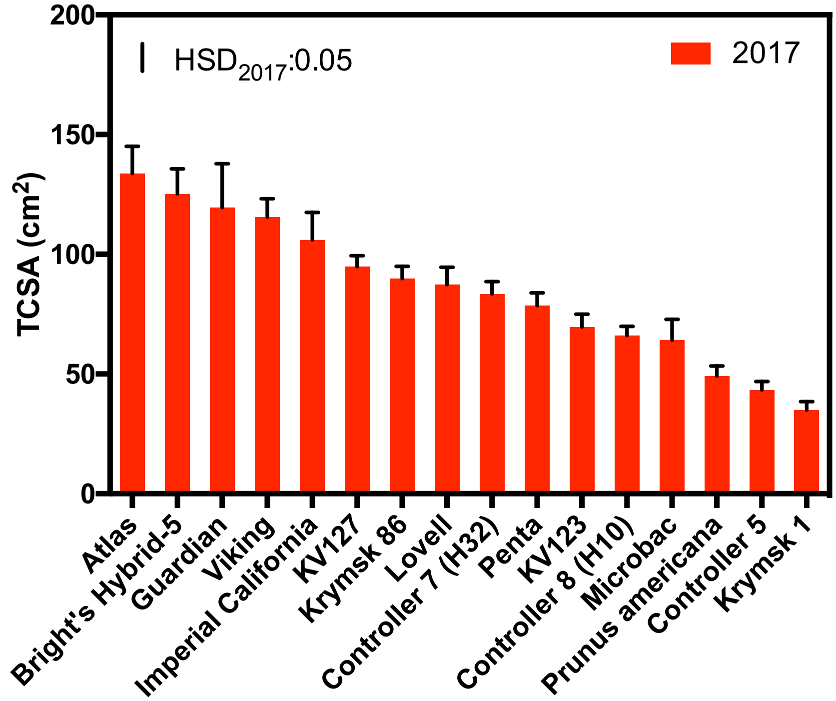


Figure 5. Trunk cross sectional area (TCSA, 2017) data of the 2009 Red Haven peach rootstock evaluation trial. Rootstocks are presented from left (large) to right (dwarf) based on tree size.

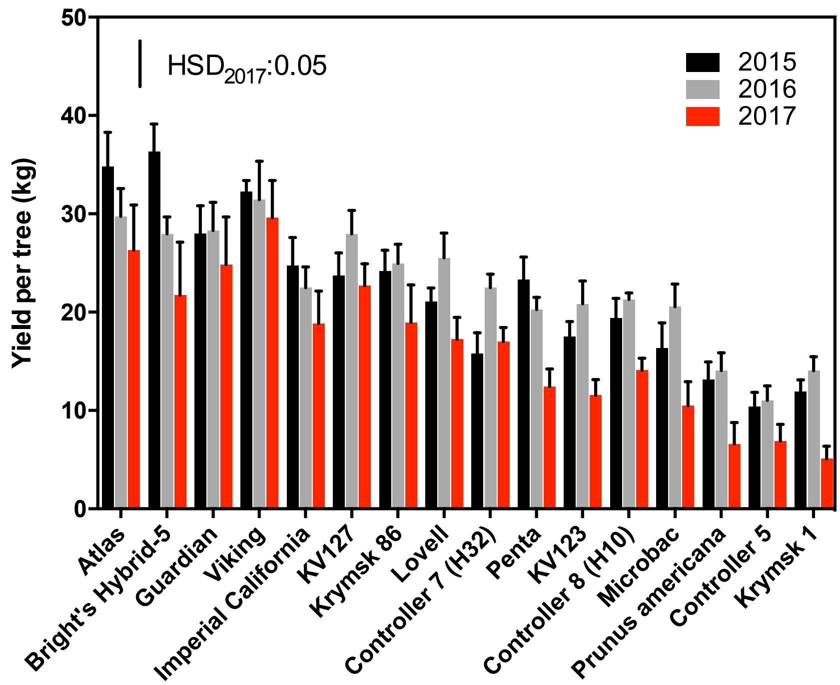


Figure 6. Yield per tree (2017) data of the 2009 Red Haven peach rootstock evaluation trial. Rootstocks are presented from left (large) to right (dwarf) based on tree size.

