Early performance of several Prunus interspecific hybrid rootstocks for Redhaven peach in southern Ontario

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ARTICLE

Early performance of several *Prunus* interspecific hybrid rootstocks for Redhaven peach in southern Ontario

J.A. Cline and C.J. Bakker

Abstract: A multi-year orchard experiment was established to measure the performance of Rootpac®-R, Rootpac®-20, Rootpac®-40, and Rootpac®-70 rootstocks using 'Redhaven' peach (*Prunus persica* var. *persica*) as the scion, compared with the 'Bailey' peach seedling rootstock, the current industry standard. Tree survival after five years was 79% on Rootpac-40, whereas the remaining rootstocks showed no tree mortality. Tree vigour and canopy height and width were influenced by rootstock genotype beginning the year of planting in 2016. For the first five years of production, Rootpac-70 consistently produced the largest trees based on truck cross-sectional area (TCSA) and by year five, all rootstocks produced trees with similar TCSAs, except for Rootpac-70, which was 38% larger than Bailey. By year five, cumulative yields were greatest on Rootpac-70, which were 10% higher than Bailey; cumulative yields of Rootpac-R, Rootpac-20, and Rootpac-30 were 98%, 89%, and 84% that of Bailey, respectively. Cumulative yield efficiency was significantly influenced by rootstock although the magnitude of the differences was small and likely of insignificant commercial importance. Rootpac-40 consistently produced the largest fruit. These results are only reflective of the orchard establishment years and additional data are required before peach producers can make fully informed decisions concerning the rootstocks evaluated in this study for their orchard systems. However, at this juncture, all the Rootpac rootstocks evaluated in this study are likely to impart excessive vigour to be used in a higher density system and offer little advantage over Bailey.

Key words: tree mortality, tree survival, rootstock suckers, cumulative yield, cumulative yield efficiency.

Résumé : Les auteurs ont réalisé une expérience pluriannuelle dans un verger en vue de vérifier le rendement des porte-greffes Rootpac®-R, Rootpac®-20, Rootpac®-40 et Rootpac®-70 avec le pêcher Redhaven (*Prunus persica* var. *persica*) comme greffon et comparer les résultats à ceux obtenus avec de jeunes porte-greffes Bailey, actuel étalon dans l'industrie. Après cinq années, le taux de survie des arbres se chiffrait à 79 % pour Rootpac-40, sans mortalité aucune pour les autres porte-greffes. Le génotype du porte-greffe a influé sur la vigueur de l'arbre ainsi que la hauteur et le diamètre de la frondaison dès la plantation, en 2016. Au cours des cinq premières années de production, Rootpac-70 a toujours donné les plus grands arbres, selon la surface de la coupe transversale (SCT). La cinquième année, les porte-greffes avaient tous produit des pêchers dont la SCT était similaire, à l'exception de Rootpac-70, dont la SCT dépassait celle de Bailey de 38 %. Rootpac-70 a enregistré le meilleur rendement cumulatif la cinquième année, soit 10 % de plus que Bailey; le rendement cumulatif de Rootpac-R, de Rootpac-20 et de Rootpac-30 correspondait respectivement à 98 %, à 89 %, et à 84 % de celui de Bailey. Le porte-greffe exerce une influence notable sur le rendement efficace cumulatif, bien que la variation soit faible et, sans doute, de peu d'importance sur le plan commercial. Rootpac-40 a toujours donné les plus gros fruits. Ces résultats ne s'appliquent qu'aux années d'établissement du verger. Il faudrait d'autres données avant que les producteurs puissent prendre une décision éclairée sur les porte-greffes évalués dans le cadre de cette étude. Néanmoins, pour l'instant, on peut dire que tous les porte-greffes Rootpac évalués devraient conférer une vigueur excessive aux arbres plantés plus densément, donc présentent peu d'avantages comparativement à Bailey. [Traduit par la Rédaction]

Mots-clés : mortalité des arbres, survie des arbres, drageons des porte-greffes, rendement cumulatif, rendement efficace cumulatif.

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Introduction

For several decades, peach cultivars grown in Ontario have been predominately grafted on 'Bailey' peach seedling rootstocks. Bailey is a *Prunus* selection from Iowa that imparts cold hardiness and uniform and reliable yields (OMAFRA 2021), but lacks vigour control and tolerance to several important abiotic and biotic stresses (Layne 1987). New genotypes for peach rootstocks possessing diverse horticultural traits are being developed worldwide to increase productivity and improve efficiency through improved tree survival, controlled tree vigour, increased fruit size and quality (Reighard and Loreti 2008; Reig et al. 2020). A wider selection of rootstocks is becoming increasingly available which has improved tolerance to abiotic stresses (such as compacted and coarse-textured soils, high-pH soils and cold winter temperatures) and biotic stresses (such as parasitic nematodes, rot fungal pathogens and orchard replant problems) (Loreti and Massai 2006; Reighard and Loreti 2008; Jiménez et al. 2011; Iglesias et al. 2018).

