

Yield and compatibility of ten tomato scion varieties grafted with 'Maxifort' rootstock

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Abstract

Many urban and peri-urban tomato growers are adopting the use of grafted plants to help reduce disease incidence and/or improve crop yields, particularly in high tunnel systems. However, little is known about how scion cultivar selection plays a role or if there is a similar impact across scion cultivars in regard to fruit yield. In our study, ten hybrid, determinate, red slicing tomato (*Solanum lycopersicum*) varieties were evaluated as scions for 'Maxifort' rootstock. Trials were conducted in 2016 and 2017 in a three-season high tunnel in Olathe, KS. All ten scion varieties were found to be compatible with 'Maxifort'. However, 'BHN 589', 'Red Deuce', 'Skyway', and 'Tasti Lee' showed significant improvements in marketable yield when grafted to 'Maxifort' indicating that they were "highly compatible" with the rootstock. Grafted 'Red Deuce' and 'BHN 589' scions had the highest fruit yield of any of the treatments that we tested and ranged from 21.4 to 23.0 lbs of marketable fruit per plant. Nongrafted 'Primo Red' was also a good option for high tunnel production and provided 19.2 lbs of marketable fruit per plant. The results of this study suggest that not all scion cultivars respond to grafting with 'Maxifort' rootstock in the same manner and we attempted to assess their compatibility based on crop productivity.

Keywords

hoophouse, high tunnel, greenhouse tomato, propagation, splice grafting, tube grafting

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Many urban and peri-urban tomato growers are adopting the use of grafted plants to help reduce disease incidence and/or improve crop yields, particularly in high tunnel systems. However, little is known about how scion cultivar selection plays a role or if there is a similar impact across scion cultivars regarding fruit yield. In our study, ten hybrid, determinate, red slicing tomato (*Solanum lycopersicum*) varieties were evaluated as scions for 'Maxifort' rootstock. Trials were conducted in 2016 and 2017 in a three-season high tunnel in Olathe, KS. All ten scion varieties were found to be compatible with 'Maxifort'. However, 'BHN 589', 'Red Deuce', 'Skyway', and 'Tasti Lee' showed significant improvements in marketable yield when grafted to 'Maxifort' indicating that they were "highly compatible" with the rootstock. Grafted 'Red Deuce' and 'BHN 589' scions had the highest fruit yield of any of the treatments that we tested and ranged from 21.4 to 23.0 lbs of marketable fruit per plant. Nongrafted 'Primo Red' was also a good option for high tunnel production and provided 19.2 lbs of marketable fruit per plant. The results of this study suggest that not all scion cultivars respond to grafting with 'Maxifort' rootstock in the same manner and we attempted to assess their compatibility based on crop productivity.

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INTRODUCTION

Grafting has been used in high tunnel vegetable production systems worldwide and is an emerging technology in the United States (Kubota *et al.*, 2008; Oda, 1999; Rivero *et al.*, 2003). Concurrently, high tunnels have become popular in the United States because they can extend the production season for warm season crops (Buller *et al.*, 2016; Carey *et al.*, 2009) and allow growers to produce cool-season crops in many parts of the US without supplemental heat (Lamont, 2009). The microclimate provided by high tunnels can result in earlier production and tomatoes (*Solanum lycopersicum*) have been shown to reach maturity as much as three weeks earlier than the open-field (O'Connell *et al.*, 2012). High tunnels and other season extension technologies are commonly used by urban and peri-urban growers that utilize intensive growing practices and cater to local markets.

Many rootstock-specific hybrids have been developed for tomato production that have genetic disease resistance to several soilborne pathogens including root-knot nematodes, fusarium and verticillium wilt, as well as bacterial wilt (Louws *et al.*, 2010). Grafting with specific rootstocks has also been shown to improve overall plant health and vigor (Albacete *et al.*, 2015; Djidonou *et al.*, 2013; Lee, 1994; Masterson *et al.*, 2016a). Grafted plants may have larger root systems, be more efficient at moving water and nutrients, and have greater vegetative production (Djidonou *et al.*, 2013; Lee, 1994).

