ISVG 2019
Program & Abstracts

II International Symposium on Vegetable Grafting

July 14-18, 2019

Charlotte, North Carolina, USA

ISHS

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Welcome Note

Welcome to the II International Symposium on Vegetable Grafting. Our world has many GRAND CHALLENGES and OPPORTUNITIES. This Symposium features a global array of scientists, extension and teaching professionals, industry leaders, students and other experts who work to advance the science, business and practice of vegetable grafting as a tool to address local to global challenges. Though grafting is “rooted” in ancient civilizations, the scientific and practical innovation represented at this Symposium is designed to make a difference in current and future vegetable farming systems. Thanks to all the delegates who will present, discuss and develop new ideas at this symposium and return to their home regions to continue this important work.

Thanks to our sponsors and thanks to the local and international leaders of the organizing and scientific committees who share the vision of “making a difference” by investing time, expertise and resources. There is a deep satisfaction in an engaged international group of people who can come together to organize, share and advance opportunities on a daily basis and through International Symposiums. This Symposium is organized under the auspices of the International Society for Horticultural Science and locally led by members of the “United States Department of Agriculture- Specialty Crops Research Initiative” vegetable grafting team, supported through the USDA-SCRI grant 2016-51181-25404.

Welcome to North Carolina and the great city of Charlotte. We hope you enjoy the science, discussions, fellowship and social activities. We hope you will make new friends and acquaintances that will last a life-time. We are confident that the outcomes of this Symposium will lead to future opportunities that address challenges faced by those we serve in our local countries and regions. Enjoy. Learn. Share. Do.

Sincerely,

Frank Louws, Chieri Kubota, Penelope Perkins-Veazie, Conveners

Sunday, July 14

5:00 - 7:00PM Registration/Badge Pickup [*Mecklenburg Ballroom Foyer*]

6:00PM Welcome Reception [*CJ's*]

Monday, July 15

7:00 AM - 5:00PM Registration Desk Open [*Mecklenburg Ballroom Foyer*]

7:00 – 8:00AM Extension Agent Breakfast (invitation only) [*Carolina A*]

8:00 – 8:30AM Symposium Opening [*Carolina C*]

Welcome by Convener (Frank Louws, NCSU, USA)

Extension In-Service Training – Welcome (Matthew Kleinhenz, OSU, USA)

ISHS Presentation (Daniel Leskovar, ISHS Representative & Francisco Pérez-Alfocea, ISHS Vegetable Grafting Working Group Chair)

8:30 – 9:20AM Keynote Lecture #1 [*Carolina C*] Moderator: Frank Louws

Grafting to Address Grand Challenges (Francisco Pérez-Alfocea, CEBAS-CSIC, Spain)

9:20 – 9:30AM Break

9:30 – 11:30AM Session 1: Use and Development of Vegetable Grafting [*Carolina C*] Moderator: Xin Zhao

9:30 – 11:10AM Oral presentations.

S1-1: Recent progress of vegetable grafting in China (Zhilong Bie, China)

S1-2: Solanaceous vegetable rootstocks in Japan (Hiroshi Matsunaga, Japan)

S1-3: Vegetable grafting in Thailand (Taweesak Klinkong, Thailand)

S1-4: Vegetable grafting: Current progress and future perspectives in Pakistan (Yuan Huang, China)**

S1-5: Development of suitable rootstock for musk melon and standardization of appropriate grafting technology for dry and humid areas of India (Vimal Chawda, India)

11:10 – 11:30AM Extension summation

11:30AM – 12:30PM Lunch [*Carolina A*]

12:30 – 1:00PM Flash Talks for Poster Session I [*Carolina D&E*] Moderator: Chieri Kubota

1:00 – 1:50PM Poster Session I (*see the list of poster presenters*) [*Carolina D&E*]

1:50 – 2:40PM Keynote Lecture #2 [*Carolina C*] Moderator: Ricardo Hernández

Rootility's Unique Rootstock Breeding System and the Innovative Applications (Rafael Meissner, Rootility, Israel)

2:40 – 2:50PM Break

2:50 – 4:30PM Concurrent Sessions 2 and 3

Session 2: Grafting Effects on Fruit Quality I [*Mecklenburg 1 & 2*] Moderator: Jonathan Schultheis	Session 3: Transplant Production and Technology I [*Mecklenburg 3*] Moderator: Ricardo Hernández
2:50 – 4:10PM: Oral presentations.	**2:50 – 4:10PM:** Oral presentations.
S2-1: Advances in watermelon quality through grafting (Penelope Perkins-Veazie, USA)	S3-1: Increasing survival and efficacy of splice-grafted watermelon using sucrose and anti-transpirant (Pinki Devi, USA)**
S2-2: Pumpkin-grafting delays watermelon fruit ripening by altering ABA signaling and other gene networks (Yong Xu, China)	S3-2: Research and application of LED lighting in the healing stage of grafted vegetable seedlings (Athanasios Koukounaras, Greece)
S2-3: Watermelon fruit quality as affected by rootstock and potassium supply (Yuan Huang, China)**	S3-3: Temperature and light intensity during healing influence survival and plant regrowth of grafted tomato seedlings (Matthew Kleinhenz, USA)
S2-4: Grafting watermelon onto interspecific hybrid squash combats hollow heart disorder (Marlee Trandel, USA)**	S3-4: Transplant quality and post-transplanting growth of grafted and non-grafted watermelon seedlings as affected by chilling during simulated long-distance transportation (John Ertle, USA)**
4:10 – 4:30PM Extension summation	**4:10 – 4:30PM** Extension summation

4:30 – 4:35PM Break

4:35 – 6:35PM Industry R&D Round-Table Discussion (*open for everyone*) [*Carolina C*] Moderator: Matthew Kleinhenz

Tuesday, July 16

7:00 AM - 5:00PM Registration Desk Open [*Mecklenburg Ballroom Foyer*]

8:00 – 8:10AM Greetings by Convener and VG Working Group Chair [*Carolina C*] (Chieri Kubota and Francisco Pérez-Alfocea)

8:10 – 9:00AM Keynote Lecture #3 [*Carolina C*] Moderator: Erin Rosskopf

Integration of Grafting into Sustainable Crop Production (Roni Cohen, ARO, Israel)

9:00 – 9:10AM Break

9:10 – 10:50AM Session 4: Vegetable Grafting in Different Production/Management Systems [*Carolina C*] Moderator: Margaret Lloyd

9:10 – 10:30AM Oral presentations.

S4-1: The role of grafting for local tomato production in high tunnels (Cary Rivard, USA)

S4-2: Grafting as a tool in organic watermelon production systems utilizing unique cover cropping strategies (Brian Ward, USA)

S4-3: 2018 progress report: an evaluation of grafting for processing tomato production in California's Central Valley (Gene Miyao, USA)

S4-4: Pruning reduces yields in grafted tomatoes planted in the field (Thomas Ingram, USA)**

10:30 – 10:50AM Extension summation

10:50 – 11:20AM Flash Talks for Poster Session II [*Carolina D&E*] Moderator: Chieri Kubota

11:20AM – 12:10PM Poster Session II (*see the list of poster presenters*) [*Carolina D&E*]

12:10PM – 1:30PM Lunch & Photo Shooting [*Carolina A*]

1:30 – 2:20PM Keynote Lecture #4 [*Carolina C*] Moderator: Gene Miyao

Application for Overcoming Interfamily Grafting and Grafting Microchip (Michitaka Notaguchi, Nagotya University, Japan)

2:20 – 2:30PM Break

2:30 – 4:10PM Concurrent Sessions 5 and 6

Session 5: Grafting Effects on Fruit Quality II [*Mecklenburg 1 & 2*] Moderator: Penelope Perkins-Veazie	**Session 6: Transplant Production and Technology II [*Mecklenburg 3*]** Moderator: Carol Miles
2:30 – 3:50PM: Oral presentations.	2:30 – 3:50PM: Oral presentations.
S5-1: Frontiers in grafting-quality science (Matthew Kleinhenz, USA)	S6-1: Promoted graft healing and quality of watermelon seedlings by environmental manipulation (Byoung Ryong Jeong, Korea)
S5-2: How grafting affects the quality of tomato fruits (Wei Liu, China)	S6-2: Optimizing transplant production of *Citrullus lanatus* \`Fascination´ and *Cucurbita maxima x moschata* \`Carnivor´ for grafting using lower light intensity and CO_2 enrichment (Brandon Huber, USA)**
S5-3: Volatile compounds and consumer perceived sensory attributes of tomato fruit as influenced by grafting and production environment (Xin Zhao, USA)	S6-3: GRANDES: An online decision support tool for grafting nurseries (Sara Masoud, USA)**
S5-4: High tunnel and field production system comparison of grafted tomato in Texas' Yield and quality traits (Daniel Leskovar, USA)	S6-4: Developing an economic decision support tool for grower adoption of vegetable grafting in the United States (Yefan Nian, USA)**
3:50 – 4:10PM Extension summation	3:50 – 4:10PM Extension summation

Gala Dinner Details (Ticket Holders Only):

5:30PM Reception [*Mecklenburg Foyer*]

6:30PM Dinner [*Carolina A*]

Wednesday, July 17

7:00 AM – 5:00PM Registration Desk Open [*Mecklenburg Ballroom Foyer*]

8:00 – 8:10AM Greetings by Convener and ISHS Representative [*Carolina C*] (Penelope Perkins-Veazie and Daniel Leskovar)

8:10 – 8:20AM Platinum Sponsor Presentations [*Carolina C*] Moderator: Cary Rivard

Syngenta TriHishtil World Vegetable Center

8:20 – 9:10AM Keynote Lecture #5 [*Carolina C*] Moderator: Chandrasekar Kousik

Vegetable Grafting in Promoting Sustainable Vegetable Production in Developing Countries (Ravishankar Manickam, World Vegetable Center, Taiwan)

9:10 – 9:20AM Break

9:20 – 11:20AM Concurrent Sessions 7 and 8

Session 7: Soilborne Disease Management **[*Mecklenburg 1 & 2*]** Moderator: Josh Freeman	**Session 8: Rootstock and Scion Interaction** **[*Mecklenburg 3*]** Moderator: Cary Rivard
9:20 – 11:00AM: Oral presentations.	9:20 – 11:00AM: Oral presentations.
S7-1: On-farm-research to evaluate efficacy of grafting to manage soilborne pathogens of tomato in North Carolina USA (Frank Louws, USA)	S8-1: Using wild relatives as a source of traits through grafting: genetic distance, heritability and vigor (Sean Fenstemaker, USA)**
S7-2: Evaluation of eggplant grafted onto commercial Solanaceae rootstocks for resistance to Verticillium dahliae (Abigail Attavar, USA)**	S8-2: Characterizing the impacts of "generative" rootstocks on growth and development of grafted tomato plants (Tian Gong, USA)**
S7-3: Carolina Strongback: a fusarium wilt and root knot nematode resistant *Citrullus amarus* rootstock for watermelon production (Patrick Wechter, USA)	S8-3: Investigating the molecular, physiological, and nutritional changes that underlie grafting-induced vigor in tomato (Margaret Frank, USA)
S7-4: Grafting on resistant rootstocks for managing Phytophthora crown rot of peppers (Chandrasekar Kousik, USA)	S8-4: Effects of interspecific Capsicum grafting combinations on horticultural performance (Andrey Vega-Alfaro, USA)**
S7-5: Identification of potential rootstock for tomato grafting from bacterial wilt screening trial in NC (Dilip Panthee, USA)	S8-5: Influence of grafting and pruning on *Solanum lycopersicum* L. cvs. Anahu and Rutgers on plant biomass partitioning in the presence and absence of *Meloidogyne incognita* (Nematoda) (George Bird, USA)
11:00 – 11:20AM Extension summation	**11:00 – 11:20AM** Extension summation

11:20 – 11:30AM Break

11:30AM – 12:20PM ISHS Business Meeting (*open for everyone*) [*Carolina C*]

11:30AM – 12:20PM Extension Agent Wrap-up [*Mecklenburg 1 & 2*] Moderators: Matthew Kleinhenz, Katie Jennings, and Russell Tronstad

12:20 – 1:20PM Lunch [*Carolina A*]

1:20 – 3:30PM Session 9: Addressing Abiotic and Biotic Factors in Grafted Vegetable Production [*Carolina C*]
Moderator: Christopher Gunter

1:20 – 3:00PM: Oral presentations.

S9-1: Prospecting Solanum rootstock biodiversity for improving nutrient use efficiency in tomato (Francisco Pérez-Alfocea, Spain)

S9-2: Mechanism of increasing salt resistance of cucumber by grafting onto salt tolerant rootstock pumpkin (Zhilong Bie, China)

S9-3: Mechanisms of tolerance to salt stress in three pepper accessions used previously as rootstocks: a physiological and genetic approach (Lidia López-Serrano, Spain)**

S9-4: Tomato rootstocks contribute to abiotic stress tolerance: emphasis on root chill tolerance (Felipe Barrios Masias, USA)

S9-5: Development of eggplant rootstocks resistant to bacterial wilt (Mohamed Rakha, Taiwan)

3:00 – 3:20PM Extension summation

3:20 – 3:30PM Break

3:30 – 4:30PM Symposium Summary, Awards, and Closing [*Carolina C*] (Frank Louws)

Thursday, July 18

Post Symposium Tour (*pre-registration required*)

Tour departs at 7AM from and returns to the Sheraton hotel by 7PM.

