Establishment performance of the 2017 NC-140 vigor-limiting peach rootstock trial across ten sites in North America

I.S. Minas[1,a], G.L. Reighard[2], B. Black[3], J.A. Cline[4], D.J. Chavez[5], E. Coneva[6], G.A. Lang[7], M. Parker[8], T.L. Robinson[9], J. Schupp[10], P. Francescato[9], J. Lordan[9], T. Beckman[11], W.W. Shane[12], J.R. Pieper[1], D.G. Sterle[1], C. Bakker[4], B. Clark[8], D. Ouellette[2], A. Swain[3] and H.E. Winzeler[10]

[1]Department of Horticulture and Landscape Architecture, Colorado State University, Colorado 80523, USA; [2]Department of Plant & Environmental Sciences, Clemson University, South Carolina 29634, USA; [3]Department of Plants, Soils and Climate, Utah State University, Utah 84322, USA; [4]Simcoe Research Station Department of Plant Agriculture, University of Guelph, ON, N3Y 4N5, Canada; [5]Department of Horticulture, University of Georgia, Georgia 30223, USA; [6]Department of Horticulture, Auburn University, Alabama 36849, USA; [7]Department of Horticulture, Michigan State University, East Lansing, MI 48824, USA; [8]Department of Horticultural Science, North Carolina State University, Raleigh, NC 27695, USA; [9]Horticulture Section, Cornell AgriTech, Geneva Campus, Cornell University, New York 14456, USA; [10]Department of Horticulture, Penn State University, Biglerville, Pennsylvania 17307, USA; [11]USDA-ARS, 21 Dunbar Road, Byron, Georgia 31008, USA; [12]Southwest Michigan Research and Extension Center, Michigan State University, MI 49022, USA.

Abstract

Eight vigor-limiting, standard, and vigorous *Prunus* rootstocks budded with 'Cresthaven' peach were planted at 10 locations in North America (nine in US and one in Canada) in spring 2017. During the first three years of establishment, significant differences among rootstocks and sites were found for survival, root suckers, tree growth, yield, fruit size, and yield efficiency. Tree survival was high (>96%) in SC, PA, MI, AL, CO, and UT and low (<75%) in NY, NC, and GA. 'Rootpac® 40' had the lowest overall survival (72%), followed by 'Controller™ 7', 'Rootpac® 20', and 'MP-29'. Rootstock suckering was excessive on 'Rootpac® 20' with 'Lovell' a distant second. The largest trees were in AL, followed by NY, SC, and UT, while the smallest trees were in CO, a short growing season site with calcareous soils and high soil pH. Averaged across all sites, the largest trees were on 'Guardian®', followed by 'Lovell', 'Rootpac® 20' and 'Controller™ 6' (76, 72, and 60% of 'Guardian®', respectively), whereas smallest trees were on 'Rootpac® 40' and 'MP-29' (both 41% of 'Guardian®'). In 2019, the first year that trees were cropped, 90% bloom varied across sites by 77 days, whereas 10% maturation differed by 55 days. However, no differences in bloom or harvest date were observed across rootstocks. Yield was highest in UT and AL (10-11 kg tree^{-1}) and lowest in NC, CO, and GA (1-3 kg tree^{-1}). The highest yields were on the most vigorous rootstocks 'Guardian®', 'Lovell', and 'Rootpac® 20', while lowest yield was on 'Rootpac® 40'. The rootstock with the highest yield efficiency was 'MP-29' while the lowest was 'Rootpac® 40'. Fruit size was large (227-298 g) in UT, SC, AL, moderate (195-213 g) in NC, PA, CO, and NY, and small (127 g) in GA. Averaged across sites, 'Controller™ 6' produced the largest fruits (249 g) while 'Guardian®' and 'MP-29' produced the smallest (210 g).