As planting density and production costs increase, developing new size-controlling rootstocks with novel traits is also of interest to peach and nectarine producers. Size control in peaches has the potential to increase yield efficiency and reduce production costs by reducing the time to prune, thin and harvest trees (Reig et al. 2020). Similar benefits in apple production have been realized since the dwarfing East Malling rootstocks were introduced in the 20th century (Marini and Fazio 2018).

Preliminary research conducted in other regions of North America by researchers affiliated with the NC-140 USDA technical committee, and other European researchers suggests that there are several new peach rootstocks with attributes suitable for the Ontario tender fruit industry (Font i Forcada et al. 2020; Reighard et al. 2015; Lordan et al. 2019). These include tolerance to drought, finer-textured (heavier) soils (which are often prone to wetter conditions than sandy soils), and resistance to parasitic nematodes and soil fungi, and replant disease (Iglesias et al. 2018). This study focuses on a series of rootstock genotypes developed by Agromillora Catalana breeding program (Agromillora Iberia S.L. Subirats, Spain), a commercial breeding company in Spain. These rootstocks have been reported to have varying degrees of size control, adaptation to different types of soil, ease of vegetative propagation via tissue culture, and good compatibility with *Prunus* species. Rootpac®-20 (synonym Densipac), Rootpac®-40 (synonym Nanopac), Rootpac®-70, and Rootpac®-R (synonym Replantpac) specifically have different levels of size control, cold hardiness, tolerance to wet soils, and resistance to root-knot nematodes (*Meloidogyne incognita*, *Meloidogyne javanica*), root-lesion nematodes (*Pratylenchus penetrans* or *Pratylenchus vulnus*) and root rot (*Rosellinia necatrix*) (Table 1). These inter-specific peach, plum, and almond hybrid rootstocks have rarely been examined in North America. The objective of this study was to evaluate the performance of these new rootstocks grafted with 'Redhaven' peach.

Material and Methods

Orchard details

Redhaven trees on five clonal rootstocks (Rootpac®-R, Rootpac®-20, Rootpac®-40, Rootpac®-70) and Bailey seedling rootstock were planted at the University of Guelph Ontario Crops Research Centre – Simcoe, ON (42°51′40″ N, 80°16′8″ W) in the spring of 2016. They were trained to a central leader training system and spaced at 1.8 m within row and 5.0 m between rows (1111 trees·ha^{-1}). The experimental design consisted of a completely randomized block design with five replications of seven trees per block — a total of 35 trees per rootstock. Trees were planted in a Wilsonville sandy loam (Brunisolic Grey Brown Luvisol) (Presant and Acton 1984) with rapid drainage and soil textures consisting of mainly lacustrine gravelly sandy till (Hohner and Presant 1989). Trees were trickle-irrigated daily with the equivalent of ~2.5 cm of water weekly (adjusted for natural rainfall) on a schedule of four irrigation run times per day. Irrigation occurred every 6 h (20 min per event) using 2 L·h^{-1} pressure-compensating emitters spaced 45 cm apart. Standard cultural and pest management practices for Ontario were used (OMAFRA 2015). Weeds were controlled within a 1-m strip on each side of the tree row using 1% (*v*/*v*) glyphosate applications in mid-May, June, and July and plastic tree guards were used to prevent contact with the bark. A permanent sod culture was established the year of planting between tree rows using a mixture of 40% perennial rye and 60% red fescue (Vineland Growers, Vineland, ON). All trees were propagated at the Simcoe Research Station in the spring of 2014. Rootpac® rootstocks were derived from tissue culture and propagated by North American Plants (Lafayette, Oregon). Bailey rootstocks were grown from seed.

Horticultural measurements

Each autumn, trunk circumference was measured 30 cm above the graft union and trunk cross-sectional area (TCSA) was calculated. The date of full bloom was recorded annually beginning in 2017 when the trees bore fruit. In the autumn, root suckers were counted and removed and tree mortality and harvest date, yield (total fruit weight [FW]) and total number of fruits per tree were recorded. In addition, total marketable yield based on local commercial standards was measured by omitting any fruit smaller than 60 mm in diameter. Crop load per tree was calculated by dividing the total number of fruits by the TCSA, and average FW was calculated by dividing total FW by total number of fruits per tree. Cumulative yield was calculated as the sum of yield from 2017 to 2020. Cumulative yield efficiency (CYE) was

Table 1. Characteristics of Bailey and Rootpac rootstocks used in this study.