List of Poster Presentations

Poster Session I (Flash Talks I: 12:30 – 1:00PM & Poster Session I: 1:00 – 1:50PM, Monday, July 15)

P1-1: Field evaluation of new watermelon grafting methods to reduce verticillium wilt (Scott Lukas, USA)

P1-2: Rootstock and plastic mulch effect on grafted watermelon flowering and fruit maturity (Pinki Devi, USA)**

P1-3: Growing new roots for tomato to boost off season production through grafting technology (Sumeet Singh, India)

P1-4: Study on the relationship between seedling age and plug seedling standardization in vegetable crops (Yang Gyu Ku, Korea)

P1-5: Influence of cylindrical paper pot system on the reduction of decreased growth caused by excessive irrigation compared with the plug system in fruit and vegetable seedlings (Il-Seop Kim, Korea)

P1-6: (cancelled)

P1-7: Using Solanum galapagense as a source of drought resistance through introgression breeding and grafting for tomato improvement (Sean Fenstemaker, USA)**

P1-8: Evaluation of tomato (Solanum lycopersicum \`Pectomech´) grafts against root knot nematode Meloidogyne incognita (Naalamle Amissah, Ghana)

P1-9: Changes of seedling quality of grafted cucumber transplants grown in cylindrical paper pot by different fertilizer concentrations and seedling growing days (Sewoong An, Korea)

P1-10: Evaluating fungicides and grafting to reduce Pythium disease in watermelon (Sean Toporek, USA)**

P1-11: Developing tomato rootstock recommendations for high tunnel production and enhancing our understanding of the \`rhizobiome´ (Cary Rivard, USA)

P1-12: Application of grafting technology for the control of tomato verticillium wilt caused by Verticillium dahliae (Yeonyee Oh, USA)

P1-13: Cost estimates for grafted, non-grafted, and direct seeded cantaloupes (Russell Tronstad, USA)

P1-14: Rootstocks affect response of grafted cucumbers to silicon supplementation (Min Wei, China)

P1-15: Grafted pepper fruits retain similar market quality to those harvested from their own-rooted counterparts across a range of rootstock and scion genotypes (Joe Scheerens, USA)

P1-16: Exploring the use of Cucurbita rootstocks for early spring planting of seedless watermelon in North Florida (Sylvia Willis, USA)**

P1-17: Screening rootstocks to mitigate the supra-thermal stress of bell pepper crops (Salvador Lopez-Galarza, Spain)**

P1-18: Screening World Vegetable Center eggplant and pepper rootstocks for resistance to verticillium wilt (Abigail Attavar, USA)**

P1-19: Grafting for open-field production of heirloom tomatoes in California (Margaret Lloyd, USA)

P1-20: Performance of grafted hybrid tomatoes within a Midwestern United States high tunnel in the absence of soilborne disease pressure (Ajay Nair, USA)

P1-21: Vegetable grafting workshops participation in the Delaware region (Rose Ogutu, USA)

P1-22: Weed competitiveness and herbicide tolerance in grafted tomato (Sushila Chaudha, USA)

P1-23: Grafting tomato as a tool to manage Fusarium solani in greenhouses (Yoel Messika, Israel)

Poster Session II (Flash Talks II: 10:50 – 11:20AM & Poster Session II: 11:20AM – 12:10PM, Tuesday, July 16)

P2-1: The study on the effect of five cucurbit rootstocks on growth, development and active substances content of medicinal pumpkin (Cucurbita pepo subsp. pepo var. Styriaca) (Majid Azizi, Iran)

P2-2: Histological and transcriptomic reveal the healing mechanism at graft junction of cucumber grafted onto squash heterografts (Xianchang Yu, China)**

P2-3: Grafted combinations affect tomato root growth and water permeability (Takashi Ikeda, Japan)

P2-4: Grafting watermelon onto pumpkin improves the nitrogen uptake and nitrogen use efficiency (Zhilong Bie, China)

P2-5: Effects of shade treatment on bioactive compounds in the fruit of pepper plants grown under high light intensity stress during summer (Yang Gyu Ku, Korea)

P2-6: Growth of grafted tomato seedlings as affected by N and P contents in a nutrient solution during cultivation after graft union formation (Yurina Kwack, Korea)

P2-7: Non-destructive characterization of grafted tomato root systems using the mini-horhizotron (Christopher Gunter, USA)

P2-8: The use of supplementary lighting enhances the quality of grafted watermelon seedlings (Athanasios Koukounaras, Greece)

P2-9: Growth change after grafting of root pruning splice grafted cucumber seedling grown in different media (Seung Jae Hwang, Korea)

P2-10: A conceptual model of smart grafted transplant production system (Sewoong An, Korea)

P2-11: Short-term mechanisms of grafted pepper using NIBER rootstock, tolerant to salinity (Lidia López-Serrano, Spain)**

P2-12: The role of ethylene in long-distance transportation of grafted vegetable seedlings (Tricia Jenkins, USA)**

P2-13: Molecular marker-assistant selection of pumpkin rootstocks for powdery mildew resistance and blooming capacity (Jiaxing Tian, China)

P2-14: Grafting bell peppers onto pepper and tomato rootstocks, and the effects on yield and plant morphology (Cary Rivard, USA)

P2-15: Environmental conditions affect silicon absorption and bloom formation on fruit surface of grafted and non-grafted cucumbers (Min Wei, China)

P2-16: Exploring chamberless healing for small-scale production of grafted tomato transplants (Tian Gong, USA)**

P2-17: Pathogenic races and putative fungal effectors in Fusarium oxysporum f. sp. lycopersici from greenhouse tomato in North Carolina (Frank Louws, USA)

P2-18: Effect of supplemental lighting source combined with intensity on quality of grafted tomato plug seedlings (Hao Wei, China)

P2-19: A meta-analysis of the effects of watermelon grafting on yield and fruit quality (Zhifeng Gao, USA)

P2-20: Functional characterization and expression analysis of influx silicon transporter LSi1 in pumpkin rootstocks and cucumber scion during bloom accumulation on cucumber fruits (Jintao Cheng, China)

P2-21: Herbicide tolerance of grafted eggplant on tomato rootstock (Sushila Chaudha, USA)

P2-22: Critical period of control of a mixed weed population in grafted triploid watermelon (Katherine Jennings, USA)

***Presenters for Young Minds Award Competition*

KEYNOTE LECTURE #1

Grafting to address grand challenges

Francisco Pérez-Alfocea

Departamento de Nutrición Vegetal, CEBAS-CSIC, Campus Universitario de Espinardo, 25, E-30100 Murcia, Spain

The discovery and implementation of grafting (watermelon onto pumpkin to alleviate soil pathogen pressure on crop productivity) at the beginning of the XXth century can be considered as a small belowground revolution, with benefits still occurring today. Indeed, alleviating soilborne diseases and extending early or late yields through rootstock-mediated vigor have been the main driving-forces for the rapid implementation of this technique, mostly in intensive high-value solanaceous and cucurbitaceous crops. Although the percentage of grafting is nearly 100% in some particular crops and in some areas, it is very low in many other species and, particularly, in developing countries. Moreover, the main agronomic traits of interest remain mostly the same, linked to the narrow genetic variability underlying the existing commercial rootstocks. Hence, the potential of using grafting in vegetables worldwide is still enormous, but further development will certainly depend on its capacity to address grand societal challenges: (i) securing food production for the increasing population; (ii) tackling malnutrition beyond feeding people; (iii) conserving natural resources (aboveground and belowground biodiversity, water and soil); and (iv) mitigation of and adaption to the climate change. Nevertheless, contributing to those societal challenges through grafting requires addressing some scientific and technical challenges: (i) identifying agronomic/societal/ environmental problems that can be alleviated by changing the root system of elite crop varieties (e.g., specific soilborne or airborne disease, abiotic stress factors, alone or in combination, use of water and fertilizers, postharvest and/or nutritional properties of the fruits, association with beneficial microorganisms in the rhizosphere, etc.); (ii) establishing publicly accessible collections and databases of the germplasm available in different graftable crop species; (iii) developing adequate protocols for germplasm phenotyping and selection as a whole plant and as rootstocks according to the target goal or environment; (iv) identifying physiological and genetic determinants of the traits of interest for conventional or biotechnological rootstock breeding; (v) on-farm demonstration of rootstock impacts and benefit/cost ratio; (vi) optimisation of management practices and well-established protocols; (vii) rootstock x scion x environment interaction database supporting farmer decisions; and (viii) developing high throughput grafting services providing high quality and affordable transplants at the right timing. For example, developing a rootstock conferring tolerance to the parasitic broomrapes for the industry cultivars, and providing cheap transplants to the farmers, could lead to another grafting-mediated belowground revolution with huge socio-economic and environmental impact in some developing countries.

KEYNOTE LECTURE #2

Rootility's unique rootstock breeding system and the innovative applications

Rafael Meissner

Rootility, Naan, Israel

Rootility is aimed to deliver higher crop yields through root focused breeding for tolerant root systems traits to abiotic stresses such as cold, heat, drought, salinity in order to optimize crop performance. Rootility has delivered proven field results with significant higher yields, maintaining crop quality while breaking yield barriers. Rootility has a strong GMO free vegetables and field crops pipeline. Rootility has developed a unique high throughput simulator (HTP) for adverse growing conditions which helps to identify root responses and to breed better roots. The system can be calibrated for different crops, different stresses and different outcomes. HTP selection system creates the ability to predict rootstock architecture by root traits profiling their influence on scion growth and yield distribution. The breeding activity is delivering rootstocks, developed by using the HTP that delivers a high correlation between root system traits and high yield measured in field. One Rootility business case is the transformation of processing tomatoes in California from a non-grafted to a grafted crop. Rootstocks bred by Rootility delivered higher yield and high quality, with less water/inputs thanks to drought tolerance and reduced field stand of plants. To allow this game changing technology, Rootility has developed a Robotic Grafting Unit in California to produce a high volume of uniform grafted plants by machine, significantly reducing the grafting costs. Rootstock are bred specifically to fit robotic grafting machines and for current standard working practices from nursery to field. The Grafting Unit in California currently provides 6 million grafted young plants per 50 days of the processing tomato season in California. Rootility future challenges include: 1) Expand the usage of unique HTP system for wide array of crops for both protected and open field growing systems. 2) Further develop HTP protocols for fast screening of high performing root systems for vegetables, field crops, fruit trees, grape, medical, aromatic and ornamental crops. 3) Collaborate with seed companies, commercial farming and food processing industries for improving new product development by using unique HTP screening system. In summary, Rootility has been a pioneer in root systems breeding. The core unique technology developed (HTP system) enables screening for better root systems with tolerance for abiotic stresses, increasing yield, and has a broad potential application in many different crops, in addition to vegetables. Rootility has proved the fit to market of grafted vegetable young plants in open field conditions enhancing grower profitability thanks to dedicated rootstock breeding and mechanization of the grafting process. In conclusion, the combination of a high throughput system and breeding for abiotic stress tolerant roots is the key factor to break yield barriers in an extremely wide range of crops/application.

KEYNOTE LECTURE #3

Integration of grafting into sustainable crop production

Roni Cohen

Institute of Plant Pathology and Weed Research, Agricultural Research Organization, Newe Ya'ar Research Center, Ramat Yishay, Israel.

Vegetable grafting has been used in Israel for the last 20 years. The original and main purpose of using this practice is reducing soil-borne disease and pest damages. Nevertheless, grafting has additional benefits and disadvantages compared to non-grafted plants; thus, evaluating these factors in addition to economic considerations has led us to the common practices applied today. Melon grafting is used mainly in the spring planting in light of the long growing season ahead. Grafted plants may cope better with low soil temperatures prevailing at the time of planting; they commonly produce higher yields and help to prevent soil-borne diseases that occur following fruit maturity. In the summer and fall seasons the grafted transplants' price and relatively low yield do not justify using grafting, whereas managing soil-borne diseases has effective and relativity cheap chemical alternatives. Similarly, grafted cucumbers are used mainly in the long winter growing season. These plants can better manage low soil and air temperatures, which offer good protection against crown rot caused by *Fusarium oxysporum* f. sp. *radicis cucumerinum*. In certain cases, using tolerant rootstocks provides partial protection from soil-borne CGMMV (Cucumber Green Mottle Mosaic Virus) infection. Most of the watermelons grown in Israel are grafted. The main motivation for this approach is to lessen damages caused by soil-borne pathogens such as *Macrophomina phaseolina* or to avoid soil fatigue, which is very common in watermelon if crop rotation is not properly used. Grafted watermelons produce higher yields but their fruit quality is often diminished. To overcome this obstacle, field trials are being carried out in order to find the best rootstock-scion compatibility. In certain cases, watermelon rootstocks can be used. The challenges involved with Cucurbita and watermelon rootstock breeding and the effects on fruit quality and the plant performance is discussed.