Keywords: *Prunus persica*, interspecific hybrid, size controlling rootstocks, yield efficiency

INTRODUCTION

Prunus spp. interspecific hybrids and plums have replaced peach [*Prunus persica* (L.) Batsch] as preferred rootstocks for peach scions in Europe and are becoming important in major production areas of North America (Reighard et al., 2020). The most common peach rootstocks are derived from *Prunus* spp. within the taxonomic section Euamygdalus Schneid, including peach seedlings (*P. persica*), almond seedlings [*P. dulcis* (Mill.) D.A. Webb], *P.*

[a]E-mail: ioannis.minas@colostate.edu

davidiana (Carr.) Franch., and interspecific hybrids of peach × almond and peach × *P. davidiana* (Reighard et al., 2020). Evaluating these novel cultivar and rootstock combinations for their responses to different pedoclimatic conditions and intensive cropping systems, i.e., simplified canopy architectures that improve productivity and labor efficiency, is warranted (Reighard and Loreti, 2008; DeJong et al., 2014).

Studies on *Prunus* spp. show that rootstock influences the performance of the grafted scion cultivar. Rootstocks influence leaf gas exchange, water relations, mineral uptake, tree size, bloom time, floral bud hardiness, yield efficiency, tree vigor, fruit ripening time, and total fruit production (Zarrouk et al., 2005; Basile et al., 2007; Reighard et al., 2020). Prior to rootstock release and commercial use, peach scion cultivars must be budded on the candidate rootstock to ascertain graft compatibility for maximum tree survival, optimum nutrition, growth, and fruit quality under standard orchard conditions (Reighard et al., 2015). In addition, adaptation or tolerance to different soils, climates, pests, and diseases also are important (Reighard et al., 2020).

Almond × peach hybrids like 'GF677' are commonly used in Mediterranean countries because they tolerate calcareous soils and lime-induced Fe chlorosis, and they also are replant tolerant and graft-compatible with peach cultivars (Giorgi et al., 2005). Almond hybrids are characterized for their vigor and adaptability in poor soils with high pH, such as regions of the western US (Reighard et al., 2020; Black et al., 2021). However, excessive peach tree vigor creates the need for heavier pruning that can increase canker incidence and tree decline and may interfere with fruit quality (Minas et al., 2018). Dwarfing rootstocks generally partition more photosynthates (sugars) to fruits because of the lower competition from the vegetative organs (Chalmers and Ende, 1975; Font i Forcada et al., 2012; Gullo et al., 2014).

Less vegetative growth improves light distribution and interception within the canopy, consequently improving photosynthetic efficiency. Conversely, excessive shading in the canopy negatively affects fruit quality, e.g., size, color, sugar, phytochemical concentration, and antioxidant activity (Font i Forcada et al., 2012; Gullo et al., 2014). Xylem anatomy and exchange of endogenous plant hormones between plant organs are the primary mechanisms of rootstock/scion interactions that affect plant productivity and fruit quality, modifying the sink rate from the fruit to the shoot (Jackson, 1993; Tombesi et al., 2010). The percentage of dry matter partitioned to fruit decreased with increasing rootstock vigor even under increasing fruit sink demand (number of fruit) due to crop load (Caruso et al., 1997; Inglese et al., 2002).

Use of precocious, dwarfing, productive and efficient rootstocks have transformed apple and sweet cherry production by allowing the development of high-density cropping systems and the adoption of two-dimensional canopy architectures (Robinson et al., 2013; Musacchi et al., 2015; Autio et al., 2017, 2020; Lang, 2019). However, research on peach dwarfing rootstocks is ongoing and has yet to provide effective tree canopy size control without affecting fruit size (DeJong et al., 2014; Minas et al., 2018). The objective of this study was to evaluate the performance of new vigor-limiting *Prunus* spp. rootstocks for peach budded to 'Cresthaven' across 10 peach growing regions in North America under the guidance of the US. Department of Agriculture (USDA) multistate project NC-140.