Roostock	Other denomination	Origin	Species	Size	Cold hardiness	Root-knot resistance[a]	Root-lesion resistance[b]	*Rosellinia necatrix*	Tolerance to wet soils[c]	Remarks	References
Bailey		United States	*Prunus persica*	5%–25% less than Lovell	Yes	3	2	—	2	—	—
Rootpac®-20	Densipac	Agromillora Catalana breeding program, Spain	Plum hybrid (*P. besseyi* × *P. cerasifera*)	Low, around 40%–50% less than GF-677	Yes	1	?	Tolerant	1	Adapts very well to high density plantation. Good adaptation to heavy soils and cold areas. Varietal denomination: Densipac	Agromillora Group 2021
Rootpac®-40	Nanopac	Agromillora Catalana breeding program, Spain	Hybrid of peach × almond (*P. dulcis* × *P. persica*) × (*P. dulcis* × *P. persica*).	Medium, approximately 25%–30% less than GF-677	Unknown	2	3	Unknown	2	Extremely well adapted to warm production conditions. Recommended for peach and nectarine. Good compatibility with peach, nectarine, almond and some varieties of Japanese plum. Anticipates ripening by 3 to 7 days depending on the variety. Produces good-size fruit.	Agromillora Group 2021
Rootpac®-70		Agromillora Catalana breeding program, Spain	Hybrid of peach × almond (*P. persica* × *P. davidiana*) × (*P. dulcis* × *P. persica*)]	Medium to medium-high, approximately 20% less than GF-677 (Agromillora Group 2021); Vigorous (Jiménez et al. 2011)	Low	—	3	Unknown	Unknown	Adapts very well to all climates, but particularly to warm conditions (low chilling areas). Good with varieties of plum, peach and nectarine. It has also proven to be compatible with some varieties of almond and apricot. Anticipates ripening by 2 to 5 days depending on the variety. Results in good fruit size in plum, peach and nectarine.	Jiménez et al. 2011; Agromillora Group 2021

Table 1. (*concluded*).

Roostock	Other denomination	Origin	Species	Size	Cold hardiness	Root-knot resistance[a]	Root-lesion resistance[b]	*Rosellinia necatrix*	Tolerance to wet soils[c]	Remarks	References
Rootpac®-R	Replantpac	Agromillora Catalana breeding program, Spain	Hybrid of plum × almond (*P. cerasifera* × *P. dulcis*)	High vigor with peach, nectarine and plum varieties. Similar to Mariana-2624, Nemaguard; 20% less vigor than GF 677	Yes	1	2	It has been shown to be resistant in sites highly infested with this soil fungus.	1	It adapts well to heavier textured soil prone to with asphyxia.	Pinochet 2010; Font i Forcada et al. 2020; Agromillora Group 2021

R

[a]Resistance to root-knot nematodes (*Meloidogyne incognita, Meloidogyne javanica*): 1 = immune or resistant, 2 = moderately resistant or some tolerance, 3 = susceptible, ? = unknown.

[b]Resistance to root-lesion nematodes (*Pratylenchus penetrans* or *Pratylenchus vulnus*); 1 = immune or resistant, 2 = moderately resistant or some tolerance, 3 = susceptible, ? = unknown.

[c]Tolerance of fine-textured soils when waterlogged; 1 = good, 2 = fair, 3 = poor.

calculated by dividing cumulative yield by TCSA in 2020. Following harvest and prior to pruning in 2020, the height and spread of the canopy were recorded.

Statistical analyses

Data were analyzed by the GLIMIX procedure of SAS (version 9.4, SAS Institute, Inc., Cary, NC) and mean separation performed using Tukey's HSD test to separate means with treatments as fixed effects. To account for crop load effects on FW, crop-load adjusted average FW was analysed using crop load as a covariate. Shapiro–Wilk test was used to test the assumption that the residuals were normally distributed. Scatterplots of studentized residuals were observed visually to test the assumption that the errors were not heterogeneous. In cases where there were large deviations from assumptions, data were corrected by log- or square root-transformation prior to analysis.

Results and Discussion

Climate of orchard location

Climate normals (30 yr average 1981–2010) for Delhi, Ontario, located approximately 25 km from the orchard site, are presented in Table 2. This region experiences a warm humid continental climate with temperatures moderated by the Great Lakes (Köppen climate classification Dfb). On average, there are 145 frost free days per year with average winter and summer temperatures of −5.4 °C and 27.3 °C, respectively, 906 mm precipitation, and average monthly rainfall of 75 mm during 1 May to 31 Aug. On average, there are 38 d where winter temperatures fall below −10 °C, and 4 d where winter temperatures fall below −20 °C. Minimum winter temperatures recorded where the study was conducted were −10.9 °C, −13.0 °C, −22.7 °C, −24.2 °C and −16.6 °C for 2016–2020, respectively (data not shown).

