Selecting Rootstock and Scion Varieties for Organic Grafted Tomato Production

Final Report on Graduate Student Project "Guidance in selecting optimal combinations of rootstock and scion varieties for organic grafted tomato production"

Bizhen Hu (Graduate Student) and
Matthew D. Kleinhenz (Major Advisor and Extension Vegetable Specialist)

Department of Horticulture and Crop Science, The Ohio State University, Ohio Agricultural Research and Development Center, 1680 Madison Avenue, Wooster, OH 44691-4096

Summary

Grafting produces an immediate physical hybrid of two varieties. Rootstock varieties are chosen for root system traits while scion varieties are selected for shoot and fruit traits. Grafting has the potential to move desirable traits to farms and gardens more quickly since it bypasses the lengthy process of true genetic hybridization involving breeding, selection and balancing the value of individual root, shoot and fruit traits. Organic tomato growers look to benefit from the use of grafted plants and their reportedly greater performance under optimal and sub-optimal conditions. However, both organic grafted plant suppliers and users are hampered by the lack of research-based information on rootstock and scion varieties; specifically, combinations that: a) can be grafted most effectively, b) resume growth most quickly after grafting and c) maximize fruit yield on real farms. The overall goal of this project was to provide comprehensive assistance to organic growers in the area of rootstock and scion variety selection. Three specific studies were completed and three major conclusions were drawn:

1) The growth of seedlings of eighteen rootstock and five scion varieties (selected based on growers' nominations and publicly available information) was charted in the greenhouse. The results indicate that seeding dates and grafting operations must be scheduled carefully to accommodate inherent differences in seedling vigor among varieties.

2) Grafts involving ninety rootstock-scion variety combinations were attempted and the percent success rate was calculated. The results indicate that 'incompatibility' is unlikely to be a barrier to grafting these varieties in the future.

3) A total of approximately 1,000 grafted plants representing all ninety rootstock-scion variety combinations were provided to thirty-one growers in eleven states throughout Ceres Trust Region and two states at other locations in the U.S. for on-farm evaluation. Overall, cooperating growers shared images, observations, and yield data of the grafted plants. Grafted plant performance varied by rootstock-scion combination and farm, and growers remain interested in additional evaluation and use of grafted plants.

Study and Objective 1. Document the relative growth rate of rootstock and scion varieties to assist farmers in scheduling seeding and subsequent grafting operations.

Introduction

Organic tomato growers use many fruiting varieties, including heirloom types. Also, the number of tomato rootstock varieties available in the U.S. increased more than ten-fold (six to seventy-three) between 2010 and 2014. These rootstock varieties were developed by twenty companies based in different regions of the world and, presumably, with varying perspectives on markets and the importance of specific traits. Also, hybrid scion varieties tend to be products of intense breeding and selection schemes emphasizing variety consistency. Rootstock varieties, by comparison, may be less consistent; some are open-pollinated and the products of screening pre-existing germplasm, less breeding and selection (King et al., 2010). Regardless, the large number of scion and rootstock varieties available to organic growers may differ widely in seedling growth rates (vigor).

Differences in seedling growth rates complicate grafting operations. For example, stem diameters of rootstock and scion seedlings must be similar to graft successfully (Leonardi and Romano, 2004). Stem diameters increase with age but not at the same rate among all varieties. Experience and research-based information regarding relative seedling growth rates of rootstock and scion varieties will help growers schedule seeding dates and grafting operations.

Little has been reported about the relative growth rates of tomato rootstock and scion varieties (Kubota et al., 2008). Lacking such information places grafters at risk of significant financial loss (e.g., due to mismatched/sized seedlings, unusable rootstock seedlings, or the need to repeat sowings). The goal of this study was to document the relative growth (vigor) of seedlings of twenty-three tomato rootstock and scion varieties, thereby assisting growers in selecting varieties and seeding dates.

Materials and Methods

Eighteen rootstock and five scion varieties were selected based on our experience and input from growers, state extension personnel, and seed company representatives. Phone calls, emails, listserv, social media and website posts, newsletters, and extension and trade publication articles were used to raise awareness of the project. Organic tomato growers from the twelve-state North Central/Ceres Trust Region were invited to nominate rootstock and scion varieties and combinations for the study through nineteen organic certifying agencies, twenty-five grower associations, five trade publications, four listservs, and eleven farmer groups. Rootstock characteristics, especially disease resistance, were identified using information provided by seed companies. The characteristics have been summarized and presented in a sortable, searchable and printable online database (http://www.vegetablegrafting.org/tomato-rootstock-table/); in this study, individual rootstock variety characteristics were used to compare/contrast and categorize them. Commercial tomato scions were categorized as hybrid or heirloom and round- or oblong-fruited types. Varieties selected for study (Table 1) were nominated by growers, commercially available and diverse in disease resistance packages (rootstock) and fruit types (scion). Collectively, the eighteen selected rootstock varieties were developed by twelve companies and contain twelve disease tolerance/resistance packages. The five selected scion varieties represent hybrid and heirloom and round- and oblong-fruited types.

Seedling emergence and growth rates were monitored in a climate-controlled greenhouse at the Ohio Agricultural Research and Development Center in Wooster, OH. All seedlings were grown using certifiable-organic practices. Seeds were sown on February 27 and 28, 2014 (Run 1) and March 28, 2014 (Run 2) in

96-cell trays (cut into two halves) with cells measuring 2.87 cm wide, 3.81 cm long, and 5.72 cm deep with a cell volume of 62.43 cm^3. Half-tray units were preloaded with Pro-Mix® MP Mycorrhizae™ Organik™ (Premier Tech, Canada) growing medium then sown to forty-eight seed of a single variety (three half-trays per variety). All half-trays were placed on Kapmat (Buffalo Felt Products Corp, NY) underlain by 4-millimeter thick plastic on elevated benches in the greenhouse. Trays were hand-misted to wetness immediately after sowing; a bench-top, automated irrigation system was used thereafter to maintain soil moisture. Forty-four drippers (each with a flow rate of 1.5 gallon/h) pulsed on for 10 min at 6:00, 9:00, 12:00, 15:00, 18:00, and 21:00 and seven foggers (each with a flow rate of 8.1 gallon/h) pulsed on for 10 s every 15 min. Supplemental fertilization and pest and disease management were not applied.