KEYNOTE LECTURE #4

Application for overcoming interfamily grafting and grafting microchip

Michitaka Notaguchi

Bioagricultural Sciences, Nagoya University, Furo-cho, Chikusa-ku, Nagoya, Aichi, Japan

Plant grafting has been an important technique in agriculture to propagate clones and to obtain benefits of certain rootstocks. However, graft-incompatibility has limited the opportunities. Recently, we found that the genus, Nicotiana has broad compatibility as a grafting scion/rootstock. Nicotiana was compatible with a wide range of vascular plants, including many vegetables and tree plants. By using Nicotiana as an interstock, we achieved a graft of tomato/Nicotiana/Arabidopsis which eventually set tomato fruit on Arabidopsis rootstock. To investigate the molecular basis of Nicotiana interfamily grafting, we performed time-course transcriptome analysis of grafting region. First, we observed upregulation of the genes related to cambium, provasculature and xylem formation and no upregulation of phloem related genes. These patterns are concomitant with morphological observation; proliferation of parenchyma tissues at the graft junction and establishment of xylem connection, without phloem connection. Second, by comparing transcriptome datasets of Nicotiana interfamily grafting and other graft combinations, several characteristic gene upregulations were identified. One of them was a cell wall modification enzyme gene and we confirmed its function in digestion of cell walls at the graft boundary. Finally, we observed formation of plasmodesmata, channels connecting neighboring cells, at the digested cell wall regions resulting in symplasmic transport of photoassimilate, phytohormones, RNAs and proteins. The scientific knowledge will enhance grafting skill. I will also introduce our recently developed grafting microchip which allows us to perform grafting without skillful hands. We combined skills of the micrografting technique used for scientific studies and an engineering technology, Micro Electro Mechanical Systems. We constructed a device for seedling-grafts and applied it in a tiny model plant, Arabidopsis. This concept could be broadened to other plants, e.g., tomatoes, to reduce the cost of graft production.

KEYNOTE LECTURE #5

Vegetable grafting in promoting sustainable vegetable production in developing countries

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Since 2000, World Vegetable Center (AVRDC) has been promoting vegetable grafting technologies to manage soil-borne diseases (e.g., bacterial wilt) and abiotic stresses (e.g., waterlogging) in South East Asia (Vietnam, Philippines, Indonesia, Cambodia and Lao PDR), South Asia (India, Bangladesh, Sri Lanka, Nepal and Bhutan), Oceania (Solomon Islands and Fiji), East Africa (Tanzania), West Africa (Mali and Burkina Faso), Central Asia (Uzbekistan, Armenia and Tajikistan), and Central America (Honduras and Belize). For sustainable vegetable production in the developing countries, efforts are being focused on low cost, effective and simplified grafting technologies, i.e., low-cost healing chambers and grafting tubes as well as open-pollinated rootstock varieties or those developed from wild species. Vegetable grafting has been introduced in existing value chains by training nursery operators and supporting skill development of women. This technology was also tested and promoted along with rain shelters for production of off-season tomatoes. Tomato line Hawaii 7996 (resistant to bacterial wilt and Fusarium wilt), and eggplant lines EG190, EG203 and EG219 (resistant to bacterial wilt, Fusarium wilt, root-knot nematode, and short-term waterlogging) and several bacterial wilt resistant sweet and hot pepper varieties were recommended as rootstocks for open field production. Experience in Asia showed the impact of grafting tomato onto selected eggplant rootstocks (EG195, EG203 and EG210) which enabled the production during hot-wet period by increasing the resistance to soil-borne diseases and flooding. For instance, the vegetable grafting technology along with rootstocks was successfully practiced in Vietnam to help stabilize tomato production (81.4 t/ha) with the benefit-cost ratio of 4.6 for grafted compared with 3.5 for non-grafted plants. Currently, World Vegetable Center is focusing on developing multiple biotic and abiotic stress tolerant rootstocks and interspecific lines with vigorous roots to support higher fruit yield in solanaceous and cucurbitaceous crops for open field and protected cultivation.

Oral Presentations

S1-1

Recent progress of vegetable grafting in China

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The earliest vegetable grafting in China was recorded in the first century, BC. However, commercial grafted vegetable production began late in 1970s. The main purposes of grafted vegetable production in China are to overcome soil-borne diseases and increase resistance to abiotic stress. In recent years, commercial vegetable grafted seedling production developed rapidly in China, which is now the largest country that produces grafted seedlings in the world. There are about 3000 companies producing grafted seedlings in China and distribute in different provinces, and Shandong Province is the no. 1 province with the most grafted seedling production companies owing to its biggest vegetable production area. The facilities and equipment related to grafted seedling production also developed very quickly, including greenhouse, plug trays, automatic seedling machine, substrate production, and environmental controlling systems, and the companies select appropriate facilities and equipment based on the climate of location and seedling production scale. Rootstock breeding developed very fast in the past several years, especially for the rootstocks of cucumber and watermelon. The research on vegetable grafting method, grafting and fruit quality, grafting and abiotic stress, rootstock-scion interaction in recent years will be presented and discussed

S1-2

Solanaceous vegetable rootstocks in Japan

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In Japan, the grafting of vegetables began in the late 1920s ahead of other countries (Tateishi, 1927). The main purpose of the first grafting was to reduce the damage of Fusarium wilt in watermelon. In Solanaceous crops, the grafting of eggplants, tomatoes and sweet peppers began in the 1930s, 1970s and 1980s, respectively. Since then, many rootstock cultivars of Solanaceous vegetables have been developed. The main purpose of breeding is to improve resistance to soilborne diseases. In eggplants, originally, *Solanum aethiopicum* was used as rootstock to control bacterial wilt and Fusarium wilt, and for its low-temperature tolerance. After the 1990s, three *S. torvum* rootstock cultivars were developed. The cultivars have resistance to bacterial wilt, Verticillium wilt, Fusarium wilt, and root knot nematode, and are therefore used as rootstocks for a wide range of Japanese eggplant scions. However, they are susceptible to some pathogroup of bacterial wilt. Then more improved cultivars with highly resistance to bacterial wilt were released. In tomatoes, the first tomato rootstock cultivar in Japan is 'BF-Okitsu 101' in 1969, with resistance to bacterial wilt and Fusarium wilt (race 1). Since the 1980s, many tomato rootstock cultivars have been developed with resistance to various kinds of soil-borne diseases e.g., Fusarium wilt (race 1, 2 and 3), Verticillium wilt, root knot nematode, bacterial wilt, ToMV, Fusarium crown and root rot, and corky root. In sweet peppers, 'Beruhomare', the first Phytophthora blight-resistant cultivar in Japan, was released in 1982, followed by 'Berumasari' with resistance to Phytophthora blight and bacterial wilt in 1992. 'Berumasari' became the most popular as a rootstock cultivar for Japanese sweet pepper. However, the damages by the diseases have gradually expanded. Since the 2000s, improved cultivars with highly resistance to bacterial wilt, Phytophthora blight, root knot nematode and PMMoV have been developed.

S1-3

Vegetable grafting in Thailand

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Vegetable grafting in Thailand was introduced in processing tomato cultivation in Northeastern provinces for controlling serious bacterial wilt caused by *Ralstonia solanacearum*. Purple eggplant cultivar was used as a rootstock for grafting with the commercial processing tomato cultivars. However the adoption was limited because of no commercial nursery, costly for farmer and also still infected by bacterial wilt pathogen. Bacterial wilt was also a major problem in eggplant cultivation. In 2007 a commercial eggplant grafted on *Solanum torvum* rootstock was introduced. It was rapidly adopted since then. Grafted eggplant on *S torvum* rootstock resistant to all major root diseases including bacterial wilt. Grafted eggplant was higher yield and longer harvesting period for over a year. Eggplant from this grafted seedling showed larger plant canopy which reduced the number of plants from 2,500 to 500 plants per acre. Grafted bitter gourd was also introduced using luffa (*Luffa cylindrica*) as a rootstock mainly for Fusarium wilt control and tolerance to water logging. The grafted bitter gourd gave higher yield and the longer harvesting period. Watermelon (*Citrullus lunatus*) grafted onto a bottle gourd (*Lagenaria siceraria* Standl.) rootstock was also successfully developed. Papaya (*Carica papaya*) grafting was introduced in 2017 targeted for a rapid propagation as an alternative method of high cost and sophisticated micropropagation, using hermaphodite mother plant as a scion and a conventional papaya seedling as a rootstock. By this method, grafted papaya plants were all hermaphodites and super-fast growing. Grafted papaya will ready to harvest within 5-6 months after transplanting, which regularly took 8-9 months for conventional seedling. With this grafting system will open the further development on a better rootstock for root diseases control and/or a possible method for papaya ringspot disease control.

S1-4

Vegetable grafting: Current progress and future perspectives in Pakistan

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Cucurbitaceae and Solanaceace vegetables such as watermelon, melons, cucumber, chilies, tomato, and eggplant are cultivated on a commercial scale in Pakistan. These vegetables are grown in plastic tunnels during the winter season and field during the summer season. These vegetables experience restricted growth because of low and high temperature during the winter and summer seasons, respectively. High temperature during the summer season often destroys growing plants leading towards reduced harvesting span. The average yield of vegetables in Pakistan is less compared with other vegetable producing countries. Biotic and abiotic stresses are the major reason for the reduced yields. Several approaches such as the use of disease and stress tolerant cultivars, balanced nutrient supply, and use of growth regulators are employed to overcome stresses. Recently, we suggested vegetable grafting as an alternative approach that can be utilized to overcome biotic and abiotic stresses such as soil borne diseases, nematodes, low and high temperatures, salinity, high and low light intensity, water scarcity, flooding, and heavy metals. The use of appropriate rootstocks (bottle gourd, pumpkin) can help improve the nutrient use efficiency, yield, fruit quality, postharvest life, and extend the harvesting window. Increasing trend of growing vegetables under protected cultivation system (plastic tunnels, greenhouses, and hydroponic cultivation) further necessitates the adoption of vegetable grafting technique in Pakistan. We have started research work on vegetable grafting, and developed a working model for the adoption of vegetable grafting in Pakistan. Currently, different public and private organizations have started working on the selection of appropriate rootstocks and grafting methods, and optimization of growing conditions. The recent progress regarding vegetable grafting and result of ongoing research trials will be will shared in this symposium.

S1-5

Development of suitable rootstock for musk melon and standardization of appropriate grafting technology for dry and humid areas of India

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In the year 2003, we started our experiments in Chhattisgarh, a state in Central India. Simultaneously, we initiated Rootstock Breeding to develop suitable rootstocks offering tolerance to different biotic and abiotic stresses. Muskmelon cultivated in regular field is often affected by Wilt, hence it is mostly cultivated in River beds. To search for solution, we collected 220 different accessions of Snap Melon (SM), Acid Melon(AM) & Wild Melon (WM), same were selfed for 4 generations & were grown on wilt infected soil & 20 Hybrid Combinations were made from the selected lines. Parent lines & Hybrid Combinations were used for grafting Melons and tested along-with self-grafted Melons which led to selection of a F1 Hybrid, which is a combination of (SM x AM). Other Rootstock solutions offered by VNR includes Eggplant Rootstock for grafting Tomatoes, Hot Pepper rootstock for Sweet Pepper and Hot Pepper, Citron Rootstock for Water Melon, Cowpea Rootstock for grafting Cowpea and Interspecific Pumpkin Rootstock. One of the challenges faced by us in standardizing the technology was the process of Healing, after trying different methods observed during our study trips abroad, we innovated a new method with use of thin White Muslin cloth in place of Polythene for covering tunnels resulting in around 98 % success in grafting and economizing cost of Production. After this we commercialized this technology in Chhattisgarh & transferred the technology to Haryana Agriculture University & trained more than fifty professional Nursery growers from different states of India. Vegetable Grafting technology has ensured production of Vegetables in non-traditional areas, with increased productivity and better returns to small tribal farmers of Chhattisgarh who are using more than three million grafted plants every year with latest agronomic practices like Raised Bed, Plastic Mulch, Drip Fertigation, Staking, etc.

S2-1

Advances in watermelon quality through grafting

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S2-2

Pumpkin-grafting delays watermelon fruit ripening by altering ABA signaling and other gene networks

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The grafting technology is implemented world-wide mainly to resist abiotic and biotic stress, and an effective method to improve watermelon production and quality. However, grafting may affect fruit development and quality in a negative way. In our experiment, pumpkin-grafted (PG) watermelon fruits showed a slower and extended ripening period compared to self-grafted (SG) fruits. The concentrations of ABA and other endogenous phytohormones were also reduced by grafting. In order to understand these changes from the gene expression level, we performed a comprehensive analysis of the fruit flesh transcriptomes between PG and SG during fruit development. 1675-4102 genes were deferentially expressed (DEGs) between PG and SG during fruit development, and functional enrichment analysis revealed that these DEGs were associated with carbohydrate biosynthesis, ABA signaling transmission and cell wall metabolism categories. Watermelon fruit ripening related gene networks were also constructed by co-expression analysis. Transcription factors, ABA receptor, auxin response factor, PP2C proteins, sucrose transporter and carotenoid isomerase were centered in these networks. These results provide a valuable resource for dissecting the candidate gene functions in fruit development altered by pumpkin-grafting and cross-talking mechanism between rootstock and scion development.