'Maxifort' is a widely-used, F1 interspecific hybrid tomato rootstock (*S. lycopersicum* x *S. Habrochaites*) (Louws *et al.*, 2010; Masterson *et al.*, 2016a;). 'Maxifort' (De Ruiters/Monsanto St. Louis, MO USA) has been reported to reduce damage and/or confer resistance to soilborne plant pathogens like fusarium wilt, root-knot nematodes and southern blight, and verticillium wilt (Louws *et al.*, 2010). 'Maxifort' rootstock has been tested with numerous scion varieties including: 'BHN 589' (Masterson *et al.*, 2016a; Meyer *et al.*, 2021), 'Maxifort' has shown to enhance plant biomass and leaf area and improved yield under little to no disease pressure as measured by both

fruit number and weight (Djidonou *et al.*, 2013; Masterson *et al.*, 2016b) and plants grafted to 'Multifort' have also demonstrated increased efficiency of N fertilizer and water uptake (Djidonou *et al.*, 2013). As a result of the benefits that rootstocks can provide, grafted plants often excel in covered production systems (like high tunnels) as compared to nongrafted plants (Oda, 1999). Not only are they able to address issues that are prevalent in high tunnels like soil salinity and soilborne diseases (Buller *et al.*, 2016; Oda, 1999), but they typically are growing for a market that can support grafting technology from an economic perspective (Rysin *et al.*, 2015).

A particular rootstock and scion combination may form a strong, lasting, and functional graft union without displaying overt symptoms of incompatibility, however, it may still be considered "moderately incompatible". Moderate graft incompatibility is observed in interspecific eggplant/tomato grafts (Goldschmidt, 2014). This incompatibility is characterized by reduced plant size, a decrease in heterograft water potential (Oda, *et. al.*, 2005), and reductions in fruit yield and quality. (Oda, *et. al.*, 2005). While most studies merely identify incompatibility based on observable symptoms, some attempt to quantify compatibility as it relates to the grafting success rate. However, descriptions of moderate incompatibility by Oda *et al.* (2005), Kawaguchi *et al.* (2008), and Goldschmidt, (2014) suggest quantifiable long-term yield and morphological attributes that may be used to compare the relative compatibility of multiple graft pairings.

Although there have been numerous reports in the literature recently that involve grafted tomato plants, these trials are typically designed to compare rootstocks or to analyze the effectiveness of specific growing practices or production systems that include grafted plants. Such experiments typically utilize one scion cultivar, or the scion cultivar may vary from site-to-site. However, it is unclear whether the effects of grafting with a particular rootstock are consistent across different scion cultivars. Therefore, our objectives were to: i) determine whether the effects of 'Maxifort' rootstock on yield are consistent across ten scion cultivars under little to no disease pressure; ii) assess the quantitative compatibility of 'Maxifort' with ten scion varieties as it relates to plant productivity; and iii) identify nongrafted or grafted rootstock and scion combinations that show potential for urban and peri-urban high tunnel production systems due to their fruit yield and productivity.

MATERIALS AND METHODS

Trials were conducted in 2016 and 2017 at the Kansas State University Olathe Horticulture Center, located in Johnson County, Kansas (lat. 38.894409N, long. 94.995437 W). The soil type at this location is a Chase silt loam. In both years, a randomized complete block design was utilized with four replications. Each replication consisted of a 180' long row and were located centrally within a single bay of a three season, multi-bay high tunnel (Haygrove, Ledbury, UK). Each bay measured 24 x 200 ft and a different bay was used each year. Each plot contained five plants and was randomly assigned within its respective replication. The list of scions being tested was based on a list of varieties that performed well in previous nongrafted tomato variety trials in high tunnels at the same site (Oxley and Rivard, 2015, 2016). In both years, 'Maxifort' was utilized as the rootstock and ten scion varieties were investigated as scion: 'BHN 589', 'Fletcher', 'Primo Red', 'Red Deuce', 'Red Morning', 'Richmond', 'Scarlet Red', 'Skyway', 'Summerpick', and 'Tasti Lee'.