A completely randomized design was used in both runs of the experiment completed in 2014 (Run 1 February-March, Run 2 March-April). Numbers of emerged seedlings were recorded daily, and emergence rate was calculated as the number of days to reach 50% and 90% of final emergence (T_{50} and T_{90}, respectively). Canopy development was assessed non-destructively using calculations of percent canopy cover provided by WinCam-mediated analysis of digital images (Bumgarner et al., 2011) taken at 12, 15, and 18 days after sowing in Run 1 and at 9, 12, and 15 days after sowing in Run 2. Seedling growth was also monitored with direct measures of plant height, stem diameter, aboveground fresh and dry weight, and leaf area 12, 15, and 18 days after sowing.

Table 1. A list of eighteen commercial tomato rootstock and five scion varieties used in this study.

Rootstock Variety	**Seed company/ distributor**	**Rootstock Variety**	**Seed company/ distributor**	**Scion Variety**	**Seed company/ distributor**
Aiboh[z]	Asahi Industries	Kaiser	Rijk Zwaan	Brandywine	NE Seed
Akaoni	Asahi Industries	Maxifort	DeRuiter Seeds	Better Boy	NE Seed
Aooni	Asahi Industries	Resistar	Hazera Seeds	Celebrity	NE Seed
Armada	Takii Seed	RST-04-105	DP Seeds	Cherokee Purple	NE Seed
Arnold	Siegers Seed Co.	RST-04-106	DP Seeds	San Marzano 2	NE Seed
B.B.	Takii Seed	Shield	Rijk Zwaan		
Beaufort	DeRuiter Seeds	Stallone	Rijk Zwaan		
Cheong Gang	Seminis Vegetable	Supernatural	A.P. Whaley Seeds		
Estamino	Enza Zaden	Trooper	Seedway		

[z] None of the seed used in this study was treated. Seed of Kaiser and Stallone was pelleted; all other seed was not pelleted. Seed of Arnold, Beaufort, Kaiser, Maxifort, Shield, and Stallone was primed; all other seed was not primed.

Leaf area, stem diameter and aboveground dry weight at 12, 15, and 18 days after sowing were fitted to a quadratic model in SigmaPlot. Further, unit-less relative seedling vigor values were calculated for each variety using a formula including four plant and two environmental variables:

$$\text{Vigor} = \frac{\text{aboveground dry weight (mg)} \times \text{stem diameter (mm)} \times \text{leaf area (cm}^2\text{)} \times (1 \times 10^7)}{(T_{90} \times \text{GDD} \times \text{PAR})}$$

Where T_{90} represents days to reach 90% of final emergence; where all biomass values and T_{90} are mean values from measures taken 18 days after sowing across two experimental runs; where Growing Degree Days (GDD) and Photosynthetically Active Radiation (PAR) represent the means of these variables accumulated by 18 days after sowing across two experimental runs; and where daily GDD is calculated using a base and ceiling temperature of 10 °C and 27 °C, respectively.

Statistical analysis was completed in SAS (version 9.3; SAS Institute, Cary, NC). Variance analysis and multiple comparisons among varieties were conducted by the GLIMMIX procedure and its LSMEANS statement. Correlations between non-destructive measures and destructive measures were analyzed using the CORR procedure.

Results and Discussion

Individual components of seedling vigor (including emergence rate and canopy development) were monitored indirectly and directly and all measures differed by variety (Fig. 1, Table 2). While growth rates differed more widely within the rootstock than the scion variety group, the shapes of growth curves of each group were similar.

Individual variety seedling vigor values ranged from 16.2 (Trooper) to 1356.5 (Kaiser), with a mean, median and standard deviation of 344.2, 197.4 and 331.5, respectively. Vigor values of all scion varieties were between 107.8 and 193.0, except for San Marzano 2 which scored 555.0. The three lowest and highest vigor values belonged to rootstock varieties. Given the wide range of growth rates among varieties, careful scheduling of seeding dates and grafting operations is essential to maximize the percentage of well-matched seedlings at grafting and, thereby, the percentage of successful grafts and efficiency of grafting operations.

Growth rates and curves can help predict when and for how long seedlings will be eligible for grafting based on stem diameter. Windows of expected graft eligibility can be estimated using data and regression like that in Fig. 1. The process developed from this study for assessing seedling vigor by combining four plant and two environmental variables can help compare varieties and other experimental units in future applications.

Estimates of percent canopy cover based on the analysis of digital images were highly correlated ($p<0.05$) with most direct measures in the early phase of seedling growth (Table 3). Therefore, going forward, digital image analysis may supplement or replace more resource-demanding measures of plant growth. Digital image analysis may save time, money, plants (when harvested for destructive measures) and other resources.