S2-3

Watermelon fruit quality as affected by rootstock and potassium supply

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Grafting watermelon onto nonself- rootstock is an effective way to solve the soilborne diseases; in addition, potassium is an essential macroelement. However, a comprehensive analysis of rootstock and potassium on the fruit quality of watermelon was lacked. In this study, the NMR-based metabonomic approaches was used to reveal the effects of nonself- rootstocks (wild watermelon, bottle gourd, pumpkin) on the fruit metabolites accumulation of watermelon at ripening stage. The plants were grown under substrate culture. Thirty eight metabolites were identified. Compared with self-grafted plants, nonself-rootstock grafting significantly increased the concentrations of citrulline and methionine. In addition, pumpkin grafting increased the accumulation of some essential amino acids, such as glutamine, isoleucine, phenylalanine and valine, but decreased the sucrose concentration. Compared with normal potassium (6 mM), fruit quality parameters, including contents of total soluble solid, sucrose, vitamin C, lycopene, β-carotene, were significantly decreased in the self- grafted plants under low potassium (0.1 mM K). However, nonself- rootstock grafting can increase watermelon fruit quality at low potassium supply. Our results suggested that watermelon fruit quality can be improved by grafting onto adequate rootstocks, under both normal and low potassium conditions.

S2-4

Grafting watermelon onto interspecific hybrid squash combats hollow heart disorder

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Hollow heart (HH) is a fruit disorder predominantly developing in triploid watermelon types. Incidence of HH can range from 0 to 65% depending upon the season making it difficult to predict or control. Fruit genetics, pollination, relative tissue firmness and environmental factors are thought to contribute to onset and development of HH. Previous research has shown that watermelon varieties with lower tissue firmness have a higher incidence of HH and that grafting a watermelon scion to a hybrid squash rootstock increases tissue firmness and decreases HH in susceptible cultivars. In this study, a HH susceptible cultivar was grafted to three rootstocks and pollen availability was reduced to follow HH formation in grafted and non-grafted watermelon. 'Liberty' was not grafted or grafted to Carnivor and Kazako (Interspecific hybrid rootstock (rs), *C. moschata* x *C. maxima*), and Emphasis (*Lageneria siceraria*, bottle gourd rs). Transplants were planted in Clayton NC with diploid pollenizers (SP-6) planted at increasing distance down the plot. Fruit were harvested, cut longitudinally, and heart tissue firmness (resistance to penetration) was measured with a FDIX penetrometer mounted on a drill press and equipped with a 0.8 cm diam. flat probe. Heart tissue was saved for confocal microscopy, composition and cell wall polysaccharide assays. Grafting onto Carnivor rs reduced HH by 28% compared to non-grafted fruit. Flesh firmness was increased by 1 N in fruit from Kazako or Carnivor rootstocks. The soluble solids content (%) was lowest in fruit from the Carnivor rootstock or from fruit with HH. Confocal micrographs were used to count the number and size (μm^3) of cells in control fruit (no HH) and fruit with moderate to severe HH. The number of fruit cells were not affected by grafting treatments or severity of HH. The surface area of the cells was largest in fruit grafted to Emphasis, (110,805 μm^3). Fruit with moderate HH also had larger cells (102,873 μm^3). Cell wall polysaccharide composition and monosaccharide quantification is ongoing to see if the cell wall pectin assembly, specifically the composition and structural arrangement of monosaccharide sugars, affects cell wall strength and tissue density differences. We hypothesize that grafted watermelons will have more complex pectin structures than non-grafted fruit and HH fruit will have less total pectin content. Results show that fruit with higher tissue firmness have lower incidence of HH and that grafting onto interspecific hybrid rs decreases HH susceptibility.

S3-1

Increasing survival and efficacy of splice-grafted watermelon using sucrose and antitranspirant

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The production of grafted watermelon seedlings on a large scale in the United States is limited by the one-cotyledon grafting technique that is most commonly used for this crop, as it requires more time and labor than splice grafting, which is used to produce large numbers of solanaceous grafted plants. Additionally, the watermelon scion is susceptible to desiccation following grafting, and rootstock regrowth can occur, which can result in graft failure and extra labor for removal, respectively. More research is needed to advance the use of splice grafting as an effective grafting method for watermelon. This study tested application of sucrose and antitranspirant solutions (2% sucrose, 2% sucrose + 2% Root Drench, 2% sucrose + 4% glycine solution) as a drench to rootstock seedlings before grafting to increase the survival of splice-grafted watermelon as compared to application of water (control). Sucrose application was split into three applications, applied every other day starting 6 days prior to grafting: 20 mL for the first and second application, and 10 mL for the third application, which was 2 days prior to grafting. Antitranspirant was applied at 20 mL in combination with the third application of sucrose. The control was 30 mL of tap water applied each day. Plants were healed in a bench-top chamber in the greenhouse following guidelines developed by this research group for this location. Survival (%) of splice-grafted watermelon seedlings 21 days after grafting was greatest for plants that received 2% sucrose + 4% glycine solution and 2% sucrose + 2% Root Drench (90% and 85%, respectively), followed by plants that received 2% sucrose solution (70%), and was lowest for plants that received water (20%) ($P < 0.0001$). These results indicate that application of sucrose with antitranspirant to splice-grafted watermelon can increase the survival of grafted watermelon seedlings.

S3-2

Research and application of LED lighting in the healing stage of grafted vegetable seedlings

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In Greece, among the vegetables, watermelon is exclusively cultivated by the use of grafted plants while high percentages (>30-50%) are also grafted in other vegetables (tomato, cucumber etc.). The production of grafted vegetable seedlings is mainly carried out by modern nurseries and the healing of grafted vegetable seedlings is considered as the most critical stage during their production process. Previously, beds inside the greenhouse were used for healing while nowadays they are replaced by chambers with fluorescence (FL) lamps as supplementary light. The aim of the present study was to study the efficacy of LED lamps in the healing chamber as an alternative lighting source for grafted watermelon seedling production. Apart from FL lamps (control treatment), LEDs employed were 12B (12% blue and 88% red), 12B+FR (12B with supplemental far-red) and AP673L (wide spectra with 12% blue), all emitting 85 μmol m^{-2} s^{-1}. To that end, the characteristics evaluated were stem length, leaf area, root and shoot weights and their ratio (R/S) as well as leaf color. According to the results, seedlings treated with 12B and 12B+FR were taller (+11% and +14%, respectively), had larger leaves (+21% and +8%, respectively), greater shoot (+24% and +22%, respectively) and root (+111% and +89%, respectively) biomass, as well as R/S ratio (+65% and +49%, respectively) compared to those treated with FL. On the other hand, seedlings treated with AP673L had higher dry root weight (+46%) and R/S ratio (+32%) compared to those treated with FL. It is concluded that red light supplemented with 12% blue and optionally far-red is ideal for the production of high quality seedlings, while a wide spectrum slightly improved seedling quality.

S3-3

Temperature and light intensity during healing influence survival and plant regrowth of grafted tomato seedlings

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Approaches used to manage light and temperature and the extent to which these key variables can be controlled within healing chambers or rooms differ widely. Also, grafted plant performance during production may be influenced by healing-stage management. Therefore, healing chamber managers benefit from setting clear targets and priorities. We tested the effects of various temperature-light combinations on tomato (*Solanum lycopersicum*) grafting and healing variables in two related experiments using a factorial set of treatments and newly-grafted 'Cherokee Purple'/'Maxifort' plants. Experiment 1 included two levels of both temperature (25/20 and 30/25 °C, day/night) and light intensity (50 and 150 μmol/m^2/s). Experiment 2 included three levels of temperature (15/25, 25/25, and 35/25 °C, day/night) and two levels of light intensity (150 and 300 μmol/m^2/s). Survival and plant regrowth (i.e., plant height, scion length, rootstock and scion stem diameter, leaf and stem fresh and dry weight, leaf area, plant compactness, specific leaf area) were monitored for 10 d after grafting. In experiment one, temperature did not affect these variables while light intensity did, and temperature-light interactions were significant for three of twelve variables. Survival exceeded 90% in all treatments and, overall, plant regrowth was greater under 150 than 50 μmol/m^2/s light; however, 30/25 °C and 150 μmol/m^2/s light typically resulted in the greatest regrowth. In experiment two, main and interactive effects of temperature and light intensity were significant for most variables. Survival was highest at 25/25 °C, regardless of light intensity, and at 35/25 °C but only under 150 μmol/m^2/s light. The combination of 25/25 °C and 300 μmol/m^2/s resulted in the largest above-ground dry weight and compactness values. The common practice of placing newly-grafted plants under very low light conditions needs to be reconsidered, provided temperature control is reliable. Still, lower light levels appear to be benefical at temperatures approaching 35°C.

S3-4

Transplant quality and growth of grafted and non-grafted watermelon seedlings as affected by chilling during simulated long-distance transportation

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Grafting of fruiting vegetable crops is a practice that is quickly gaining traction in the United States as a means for disease suppression and improved crop performance. Producers typically purchase high value grafted seedlings from specialized nurseries, which may be distantly located due to the limited availability. During long-distance shipment, plants can be exposed to low temperature as a source of injury that reduces transplant quality (visual quality and growth capacity). However, limited information is available regarding effects of low temperature on grafted vegetable seedlings and their performance after transplanting. In this preliminary study, watermelon (*Citrullus lanatus*), a most chilling sensitive member of the Cucurbitaceous family, was tested. 'SSX-8585' seeded watermelon seedlings were grafted onto 'Strong Tosa' interspecific hybrid squash (*Cucurbita maxima* × *C. moschata*) rootstocks. Grafted and non-grafted seedlings were subjected to a 72-hour shipping temperature simulation of 12 °C, within which seedlings were exposed to 3 °C for 0 – 48 hours. Seedlings were rated for visual damage on true leaves before the 72-h treatments, and then 24 hours after treatment. Regardless of grafting, watermelon seedlings showed only minor necrosis after 24 hours of treatments and were considered tolerant to an exposure of 3 °C up to 48 hours. This temperature is lower than previously reported thresholds for growing or storing watermelon plants without damages (12 – 15 °C). Seedlings were transplanted to individual pots filled with substrate in a greenhouse for assessing post-transplanting growth (December 2018 to February 2019). Regardless of grafting or exposure to chilling temperatures, no significant differences were observed in days to first male and female flowers nor nodal positions of flower development. Our results suggest that watermelon seedlings can be shipped under moderately cold conditions (3 °C - 12 °C) for 2-3 days without causing notable impact on transplant quality.

S4-1

The role of grafting for local tomato production in high tunnels

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The production of vegetables in high tunnels is changing the way specialty crops are grown in the United States. High tunnel technology is being rapidly adopted in regions where growing conditions may be difficult such as the Central US in order to protect high-value crops from storms and damaging winds. High tunnels can also provide season extension opportunities and protect the crop from early and late frost events. However, soilborne disease management can be challenging in these systems due to the limited growing space that they afford. Grafting tomatoes with inter-specific rootstock is common worldwide for protected crop production and is gaining popularity in the US. Research is being conducted at Kansas State University to help facilitate the successful implementation of grafting for small-acreage and high tunnel growers. Coordinated rootstock trials have indicated that yield can be significantly increased with the use of 'Arnold', 'Colosus', 'DRO141TX', and 'Maxifort' rootstocks ($P < 0.05$) whereas others may show no significant benefits. Fruit quality studies showed that brix level in the fruit was similar across treatments, but titratable acidity was significantly affected by rootstock ($P < 0.05$). An examination of the microbial community within and surrounding the root system suggest that vigorous rootstocks may provide for a higher diversity of bacteria in the rhizobiome. Rootstock/scion compatibility trials have also indicated that certain scions are affected differently by vigorous rootstock than others. When grafted with 'Maxifort' rootstock, the yield of 'Primo Red' was increased by 4% whereas in 'Tasti Lee', yield was increased by 60%. As high tunnel technology continues to grow and evolve in the US, the role of grafting with vigorous and disease resistant tomato rootstocks will continue to be a critical component for sustainable and organic production.