All grafted and nongrafted transplants were produced at the Kansas State University Olathe Horticulture Center (Olathe, KS). Grafting was performed using the tube-grafting technique, also known as splice grafting or Japanese top-grafting (Hartmann *et al.*, 2014; Masterson *et al.*, 2016b). Prior to grafting, approximately 80-90% of the leaf area of the scion was removed and care was taken not to damage the apical meristem as outlined by Masterson *et al.*, (2016b) and further described by Meyer *et al.*, (2017). Rootstock and scion seedlings were grown in soilless potting

medium and were grafted when they were approximately three and a half to four weeks (at the two to four true leaf stage) and were held together for the duration of the healing process with a silicon clip (Hydro-Gardens, Colorado Springs, CO). All grafted seedlings were placed inside a healing chamber with a polyethylene film covering and three layers of 55% shade cloth. The healing chamber used a supplemental cool-mist humidifier and polyvinylchloride (PVC) pipe to distribute water vapor. Established healing chamber management protocols developed for tomatoes were followed (Rivard and Louws, 2011). Following graft union formation, all grafted seedlings were removed from the healing chamber and grown in the greenhouse for at least 14 d before transplanting to re-acclimate to greenhouse conditions post-grafting.

Cultural methods were consistent with commercial urban and/or peri-urban high tunnel tomato production. In-row plant spacing was 18 inches and rows were 5 ft apart (center-to-center). One empty space was left between plots. A plasticulture, raised bed growing system was used, and weeds were suppressed via woven fabric mulch between rows and polyethylene mulch (1.25 mil) over the beds. Water was applied throughout the growing season by drip irrigation. The 2016 trial was planted on 18 April 2016, and harvesting occurred on 28 June, 5, 11, 14, 19, and 25 July, 1, 5, 9, 12, 22, and 29 August, and 6, 13, 19, and 27 September. The 2017 trial was planted on 2 May 2017, and harvesting occurred on 3, 10, 16, 24, and 31 July, 7, 14, 19, and 28 August, 5, 11, 18, and 24 September, and 2 October.

Regular plant observations were taken in both trials to assess the presence of diseased or damaged plants. Total fruit yield was graded into marketable and unmarketable fruit based on the presence of fruit diseases, blossom end rot, and/or pest damage. For each plot, fruit weight and number were recorded for both marketable and unmarketable fruit. On the day of the final harvest of each growing season, all undamaged green fruit larger than 1.5 inches in diameter were harvested and included in the marketable yield. All raw yield data were analyzed in SAS Studio: University Edition (version 9.4; SAS Institute Inc. Cary, NC) and showed no significant deviation from variance homogeneity using Levene's Test for Homogeneity, unless otherwise specified; additionally, goodness-of-fit tests for the normal distribution concluded that the data had an approximately normal distribution for total yield (lbs), marketable yield (lbs), total fruit size (lbs), marketable fruit size (lbs), total fruit number, marketable fruit number, and graft-induced changes in marketable yield (lbs and percent). Where data failed all goodness of fit tests for the normal distribution, nonparametric Analysis of Variance (ANOVA) tests were used to compare median values. ANOVA found significant year*treatment interactions occurred when the data from the two trials were combined. Therefore, data that was available from both years was standardized for the independent variable, year, using the z-score standardization procedure. This allows for the comparison of certain independent variables (graft status and scion variety) across multivariate data sets, which have significant differences in mean, range and standard deviation. A three-way repeated-measures factorial ANOVA was used to check for statistical interactions and to compare main and simple effects. The three factors that were tested included year, graft status (grafted vs. nongrafted), and scion variety. Where significant effects were identified, a mean separation test was carried out using Tukey's Honest Significant Difference Test ($\alpha = 0.05$). The least squares mean values for the transformed data were also back-transformed after testing for presentation of the data in the tables.

To address the second objective of this study, Table 2 was created to show the changes in actual and normalized (percent) marketable yield data between grafted and nongrafted plants for each scion variety. Normalized yield data shows the percent change, which is calculated as the actual difference between grafted and nongrafted plants as a proportion (%) of the yield of the nongrafted plants within each replication ($\% \text{ change} = [(\text{grafted yield}/\text{nongrafted yield}) - 1] \times 100$).

One-way ANOVAs were used to compare the numerical and percent changes in fruit size resulting from grafting as a function of scion variety for both years independently.