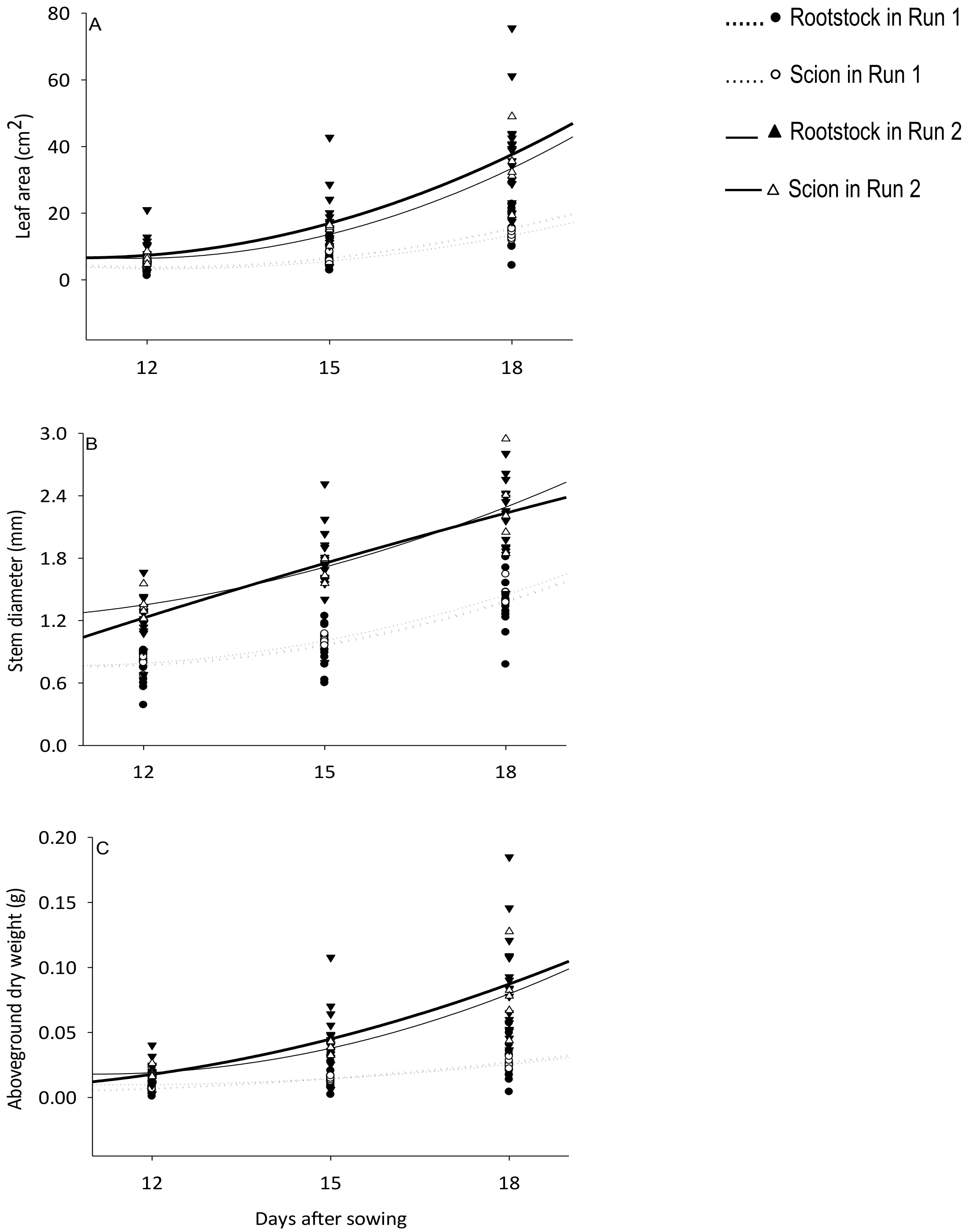


Fig. 1. Quadratic regression of leaf area (A), stem diameter (B) and aboveground dry weight (C) of eighteen tomato rootstock and five scion varieties in a greenhouse experiment in Wooster, OH (Run 1 February 27-March 17 and Run 2 March 28-April 15). Each data point is the average of a variety on the specified day.

Table 2. Seedling vigor values calculated for twenty-three varieties of greenhouse-grown tomato using a formula including four plant and two environmental variables.

Variety[z]	**Aboveground dry weight (mg)**	**Stem diameter (mm)**	**Leaf area (cm^2)**	**T_{90}**	**Vigor**[y]
Trooper	20.4	1.1	10.9	9.4	16.2
Shield	31.4	1.6	16.2	6.9	71.9
Aiboh	36.1	1.6	15.0	6.5	82.2
Estamino	34.9	1.5	23.5	8.5	86.8
Supernatural	42.7	1.7	18.0	7.3	105.5
Aooni	43.2	1.6	21.2	8.6	105.6
Cherokee Purple	36.0	1.7	16.9	5.7	107.8
Brandywine	44.3	1.9	22.4	6.2	183.8
Better Boy	53.7	1.7	21.6	6.4	188.4
Celebrity	50.1	1.8	24.5	7.0	193.0
RST-04-105	49.2	1.8	28.5	7.9	195.4
Resistar	44.8	1.9	24.3	6.4	197.4
RST-04-106	54.3	1.9	26.7	6.4	267.6
Akaoni	61.1	1.9	26.9	6.6	283.2
Cheong Gang	58.0	1.8	27.5	5.8	305.7
B.B.	58.3	2.1	27.7	5.9	360.0
Armada	72.5	2.1	27.1	6.2	416.3
Stallone	71.1	1.9	30.6	5.6	443.9
Beaufort	66.5	1.9	28.6	4.2	539.4
San Marzano 2	79.5	2.3	32.2	6.5	555.0
Arnold	82.4	2.0	35.8	4.0	916.5
Maxifort	93.3	2.1	40.5	5.1	938.2
Kaiser	110.4	2.0	49.1	4.9	1356.5

[z] Five varieties in bold are scions. The other eighteen varieties are rootstocks.

[y] $$\text{Vigor} = \frac{\text{aboveground dry weight (mg)} \times \text{stem diameter (mm)} \times \text{leaf area (cm}^2\text{)} \times (1 \times 10^7)}{(T_{90} \times \text{GDD} \times \text{PAR})}$$

Where T_{90} represents days to reach 90% of final emergence; where all biomass values and T_{90} are mean values from measures taken 18 days after sowing across two experimental runs; where Growing Degree Days (GDD) and Photosynthetically Active Radiation (PAR) represent the means of these variables accumulated by 18 days after sowing across two experimental runs; and where daily GDD is calculated using a base and ceiling temperature of 10 °C and 27 °C, respectively. In this study and calculation, GDD and PAR are 259.5 and 63086.5, respectively.