Tree survival

Tree survival was influenced by rootstock genotype in 2019 and 2020, but not in the prior formative years (Table 3). In 2019, tree survival was significantly lower on Rootpac-40 (88%; $P = 0.0014$) compared with the other rootstocks, which had no mortality. Tree survival of Rootpac-40 declined to 79% in 2020 ($P < 0.0001$), while no further mortality on any of the other rootstocks was observed. The cause of tree death of Redhaven on Rootpac-40 rootstocks was unclear. However, it was likely associated with a pathogen that infected the rootstock or caused by winter injury, leading to complete and rapid tree decline. In a rootstock study in Spain where Rootpac-70 and Rootpac-R were investigated among 16 rootstocks and no tree mortality was observed after 9 yr (Font i Forcada et al. 2020); Rootpac-40 was not included in that study. Mestre et al. (2015) observed no tree mortality of Rootpac-R after 13 yr in a study of 12 rootstocks using Big Top nectarine as the scion while Ben Yahmed et al. (2016) observed 20% tree mortality in

Table 2. Frost-free days, temperature, and rainfall parameters, based on 30 yr climate normals (1981–2010), Delhi, Ontario, Canada[a].

Frost-free days	145
Average min winter temperature (°C)	−5.4
Average max summer temperature (°C)	27.3
Average number of days below −10 °C	38
Average number of days below −20 °C	4
Average annual rainfall (mm)	906
Average monthly rainfall (mm)	75
Average monthly rainfall, May–August (mm)	89

[a]Source: Environment Canada 2021.

Table 3. Tree survival (%) of Redhaven peach trees, as affected by rootstock over 5 yr. Trees planted in 2016 and trained to a central leader training system.

Rootstock	2016	2017	2018	2019	2020
Rootpac®-R	100	100	100	100a	100a
Rootpac®-20	100	100	100	100a	100a
Rootpac®-40	100	100	100	88b	79b
Rootpac®-70	100	100	100	100a	100a
Bailey	100	100	100	100a	100a
P value	—	—	—	0.0014	<0.0001

Note: Mean values followed by the same letter within a given column are not significantly different according to Tukey's HSD test at $P = 0.05$.

Rootpac-70 after the first year of planting in an orchard in a Subirana (flat peach cultivar) orchard in northern Tunisia. In a Spanish study, Pinochet (2010) reported no tree mortality of a Japanese plum cultivar on Rootpac-R rootstock after year nine.

A unique aspect of Rootpac-40 and Rootpac-R compared with the other rootstocks examined in this study is that Rootpac-40 and Rootpac-R are peach × almond hybrid and plum × almond hybrid, respectively, with up to 50% almond genetics. In comparison, Rootpac-20 and Rootpac-70 have up to 25% almond parentage and Bailey no almond parentage (Font i Forcada et al. 2020). Almond (*P. dulcis*) is native to Persia and as such, it is better adapted to warmer growing regions than that experienced in southern Ontario. It is plausible that Rootpac-40 is more susceptible to winter injury for this reason, however that does not explain when Rootpac-R had no tree mortality. Another possibility is delayed incompatibility between the scion and Rootpac-40 rootstock, causing tree collapse. However, based on previous research by Çetinbaş et al (2018) who found no incompatibility with *P. persica* (peach and nectarine cultivars) within 1 yr of grafting, delayed incompatibility is a less likely cause of tree mortality.

Tree vigour

Tree vigour, as indicated by TCSA and canopy height and width, was influenced by rootstock selection from the time of planting in 2016 onward (Table 4). Based on TCSA, Rootpac-70 was consistently the largest rootstock (38% larger than Bailey) followed by Rootpac-R and Rootpac-40 (9% larger than Bailey). Rootpac-20 was the smallest of the Rootpac rootstocks (2% larger than Bailey). By year five (2020), all rootstocks produced trees with similar TCSA, except for Rootpac-70, which was significantly larger ($P < 0.0001$). Rootpac-70 was 38% larger than Bailey, while Rootpac-R and Rootpac-40 were both ~10% larger than Bailey, and Rootpac-20 was 2% larger than Bailey. It is difficult to compare tree vigour of the Rootpac rootstock series in this study with other studies who use a rootstock standard different than Bailey. Notwithstanding, comparisons can be made with the Rootpac rootstocks. In a Spanish study using Big Top as the scion, in the 11th year, Rootpac-20 and Rootpac-40 had each 31% less vigour than Rootpac-70 (Reig et al. 2020). These data are fairly consistent with the present study were Rootpac-20 and Rootpac-40 were 26% and 21% less vigorous than Rootpac-70, respectively. In a preliminary Italian study using Big Top and Rome Star as scions, trees on Rootpac-20 and Rootpac-40 had the least vigour among six rootstocks in year three. However overall tree vigour was influenced by planting location and training system (Scalisi et al. 2018). In a study on almonds, Lordan et al. (2019) found Rootpac-20 was the most dwarfing of ten rootstocks and had approximately 25% and 30% less vigour than Rootpac-R and Rootpac-40. No other studies in the current literature have compared any of the Rootpac rootstocks with Bailey to our knowledge.