S4-2

Grafting as a tool in organic watermelon production systems utilizing unique cover cropping strategies

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Organic watermelon (*Citrullus lantus* var. lanatus) production is limited and nearly nonexistent in the Southeast United States and found only on a few farms. This makes creating an organic watermelon industry attractive to both transitioning conventional and organic growers. Organic watermelon production is plagued with the same disease, insect and weed issues facing commercial conventional watermelon production. The research focuses on grafting utilizing both disease resistant, rootstock including interspecific hybrid squash (*Cucurbita maxima* × *Cucurbita moschata* cv. Carnivor), citron (Citrullus amarus. cv. Carolina Strongback) and bottle gourd (*Lagenaria sicereria* cv. Emphasis) and grafted to scion commercial cultivars 'Sweet Dawn' and 'Fascination' shows an ever-increasing promise of making organic watermelon not only possible but also lucrative. The addition of habitat modification with wildflower strips that act as a banker and trap crop aiding in the control of various insect pests as well as aiding in pollination by attracting native pollinators. Additionally, the use of white clover (*Trifolium repens* cv. Regal Graze Ladino) as a cover crop between plasticulture rows eliminates the need for manual, organic herbicide or flame weed control. The combinative effects of these cultural practices have proven effective in producing yields and quality, especially brix levels, comparable and in some case exceeding commercial conventional levels at the Clemson Coastal Research and Education Center Organic Research Farm, Charleston, South Carolina. Using strategic planting dates that work around market distribution peaks allow for increased prices and typical prices at distribution points up to four times typical conventional watermelon prices. Grafted watermelon utilizing the cultural practices both increases yield including individual watermelon weight and total yield per hectare and brix levels.

S4-3

2018 progress report: an evaluation of grafting for processing tomato production in California's Central Valley

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The benefit of grafting for California processing tomato production in the lower Sacramento Valley was evaluated in commercial tomato fields, one each year from 2016 to 2017. Results were reported at a 2018 ISHS symposium. Two trials were conducted thereafter in 2018, which added depth to the evaluation. The investigation focused on fruit yield and quality of popular cultivars grafted onto rootstocks. Treatments included primarily three rootstocks (Maxifort, Multifort and DR 0138TX and later FusaPro and a few non-commercial rootstocks) and four scions (H 8504, DR 319, N 6428 and HM 3887, although not all together) plus each of the non-grafted scion as controls. Grafting was performed at commercial greenhouses. Within the fields, seedlings were transplanted with growers' 'finger-style' Mechanical Transplanter® **per norm. Planting depth was 10 cm or more below the bed top which buried the graft union. The trial design was a randomized complete block with four replications. Plots were a single plant line on a 1.5-m centered bed and 30.5 m long. In 2018, plot length was shortened to either 16.8 or 19.8 m at the respective sites as plant loss occurred prior to the field planting. One trial was planted with double lines per** bed. Emergence of wild rootstock shoots (which were removed) was minimal in years 1 and 3; and none in year 2. Irrigation was by buried drip at a depth of 25 cm. Harvest was mechanical using the grower's harvester and crew or a custom harvest operation. Grafting increased yields, on average, by 10% in 2016 trial, 19% in 2017 trial; and 8% to 29% in 2018 trials. Scion choice made a difference in yield outcome, but rootstock choice did not until 2018 when a few rootstocks had yields similar to the control. Brix performance was related to scion, but not to rootstock. No interaction (unique combination) occurred between scion and rootstock for yield or Brix in any year. Grafting for processing tomato production is not economically attractive without substantial yield improvement, a lower cost for grafted plants and rootstock seed or reduced planting density. The test will be conducted in the upper San Joaquin Valley in 2019 and 2020.

S4-4

Pruning reduces yields in grafted tomatoes planted in the field

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In 2017 and 2018 field trials were conducted on 'Tasti-Lee' and 'Mountain Fresh Plus' (MFP) tomatoes grafted onto the rootstock 'Beaufort'. Both scions were planted in a factorial design with four replicates to determine the interactions between grafted plants exposed to various cultural practices. Pruning (up to the first flower cluster), spacing (22 vs. 24 inches), and variety were the main effects included. Fruit yield was collected, and sorted into culls and marketable, and marketable yield per acre was calculated for each treatment group. In both years both scions grafted onto the rootstock 'Beaufort' had higher yields than non-grafted plants. Also, in both years non-pruned grafted plants had higher yields than pruned grafted plants ($P < 0.05$). Compared to the non-grafted 'Tasti-Lee' the pruned grafted tomatoes had +32% more marketable fruit per acre, and non-pruned grafted tomatoes had +57% more fruit compared to non-grafted. In 'MFP' pruned grafted plants produced +35% more fruit than non-grafted, while non-pruned tomatoes had 47% more fruit than non-grafted 'MFP'. The yield increases simultaneously increased the fruit sizes at all levels in both scions, not just overall yield. Spacing had no effect on yield, both 22 and 24 inch spacings produced statistically and interchangeably numerically similar yields per acre. Spacing also had no significant effect on fruit size. This indicates growers can plant fewer grafted plants per acre at 24 inches, and see the same yields as if they planted at 22 inches. Growers may be able to offset the higher cost of grafted plants by planting fewer plants per acre, and not pruning those grafted plants.

S5-1

Frontiers in grafting-quality science

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S5-2

How grafting affects the quality of tomato fruits

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Owing to the advantages, such as increasing abiotic/biotic stress, grafting is getting more and more popular in tomato production. Tomato fruits are widely eaten fresh and the quality is concerned by both the consumer and the producer. So we studied how grafting affected the quality of tomato fruits. The experiment was conducted under substrate culture system in the greenhouse. The scion tomato variety was '*Lucius*' and the rootstock tomato was '*Guozhen No. 1*'. Self-rooted '*Lucius*' plants were used as the control. We analyzed the fruit quality of the first and the third clusters and found that, compared to the control, soluble carbohydrate and lycopene contents in '*Guozhen No. 1*' grafted tomato fruits were significantly increased. Soluble carbohydrate contents in the first and third clusters were increased by 9.0% and 10.3% respectively. Lycopene contents in the first and third clusters were increased by 24.9% and 26.6% respectively. The gene expression of lycopene cyclase (LCY), phytoene dehydrogenase (PDS) and phytoene synthase (PSY1 and PSY2) in fruit at different development stages (green stage, turning stage, red stage and full ripening stage) were detected by Q-PCR. The results showed that the transcription levels of two lycopene synthesis genes PDS and PSY1 were remarkably higher in '*Guozhen No.1*'grafted friuts than those in the control. Net photosynthesis was also measured and no significant difference appeared. There was no significant difference of Vitamin C and organic acid contents among the treatments. Besides '*Guozhen No. 1*', another tomato variety '*Jingfan 302*' was also used as rootstock to graft '*Lucius*', but no noticeable improvement of quality was found.

S5-3

Volatile compounds and consumer perceived sensory attributes of tomato fruit as influenced by grafting and production environment

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While grafting is becoming an important tool for improving soil-borne disease management and fruit yields in tomato production, there is a lack of systematic studies of aroma volatile compounds and consumer sensory analysis of grafted tomato fruit. In this study, the 'Garden Gem' tomato scion known for its excellent flavor was grafted onto 'Multifort', a vigorous interspecific tomato hybrid rootstock, with non-grafted 'Garden Gem' as the control. Plants were transplanted into open field and high tunnel plots in a certified organic field for spring tomato production in Citra, FL, USA. The experiment was arranged in a split plot design with production environment as the whole plot factor and grafting as the subplot factor with 3 replications. Red ripe tomato fruit were harvested at 68 and 83 days after transplanting for volatile profile analysis and consumer taste test. Thirty-five volatile compounds were detected in fruit samples from each harvest. Hexanal and *cis*-3-hexenal showed the highest concentrations in both harvests but their levels did not determine the volatile profile differentiation among treatments. Discriminant analysis of the volatile data demonstrated a marked effect of harvest time on volatile levels. Compared with the late harvest, the overall levels of aroma volatiles were higher in the early harvest, while grafting and production environment did not exhibit pronounced effects on volatile profiling. In the late harvest, grafting and production environment effects only showed up in four volatile compounds with relatively low levels according to the discriminant analysis. Overall appearance, acceptability, flavor, color, sweetness, acidity, firmness, and juiciness were evaluated in consumer taste tests (100 or 102 panelists). Similar ratings of almost all the sensory attributes were found in both harvests, except that darker fruit color was perceived in samples harvested from high tunnels regardless of grafting.

S5-4

High tunnel and field production system comparison of grafted tomato in Texas' Yield and quality traits

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Successful integration of grafting into current tomato production practices could open new opportunities for Texas tomato growers to effectively manage soil diseases, abiotic stresses, and improve fruit quality and yield. A multilocation (Lubbock, Uvalde, Overton, and Weslaco) trial was conducted to evaluate yield and quality traits of grafted tomatoes in high tunnel (HT) and open-field (OF) conditions during the growing season of spring of 2017 and 2018. Two determinate tomato cultivars 'TAMU Hot' and 'Tycoon' in 2017 and 'TAMU Hot' and 'HM1823' in 2018 were grafted onto two interspecific hybrid rootstocks, 'Estamino' and 'Multifort'. Non-grafted 'TAMU Hot' and 'Tycoon' were used as controls. Differences in yields and quality traits due to the production system (HT vs. OF) were far greater than those of the grafting. Over the four locations, high tunnel increased marketable yields by 143% in 2017 and by 96% in 2018 relative to open-field production system. Further, grafting with either of the two rootstocks significantly enhanced marketable yields by 8% to 59% in 2017 and by 14% to 19% in 2018, depending on the location. Strongest yield increase was achieved with plants grafted on 'Multifort' rootstock. Yield increase in grafted plants was mainly due to significant increases in average fruit weight. Except for a decrease in ascorbic acid concentration of grafted fruits relative to non-grafted controls in 2017 but not 2018, grafting with the two rootstocks exhibited no major changes on other quality attributes (sucrose, glucose, fructose, polyphenol, lycopene, β-carotene, lutein, BRIX, and titrable acidity). In contrast, these quality traits were more influenced by the production system with significant increase due to high tunnel system. Results from this study demonstrate that grafting along with protected environment system clearly have the potential to significantly increase tomato productivity across Texas regions with minimal influence on the quality traits.

S6-1

Promoted graft healing and quality of watermelon seedlings by environmental manipulation

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In Republic of Korea, the demand for grafted vegetable plug seedlings has been increasing year by year, and also crop growers are increasingly demanding high-quality grafted seedlings. However, because of the climate change and some extreme weather conditions encountered during the summer and winter seasons in the country, the quality of grafted vegetable seedlings has been affected and could not always meet the increasing demand for quantity and quality. Therefore, improving quality of plug seedlings become a valuable research topic, especially of grafted seedlings of fruit vegetables, through environmental manipulation in plug production greenhouses. In this study, light (quality, intensity, and duration), temperature, and relative humidity, which have been found to be common issues, were the target factors. As the model plants for all experiments in this study, two cultivars of watermelon (*Citrullus vulgaris* Schrad.) 'Speed' and 'Sambok Honey' grafted onto the 'RS Dongjanggun' bottle gourd (*Lagenaria siceraria* Standl.) rootstock were used. The LEDs amplifying red and blue wavelength such as W1R2B1 LEDs promoted graft healing and quality of grafted seedlings during or after the graft healing period. The light intensity of 100 $\mu mol \cdot m^{-2} \cdot s^{-1}$ photosynthetic photon flux density (PPFD) was sufficient as the main light source during the graft healing period or supplementary light source after the healing period for grafted seedlings. The lighting duration of 16 h (on)/8 h (off) was more effective for graft healing and improving the quality of grafted seedlings, especially after the graft healing period. The constant temperatures (0 DIF), such as 23℃/23℃ (day/night), was less stressful and most effective for healing of grafted seedlings. As compared to a saturated relative humidity, a slight vapor deficit such as 97-98% RH (VPD of 0.4-0.7 $g \cdot m^{-3}$) accelerated graft healing.

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S6-2

Optimizing transplant production of *Citrullus lanatus* `Fascination´ and *Cucurbita maxima x moschata* `Carnivor´ for grafting using lower light intensity and CO_2 enrichment

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Grafted watermelon seedlings offer several advantages for growers including resistance/tolerance to soil borne pathogens and increased yields. Consequently, the demands for grafted seedlings has increased. Precision Indoor Propagation (PIP) are enclosed propagation systems that precisely control environmental factors to increase plant quality and uniformity. However, PIP systems are energy intensive due to electrical lighting as the sole source light for photosynthesis. CO_2 enrichment is inexpensive in systems with low air exchange rates and has shown to improve yield for many crops. The objective of this experiment is to reduce the light requirements using increased CO_2 levels to maintain a high-quality seedling with reduced energy consumption. One watermelon scion was grown; 'Fascination' and one rootstock 'Carnivor'. Plants were subject to three different light intensities of 100 ± 6, 150 ± 10, and 200 ± 11 photosynthetic photon flux (µmol m^{-2} s^{-1}) (18 h) with a percent photon flux ratio of 42Blue:58Red. Furthermore, plants were also subjected to three different CO_2 concentrations 439 ± 23 (ambient), 1018 ± 42, and 1589 ± 10 µmol mol^{-1}. The room air had a day/night temperature of 25.3°C ± 0.1°C, and 39.2 ± 7% RH. Seedlings were grown until the transplant stage, with two harvest intervals to observe dry mass and other morphological and physiological characteristics to quantify plant quality. Results following two repeated studies show that at the same light intensity (200 µmol m^{-2} s^{-1}) plants in 1589 ± 10 µmol mol^{-1} CO_2 enrichment had 24-34% greater dry mass, 11-23% greater leaf area, and 20-85% higher photosynthetic rate than plants in the control 439 ± 23 µmol mol^{-1}. In addition, with 1589 ± 10 µmol mol^{-1} CO_2 enrichment the same quality plant (dry mass) can be produced with a reduction of 35-38% less light than the standard 200 mmol m^{-2} s^{-1} thus reducing production costs.