Table 3. The relationship between percent canopy cover based on digital image analysis and direct measures of seedling aboveground fresh and dry weight, stem diameter, leaf area, and plant height for eighteen tomato rootstock and five scion varieties grown in a greenhouse in Wooster, OH in February-April, 2014.

Correlation	**Run 1** [z]			**Run 2**[z]	
	Day 12	Day 15	Day 18	Day 12	Day 15
Percent canopy cover: Aboveground fresh weight	0.71[y] (0.0002)	0.80 (<0.0001)	0.86 (<0.0001)	0.76 (<0.0001)	0.65 (0.0009)
Percent canopy cover: Aboveground dry weight	0.47 (0.0228)	0.84 (<0.0001)	0.88 (<0.0001)	0.79 (<0.0001)	0.73 (<0.0001)
Percent canopy cover: Stem diameter	0.56 (0.0054)	0.57 (0.0047)	0.78 (<0.0001)	0.59 (0.0028)	0.71 (0.0002)
Percent canopy cover: Leaf area	0.95 (<0.0001)	0.90 (<0.0001)	0.90 (<0.0001)	0.85 (<0.0001)	0.69 (0.0003)
Percent canopy cover: Plant height	0.07 (0.766)	0.14 (0.513)	0.59 (0.0031)	0.15 (0.5027)	0.51 (0.0129)

[z] Run 1 (February 27-March 17, 2014); Run 2 (March 28-April 15, 2014). Digital images were not taken on day 18 in Run 2.

[y] Pearson Correlation Coefficient (R^2) followed by probability value in parentheses. N = 23.

Study and Objective 2. Monitor graft success and grafted plant re-growth in the greenhouse for ninety rootstock-scion variety combinations.

Introduction

Grafting is a process similar to organ transplantation. It is influenced by the level of genetic compatibility between 'donor' and 'recipient'; in this case, rootstock and scion. Growers often ask about the relative compatibility of various rootstock-scion combinations. There is no clear and unified definition of rootstock-scion compatibility or incompatibility. However, if grafted plant healing and growth rates, and subsequent fruit yield and quality are an indication (King et al., 2010; Salvatierra et al., 1998; Wang and Kollmann, 1996), compatibility may vary widely among combinations. Severe incompatibility leads to graft failure and thus catastrophic financial loss for grafted plant suppliers and users. Problems associated with incompatibility can be solved by proper rootstock-scion selection (Lee 1994).

Only a small number of the seventy-three commercially available tomato rootstock varieties have been studied in combination with scions popular among U.S. organic growers, including in the Ceres Region. The lack of information on commercially available rootstock varieties and their combinations with popular scions is currently a major barrier to the wider application of grafting in commercial tomato production in the U.S. (Kubota et al., 2008). The goal of this study was to test the graft success and healing rate of ninety rootstock-scion combinations selected based on grower and other input.

Materials and Methods

Experimental plants were produced using methods and facilities described in Study 1 (pp. 2-3). Plants were grafted when they reached 1.5 to 2.5 mm in stem diameter. The date that each plant emerged was noted. Plants that emerged within the same 3-day period and of a similar size were selected to minimize variation within groups of grafted plants. One experienced and seven inexperienced grafters were employed. All new grafters were trained in two, 1-hr practice sessions. Each grafter prepared 50-100 plants before preparing experimental plants. A standard cleft grafting method (Bumgarner and Kleinhenz, 2013) was used to prepare all experimental plants. In Run 1, grafting days were March 19, 21, 24, and 25, 2014; in Run 2, grafting days were April 12, 14, 15, 16, 18, and 21, 2014. A total of 1080 plants representing the ninety combinations in each run were randomly assigned to a grafter on one of the grafting days when plants reached 1.5 to 2.5 mm in stem diameter. In addition, 24 control plants (self-grafted Cherokee Purple) were grafted by each grafter on each grafting day, and used as the common control to track graft success by grafter.

Newly-grafted plants were placed in a healing chamber in the same greenhouse immediately after grafting. The healing chamber was constructed using a polyvinyl chloride (PVC) frame covered by one layer of clear plastic sheeting overlain by one layer of shade cloth (50% light transmission in PAR). Within the chamber, an automatic irrigation system with drippers and foggers was used to maintain high moisture. The four sides of the healing chamber were opened gradually over time, as weather and plant status allowed, to lower relative humidity and limit adventitious root development. Temperature and relative humidity in the healing chamber were recorded continuously at 5-min intervals with Hobo ProV2 data loggers (version 2.5.0, Onset Computer Co., Pocasset, MA, USA) throughout the study. The average temperature in the healing chamber during Run 1 was 73°F and relative humidity was 87%; during Run 2, the average temperature and relative humidity was 74°F and 88%, respectively. Plant survivorship was rated two weeks after grafting using the method of Johnson and Miles (2011) in which plants with a completely wilted scion are rated as dead (failed graft) and all others are rated as living (successful graft).

Living plants were categorized into high- and low-quality according to the level of graft union re-formation. A rootstock-scion connection of at least 50% was scored as high-quality and connections of less than 50% were scored as low-quality. The percentage of high-quality plants was recorded for each of the ninety variety combinations prepared.