Tree height is an important component of training system. Target tree size in the central leader spindle trees used in this study is approximately 3.5 m. However, in a higher density system using a size controlling rootstock, developing a shorter, less vigorous bi-dimensional canopies with a ~3 m height would be desirable (Reig et al. 2020). Tree width and height in year five were both influenced by rootstock selection (Table 4). Trees on Rootpac-70 and Bailey produced the tallest trees compared with the other rootstocks, which were similar in height. Canopy width was also influenced by rootstock selection ($P < 0.0001$). Trees on Rootpac-70, Rootpac-20, and Bailey had the widest canopies, while trees on Rootpac-R were slightly narrower. Rootstock effect on tree width is confounded by the need to prune trees when they reach their allotted space of 1.8 m (i.e., to prevent encroachment on adjacent trees). Thus, both tree height and width data must be interpreted cautiously. On all rootstocks, Redhaven exceeded the 1.8 m spacing by the fifth leaf, indicating that Redhaven trees will require annual pruning thereon to contain them within this space. Overall, none of the Rootpac rootstocks provided a narrower canopy than Bailey. While tree height of Rootpac-R, Rootpac-20 and Rootpac-40 were slightly shorter than Bailey by year five,

Table 4. Tree growth, as represented by tree trunk cross-sectional area, of Redhaven peach trees, as affected by rootstock over 5 yr. Trees planted in 2016 and trained to a central leader training system.

	Trunk cross-sectional area (cm^2)					Tree width	Tree height
Rootstock	2016	2017	2018	2019	2020	2020 (m)	2020 (m)
Rootpac®-R	9.1a	16.6a	26.3b	32.8b	40.1b	2.6b	3.4b
Rootpac®-20	6.7b	12.3b	22.7cd	29.9bc	37.6b	2.7ab	3.4b
Rootpac®-40	6.5b	12.1b	23.5c	30.5bc	39.8b	2.5b	3.3b
Rootpac®-70	9.5a	17.0a	29.5a	38.5a	50.6a	2.8a	3.9a
Bailey	5.0c	10.5c	21.1d	28.2c	36.7b	2.7ab	3.7a
P value	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

Note: Mean values followed by the same letter within a given column are not significantly different according to Tukey's HSD test at $P = 0.05$.

Table 5. Number of suckers (no/tree) of Redhaven peach trees, as affected by rootstock over 4 yr. Trees planted in 2016 and trained to a central leader training system.

Rootstock	2017	2018	2019	2020	Cumulative (2017–2020)
Rootpac®-R	0.3Ab	1.2a	1.9b	2.5b	5.9b
Rootpac®-20	0.7A	1.8a	5.7a	8.6a	16.9a
Rootpac®-40	0.0B	0.0b	0.0b	0.0b	0.0c
Rootpac®-70	0.1B	0.2b	0.3b	0.3b	0.9bc
Bailey	0.0B	0.0b	0.1b	0.0b	0.1bc
P value	0.0033	<0.0001	<0.0001	<0.0001	<0.0001

Note: Mean values followed by the same letter within a given column are not significantly different according to Tukey's HSD test at $P = 0.05$.

these rootstocks likely still impart excessive vigour to be used in a higher density system.

Rootstock suckers

The number of rootstock suckers per tree was significantly influenced by rootstock selection in all years in which there was sucker development. The quantity of cumulative root suckers for the years 2017 to 2020 was also influenced by rootstock selection ($P < 0.0001$) (Table 5). Rootpac-20 had the greatest propensity to sucker, followed by Rootpac-R. Low and insignificant suckering occurred on trees with Rootpac-40, Rootpac-70, and Bailey rootstocks. The higher tendency to sucker of Rootpac-20 and Rootpac-R could be related with its plum parentage (Table 1). Mestre et al. (2017) also reported that rootstock suckering is a drawback inherent with some plums. Reig et al. (2020) found similar rootstock suckering for Rootpac-20 and Rootpac-40 (on average 3 rootstock suckers per trees) and less suckering for Rootpac-70 using Big Top as the scion. Mestre et al. (2015) found very low suckering in Rootpac-R per tree during year 13 of production. Rootstock suckers are undesirable in the orchard because they can act as infection sites for disease and harbor pests. If suckers are profuse, they also can interfere with in-row weed management and can absorb systemic herbicides such as glyphosate, potentially injuring the tree (Johnson et al. 2011).