RESULTS

There was no evidence of any major soilborne or foliar disease in either year. The main effects of graft status and scion were found to be significant for all aspects of both marketable and total fruit yield, and were the strongest effects observed overall. The graft status*scion interaction was not statistically significant, but the simple effects are shown in Table 1 to inform the reader of trends that occurred between grafted and nongrafted plants of all ten varieties. Significant increases in marketable yield (lbs/plant) were observed for four scion cultivars when 'Maxifort' rootstock was utilized ($P < 0.05$; Table 1). 'BHN 589', 'Red Deuce', 'Skyway', and 'Tasti Lee' had 40.1% to 52.8% higher marketable fruit yield compared to nongrafted plants. Grafted 'Red Deuce' on 'Maxifort' was the highest yielding variety by weight in terms of both marketable and total yield. Nongrafted 'Skyway' had the lowest marketable yield (lbs/plant), while nongrafted 'Richmond' was the lowest yielding variety overall (Table 1).

Although not all the grafted plants had significantly more marketable fruit yield than their nongrafted counterparts, the mean values from the grafted scion varieties were numerically higher than the nongrafted controls (Table 1). Table 2 shows these changes in actual and normalized marketable yield data between grafted and nongrafted plants for each scion variety and were calculated and analyzed by replication. An ANOVA found no statistically significant differences in graft-induced per-plant marketable yield change (by weight), though it is interesting to note that 'BHN 589' and 'Tasti Lee' showed 3.7 to 3.8 times the numerical improvement of 'Primo Red' when grafted. Grafting with 'Maxifort' rootstock had a dramatic range of impact across the ten varieties (Table 2). Changes in fruit yield ranged from 1.47 lbs to 7.04 lbs per plant. A nonparametric ANOVA found significant differences in percent changes in total yield between 'Tasti Lee' and 'Primo Red'. The range in percent change was 9.2% to 59.5% (Table 2). The yield of 'Tasti Lee' and 'Skyway' improved the most by 'Maxifort' rootstock, which increased marketable fruit yield by more than 55%. The marketable fruit yield of 'Red Deuce', 'Fletcher', and 'BHN 589' were improved by 41.0% to 47.8%.

DISCUSSION

All the scions that were tested in this study were compatible with 'Maxifort' rootstock. More specifically, 'BHN 589', 'Red Deuce', 'Skyway', and 'Tasti Lee' produced significantly more marketable fruit when grafted with 'Maxifort' and may be considered highly compatible varieties. This is consistent with previous studies that report improved yields for plants grafted with 'Maxifort' rootstock (Masterson *et al.*, 2016a; Meyer *et al.*, 2021; Rivard and Louws, 2011). There was increased fruit number from plants that were grafted with 'Maxifort' rootstock and this is consistent with what was reported by Djidonou *et al.* (2013) and Masterson *et al.*, (2016a). The greatest graft-induced percent and total improvements in marketable yield (by weight) occurred for the lowest yielding nongrafted varieties like 'Skyway' and 'Tasti Lee', which improved by 6.0 and 7.0 lbs respectively (56.4% and 59.9%) when grafted. The highest yielding nongrafted variety, 'Primo Red', improved by only 1.5 lbs (9.2%) when grafted onto 'Maxifort' and the difference in percent

Table 1. Simple effects of scion and graft-status on marketable and total fruit yield and size for grafted and nongrafted tomatoes grown in a high tunnel in 2016 and 2017 in Olathe, KS.