Graft quality was also assessed by dye (Erythrosine B) movement to indicate water flow in eight combinations (eight rootstocks, Aiboh, Akaoni, Aooni, B.B., RST-04-106, Shield, Stallone and Supernatural, grafted to the same scion Cherokee Purple). Two weeks after grafting, plants were excised at the soil line, and the cut surface was placed in a solution of Erythrosine B (0.7% m/v) for 15 min. Dye movement was measured from the cut surface to the stain terminus (as total stained length) and from the graft union to the stain terminus (as stained length above the graft union). Plant height was measured from the cut surface to the meristem. Water potential of the largest leaf on the scion was measured with a pressure chamber (Model 615; PMS Instrument Co., Albany, OR). Rootstock and scion stem diameter were measured with a Traceable® digital caliper (Control Company, Friendswood, Texas) immediately after grafting and two weeks after grafting. Stem diameter relative growth (SDRG) was calculated as:

$$\text{SDRG} = \frac{\text{(diameter two weeks after grafting - diameter immediately after grafting)}}{\text{diameter immediately after grafting}} \times 100\%$$

Results and Discussion

Percentages of successful and high quality grafts were unaffected by rootstock-scion combination in either run of the study (Table 4). Survival was at least 92% and averaged 97% across all combinations. Graft day and grafter significantly affected survivorship and percentage of high-quality grafted plants in both runs ($p<0.05$), indicating that environmental conditions after grafting and grafting skill influenced plant condition. Therefore, within these varieties, genetic incompatibility is less of a concern than grafter skill and grafting-healing conditions.

Relative and absolute amounts of dye movement were unaffected by variety combination as tested with Cherokee Purple (scion) grafted to Aiboh, Akaoni and Aooni (Table 5) and as tested with Cherokee Purple (scion) grafted to B.B., RST-04-106, Shield, Stallone, and Supernatural (Table 6). Interestingly, water potential in the largest leaf was higher in the Aiboh-Cherokee Purple combination than in the Akaoni- and Aooni-Cherokee Purple combinations, suggesting that Abioh-grafted plants may have greater access to water after grafting. Rootstock and scion stem diameter relative growth were largely unaffected by variety combination, although scion stem diameter was greatest when RST-04-106 was used as the rootstock and smallest when Shield was used as the rootstock (data not shown).

Overall, dye movement data were consistent with graft success and quality data. Collectively, the data indicate that compatibility and desirable levels of early-phase regrowth can be expected within the combinations tested.

Table 4. Graft survivorship and percentage of high-quality grafted plants of eighteen tomato rootstocks and five scions.

	Survivorship (%)	Percentage of high-quality plants (%)
Rootstock		
Aiboh	97 ± 1[z]	63 ± 8
Akaoni	100 ± 0	67 ± 8
Aooni	97 ± 1	53 ± 7
Armada	97 ± 1	50 ± 10
Arnold	97 ± 1	50 ± 11
B.B.	92 ± 3	49 ± 10
Beaufort	99 ± 1	53 ± 13
Cheong Gang	98 ± 1	59 ± 8
Estamino	98 ± 1	56 ± 10
Kaiser	96 ± 3	53 ± 10
Maxifort	98 ± 1	48 ± 11
Resistar	98 ± 1	58 ± 7
RST-04-105	99 ± 1	48 ± 11
RST-04-106	97 ± 1	61 ± 12
Shield	95 ± 3	66 ± 11
Stallone	98 ± 2	68 ± 8
Supernatural	95 ± 3	60 ± 12
Trooper	100 ± 0	71 ± 8
Self-grafted control	95 ± 1	50 ± 3
Scion		
Brandywine	97 ± 1	60 ± 5
Better Boy	98 ± 1	58 ± 6
Celebrity	95 ± 1	56 ± 5
Cherokee Purple	98 ± 1	60 ± 5
San Marzano2	97 ± 1	52 ± 5
Self-grafted control	95 ± 1	50 ± 3

[z] N=10 for rootstock, N=36 for scion, N=66 for self-grafted control. Data are presented as means ± SE.

Table 5. Total stained length, stained length above the graft union, percentage of stained length to plant height, and water potential 2 weeks after grafting of three rootstocks (Aiboh, Akaoni, and Aooni) grafted to the same scion (Cherokee Purple).

Rootstock	Total stained length (cm)	Stained length above the graft union (cm)	Stained length: plant height (%)	Water potential
Aiboh	5.3 A[z]	2.1 A	70.6 A	-4.1 B
Akaoni	6.5 A	2.8 A	81.0 A	-5.3 A
Aooni	6.3 A	2.3 A	74.7 A	-5.3 A

[z] Means within columns followed by the same letter are not significantly different as separated by a pdiff option ($p<0.05$) in the LSMEANS statement with the Tukey method for multiple comparison adjustment in the GLIMMIX procedure (SAS version 9.3; SAS Institute, Cary, NC).

Table 6. Total stained length, stained length above the graft union, percentage of stained length to plant height, and scion stem diameter relative growth 2 weeks after grafting of five rootstocks (B.B., RST-04-106, Shield, Stallone, and Supernatural) grafted to the same scion (Cherokee Purple).

Rootstock	Total stained length (cm)	Stained length above the graft union (cm)	Stained length: plant height (%)	Scion stem diameter relative growth (%)
B.B.	7.2 A[z]	4.2 A	92.9 A	59.1 AB
RST-04-106	7.5 A	3.7 A	95.1 A	82.8 A
Shield	6.4 A	3.0 A	89.7 A	47.0 B
Stallone	7.3 A	2.5 A	88.9 A	65.0 AB
Supernatural	6.6 A	2.5 A	80.9 A	67.5 AB

[z] Means within columns followed by the same letter are not significantly different as separated by a pdiff option ($p<0.05$) in the LSMEANS statement with the Tukey method for multiple comparison adjustment in the GLIMMIX procedure (SAS version 9.3; SAS Institute, Cary, NC).

Fig. 2. Top row, left to right: Seedlings of 18 tomato rootstock and 5 scion varieties growing in the greenhouse, grafters preparing plants, and newly grafted plants in a healing chamber for the first two weeks after grafting. Middle row, left to right: Rating grafted plant survival rating using scion wilting (death

at left, living at right). Bottom row, left to right: Rating graft quality using measures of plant height (soil line to meristem), stem diameter, and dye movement in de-rooted plant as visualized at right.