MATERIALS AND METHODS

Plant material and locations

The 2017 NC-140 Peach Rootstock Trial is evaluating eight peach rootstocks that impart varying levels of vigor across 10 sites in the United States and Canada: Alabama (AL), Colorado (CO), Georgia (GA), Michigan (MI), New York (NY), North Carolina (NC), Ontario (ON), Pennsylvania (PA), South Carolina (SC) and Utah (UT). The scion cultivar is 'Cresthaven'. The rootstocks include three *P. persica* hybrids ('Controller™6', '7' and '8'), three interspecific *Prunus* hybrids ('Rootpac®20' and '40' and 'MP-29'), and two *P. persica* seedlings ('Lovell' and 'Guardian®') which serve as standard peach rootstock controls (Table 1).

Table 1. Rootstock genetic origin information.

Rootstock	Breeder, Country	Genetic origin
Controller™ 6 (HBOK 27)	UC Davis, CA, USA	Peach x peach hybrid (*Prunus persica* × *P. persica*)
Controller™ 7 (HBOK 32)	UC Davis, CA, USA	Peach x peach hybrid (*P. persica* × *P. persica*)
Controller™ 8 (HBOK 10)	UC Davis, CA, USA	Peach x peach hybrid (*P. persica* × *P. persica*)
MP-29	USDA, GA, USA	Plum x peach interspecific hyb. (*P. umbellata* × *P. persica*)
Rootpac® 40 (Nanopac)	Agromillora Iberia, Spain	Almond x peach interspecific hyb. [(*P. dulcis* × *P. persica*) × (*P. dulcis* × *P. persica*)]
Rootpac® 20 (Densipac)	Agromillora Iberia, Spain	Plum x peach interspecific hybrid (*P. besseyi* × *P. persica*)
Guardian®	Clemson/USDA, SC, USA	Peach seedling (*P. persica*)
Lovell	G.W. Thissell, CA, USA	Peach seedling (*P. persica*)

Experimental design

'Cresthaven' trees were planted in Spring 2017 at a spacing of 1.8×4.5 m and a planting density of 1196 trees ha^{-1}. The trees were trained to the perpendicular-V or KAC-V training system (DeJong et al., 1994). Each site was planted as a randomized complete block design with 4 or 5 replications of four-tree plots per rootstock. The two central trees per replicated plot are used for data collection, while the two trees to either side are used as border trees to minimize light competition interference between rootstocks of different vigor. 'MP-29' was only planted at the US sites and not in Canada due to intellectual property restrictions. Orchards received standard cultural practices for each location and were irrigated.

Data collection and analyses

Data collection occurred at planting (spring 2017) and during the growing seasons of 2017 (1st leaf), 2018 (2nd leaf), and 2019 (3rd leaf). Annual tree survival, trunk circumference (at 30 cm above graft union) for calculating trunk cross sectional area (TCSA), root sucker counts, 90% bloom Julian date, 10% maturity Julian date, yield, calculated yield efficiency (yield cm^{-2} of TCSA), and mean fruit weight were recorded. One-way analysis of variance (ANOVA) was used to detect differences among rootstock genotypes across all locations and among locations (across rootstocks) using JMP® Pro 15.0 (SAS Institute Inc., Cary, NC). When a significant difference was detected among rootstock or location, means were separated by Tukey Kramer Honestly significant difference (HSD) test at p=0.05.

RESULTS AND DISCUSSION

During the first three years of establishment, significant differences among rootstocks and sites were found in survival, root suckers, tree vigor, yield, fruit size, and yield efficiency. 'MP-29' were the largest trees at planting across all sites, followed by 'Guardian®' and 'Lovell'. 'Controller™ 6' and 'Rootpac® 40' nursery stock trees were the smallest (Table 2). The different sites received fairly similar size trees from the nurseries, with CO and SC receiving slightly larger and NC slightly smaller trees compared to the other (Table 3).