Yield, cumulative yield, yield efficiency

There was a strong rootstock effect on yield beginning in year three (2017), when the trees began bearing fruit (Table 6). There was also a strong rootstock effect on cumulative yield ($P < 0.0001$) and CYE ($P < 0.001$) at year five (Table 6). In 2017, Rootpac-70 yielded the most fruit, while Rootpac-20 yielded the least. Rootpac-70 continued to yield the most fruit in 2018 through 2020, whereas beginning in 2018 and thereafter, Rootpac-40 yielded the fewest fruit. In two of four years (2019 and 2020), Rootpac-R was among the highest yielding rootstocks. Cumulative yields were greatest on Rootpac-70, and 10% higher than Bailey. Bailey, the industry standard rootstock, was among the highest yielding rootstock in the last two years of cropping (2019 and 2020). However, cumulative yields on Bailey were intermediate amongst the rootstocks tested and 9% lower than Rootpac-70. The cumulative yields of Rootpac-R, Rootpac-20, Rootpac-40, and Rootpac-70 were 98%, 89%, 83% and 110% that of Bailey, respectively. There was also a significant rootstock effect on cumulative marketable yield; averaged over all rootstocks, approximately 10% of fruit were unmarketable because of undersized or immature fruit.

Table 6. Total fruit yield, cumulative yield, cumulative marketable yield (kg tree^{-1}), total and cumulative yield efficiency (kg·TCSA^{-1}) in year 2020 of Redhaven peach trees, as affected by rootstock over 4 yr. Trees planted in 2016 and trained to a central leader training system.

Rootstock	2017	2018	2019	2020	Cumulative total yield (2017–2020)	Cumulative marketable yield (2017–2020)	Cumulative (total) yield efficiency (2020)
Rootpac®-R	1.7bc	11.4ab	12.6ab	12.1a	37.9bc	34.1b	0.96ab
Rootpac®-20	1.5c	9.3c	11.2bc	12.6a	34.6cd	30.9c	0.95b
Rootpac®-40	2.2ab	10.3bc	10.3c	9.5b	32.6d	28.5c	0.85b
Rootpac®-70	2.5a	12.7a	13.5a	13.9a	42.6a	38.2a	0.85b
Bailey	1.7bc	10.1bc	13.0ab	14.0a	38.8b	35.7ab	1.06a
P value	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

Note: values followed by the same letter within a given column are not significantly different according to Tukey's HSD test at $P = 0.05$.

In general, rootstock differences in cumulative marketable yield were similar to the trends in total cumulative yield. Trees on Rootpac-70 and Bailey had the greatest cumulative marketable yield, while trees on Rootpac-20 and Rootpac-40 had the least.

Whether these rootstock differences in yield will continue as the trees mature and continue to grow is unclear. However, it is likely that Rootpac-70 will become less productive in comparison to the other rootstocks as more pruning is required to restrict it to its planting space. The cumulative yield data are more indicative of the early yield potential of Redhaven on the examined rootstocks rather than the absolute yields that could be obtained at a particular location. This is because tree productivity is influenced by tree nutrient status and environmental and orchard management factors; when these factors are optimized, the full potential of the rootstock will be realized.

CYE was calculated using the sum of four years of yield (2017–2020) and the TCSA in year five (2020). This method was used to normalize yields amongst rootstocks that range in tree vigour. CYE was significantly influenced by rootstock selection ($P < 0.0001$), although the magnitude of the differences was small and likely of insignificant commercial importance (Table 6). Trees on Bailey were more yield-efficient than Rootpac-20, Rootpac-40, and Rootpac-70. In turn, all of them did not differ significantly from Rootpac-R. Since the trees are still in their early years of production, the CYE data may not adequately predict cumulative yields of mature orchards. Once tree canopies fill their allotted space, rootstock effects on yield efficiency are influenced differentially by pruning severity. In other investigations reporting the yield performance of Rootpac rootstocks, Reig et al. (2020) found cumulative yields of Big Top on Rootpac-20, Rootpac-40 and Rootpac-70 rootstocks were similar after in their eleventh year, but the yield efficiency of Rootpac-70 was numerically lower (but not statistically different) - owing to its greater vigour.

Fruit weight

Higher tree crop loads can negatively influence FW, hence the requirement to thin peaches (Coneva and Cline 2006). To normalize any effect of vary crop loads among rootstocks, FW was adjusted using crop load as a co-variate using the method of Marini et al. (2012). Crop load-adjusted FW and overall average FW were influenced by rootstock selection every year from 2017 through 2020 (Table 7). Annually, Rootpac-40 consistently produced the largest fruit while Rootpac-20 consistently produced the smallest fruit. Rootpac-R, Rootpac-70 and Bailey produced fruit of intermediate weight. On average over the four years of cropping, Rootpac-40 produced fruit 16% larger than Bailey, while Rootpac-20, Rootpac-R and Rootpac-70 produced fruit 7%, 4% and 3% smaller than Bailey, respectively. Crop load averaged 1.0, 3.0, 2.7 and 1.8 fruit cm^{-2} TCSA in 2017 through 2020

Table 7. Adjusted mean weight of marketable fruit (g) of Redhaven peach trees, as affected by rootstock over 4 yr. Trees planted in 2016 and trained to a central leader training system[a].