Study and Objective 3. Assess the performance of grafted plants grown on organic farms.

Introduction

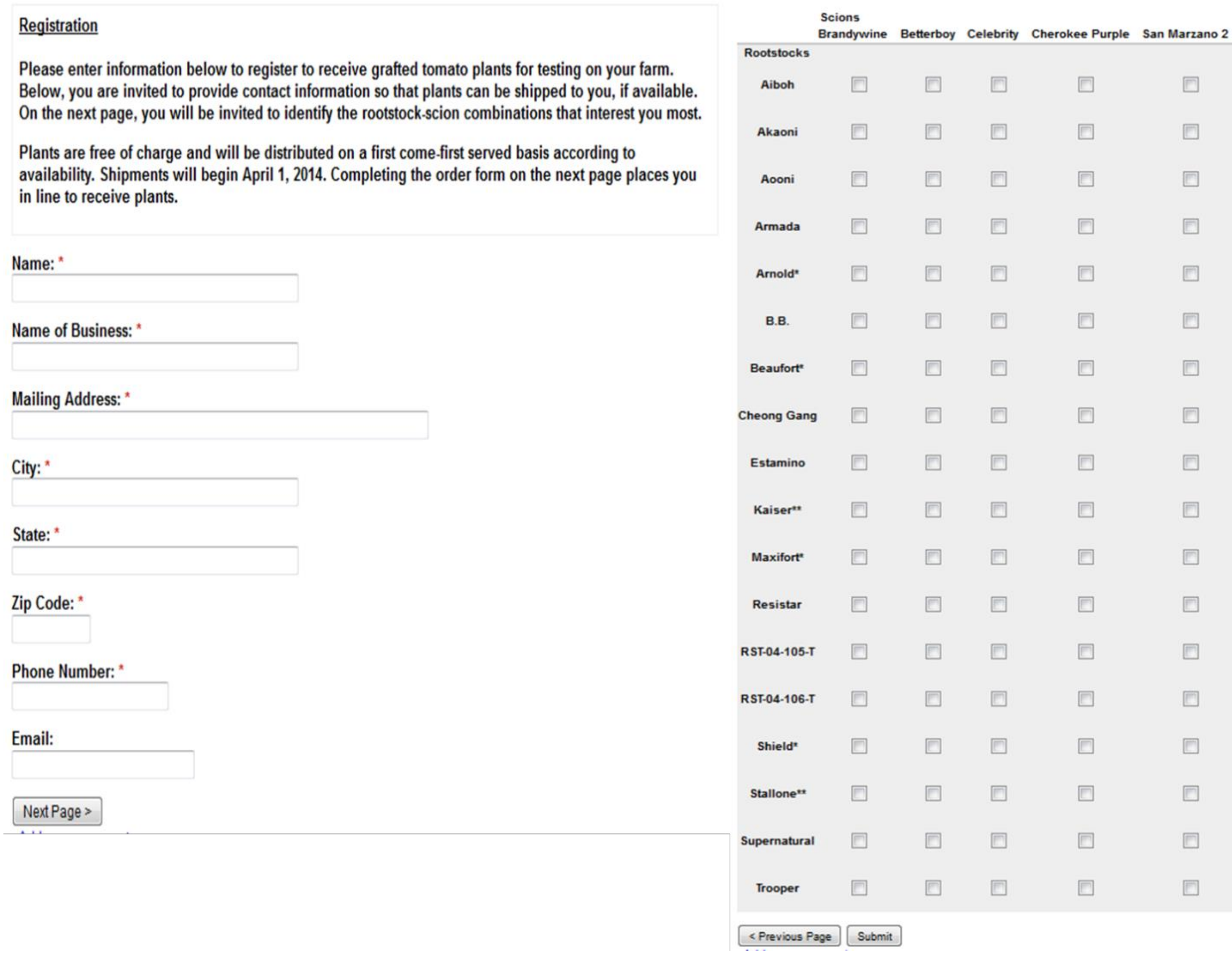
The on-farm performance, especially yield, of grafted plants shapes grower perspectives of them. Earlier reports employing a smaller number of rootstock-scion combinations indicate that growth, yield and yield components vary with combination and growing conditions (Khah et al., 2006; Turkmen et al., 2010). The goal of this study was to document the overall performance of a much larger number of variety combinations under a wider range of conditions.

On-farm evaluations were completed by: 1) providing grafted plants representing multiple combinations to cooperating organic farmers in the Ceres Trust region and 2) requesting feedback on plant growth and yield from growers. Randomized and replicated plots were also established at the OARDC in Wooster, OH in order to observe the physiological development and yield of sixty-three rootstock-scion combinations.

Materials and Methods

As in selecting rootstock and scion varieties for use in previous stages of the project, growers were invited to participate in on-farm evaluations through the collaboration and use of nineteen organic certifying agencies throughout the North Central U.S., twenty-five grower associations and NGO-organizations, five trade publications, four listservs and eleven farmer groups.

A total of eighty-two growers in the North Central U.S., with others located on the Eastern and Western coasts of the U.S., requested plants using an online form (Fig. 1). Individual growers requested 2-90 variety combinations. Requests to participate in the evaluation exceeded the number of plants available for distribution by nearly three-fold. From these, thirty-one growers representing thirteen states (AR, IA, IL, IN, MA, MI, MN, MO, ND, NJ, OH, SD, WI) were selected. Grower selection was based on a first come, first serve basis in proportion to the number of requests received for each state and the availability of grafted plants. Selected participants comprised small- to mid-size, field and high tunnel growers with varying levels of experience.