Best rootstock performance in terms of survival was observed with 'Guardian®' (96%) and 'Lovell' (94%), followed by 'Controller™ 8' (89%) and '6' (88%), 'MP-29'(87%), 'Rootpac® 20' (86%) and 'Controller™ 7' (85%) (Table 2). Across all sites, the rootstock with the worst survival rate was 'Rootpac® 40' (72%). The low survival rate might have been associated with the relatively limited growth of these trees in the nursery and generally poor establishment in the first season. Overall rootstock survival was high (>90%) at most sites except NY (49%). Survival in NC and GA was 74 and 73% survival rate, respectively (Table 3). At the NY site, the most losses were trees on the 'Controller™' series, 'Lovell', and 'Rootpac® 40'. The NY site is characterized by heavy soils and a cold climate.

Table 2. Third leaf 'Cresthaven' peach tree survival, sucker count, trunk cross-sectional area (TCSA) at planting and 3 years after establishing each rootstock across locations. Relative tree size compared to 'Lovell' and Guardian® for rootstock vigor classification is also provided.

Rootstock	Survival (%)	Suckers (count)	TCSA (cm^2) at planting (2017)	TCSA (cm^2) 3rd leaf (2019)	% of Lovell (2019)	% of Guardian (2019)
Controller™ 6	87.7[a]	0.3[b]	0.4[f]	24.3[cd]	78.9	60.1
Controller™ 7	85.0[ab]	0.1[b]	0.7[ef]	18.7[de]	60.7	46.3
Controller™ 8	89.0[a]	0.3[b]	1.0[d]	21.1[de]	68.5	52.2
MP-29	86.8[ab]	0.1[b]	2.2[a]	16.6[e]	53.9	41.1
Rootpac® 20	86.1[ab]	4.1[a]	0.8[de]	29.1[bc]	94.5	72.0
Rootpac® 40	72.1[b]	0.0[b]	0.5[ef]	16.4[e]	53.2	40.6
Guardian®	96.0[a]	0.9[b]	1.8[b]	40.4[a]	131.2	100.0
Lovell	94.0[a]	1.1[b]	1.3[c]	30.8[b]	100.0	76.2
Estimated HSD	15.7	3.0	0.2	6.5		

Means in columns followed by a different letter within each cultivar indicate significance at P=0.05 according to Tukey (HSD) test.

Table 3. Third leaf (2019) 'Cresthaven' peach tree survival, sucker count, trunk cross-sectional area (TCSA) at planting (2017), and 3 years after establishment at each location.

Site	Survival (%)	Suckers	TCSA (cm^2) at planting (2017)	TCSA (cm^2) 3rd leaf (2019)
AL	97.1[a]	1.3[abc]	n/a	43.2[a]
CO	97.5[a]	2.4[a]	1.2[a]	13.5[e]
GA	72.5[b]	1.2[abc]	n/a	15.7[de]
MI	98.8[a]	n/a	1.0[ab]	19.1[de]
NC	73.7[b]	0.4[bc]	0.9[b]	27.8[bc]
NY	48.7[c]	2.1[ab]	1.0[ab]	33.0[b]
ON	90.0[a]	0.0[c]	1.0[ab]	21.5[cd]
PA	100.0[a]	0.4[bc]	n/a	27.1[bc]
SC	100.0[a]	0.7[bc]	1.2[ab]	30.3[b]
UT	96.0[a]	0.1[c]	n/a	28.8[b]
Estimated HSD	16.3	1.7	0.3	7.3

Means in columns followed by a different letter within each cultivar indicate significance at P=0.05 according to Tukey (HSD) test.

Suckering was low across most rootstock cultivars tested except for 'Rootpac® 20', which produced an excessive number (i.e., 4) of suckers across all locations. The most vigorous rootstocks, 'Lovell' and 'Guardian®', were a distant second with one sucker per tree (Table 2). Suckering was relatively low across the trial sites, with CO, NY, AL, and GA producing the most suckers (Table 3).

'Cresthaven' tree vigor and size were significantly influenced by rootstock and location. After three growing seasons (2017-2019), trees on 'Guardian®' were the largest, followed by 'Lovell', 'Rootpac® 20' and 'Controller™ 6' (Table 2). The smallest trees were on 'Controller™ 7', 'MP-29', and 'Rootpac® 40'. This trend was consistent across the establishment years (2017-2019).