Rootstock	2017	2018	2019	2020	Average
Rootpac®-R	157ab	141bc	138c	172bc	149bc
Rootpac®-20	141b	131c	143bc	171c	144c
Rootpac®-40	172a	174a	170a	219a	179a
Rootpac®-70	149ab	143b	149bc	183bc	151bc
Bailey	145ab	148b	156ab	187b	155b
P value	0.0219	<0.0001	<0.0001	<0.0001	<0.0001

Note: Mean values followed by the same letter within a given column are not significantly different according to Tukey's HSD test at $P = 0.05$.

[a]Values adjusted using crop load (kg fruit·cm^{-2} trunk cross-sectional area) as a covariate.

(after hand-thinning), respectively and did not exceed 3.2 fruit cm^{-2} TCSA for any rootstock (data not shown). This finding suggests that crop load did not limit fruit weight for any of the rootstocks.

In the study by Reig et al (2020), no difference in average FW of Big Top peach on Rootpac-20, Rootpac-40 and Rootpac-70 from year three to 11 were observed.

Notwithstanding the importance of the findings outlined above, this preliminary study had some limitations. While important, it was beyond the scope of this study to measure the abiotic and biotic factors influencing rootstock growth and performance. Further research examining the high mortality rate of Rootpac-40 is required should this rootstock be adopted commercially in this growing region. In addition, fundamental understanding and verification of resistance to nematodes and root rot (*Rosellinia necatrix*) are required should any of the Rootpac rootstocks become commercially important in Ontario.

Conclusions

In this study, four inter-specific peach, plum, and almond hybrid clonal rootstocks from the Agromillora Catalana breeding program were tested along with Bailey peach seedling rootstock using the peach scion Redhaven. After 5 yr, there were significant effects in the metrics used to measure rootstock performance: tree survival, vigour, suckering, cumulative yield, cumulative yield efficiency and fruit size.

This study, the first to evaluate Agromillora germplasm in Canada, provides guidance on the early performance of these rootstocks in the first 5 yr of production. Based on the results, Rootpac-R, Rootpac-20, Rootpac-40 and Rootpac-70 offer no dwarfing control or improved yield efficiency over that of the industry standard, Bailey. Therefore, there appears to be limited value in adopting the use of any of the Agromillora peach, plum, or almond interspecific rootstocks tested in this study in Ontario or regions with similar soils and growing regions. The exception would be that if the Rootpac series offered greater tolerance to abiotic and biotic soil factors than Bailey, further investigation would be warranted. Further, because of its high mortality of Rootpac-40, peach producer would be prudent to exercise extra caution when considering this rootstock when using in similar climatic regions. The results of this study will help inform peach and nectarine producers of the characteristics of these rootstocks to enable better rootstock selection for their orchard training systems. Since rootstock selection can profoundly impact orchard profitability and return on investment, peach and nectarine producers should be aware of new and novel rootstock opportunities when establishing a new orchard.

Contributors' Statement

J. Cline conceptualized and planned the experiment and developed the methodology. C. Bakker managed the orchard, assisted with data collecting, data processing and statistical analyses. J. Cline reviewed the literature and wrote the manuscript.

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References

Agromillora Group. 2021. Genetics for an efficient agriculture. [Online]. Available from https://www.agromillora.com/wp-content/uploads/2020/05/Agromillora_Rootpac_English.pdf [13 July 2021].

Ben Yahmed, J., Ghrab, M., Moreno, M.Á., Pinochet, J., and Mimoun, M.B. 2016. Performance of 'Subirana' flat peach cultivar budded on different *Prunus* rootstocks in a warm production area in North Africa. Scientia Hort. **206**: 24–32. doi:10.1016/j.scienta.2016.04.031.

Çetinbaş, M, Butar, S., Koçal, H., Sesli, Y., and Seferoğlu, H.G. 2018. Graft-compatibility of rootpac rootstocks with nectarine and peach cultivars. Acta Hort. **1281**: 105–112.

Coneva, E.D., and Cline, J.A. 2006. Blossom thinners reduce crop load and increase fruit size and quality of peaches. HortScience, **41**(5): 1253–1258. doi:10.21273/HORTSCI.41.5.1253.

Environment Canada. 2021. Canadian climate normals 1981-2010 station data [Online]. Available from https://climate.weather.gc.ca/climate_normals/results_1981_2010_e.html?stnID=4624&autofwd=1 [21 July 2021].

Font i Forcada, C., Reig, G., Mestre, L., Mignard, P., Betrán, J.Á., and Moreno, M.Á. 2020. Scion × rootstock response on production, mineral composition and fruit quality under heavy-calcareous soil and hot climate. Agronomy, **10**: 1159. doi:10.3390/agronomy10081159.

Hohner, B. and Presant, T. 1989. Soils of the Horticultural Experiment Station Simcoe. Publication No. 89-3. Ontario Institute of Pedology. 48 p.