Registration

Please enter information below to register to receive grafted tomato plants for testing on your farm. Below, you are invited to provide contact information so that plants can be shipped to you, if available. On the next page, you will be invited to identify the rootstock-scion combinations that interest you most.

Plants are free of charge and will be distributed on a first come-first served basis according to availability. Shipments will begin April 1, 2014. Completing the order form on the next page places you in line to receive plants.

Name: *

Name of Business: *

Mailing Address: *

City: *

State: *

Zip Code: *

Phone Number: *

Email:

Next Page >

Rootstocks \ Scions	Brandywine	Betterboy	Celebrity	Cherokee Purple	San Marzano 2
Aiboh	☐	☐	☐	☐	☐
Akaoni	☐	☐	☐	☐	☐
Aooni	☐	☐	☐	☐	☐
Armada	☐	☐	☐	☐	☐
Arnold*	☐	☐	☐	☐	☐
B.B.	☐	☐	☐	☐	☐
Beaufort*	☐	☐	☐	☐	☐
Cheong Gang	☐	☐	☐	☐	☐
Estamino	☐	☐	☐	☐	☐
Kaiser**	☐	☐	☐	☐	☐
Maxifort*	☐	☐	☐	☐	☐
Resistar	☐	☐	☐	☐	☐
RST-04-105-T	☐	☐	☐	☐	☐
RST-04-106-T	☐	☐	☐	☐	☐
Shield*	☐	☐	☐	☐	☐
Stallone**	☐	☐	☐	☐	☐
Supernatural	☐	☐	☐	☐	☐
Trooper	☐	☐	☐	☐	☐

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Fig. 3. The online form for grower registration for on-farm evaluation.

A total of nearly 1,000 grafted plants were shipped to the thirty-one farms in thirteen states. Coordination of shipping of grafting tomato plants to different latitudes varying in planting times by two months involved close monitoring of regional weather conditions. A shipping process and standard set of contents were developed. Each shipment contained special labeling and a nursery inspection certificate on the outside of the container. Documents, including an instruction sheet (Fig. 4), disclaimer sheet, packing slip, and Japanese beetle inspection certificate (if required) and plants were included in each box. Grafted plants were rolled in wet white paper towels and then packed in zippered, one-gallon bags with wet vermiculite, a single variety combination per bag and a maximum of five plants per combination. Up to five bags of grafted plants and dunnage to limit movement during transit were included in each box. All grafted plants were shipped by express service to selected growers April 15-16, 2014. Plants were transplanted on each farm from mid-May to early June and grown under various production systems (Fig. 5).

THE OHIO STATE UNIVERSITY
COLLEGE OF FOOD, AGRICULTURAL, AND ENVIRONMENTAL SCIENCES

CERES TRUST

Grafted Tomato Plants for On-Farm Testing from the Ohio State University

Thank you for your interest in our work of evaluating grafted tomato plants and congratulations on being selected as a host site.

You are receiving 4-6 plants of each of up to 10 rootstock-variety combinations. All combinations should represent ones in which you expressed an interest in the online farm registration.

The cleft graft method was used to prepare the plants approximately 3-4 weeks ago. The graft union of the plants you receive may differ in appearance from the union of plants sold commercially because grafting methods and techniques vary by propagator. Regardless, the plants are acceptable for field (or high tunnel) planting.

Handling and Planting Instructions:

Allow the plants to acclimate to your local environment for 1-3 days before planting them. When removing plugs, place fingers at the base (rootstock) just above the soil line and pull gently to minimize mechanical stress at the graft union.

Tube clips can be removed before planting or they can be allowed to fall off naturally as stems grow. Regardless, do NOT bury the graft union at planting. Ideally, the graft union should remain 1 inch above the soil line to limit root establishment from the scion (top). Further plant care and maintenance can be similar to your standard best practices.

Evaluation: Growers are asked to document plant vigor, overall health and productivity (e.g., yield). This information can be provided to our Team anytime but no later than the end of the growing season (for reporting purposes). We will contact you to facilitate the process.

Consultation will be available as needed during your growing season.

Please contact Dr. Matt Kleinhenz at (330) 263-3810 or kleinhenz.1@osu.edu with any concerns or questions.

Disclaimer: Our grafted tomato plants are grown, grafted and cared for with the utmost attention. However, even in the best of circumstances, plant health can be altered unfavorably. Plants should be thoroughly inspected prior to planting to prevent exposure of other production to adverse conditions.

USDA

Vegetable Production Systems Laboratory, Department of Horticulture and Crop Science, The Ohio State University
Ohio Agricultural Research Development Center – 1680 Madison Avenue, Wooster, Ohio 44691

Fig. 4. The grower instruction sheet shipped to cooperating growers with the grafted plants

Fig. 5. Grafted plants growing on cooperating growers’ farms at various latitudes under diverse production systems and management for on-farm evaluation.

Cooperating farmers were asked to record and share observations on plant growth and performance, digital images, and data on total and marketable fruit yield from each rootstock-scion combination provided to them.

In addition, plots containing sixty-three rootstock-scion combinations (including ungrafted controls) were also established at the OARDC in Wooster, Ohio on June 4, 2014. Three plots of each combination that included a common scion were set in a completely randomized design, with three plants in each. Standard, conventional irrigation and fertility management was applied to all plots, and plants were supported using a modified Florida weave system. Planned data collection included images of each plot at regular intervals, timing of physiological milestones such as first flowering and first fruit, as well as plant height at flowering and number of trusses at designated times.

Unfortunately, on July 30, 2014, Tobacco Mosaic Virus (TMV) was diagnosed in the majority of the planting. The disease was likely introduced by workers who had used tobacco before working on pruning and twining plants. After disease diagnosis, plant management (especially twining) was discontinued to prevent further spread within the plot and to limit the infection to that field.