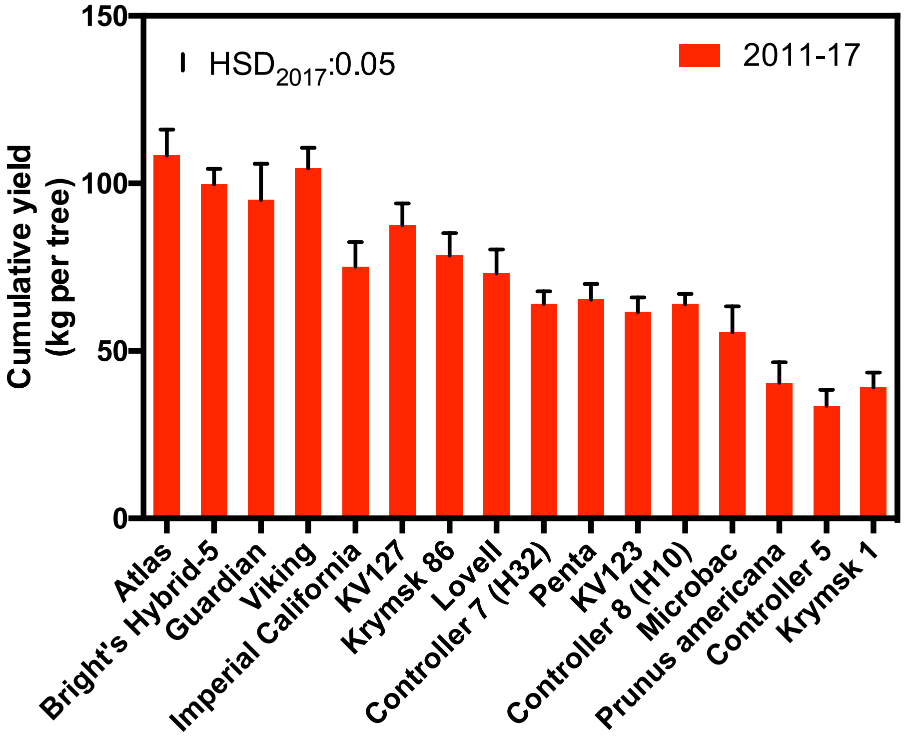
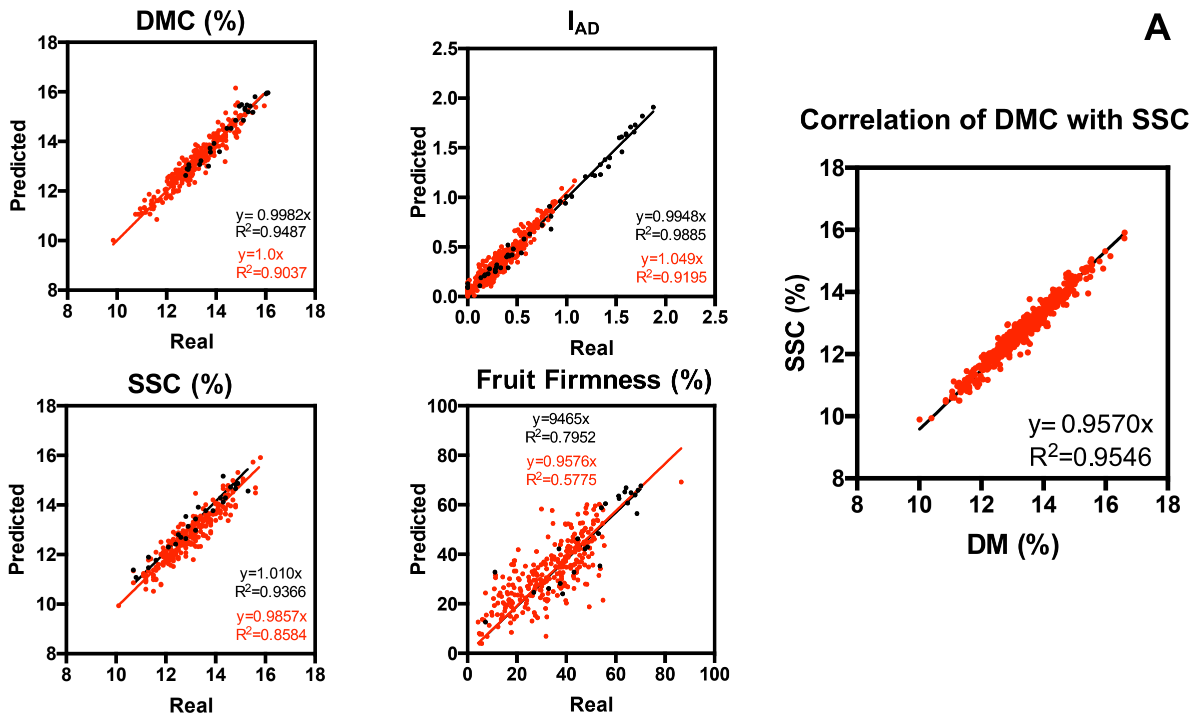


Figure 7. Cumulative yield per tree (2011-17) data of the 2009 Red Haven peach rootstock evaluation trial. Rootstocks are presented from left (large) to right (dwarf) based on tree size.