Scion ^z	Graft status ^z	Mkt yield (lbs/plant)		Total yield (lbs/plant)		Marketable yield (fruit no./plant)			Total yield (fruit no./plant)				
						2016	2017		2016	2017			
BHN 589	Grafted	21.4	ab ^y	27.0	ab ^y	42.8	a ^y	44.5	a ^y	54.7	a ^y	61.6	a ^y
	Nongraft	14.0	cdefg	19.2	b*cd	35.3	abc	35.8	ab	50.3	ab	54.6	ab
Fletcher	Grafted	17.8	abcde	22.0	abc	38.6	abc	41.9	ab	50.4	ab	55.1	ab
	Nongraft	12.3	efg	14.7	cd	34.2	abc	34.5	ab	43.1	ab	43.8	ab
Primo Red	Grafted	21.0	ab	26.5	ab	32.2	abc	39.2	ab	41.0	ab	55.0	ab
	Nongraft	19.2	abcd	22.1	abc	40.8	ab	37.2	ab	47.2	ab	47.3	ab
Red Deuce	Grafted	23.0	a	27.6	a	32.3	abc	35.6	ab	39.1	ab	48.4	ab
	Nongraft	15.9	bcdefg	19.5	a*bcd	32.8	abc	26.2	b	40.4	ab	36.8	b
Red Morning	Grafted	21.6	ab	27.3	ab	34.3	abc	37.1	ab	46.1	ab	50.6	ab
	Nongraft	17.1	abcdefg	20.4	abcd	35.4	abc	34.3	ab	43.8	ab	46.1	ab
Richmond	Grafted	15.5	bcdefg	19.2	bcd	23.5	c	35.3	ab	31.9	b	44.8	ab
	Nongraft	10.9	fg	12.6	d	27.2	bc	29.7	ab	32.8	ab	36.2	b
Scarlet Red	Grafted	16.4	bcdefg	20.7	abcd	29.7	abc	34.3	ab	39.8	ab	45.7	ab
	Nongraft	13.4	defg	17.2	cd	31.4	abc	37.3	ab	43.5	ab	47.9	ab
Skyway	Grafted	17.3	abcdef	23.0	abc	28.3	abc	32.5	ab	42.6	ab	45.0	ab
	Nongraft	10.7	g	15.6	cd	23.6	c	28.2	b	40.5	ab	39.9	b
Summerpick	Grafted	16.8	abcdefg	23.0	abc	24.5	c	34.9	ab	36.9	ab	49.1	ab
	Nongraft	12.1	efg	15.6	cd	24.6	c	30.8	ab	34.2	ab	40.1	b
Tasti Lee	Grafted	20.1	abc	22.8	abc	40.5	ab	45.0	a	46.7	ab	55.4	ab
	Nongraft	12.5	efg	14.8	cd	33.2	abc	34.2	ab	41.2	ab	44.1	ab

Table 2. Actual and percent change in marketable yield of ten tomato varieties due to grafting with 'Maxifort' rootstock when grown in a high tunnel in 2016 and 2017 in Olathe, KS.

Scion ^z	Change in mkt yield (lbs/plant)	% Change in mkt yield	
Tasti Lee	7.04	59.5%	b ^y
Skyway	6.00	56.4%	ab
BHN 589	6.86	47.8%	ab
Fletcher	5.01	42.5%	ab
Red Deuce	6.42	41.0%	ab
Richmond	4.13	39.7%	ab
Summerpick	4.24	36.6%	ab
Red Morning	4.05	25.1%	ab
Scarlet Red	2.73	20.9%	ab
Primo Red	1.47	9.2%	a

change between 'Primo Red' and 'Tasti Lee' was statistically significant (Table 2). The effect of the rootstock on the composite plant may have a "limiting return", and higher performing scion varieties have less to gain from the replacement of their native root system with a high performing rootstock.

Descriptions of moderate graft incompatibility by Oda *et al.* (2005), Kawaguchi *et al.* (2008), and Goldschmidt, (2014) suggest that quantifiable attributes like yield and plant size may be used to compare the relative compatibility of multiple graft pairings. In this study, we normalized the benefit of grafting based on the yield of the nongrafted plant. We were therefore able to quantitatively assess the benefits of 'Maxifort' when grafted with ten different scions. In our study, we did not identify any scions that were acutely incompatible with, or demonstrated a late season decline, in health or overall decreased productivity (symptoms of delayed or moderate incompatibility) when grafted onto 'Maxifort' rootstock. In this study, the varieties that were tested fell in two categories regarding compatibility. 'Primo Red', 'Scarlet Red', and 'Red Morning' had marketable fruit yield increases that ranged from 9.1% to 25%. These varieties did not show a statistical difference between grafted and nongrafted plants and could be considered "compatible" with 'Maxifort' rootstock. Conversely, we found that grafting with 'Maxifort' rootstock had a significant positive effect on the marketable yields of 'BHN 589', 'Red Deuce', 'Skyway', and 'Tasti Lee', in a high tunnel setting, which ranged from 41.0% to 59.5%. These "highly compatible" scion varieties consistently provided more than 40% increases in fruit yield. The other varieties that were evaluated could be considered moderately compatible and ranged from 25% to 40% increases in fruit yield.