Yield measurement was also curtailed. Instead of multiple planned harvests, a single harvest was done between Oct 1 and Oct 8, collecting fruit from 2 or 3 replicated plots for 4 of the 5 scions. No yield trends were observed between grafted and ungrafted plants or between rootstocks, undoubtedly due in part to the poor condition of plants and harvested fruit.

Results and Discussion

Growers provided both qualitative and quantitative feedback about the performance of grafted plants they received through this project and grew on their farm for evaluation. Plans were to record the development and yield of sixty-three rootstock-scion combinations grown on at the OARDC in Wooster, OH were also set.

On-farm evaluation showed that plant growth and yield differed by variety combination and by farm. Sixteen grower-cooperators provided feedback of the grafted plants sent to them and grown on their farms. Seven growers were able to compare grafted plants with their ungrafted counterparts, six growers concluded that grafted plants showed superior performance than the ungrafted plants, and one grower concluded that grafted plants did not differ from ungrafted plants in yield. One grower observed various disease resistance properties in different variety combinations. Two growers observed improved disease and flood resistance in grafted plants compared to their ungrafted counterparts. Five growers had crop failure due to unexpected animal damage, pesticide, or flooding issues, and three growers had problems in rootstock shoot re-growth and the production of unusable rootstock fruit. Three growers provided education and outreach to other growers about grafting using plants sent to them through this project.

The knowledge base of both the experimental team and grower-cooperators was increased greatly through the on-farm evaluation process. For example, the experimental team gained valuable insights on aspects of the logistics of conducting an experiment involving grafted plants and more than thirty growers in thirteen states. Completing the on-farm evaluation also underscored that interest in grafted plants and other grower-centered tools is high within the region. Grower-cooperators became more familiar with rootstock and scion variety selection and grafted plant management and performance. Future projects will seek to integrate the knowledge and skills gained during the evaluation in addressing other farmer concerns.

Outreach

Organic farmers contributed significantly to the three studies completed in this project. Hundreds of tomato farmers and educators in the region were contacted by phone calls, emails, list-serv, social media and website posts to raise awareness of this project and the principles and practices of tomato grafting. Farmers were invited to nominate rootstock and scion varieties and combinations, and to participate in the on-farm evaluation. About 1,000 grafted plants were given to thirty-one farmer cooperators and repeated communication was established to provide information to and obtain feedback from growers.

Three cooperating farmers provided education and communication opportunities for other farmers to view their grafted plants they received from this project. Also, over 500 individuals were exposed to the grafted plants sent to one farm through their volunteerism and tours, and over 1,000 people had access to learn about the grafted plants through the social media network of the same farm. Project-related Facebook (http://www.facebook.com/osuvpslab) posts originating with the project team also increased awareness of the project and its findings. Project findings were also shared in five extension presentations reaching 344 stakeholders (primarily growers), in one workshop with sixty-two participants and in one grower association roundtable forum involving thirty growers. Results were published in the Midwest Vegetable Trial Report for 2014 (https://ag.purdue.edu/hla/fruitveg/MidWest%20Trial%20Reports/2014/001_MVTR%202014_FULL-errata.pdf). Also, seven undergraduate students from The Ohio State University Agricultural Technical Institute were trained in and became familiar with tomato grafting.

Technical summaries of this project were also delivered at the 2014 American Society for Horticultural Science Annual Conference (https://ashs.confex.com/ashs/2014/webprogramarchives/Paper19951.html) and the 3rd National Grafting Symposium (http://www.vegetablegrafting.org/resources/grafting-symposia/2015-vegetable-grafting-symposium/). A manuscript for a peer-reviewed journal article based on results from studies 1 and 2 of the project has been submitted.

References

Bumgarner, N.R., M.A. Bennett, P.P. Ling, R.W. Mullen, and M.D. Kleinhenz. 2011. Canopy Cover and Root-zone Heating Effects on Fall- and Spring-grown Leaf Lettuce Yield in Ohio. HortTechnology. 21(6): 737-744.

Bumgarner, N. and M.D. Kleinhenz. 2013. Grafting guide, a pictorial guide to the cleft and splice graft methods as applied to tomato and pepper. The Ohio State University, Bulletin 950.

Johnson S.J. and C.A. Miles. 2011. Effect of healing chamber design on the survival of grafted eggplant, tomato, and watermelon. HortTechnology 21(6):752-758.

Khah, E.M., E. Kakava, A. Mavromatis, D. Chachalis, and C. Goulas. 2006. Effect of grafting on growth and yield of tomato (*Lycopersicon esculentum* Mill.) in greenhouse and open-field. J. Applied Hort. 8(1):3-7.

King, S.R., A.R. Davis, X. Zhang, K. Crosby. 2010. Genetics, breeding and selection of rootstocks for Solanaceae and Cucurbitaceae. Sci. Hort. 127:106-111.

Kubota, C., M.A. McClure, N. Kokalis-Burelle, M.G. Bausher, and E.N. Rosskopf. 2008. Vegetable grafting: History, use, and current technology status in North America. HortScience 43(6):1664-1669.

Lee, J.M. 1994. Cultivation of grafted vegetables I. Current status, grafting methods, and benefits. HortScience 29(4):235-239.

Leonardi, C. and D. Romano. 2004. Recent issues on vegetable grafting. Acta. Hort. 631:163-174.

Salvatierra, M.A.G., H. Gemma, and S. Iwahori. 1998. Partitioning of carbohydrate and development of tissues in the graft union of peaches grafted on *Prunus tomentosa* Thunb. rootstock. J. Japan. Soc. Hort. Sci. 67(4):475-482.

Turkmen, O., M. Seymen, and A. Dursun. 2010. Effects of different rootstocks and cultivars on yield and some yield components of grafted tomato. Bulletin UASVM Hort. 67(1):284-291.

Wang Y. and R. Kollmann. 1996. Vascular differentiation in the graft union of in-vitro graft with different compatibility. – structural and functional aspects. J. Plant Physiol. 147:521-533.