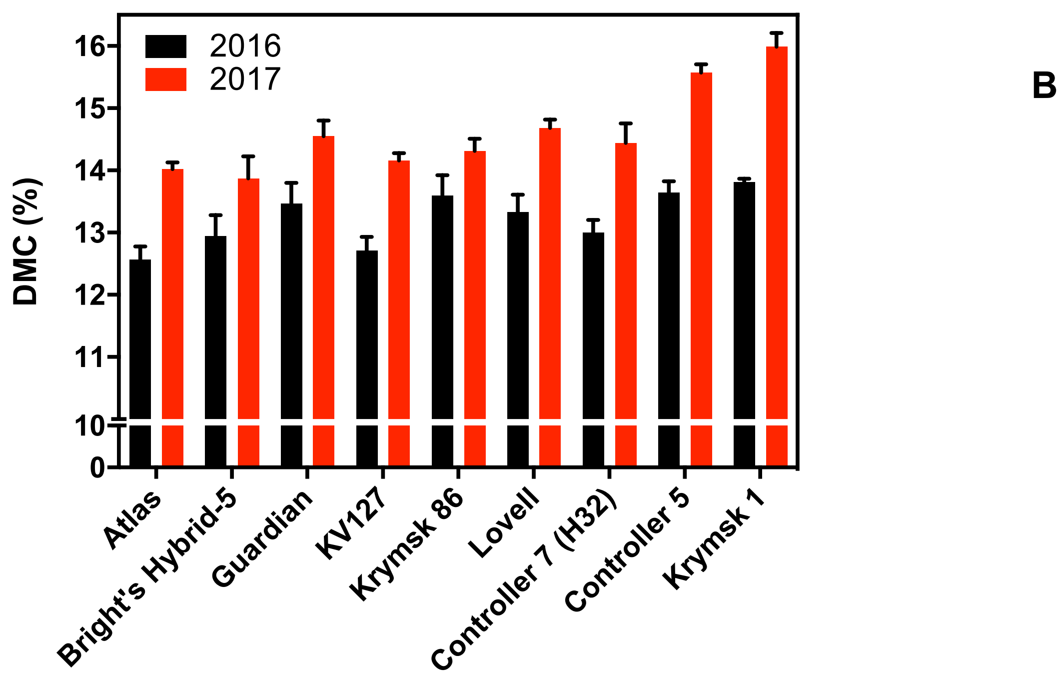


Figure 8. Validation data of the non-destructive models created to estimate internal fruit quality of 'Red Haven' peaches (A). Effect of rootstock on 'Red Haven' peach internal fruit quality estimated as dry matter content (DMC) in 2016 and 2017. Rootstocks are presented from left (large) to right (dwarf) based on tree size.

Table 3. Tree and yield characteristics in 2017 of Honeycrisp apple trees in the 2010 NC-140 Apple rootstock trial at the CSU's WCRC-OM, Grand Junction, CO.

Vigor Category	Rootstock	TCSA (2017, cm^2)	Yield per tree (2017, kg)	Fruit weight (2017, g)	Cumulative yield per tree (2011-2017, kg)
Large semi-dwarf	B.7-20-21	46.9	7.9	275.7	20.9
	B.64-194	60.6	8.0	267.7	17.5
	B.70-6-8	44.5	6.9	244.7	16.8
	B.67-5-32	51.1	9.1	264.5	15.9
	B.7-3-150	43.2	8.6	243.3	24.1
Moderate semi-dwarf	CG.3001	31.7	5.4	265.2	14.4
Small semi-dwarf	PiAu 51-11	30.5	6.0	225.5	18.8
	PiAu 9-90	28.4	4.8	215.6	13.4
	CG.4004	30.0	6.0	269.6	21.2
Large dwarf	CG.5222	27.2	13.6	213.9	26.5
	M.9 Pajam 2	24.4	7.9	269.4	28.5
	CG.4814	23.8	2.8	258.2	21.4
	G.41 N	26.4	0.8	250.0	18.0
	CG.3041	25.5	5.1	262.8	22.3
	G.935 TC	24.7	1.5	269.3	15.9
	M.26 EMLA	23.7	7.0	229.5	19.8
	Supp.3	24.6	4.9	256.6	11.4
	G.202 N	23.1	1.3	224.4	13.7
	CG.5087	23.6	8.0	365.8	18.3
Moderate dwarf	M.9 NAKBT337	21.0	4.8	286.2	25.6
	CG.4214	17.7	6.0	254.4	26.0
	G.11	19.7	4.5	322.3	17.9
	G.41 TC	22.4	5.0	240.0	26.4
	G.202 TC	19.4	8.6	182.5	20.9
	B.10	18.9	5.8	233.0	17.2
Small dwarf	B.9	9.2	4.5	200.7	12.4
	CG.4003	15.1	8.7	287.3	15.1
	CG.2034	13.6	1.0	219.9	7.1
Sub-dwarf	B.71-7.22	4.6	1.2	164.4	2.9
	Estimated HSD	4.8*	2.2	43.2	

*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.