According to previously published variety trial reports, 'Primo Red' (Oxley and Rivard, 2015; Rogers and Wszelaki, 2012; Wszelaki and Rogers, 2009) and 'Red Deuce' (Oxley and Rivard, 2015) are consistently high-yielding varieties. 'BHN 589' typically also has high fruit yield placing in the top half within every trial it where it was tested (Oxley and Rivard, 2015; Rogers and Wszelaki, 2012; Wszelaki and Rogers, 2009). 'Scarlet Red' (Oxley and Rivard, 2015) and 'Tasti Lee' (Oxley and Rivard, 2015) often performed near the middle or bottom in their respective trials. For trials reported in the literature, 'Fletcher' consistently performed at a nearly or slightly above average level (Rogers and Wszelaki, 2012; Wszelaki and Rogers, 2009), though for our trial 'Fletcher' performed below average. With the exceptions of 'Summerpick' and (to a lesser extent) 'Fletcher', nongrafted yield data for our study showed very comparable trends to previous studies.

The combinations that we tested here spanned a range of 10.7 to 23.0 lbs of marketable fruit yield per plant when averaged across the two growing seasons. This wide range in our yield data should be useful to growers that are interested in any of the twenty grafted combinations or nongrafted cultivar options that we tested. 'Red Deuce' grafted onto 'Maxifort' rootstock showed a high degree of compatibility and produced the highest marketable (and total) yield of any variety we tested. The marketable yield of 'Red Deuce' on 'Maxifort' was 6.5% higher than the second highest combination, 'Red Morning' grafted onto 'Maxifort'. In addition to those two varieties, 'BHN 589', 'Primo Red', and 'Tasti Lee' all provided at least 20 lbs of marketable fruit per plant when grafted onto 'Maxifort'. For this reason, growers that are already utilizing these scion cultivars for high tunnel production should consider grafting their tomatoes onto 'Maxifort' rootstock to improve productivity.

It should be noted that nongrafted 'Primo Red' and 'Red Morning' were ranked in the top half of the twenty different treatments tested and had higher fruit yield than several grafted varieties. Despite its lack of graft-induced performance benefit, nongrafted 'Primo Red', in particular, may also have potential for commercial high tunnel production. Nongrafted 'Primo Red' was ranked sixth overall by marketable yield and produced 19.2 lbs of marketable fruit per plant. It was the

highest yielding nongrafted variety and performed at a level comparable to many of the grafted varieties in terms of both marketable and total yield. 'Primo Red' may therefore be an excellent option for commercial high tunnel growers who do not wish to use grafted plants.

CONCLUSIONS

To our knowledge, this is the first report that examines the impact of scion on the benefit of grafting with 'Maxifort' rootstock within a single, controlled trial. We found that implementing 'Maxifort' had a significant positive effect on the marketable yields of 'BHN 589', 'Red Deuce', 'Skyway', and 'Tasti Lee', in a high tunnel setting whereas 'Primo Red', 'Red Morning' and 'Scarlet Red' did not have a significant effect. We did not see a statistically significant interaction effect between graft-status and scion. Future work in this area would benefit from utilizing multiple rootstocks to better explore interactions that occur between rootstock and scion genotype. An interesting approach for future research would be to compare high- and low-yielding varieties that have undergone reciprocal grafting to further elucidate the complex relationship that may occur between rootstock and scion.

Grafting with 'Maxifort' rootstock has the potential to significantly improve the marketable yield across a wide variety of hybrid determinate tomato cultivars. Varieties like 'BHN 589', 'Red Deuce', 'Skyway', and 'Tasti Lee' show significant benefit from grafting on 'Maxifort' rootstock in our study. Growers that are already utilizing these cultivars should consider grafting their tomatoes with 'Maxifort' rootstock to improve the productivity and profitability of their operations. 'Red Deuce' grafted onto 'Maxifort' rootstock produced the highest marketable and total yields of any of the combinations that were tested. Other varieties like 'Primo Red' may still be useful for commercial production, though the benefit of grafting may be negligible. As researchers and growers in the U.S. continue to explore the use of grafted tomatoes for urban and peri-urban production, identifying combinations of rootstock and scion that maximize productivity and reduce the risk of disease outbreaks will be critical to successful high tunnel tomato production. These data provide an overview of how scion genotype can impact the benefit of grafting with vigorous rootstock under little disease pressure and identify specific combinations that are highly compatible.

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