S6-3

GRANDES: An online decision support tool for grafting nurseries

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Continuous improvement of resource efficiency is a mandatory requirement for production facilities to survive in today's competitive global marketplace. In any production facility, especially those concerning bioproducts such as grafting nurseries, an optimized resource allocation and layout design can lead to a reduction in production costs, which in return sharpens the competitive edge of the facility. To achieve lower production cost without sacrificing quality, we have developed an online GRAfting Nursery DEcision Support (GRANDES) tool which provides assistance in terms of design and resource management. GRANDES has a friendly user-interface where inputs such as demand patterns, propagation stages, and machinery can be submitted and a backend in which simulation and optimization models are run based on the given inputs to find efficient solutions within as low as ten hours. In the website, users can set their product (e.g., tomato, watermelon) and grafting mode (i.e., manual, semi-automated, or fully automated). They have the option to completely customize the machinery level of their ideal setup by defining the speed, price, power consumption, needed labor, and success rate for different operations such as seeding, mixing, sorting, and grafting. They also can modify the duration of propagation stages such as germination, pre-sort grow, or post-graft grow for summer and winter. The users can adjust the utility, labor, and operations related expenditures by setting the electricity rate, salary of skilled and unskilled labor, trays' type, size, and price, price of substrate and fertilizer, over seed rate, and many other features. In addition, the users can adapt the greenhouse, headhouse and germination chambers' expenses by defining construction cost, the utilized technology (e.g., polyethylene double layer, corrugated polycarbonate, or glass), operational days per year, and floor utilization rate. In this work, multiple experiments are conducted to demonstrate the capabilities of GRANDES and explain the logic behind it.

S6-4

Developing an economic decision support tool for grower adoption of vegetable grafting in the United States

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Despite the effectiveness of grafting for improving soil-borne disease management and crop yield in vegetable production, the overall adoption rate of grafting is still low among vegetable growers in the United States. The additional cost associated with high prices of grafted transplants is one of the major barriers. In addition, since crop yields may vary with production systems and seasonal conditions, growers may not be fully informed about the benefits and costs of adopting grafted plants for their site-specific production conditions for decision making. This study aims at developing a decision support tool to provide vegetable growers comprehensive information regarding the economic costs and benefits of grafting technology. The tool allows growers to conduct three key types of economic analysis based on the features of their own production systems and conditions. The partial budget analysis is used to compare details that contribute to the added or reduced costs and returns between the two production scenarios, i.e., using grafted versus non-grafted transplants. The tool also provides the ability for growers to conduct sensitivity analysis and therefore, helps them determine how the net return changes under various scenarios in correspondence to a changing factor (e.g., yields and transplant prices). In addition, the breakeven analysis is offered to calculate the threshold of a factor (e.g., selling prices and yields) at which the grafted and non-grafted production systems generate the same net return. It is expected that this economic decision support tool will help motivate more vegetable growers to consider integrated use of grafting to benefit their production when they can better assess the economic feasibility of vegetable grafting, taking into consideration some real-time factors directly relevant to their production systems and scenarios.

S7-1

On-farm-research to evaluate efficacy of grafting to manage soilborne pathogens of tomato in North Carolina USA

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Tomato production in high tunnel and open field systems represent an important component of the vegetable industry in NC. NC is a unique state with a broad range of climactic zones ranging from sub-tropical ecological zones in eastern NC to temperate zones in the mountainous western region. Likewise, soil types range from "Coastal Plain" sands to "Piedmont" heavy clays. The geographical and geological diversity also allows for a high diversity of soilborne pathogens. Major pathogens include *Ralstonia solanacearum* (race 1 biovar1; bacterial wilt), *Fusarium oxysporum* f.sp. *lycopersici* (races 0, 1 and 2; Fusarium wilt), *Verticillium dahliae* (races 1 and 2; Verticillium wilt), *Sclerotium rolfsii* (southern stem blight) and *Meloidogyne incognita* (southern root knot nematode). A series of on-farm-research (OFR) projects were initiated to determine the efficacy of grafting as an IPM tactic to limit losses due to these pathogens. OFR projects take advantage of natural sources of inoculum under commercial production conditions. Trials were typically arranged as randomized complete block designs with four replications of each rootstock treatment. Scion cultivars were selected by the cooperating grower. Growers provided all management inputs including land preparation, staking, tying, and water, fertility and pest management (foliar diseases and insects) inputs. NC State personnel provided the plants, grafted on university facilities or donated by professional grafting companies, managed planting and secured pathology and agronomic data. In many cases, grafting was compared to other management tactics such as soil fumigation. The OFR model enabled superior feedback from growers and other stakeholders (seed companies, grafting nursery companies) and large datasets to analyze the efficacy and economics of grafted tomatoes as an IPM tool in a range of production systems and geographical regions. Research outcomes were then translated into extension products and talks. In many cases, growers gave presentations, hosted field days or participated on panel discussions.

S7-2

Evaluation of eggplant grafted onto commercial Solanaceae rootstocks for resistance to *Verticillium dahliae*

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Verticillium wilt (caused by *Verticillium dahliae* Kleb.) can be a limiting factor for eggplant (*Solanum melongena* L.) production in Washington state and elsewhere in the world. Grafting can be used as an effective management strategy for the disease, but the resistance of commercial rootstocks is not well known. In this study we evaluated the verticillium wilt resistance and effect on plant productivity of three tomato and two eggplant rootstock cultivars and heirloom tomato cv. Cherokee Purple as a rootstock, with 'Night Shadow' as the scion. The experimental field site was at Washington State University's Northwestern Washington Research and Extension Center in Mount Vernon, WA. The field was naturally infested with *V. dahliae*, where pre-plant soil populations were 28 $cfu\cdot g^{-1}$ in 2016 and 5 $cfu\cdot g^{-1}$ in 2017. Both years, each plant was inoculated at transplanting to ensure infection, with 5 mL of a conidial suspension of 8 x 10^6 (2016) and 2.35 x 10^6 conidia per mL of *V. dahliae* (2017). Final disease severity in 2016 was greatest for non-grafted 'Night Shadow', and in 2017 'Night Shadow'/'Survivor' had the least disease severity. In 2016, 'Night Shadow'/'Meet' had greater yield than non-grafted 'Night Shadow' and 'Night Shadow'/'Cherokee Purple'. In 2017, yield was greatest for 'Night Shadow'/'Cherokee Purple' and least for 'Night Shadow'. Greatest plant biomass in 2017 was for 'Night Shadow'/'Cherokee Purple' and was comparable to commercial rootstocks, indicating that 'Cherokee Purple' could potentially be used as a rootstock. In conclusion, our study demonstrated that grafting could benefit eggplant production in verticillium wilt infested fields in Washington, and tomato cultivars with resistance to verticillium wilt could potentially function as rootstocks, thus reducing the cost of purchasing rootstock seed.

S7-3

Carolina Strongback: a fusarium wilt and root knot nematode resistant *Citrullus amarus* rootstock for watermelon production

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Carolina Strongback was developed from sequential fusarium wilt resistance selection and single seed decent from an original hybridization of USVL-246FR2 (*Citrullus amarus*) and USVL252-FR2 (*Citrullus amarus*), USDA germplasm releases with tolerance to *Fusarium oxysporum* f. sp. *niveum* races 1 and 2. Carolina Strongback has been tested in greenhouse and field trials for the past several years as a grafting rootstock for seedless watermelon production. This rootstock was granted provisional Plant Variety Protection (PVP) in 2018. Current data including recent field trialing and resistance studies will be presented at this workshop.

S7-4

Grafting on resistant rootstocks for managing Phytophthora crown rot of peppers

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Pepper (bell and hot) is a major vegetable crop grown across most states on 64,450 acres and valued at $785 million in 2017 in the U.S.A. *Phytophthora capsici* which causes crown and root rot of peppers is prevalent in most of these pepper producing regions. The primary means of managing Phytophthora crown rot is through fungicide applications. Many effective fungicides are currently available for conventional pepper growers. Numerous germplasm sources with resistance have also been identified and utilized in various breeding programs. Two crown rot resistant lines were developed from PI 201232 obtained from the U.S. National Plant Germplasm system (https://npgsweb.ars-grin.gov). After screening and selections for three generations in a greenhouse, two lines with high levels of resistance were developed. The two lines were different with respect to fruit shape and size. They were also highly resistant to a South Carolina isolate of *P. capsici* in inoculated greenhouse and field evaluations compared to cultivars; Jupiter, Paladin, and Charleston Belle. The pepper cultivar Jupiter which is highly susceptible to *P. capsici* was used as the scion and grafted onto the two resistant lines. Jupiter grafted onto itself was used as the susceptible control in two trials conducted in a heavily infested field in summer and fall of 2018. The areas under disease progress curves (AUDPC) for Jupiter grafted on the two lines was significantly lower compared to Jupiter grafted onto itself. Majority of the self-grafted Jupiter plants (90%) were dead by the by end of the two seasons due to crown rot. Grafting on resistant pepper rootstocks will be an added strategy for managing *P. capsici* especially in organic production where highly effective fungicides are not available for management of the disease.

S7-5

Identification of potential rootstock for tomato grafting from bacterial wilt screening trial in NC

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Bacterial wilt (BW), caused by *Ralstonia solanacearum,* is a serious disease of tomato world-wide. Although it has long been a severe disease in tropical areas, it is becoming more widespread and severe in more temperate climates. It is unusually critical where plastic mulch and drip irrigation are used, likely because of increased moisture and temperature in the soil is more conducive to its development. In North Carolina, severity and incidence of BW have risen in recent years. To combat the problem by breeding, evaluation of potential resistant breeding lines derived from Hawaii 7998 was started in 2009 in a field in western NC where BW is endemic for several years. Objectives of the experiment were to improve for BW resistance. Disease-free plants selected from the 2009 and 2010 study and putative resistant lines from the World Vegetable Center (formerly AVRDC) were used as parents in crosses to advanced breeding lines lacking BW resistance. We continued selection for BW resistance over the years. Problem with the selection process was that there was a negative correlation between fruit size and BW resistance, which has been a challenge to improve both traits simultaneously. With the advancement of grafting technology, it is possible to use the BW resistant lines even with smaller fruit size as rootstocks; it is possible to utilize those lines as rootstocks. Considering that opportunity, there are at least four lines which can be utilized as rootstock for grafting. These lines have shown resistance to BW consistently over years and location. These lines are being evaluated for their suitability as rootstock at a broader scale.

S8-1

Using wild relatives as a source of traits through grafting: genetic distance, heritability and vigor

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The introgression of new traits from wild relatives using traditional and marker-assisted breeding is a proven but time-consuming and costly approach to improve tomato plants. Interspecific hybrid rootstocks (RS) developed from wide genetic crosses offer growers an alternative, faster way of delivering traits derived from wild germplasm. Grafting to RS is now commonly used in annual vegetable production to control root system diseases, replace fumigation, and impart vigor. The primary objective of this study was to address the feasibility of using grafted plants in soil-based production to improve the yield and quality of processing tomato varieties. Beyond trialing and selecting superior RS, we measured the heritability of scion characteristics influenced by RS and grafting. In addition, we measured the contribution of individual parents to the hybrid RS. Estimates of heritability provide a measure of the genetic signal for important traits and allowed us to assess the relative importance of RS and environment. We used a randomized complete block design with two replicates in two locations and included 13 experimental RS, 4 commercial RS, self-grafted (positive control) and un-grafted scion (negative control). Four scions were used and included the commercial varieties Heinz 8504 and Heinz 5108; an F1 hybrid developed at OSU, FG12-407; and the high lycopene inbred line FG99-218. We determined that some RS were able to impart vigor measured as canopy width. In general, yield was not significantly improved for commercial hybrids. Yield was significantly improved in the weak scion FG99-218, which underperforms compared to elite commercial cultivars when un-grafted. Grafting improved the yield of FG99-218 without compromising its high lycopene concentration. Analysis of the parental contributions to measured traits demonstrated that selections of Solanum habrochaites as a parent tend to increase the number of adventitious shoots formed by the RS. Parental contributions for yield, vigor and quality were also analyzed and parents for the development of new hybrid tomato RS cultivars were identified.