As previously reported and currently accepted as estimates, peach rootstock vigor classification in the US is bracketed as follows: vigorous rootstocks are >110% the size of 'Lovell' as estimated by TCSA. Standard size rootstocks are 110-90% of 'Lovell' size, semi-dwarfing rootstocks are 60-90% of 'Lovell', and dwarfing rootstocks are <60% the size of 'Lovell' (Reighard et al., 2015, 2018). Based on this rootstock vigor classification and the establishment TCSA data across all sites in this trial, 'Guardian®' (131% of Lovell) would be

classified as vigorous rootstock across all sites. 'Lovell' and 'Rootpac® 20' (95% of Lovell) are standard size. On the other hand, all 'Controller™' series rootstocks are semi-dwarfing (61-79% of Lovell), with 'Controller™ 6' being the most vigorous among them (Table 2). Only 'MP-29' and 'Rootpac® 40' are classified as dwarfing (54 and 53% of Lovell, respectively). The relative tree size comparisons with 'Guardian®' across all rootstocks is provided in Table 2. The largest 'Cresthaven' trees were in AL, followed by NY, SC, and UT, whereas the smallest trees were in CO, which has a short growing season and calcareous soils with a high soil pH.

Full bloom and fruit maturation date were only recorded at 6 locations during the first 3 years of establishment, and neither were affected significantly by rootstock genotype (Table 4). 'MP-29' appeared to be blooming first, but data variability prevented statistically significant differences. However, as expected, full bloom and maturation dates were significantly different between locations. Full bloom varied by 77 days, whereas fruit maturation varied by 55 days across the sites in 2019, the first year the trees were cropped. SC was earliest site to bloom at 70 Julian days and ON the last at 145 Julian days. SC and AL had the earliest maturation dates, and UT was the latest, as there were no crops reported in MI and ONT due to winter and spring low temperatures, respectively.

Table 4. Third leaf (2019) 'Cresthaven' peach average 90% bloom date, maturation date (10% ripe), yield, fruit fresh weight (FW), and yield efficiency on each rootstock across locations.

Rootstock	90% bloom (Julian day)	10% ripe (Julian day)	Yield (kg tree^{-1})	Fruit FW (g)	Yield efficiency (kg cm^{-2})
Controller™ 6	103.0^{a}	226.2^{a}	4.7^{bc}	249.2^{a}	0.17^{ab}
Controller™ 7	102.9^{a}	221.8^{a}	4.3^{bc}	228.7^{ab}	0.18^{ab}
Controller™ 8	102.5^{a}	225.7^{a}	4.4^{bc}	230.9^{ab}	0.16^{ab}
MP-29	92.8^{a}	221.6^{a}	4.6^{bc}	210.4^{b}	0.26^{a}
Rootpac® 20	100.1^{a}	221.8^{a}	6.5^{b}	230.3^{ab}	0.19^{ab}
Rootpac® 40	101.7^{a}	219.2^{a}	3.0^{c}	241.6^{ab}	0.14^{b}
Guardian®	104.1^{a}	223.5^{a}	9.8^{a}	210.4^{b}	0.22^{ab}
Lovell	107.8^{a}	228.4^{a}	6.9^{b}	227.3^{ab}	0.19^{ab}
Estimated HSD	15.1	9.5	2.9	38.8	0.1

*Means in columns followed by a different letter within each cultivar indicates significance at P=0.05 according to Tukey (HSD) test.

Rootstock significantly influenced yields per tree (Table 4). The highest yields for the first crop of the trial (2019) were on the most vigorous rootstocks such as 'Guardian®' (9.8 kg tree^{-1}), Lovell (6.9 kg tree^{-1}), and 'Rootpac® 20' (6.5 kg tree^{-1}), while the lowest was on 'Rootpac® 40' (3 kg tree^{-1}) (Table 4). The rootstocks with the highest yield efficiency were the dwarfing 'MP-29' (0.26 kg cm^{-2} of TCSA) and the vigorous 'Guardian®' (0.22 kg cm^{-2}), while the least yield efficient was the dwarfing 'Rootpac® 40' (0.14 kg cm^{-2} of TCSA) (Table 4).