Iglesias, I., Carbó, J., Bonany, J., Garanto, X., and Peris, M. 2018. Patrones de melocotonero: situación actual, innovación, comportamiento agronómico y perspectivas de futuro. Revista de Fruticult. **61**: 6–42.

Jiménez, S., Pinochet, J., Romero, J., Gogorcena, Y., Moreno, M.Á., and Espada, J.L. 2011. Performance of peach and plum based rootstocks of different vigour on a late peach cultivar in replant and calcareous conditions. Scientia Hort. **129**: 58–63. doi:10.1016/j.scienta.2011.03.006.

Johnson, R., Andersen, W., Autio, T., Beckman, B., Black, P., Byers, J., et al. 2011. Performance of the 2002 NC-140 cooperative peach rootstock planting. J. Amer. Pomol. Soc. **65**: 17–25.

Layne, R.E.C. 1987. Peach rootstocks. Pages 185–216 in Rootstocks for fruit crops. R.C. Rom and R.F. Carlson, eds., Wiley, New York.

Lordan, J., Zazurca, L., Maldonado, M., Torguet, L., Alegre, S., and Miarnau, X. 2019. Horticultural performance of 'Marinada' and 'Vairo' almond cultivars grown on a genetically diverse set of rootstocks. Scientia Hort. **256**: 108558. doi:10.1016/j.scienta.2019.108558.

Loreti, F., and Massai, R. 2006. Bioagronomic evaluation of peach rootstocks by the Italian MiPAF targeted project. Acta Hort. **713**: 295–302. doi:10.17660/ActaHortic.2006.713.43.

Marini, R.P., Autio, W.R., Black, B., Cline, J.A., Cowgill, W., Jr, Crassweller, R., et al. 2012. Summary of the NC-140 apple physiology trial: the relationship between 'Golden Delicious' fruit weight and crop density at 12 locations as Influenced by Three Dwarfing Rootstocks. J. Amer. Pomol. Soc. **66**(2): 78–90.

Marini, R.P., and Fazio, G. 2018. Apple rootstocks: history, physiology, management, and breeding. Hortic Rev. **45**: 197–312. doi:10.1002/9781119431077.ch6.

Mestre, L., Reig, G., Betran, J.A., Pinochet, J., and Moreno, M.Á. 2015. Influence of peach–almond hybrids and plum-based rootstocks on mineral nutrition and yield characteristics of 'Big Top' nectarine in replant and heavy-calcareous soil conditions. Scientia Hort. **192**: 475–481. doi:10.1016/j.scienta.2015.05.020.

Mestre, L, Reig, G, Betrán, J.A., and Moreno, M.A. 2017. Influence of plum rootstocks on agronomic performance, leaf mineral nutrition and fruit quality of 'Catherina' peach cultivar in heavy-calcareous soil conditions. Spanish J. Agric. Res. **15**: e0901. doi:10.5424/sjar/2017151-9950.

OMAFRA. 2015. Guide to Fruit Production 2014-2015. Publication 360. Queens Printer of Ontario, Toronto. 320 p.

OMAFRA. 2021. Peach rootstocks. [Online]. Available from http://www.omafra.gov.on.ca/english/crops/hort/news/tenderfr/tf1705a1.htm [5 April 2021].

Presant, E.W., and Acton, C.J. 1984. The Soils of the Regional Municipality of Haldimand-Nofolk, Report No. 57 of the Ontario Institute of Pedology, L.R.R.I. Contribution No. 84–13, Research Branch, Agriculture Canada, Ottawa, Ontario, 100 p.

Pinochet, J. 2010. 'Replantpac' (Rootpac® R), a plum-almond hybrid rootstock for replant situations. HortSci. **45**: 299–301. doi:10.21273/HORTSCI.45.2.299.

Reig, G., Garanto, X., Mas, N., and Iglesias, I. 2020. Long-term agronomical performance and iron chlorosis susceptibility of several *Prunus* rootstocks grown under loamy and calcareous soil conditions. Scientia Hort. **262**: 109035. doi:10.1016/j.scienta.2019.109035.

Reighard, G.L. and F. Loreti. 2008. Rootstock development. Pages 193–220 in Layne, D.R. and D. Bassi, eds. The peach: botany, production and uses. CAB International, Wallingford, U.K. doi:10.1079/9781845933869.0193.

Reighard, G., Bridges, W., Jr., Archbold, D., Wolfe, D., Atucha, A., Pokharel, R., et al. 2015. NC-140 peach rootstock testing in thirteen U.S. States. Acta Hortic. **1084**: 225–232. doi:10.17660/ActaHortic.2015.1084.32.

Scalisi, A., Lo Bianco, R., Caruso, T., Giovannini, D., Sirri, S., and Fontana, F. 2018. Preliminary evaluation of six *prunus* rootstocks for peach in Italy. Acta Hort. **1228**: 273–278. doi:10.17660/ActaHortic.2018.1228.41.

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