S8-2

Characterizing the impacts of "generative" rootstocks on growth and development of grafted tomato plants

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Recently, so-called "generative" rootstocks have been introduced by seed companies. Potential advantages in limiting excessive vegetative growth and promoting steady fruit production throughout the season in grafted tomato production are claimed. These claims regarding "generative" tomato rootstocks are made in contrast to rootstocks that have the tendency to cause excessive vegetative growth in grafted plants, leading to possible delay in onset of flowering and fruit set. However, little research-based information is currently available to characterize such effects of "generative" and "vegetative" rootstocks on growth and development of grafted tomatoes. In this greenhouse study, eight tomato hybrid rootstocks with different descriptions of their attributes including generative, vegetative, vigorous, and mid vigor were grafted with two grape tomato scions, 'BHN 1022', 'Ruby Crush', and two beefsteak tomato scions, 'Skyway' and 'Red Morning'. The tomato scion cultivars vary in their growth and fruiting characteristics. Non-grafted and self-grafted tomato scions were used as controls. A completely randomized design was used for destructive sampling (r=3) and for phenotyping measurements (r=6). Plant height, stem diameter, leaf number, and SPAD were monitored on a weekly basis. Time of inflorescence appearance and flowering was also assessed. Destructive sampling took place at three plant stages: vegetative growth, inflorescence development, and early harvest. Leaf area, leaf number, leaf fresh/dry weight, stem fresh/dry weight, and root fresh/dry weight along with other root morphology characteristics were measured. Flowers and fruits were measured when present to determine biomass partitioning. Clustering and multivariate analyses were conducted to characterize rootstock effects. Results will be discussed to elucidate the scion-rootstock interactions within the context of rootstock clustering analysis.

S8-3

Investigating the molecular, physiological, and nutritional changes that underlie grafting-induced vigor in tomato

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In tomato, the grafting of elite fruit producing shoots (scions) onto vigorous, interspecific hybrid root systems significantly increases yield. We refer to this phenomenon as "grafting-induced vigor". Using molecular (RNA-sequencing), ionomomic, and physiological profiling of reciprocally grafted Maxifort and M82 genotypes we examine the effect that grafting-induced vigor has on whole plant responses. Here, we present data showing that grafting with Maxifort has a profound effect on the gene expression patterns, macro and micro nutrient profiles, and photosynthetic efficiency of domesticated tomato root and shoot systems. Moreover, we show that phenotypes that are associated with grafting-induced vigor are emergent traits that are not expressed in either of the self-grafted "parents". By combining these multiple methods for molecular, nutritional, and physiological phenotyping, we are able to build an integrated understanding of how grafting-induced vigor impacts organismal plant phenotypes.

S8-4

Effects of interspecific Capsicum grafting combinations on horticultural performance

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The objectives of this study were to evaluate the effect of Capsicum interspecific grafting combinations as compared to non-grafted and self-grafted checks and to identify factors that optimize the rate of graft-take in grafted Capsicum seedlings. Three commercially available *C. annuum* cultivars (California Wonder, Dulcitico and Natalie) were chosen as scions, and grafted onto commercial cultivars Habanero Early (*C. chinense*) and Aji Rico (*C. baccatum*). Field trials were conducted at West Madison Agricultural Research Station (WM, Madison, WI) in 2017 and 2018 and in San Carlos, Costa Rica (CR) in 2018. A factorial experiment was carried out to identify factors that promote graft-take rate in Capsicum spp. No significant difference was observed among grafted, self-grafted and non-grafted plants for marketable yield in WM. Significantly higher yields were observed between environments. Additionally, 22% increase in marketable yield across all scions grafted onto Habanero Early was observed at WM for both years. Similarly, an increase of 5%-15% was found in the Dulcitico-Aji Rico combination at WM, whereas the combination Natalie-Aji Rico tended to decrease yield by 9% over both years. These yield changes suggest potentially beneficial scion-rootstock interactions. Aji Rico rootstock tended to result in reduced days-to-flowering when grafted on Dulcitico and Natalie scions across all locations when compared to non-grafted plants. Natalie, when grafted onto Habanero Early, resulted in significantly larger fruit size compared to non-grafted plants. No differences in fruit quality characteristics were observed among grafted, self-grafted and non-grafted plants. Healing chamber and ascorbic acid are the most important factors contributing to grafting success during the recovery phase post grafting. Other factors like grafting spot or diameter of stem do not significantly affect graft-take rate but have impacts on quality characteristics of grafted seedlings.

S8-5

Influence of grafting and pruning on *Solanum lycopersicum* L. cvs. Anahu and Rutgers on plant biomass partitioning in the presence and absence of *Meloidogyne incognita* (Nematoda)

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Understanding the impacts of horticultural practices and root-knot nematodes on plant biomass partitioning is important for selection of rootstocks and scions for grafted greenhouse vegetable crops. The objective of this research was to determine the impact of homo and hetero-grafting of *Solanum lycopersicum* L. on biomass partitioning among stem/leaf, fruit and root tissues in the presence and absence *Meloidogyne incognita* (Nematoda), under three pruning regimes (none, optimal and heavy). Non-grafted *S. lycopersicum* cultivars Anahu and Rutgers were used as controls. In the absence of *M. incognita*, non-grafted Anahu and Rutgers had different biomass partitioning signatures. Anahu allocated more of its fresh weight to stem and leaf tissue, compared to Rutgers, while Rutgers partitioned more of its more biomass to fruit tissue. Root biomass partitioning was not significantly different between these cultivars. In the presence of *M. incognita*, non-grafted and non-pruned Anahu and Rutgers possessed the same biomass partitioning signatures as in the absence of *M. incognita*. With heavy pruning in the presence *M. incognita*, both Anahu and Rutgers allocated most of their biomass fruit tissue. Biomass partitioning with optimal pruning and no pruning was similar except for homo and hetero-grafted Rutgers at a high initial population density of *M. incognita*. Under these conditions, homo and hetero-grafted Rutgers allocated more biomass to fruit than to stem/leaf tissue. While non-grafted and non-pruned Anahu were not completely resistant to *M. incognita*, there were significantly fewer *M. incognita* females associated with Anahu, compared to Rutgers. The same was true for homo-grafted Anahu, but not for hetero-grafted Rutgers. In the case of heavy and optimal pruning, the final population density of *M incognita* was high on both non-grafted and homo-grafted Anahu. When the plants were not pruned in the presence of *M. incognita*, fruit yield was significantly less, compared to plants maintained in the absence of *M. incognita*. In conclusion, the impacts of grafting, pruning and *M. incognita* can impact *S. tuberosum* biomass partitioning, fruit yield and nematode development under greenhouse conditions.

S9-1

Prospecting Solanum rootstock biodiversity for improving nutrient use efficiency in tomato

Purificación Martínez-Melgarejo[1], Michele Angello[2], Alfonso Albacete Monero[1], Francisco Pérez-Alfocea[1] and Cristina Martínez-Andújar[1]

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Agricultural productivity must increase by 60% to feed the expected population of 9.6 billion people in 2050, and this increment need to be achieved in parallel to the socio-environmental sustainability of the natural resources. In other words, it is necessary to produce more with less or more with the same. In general, the crop efficiency in the use of fertilizers is estimated to be below 50%, therefore existing a huge scope for reducing the inputs without penalizing yield. While nutrient-related traits have been rarely targeted in breeding programs, the belowground root traits offer an interesting opportunity for this purpose. Indeed, the root system serves as the interphase between the soil, where the nutrients are located, and the shoot, where the nutrients are transported and converted into (normally) harvestable biomass. Consequently, the root has a significant role in the nutrient use efficiency of the crop by affecting both the nutrient capture efficiency from the soil (through changes in root system architecture and nutrient-transport components) and the nutrient use efficiency in the shoot (through influencing shoot growth and physiology and their control by nutrient availability). Using rootstocks additionally offers the possibility of straight enhancement of root traits without almost altering the properties of the elite scion varieties (Albacete et al., 2015). Here we present some preliminary data on prospecting the genetic variability of *Solanum sp* in response to nutrient (N, P, K) deficiency in order to select genotypes as a basis for developing nutrient-efficient tomato rootstocks. A total of 96 genotypes, including the cultivated tomato *Solanum lycopersicum*, the wild species *S. pennellii*, *S. habrochaites*, *S. pimpinellifolium* and *S. neorickii*, and the introgression lines derived from crosses between the domestic tomato and some of its wild relatives, have been evaluated during the vegetative development stage under low N, P and K fertilization. Under N, P and K- deficiency conditions, variation in plant biomass was 4.2, 2.4 and 2.3-fold, respectively. Based on both above and belowground productivity, 11 genotypes with specific of broad resilience under the different individual nutrient deficiencies were selected for further evaluation as rootstocks of an elite commercial variety.

S9-2

Mechanism of increasing salt resistance of cucumber by grafting onto salt tolerant rootstock pumpkin

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Plant salt tolerance can be improved by grafting onto salt-tolerant rootstocks. However, the underlying mechanisms behind this phenomenon remain largely unknown. To address this issue, we used a range of physiological and molecular techniques to study responses of self-grafted and pumpkin-grafted cucumber plants exposed to 75 mM NaCl stress. Grafting with salt-tolerant pumpkin as the rootstock effectively improves the growth of cucumber under different salt conditions by limiting Na^+ transport from the pumpkin rootstock to the cucumber scion. We identified gene function of High-affinity potassium transporter CmHKT1;1 from *Cucurbita moschata*, heterologous expression analyses in yeast mutants indicated that CmHKT1;1 is a Na^+-selective transporter. The transient expression in tobacco epidermal cells and in situ hybridization showed CmHKT1;1 localization at plasma membrane, and preferential expression in root stele. Moreover, ectopic expression of CmHKT1;1 in cucumber decreased the Na^+ accumulation in the plants shoots, these findings suggest that CmHKT1;1 plays a key role in the salt tolerance of grafted cucumber by limiting Na^+ transport from the pumpkin rootstock to the cucumber scion. Salinity stress resulted in a sharp increase in H_2O_2 production, reaching a peak 3 h after salt treatment in the pumpkin-grafted cucumber. This enhancement was accompanied by elevated relative expression of respiratory burst oxidase homologue (RBOH) genes RbohD and RbohF and a higher NADPH oxidase activity. The decreased leaf Na^+ content of pumpkin-grafted plants was achieved by higher Na^+ exclusion in roots, which was driven by the Na^+/H^+ antiporter energized by the plasma membrane H^+-ATPase, as evidenced by the higher plasma membrane H^+-ATPase activity and higher transcript levels for PMA and SOS1. Inhibition of the NADPH oxidase-mediated H_2O_2 signaling in the root also abolished a rapid stomatal closure in the pumpkin-grafted plants. We concluded that the pumpkin-grafted cucumber plants increase their salt tolerance via a mechanism involving the root-sourced respiratory burst oxidase homologue-dependent H_2O_2 production, which enhances Na^+ exclusion from the root and promotes an early stomatal closure.

S9-3

Mechanisms of tolerance to salt stress in three pepper accessions used previously as rootstocks: a physiological and genetic approach

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Salt stress is a global problem that affects growth and production in agriculture. Not all plants are able to reach tolerance on the same way, since it is a multicomponent stress where multiple factors are implicated. The maintenance of Na^+ and K^+ homeostasis is a very important trait to reach the tolerance. Pepper, our case of study, is sensitive to salinity, so studying genes related to how ions are managed in the tissues is of vital importance. To reach this aim, we have measured ions concentration and the relative genes expression in leaves and roots of the putative genes HKT1, NHX1 and SOS1, which expresses transporters implicated in sodium and/or potassium transport to the cytosol and vacuole and the expulsion of Na^+ out of the cells, respectively. We measured them in three different species of the genus *Capsicum* spp. (code A25, B14 and C12). Under salinity stress, we observed in C12 an accumulation of Na^+ in leaves associated with a low expression of HKT genes, which mediate Na^+ translocation to the phloem; also, an accumulation of sodium in vacuoles of root cells was measured by NHX1 gene over expressed. Respect to A25 plants, there was an accumulation of Na^+ in the vacuole by NHX1 in leaves and roots; in both cases Na^+ entered in the plant by HKT1, but only in roots the expression of SOS1 was higher, surely favoring Na^+ expulsion. Finally, B14 avoided Na^+ accumulation in leaves by HKT1 but we observed an accumulation of the cation in root cytoplasm by a non-differential expression of NHX1 and SOS1 genes. All these mechanisms were validated by the differential values of the ratio Na^+/K^+. As consequence, in our case we could confirmed that different strategies for pepper plants can be implemented in order to overcome salinity stress, using these mechanisms for future breeding programs to design tolerant rootstocks. This work has been financed by INIA (Spain) through the project RTA2017-00030-C02-00 and the European Regional Development Fund (ERDF). López-Serrano L. is beneficiary of a doctoral fellowship (FPI-INIA).

S9-4

Tomato rootstocks contribute to abiotic stress tolerance: emphasis on root chill tolerance

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Low soil temperatures affect root establishment, growth, nutrient and water uptake, hampering shoot growth and delaying harvest. Growers in northern latitudes and higher elevations such as in Northern Nevada face, during the spring, adequate air temperatures during the day, but sub-optimal soil temperatures that may drop to ≤8 °C. To adapt and optimize warm-vegetable production early in the season, growers could rely on the use of low-temperature tolerant rootstocks, yet information on which and how rootstocks can improve management strategies does not exist. We evaluated four commercial tomato rootstocks (Estamino, Maxifort, RST-04-106T and SuperNatural) grafted with a common scion and the own-rooted scion/cultivar (BHN589) (five phenotypes total). Several root and shoot physiological traits were evaluated under sub-optimal and control root temperatures. Root hydraulic conductivity (*Lp*) decreased in roots exposed to cold temperatures, but rootstocks such as Supernatural were able to maintain higher root hydrostatic *Lp*. Changes in root osmotic *Lp* varied among the phenotypes as well. Lower root water uptake capacity and reduced transpiration may lower C assimilation capacity and reduce total biomass. Field evaluations showed slower canopy development in the own-rooted cultivar and changes in nutrient uptake such as phosphorus and calcium among phenotypes, especially early in the season. Shoot and fruit biomass was affected by the phenotypes, and our data shows that some rootstocks (e.g., Estamino and Maxifort) may improve C assimilation and total fruit yield. This data suggests that some tomato rootstocks offer abiotic stress tolerance to soil sub-optimal temperatures, and grafting is a viable technique to overcome these challenges.