Yields differed significantly across locations. Yield was highest in UT and AL with 11.3 and 9.5 kg tree^{-1}, respectively, and lowest in NC, CO, and GA with 2.8, 0.9, and 0.6 kg tree^{-1}, respectively (Table 5). Yield efficiency was highest in UT with 0.42 kg cm^{-2} of TCSA, followed by PA with 0.26 kg cm^{-2} of TCSA (Table 5).

'Cresthaven' trees on 'Controller™6' produced the largest fruits (249 g), followed by 'Rootpac®40' (241 g), 'Controller™8' (231 g), 'Rootpac®20' (230 g), 'Controller™7' (229 g), and 'Lovell' (227 g) (Table 5). Fruit were smallest on 'Guardian®' and 'MP-29' (210 g), which is a commercially acceptable fruit size for most peach industries. Fruit size was largest in UT (298 g), followed by SC (267 g) and AL (227 g). Fruit size was moderate to large fruit size was recorded in NC (213 g), PA (202 g), CO (200 g), and NY (195 g), and small in GA (127 g.) These fruit size values do not necessarily reflect inherent traits of the rootstocks since they are from the initial cropping season, and crop loads were not adjusted in proportion to tree vigor. Since the most vigorous trees produced greater loads of fruit. Also, since 'Cresthaven' is a high chill cultivar, it is suffering from the recent low chill winters in the southeastern US, especially in GA, as indicated by its poor tree growth, yield, and fruit size.

Table 5. Third leaf (2019) 'Cresthaven' peach tree bloom date (90%), maturation date (10% ripe), yield, fruit fresh weight (FW), and yield efficiency at each location.

Site	90% bloom (Julian day)	10% ripe (Julian day)	Yield (kg tree^{-1})	Fruit FW (g)	Yield efficiency (kg cm^{-2})
AL	75.1^{e}	197.5^{e}	9.5^{ab}	227.1^{c}	0.22^{b}
CO	102.0^{d}	238.6^{c}	0.9^{d}	199.8^{d}	0.05^{c}
GA	n/a	n/a	0.6^{d}	127.9^{e}	0.03^{c}
MI	n/a	n/a	n/a	n/a	n/a
NC	n/a	n/a	2.8^{d}	213.9^{cd}	0.08^{c}
NY	128.0^{b}	246.0^{b}	6.9^{bc}	194.6^{d}	0.23^{b}
ONT	145.0^{a}	n/a	n/a	n/a	n/a
PA	n/a	224.0^{d}	7.2^{bc}	202.2^{d}	0.26^{b}
SC	69.8^{f}	197.3^{e}	6.4^{c}	266.9^{b}	0.21^{b}
UT	112.0^{c}	252.2^{a}	11.3^{a}	298.4^{a}	0.42^{a}
Estimated HSD	5.4	6.2	2.3	25.0	0.13

*Means in columns followed by a different letter within each cultivar indicate significance at P=0.05 according to Tukey (HSD) test.

CONCLUSIONS

Results from this study cover the establishment phase of the trial across 10 sites in North America. Past NC-140 peach rootstock trials have shown rootstock productivity and performance can be characterized effectively after at least three bearing years (Reighard et al., 2004, 2015, 2018, 2020). With only three years since planting and one cropping season, preliminary impressions suggest that the 'Controller™ ' series of rootstock may provide some promising options for the semi-dwarfing category of vigor control, and 'MP-29' may be promising as a dwarfing rootstock with generally good performance across the different locations of this trial. Definitive conclusions on the performance of these rootstocks, with respect to vigor, yield, fruit size and quality, and overall site adaptability, can only be made with the collection of additional data in subsequent growing seasons.

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