S9-5

Development of eggplant rootstocks resistant to bacterial wilt

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Bacterial wilt, caused by *Ralstonia solanacearum*, is one of the most damaging plant diseases for Solanaceous crops in tropics and subtropics. Rootstock replacement through grafting is considered an effective method to manage bacterial wilt. There are only a limited reliable resistant rootstock sources are available to the growers. Hence, it is necessary to identify more resistant sources against different strains under different environments. A total of 210 accessions of cultivated eggplant and 186 wild accessions from the WorldVeg and Valencia University genebanks were evaluated for resistance to bacterial wilt. Five accessions of eggplant and 12 wild accessions showed high and stable resistance to different bacterial wilt strains. Furthermore, more than 35 eggplant hybrids were developed at WolrdVeg, and high levels of resistance against to bacterial wilt strains were detected in four eggplant hybrids. The identified resistant eggplant rootstocks showed good graft compatibility with tomato, which can be used as sources for rootstocks globally to manage bacterial wilt disease sustainably. Future studies are needed to map bacterial wilt-resistant QTLs and pyramiding different resistance genes into a single target a rootstock that would potentially provide multiple and durable resistance to bacterial wilt.

Poster Presentations

P1-1

Field evaluation of new watermelon grafting methods to reduce verticillium wilt

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Grafting watermelon with disease resistant rootstock can be effective to control verticillium wilt, a disease significantly impacting production in the Pacific Northwest region of the United States. Despite well-established benefits, growers have been slow to adopt watermelon grafting on a large scale, partially because of the high cost of current grafting methods (one cotyledon grafting) and partially due to reports of reduced fruit quality. Splice grafting is the fastest and most efficient grafting method, and solanaceous crops are grafted exclusively using this method. Research has shown that splice grafting can be successful for watermelon, and now field evaluation is needed to validate preliminary findings. The objectives of this trial are to 1) evaluate new cost-effective grafting methods for watermelon grafted with verticillium resistant rootstock; and 2) establish harvest recommendations for grafted watermelon. Two commercial interspecific hybrid squash rootstocks, 'Tetsukubato' and 'Super Shintosa', with two grafting methods, the splice method and the one-cotyledon method are being evaluated. This study will help develop field performance attributes and harvest indices of watermelons grafted using both methods. Measures will be collected to ascertain field survival and plant health parameters, as well as indicators of flowering time, harvest time, and internal fruit quality affected by grafting with both methods. Results will be presented based on our field trial to be conducted in summer 2019, thus pre-harvest measures will be discussed, such as plant survival, health and flower initiation data.

P1-2

Rootstock and plastic mulch effect on grafted watermelon flowering and fruit maturity

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Grafting commercially desirable watermelon cultivars onto suitable rootstocks can be effective to control biotic and/or abiotic stresses. Rootstocks may affect the date of first flowering and rate of fruit ripening, making it difficult to harvest ripe fruit from grafted and non-grafted plants concurrently and may account for conflicting reports regarding the fruit quality of grafted watermelon. Plastic mulch, commonly used for watermelon production, can increase early season soil temperature and could contribute to earlier flowering and fruit maturity of grafted watermelon. The objective of this study was to determine if type of rootstock and plastic mulch would affect flowering and fruit maturity of grafted watermelon. Seedless watermelon cv. Secretariat was grafted onto four different types of rootstocks, *Lagenaria siceraria* cv. Pelop*, Benincasa hispida* cv. Round, and two interspecific hybrid squash rootstocks *Cucurbita maxima* x *C. moschata* cvs. Super Shintosa and Tetsukubato, and compared to non-grafted 'Secretariat' (control). Plants were field grown using black and clear plastic mulch at the Washington State University Northwestern Washington Research and Extension Center in 2018, and fruit were harvested 0, 7 and 14 days after both the leaflet and tendril attached to the fruit pedicel were completely dry. No differences in flowering and fruit maturity were seen with mulch type. Flowering was 15 days later for 'Secretariat' grafted onto 'Round' compared to 'Secretariat' grafted onto 'Tetsukubato'. First flowering was 37 DAT (days after transplanting) for 'Secretariat' grafted onto 'Tetsukubato', followed by 44 DAT on average for 'Super Shintosa', 'Pelop' and non-grafted 'Secretariat', and 52 DAT for 'Secretariat' grafted onto 'Round' (P = 0.0004). Fruit quality attributes such as hard seed, hollow heart formation, total soluble solids and lycopene content in fruit were not different among mulch type, rootstock treatment or harvest date. This study is being repeated in 2019.

P1-3

Growing new roots for tomato to boost off season production through grafting technology

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Being one of the most essential commercial vegetable merchandise Tomato (*Solanum lycopersicum* L.) is cultivated extensively in the world. Enjoying its commodious adaptability it can be grown under ample climatic ranges. India is apt with suitable climate for round the year production of tomato but its cultivation is limited under excessive soil moisture. Tomato production during rainy season (July–September) is a strenuous job due to persistent heavy rainfall and poor drainage which induces water logging that frequently reduces oxygen in soil, which results in sudden death of plant. The objective of the present study was to evaluate the potential of grafting tomato scion (Punjab Varkha Bahar 4) onto eggplant (PBH-3) rootstock for improving the physiological tolerance of tomato plants against flooding. Eggplant roots are relatively tolerant to flooding stress and survive better under excess water and show better graft union compatibility with tomato. Plants were grown in the rainy season and were subjected to flooding conditions during that period. Grafted plants with PBH-3 (Eggplant) as rootstock unveiled better establishment of grafted plants, superior physiological adaptation and improved fruit yield and quality character›s over the Non-grafted plants under flooding stress. The gas exchange parameters, photosynthesis rate (PN), stomatal conductance (gs) and internal CO_2 concentration (Ci), chlorophyll fluorescence, leaf water potential (L) and chlorophyll content showed a lesser decline in grafted plants as compared with Non-grafted plants. Accumulation of total sugar and reducing sugar in the leaves of grafted plants are favored under flood stress conditions and plants recovered more rapidly than Non-grafted plants. Tomato plants grafted on eggplant rootstock gave better results for off season (rainy season) production than non-grafted tomatoes, providing healthier establishment and wider adaptability of plants under high water stress conditions.

P1-4

Study on the relationship between seedling age and plug seedling standardization in vegetable crops

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Seedling quality is an important stage of vegetable crops affecting the growth and yield of cultivated crops. Two main experiments were carried out to set the standard quantitative criteria for plug seedling production; one studied the seedling quality characteristics (seedling age, plant height, leaf number, leaf area) and processing stage (sowing date, grafting date and shipping date) of six plug seedling production sites in Korea and analyzed the correlation between the quality of the collected seedlings and the seedling age and growing temperature, the other conducted to elucidate the effects of pepper, tomato, cucumber, and watermelon seedling age on growth and development after planting, fruit setting, and yield, to establish the standard for plug seedlings. When the seedling age was shorter than the standard, the growth and development after planting and the fruit number and weight increased. However, the growth and development decreased for older seedlings. After planting, the initial yields of these vegetable crops were higher when the raising seedling age was shorter. Based on the growth and yield of pepper and tomato, the appropriate raising seedling ages were 45–55 days and 40–50 days, respectively. Therefore, based on the results of these experiments, we discuss the standard quantitative quality criteria for raising seedling ages.

P1-5

Influence of cylindrical paper pot system on the reduction of decreased growth caused by excessive irrigation compared with the plug system in fruit and vegetable seedlings

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The most important goal for a nursery manager is to produce high quality seedlings; however, a major problem of seedling companies is accorded by excessive irrigation. It can reduce the number of saleable seedlings produced and less on the transplant quality traits. Cylindrical paper pot system (CPP) on seedlings were better ventilated than plug tray system (Plug), so we expected to reduce the damage caused by excessive irrigation. This study determined the reduction effect of seedling growth on the CPP on the quality of vegetable seedlings. This system was designed by using paper sleeves which wrapped commercial growing substrate. Twenty-four days after sowing, cucumber, tomato and watermelon seedlings were grafted onto each rootstock ('Huckjong', 'Super Dotearang' and 'Joeunggul') and transplanted either on a 32-cell (64 cm^3) plug (control) or cylindrical paper pot (64 ml). Seedlings were fertigated with overhead irrigation twice a week with Wonder Grow fertilizers (N 10, P 8, K 25, B 0.1, S 5, Mn 0.05, Fe 0.05, Zn 0.01) after grafting. Irrigation treatment was divided into three steps 100% (Control), 150% and 200%, based on the appropriate irrigation amount. After transplanting, seedlings were harvested every 6 days for 30 days for analysis of root and shoot height and weight. For plant height of cucumber and tomato, Plug decreased by 3-5% compared than CPP as the water amount increased. In result of watermelon's plant height, Plug increased by 6.6% compared than CPP. Like this, watermelon's plant height isn't showed trend of difference between Plug and CPP. Shoot fresh weights were shown same trend like plant heights. Cucumber and Tomato looks like affected by irrigation amount on CPP and Plug, but watermelon was shown the tendency only Plug. The leaf area of cucumbers and tomatoes of Plug decreased by 4.8-15.6 cm^2 more than CPP. But watermelon's leaf area of Plug increased 26.9 cm^2 than CPP. In contrast, root fresh weight is not shown the trend that decrease by much irrigation, like plant height, shoot fresh weight and leaf area. In conclusion, CPP has less damage to excessive irrigation than Plug. This aspect is lager in the shoot development than root development.

P1-6

Cancelled

P1-7

Using *Solanum galapagense* as a source of drought resistance through introgression breeding and grafting for tomato improvement

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The objective of this study is to determine the genetic basis of water stress tolerance in *Solanum galapagense* accession LA1141 and assess whether this trait can be transferred to cultivated tomato through breeding or grafting. A greenhouse study was conducted to quantify the water stress response of 162 inbred backcross lines (IBLs) from the cross between LA1141 and *S. lycopersicum* cv. Ohio 8245. This experiment was conducted twice. We used an augmented design with over-replicated parents as controls to account for environmental variation in the greenhouse. Resistance to water stress was assessed each day over seven days between 9 and 11 AM. Plants were rated using a wilt index. Leaf temperature was measured using an infrared thermometer and FLIR image analysis. The traits used for genetic mapping were peak temperature, area under the temperature progression curve (AUTPC), leaf temperature at day 3, leaf temperature at day 6, wilt at peak temperature, and area under the wilt progression curve (AUWPC). One-hundred sixty-eight single nucleotide polymorphism (SNP) markers were used to test for associations as a way to identify loci affecting water stress. Seven putative QTL were identified as significant at P = 0.05. Three of these were significant at P = 0.01. A genetic region on chromosome 5 was observed for four of the six traits and explained 6 percent of the observed variation. Eight selections were made from the 162 IBLs for the development of a validation population and for grafting experiments.

P1-8

Evaluation of tomato (*Solanum lycopersicum* \`Pectomech´) grafts against root knot nematode *Meloidogyne incognita*

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Grafting is a site specific management tool that tomato growers can use to overcome soil borne disease without the use of chemical fumigants and/or pesticides. Root-knot nematode-resistant tomato cultivars and eggplant provide alternatives for nematode management, since e, susceptible cultivars can be grafted onto nematode-resistant rootstocks. In this study four *Solanum lycopersicum* "Pectomech" grafts were evaluated for resistance, yield and fruit quality attributes under varying *Meloidogyne incognta* inoculum levels (0, 500, 1000 and 5000). The rootstocks used in the study were *Solanum lycopersicum* "Samrudhi F1", *Solanum lycopersicum* "Mongal F1", *Solanum macrocarpon* and *Solanum aethiopicum* (accession A2). The varying levels of inoculum had no significant effect on the gall score index (GI ≤ 2) and the nematode reproductive factor (RF ≤ 1). The success of Pectomech/*S. macrocarpon* grafts and Pectomech/*S. aethiopicum* grafts were higher (93% and 94%) compared to those of Pectomech/*S. lycopersicum* "Mongal" F1" grafts (0%) and Pectomech /*S. lycopersicum* "Samrudhi" grafts (0%). The combinations of rootstocks and inoculum levels had no significant effect on fruit quality and shelf life. Screening of the rootstocks using Mi gene specific primers revealed that even though *S. lycopersicum* "Samrudhi F1" and *S. lycopersicum* "Mongal F1" possessed the Mi gene they performed poorly in graft combinations with *Solanum lycopersicum* "Pectomech" whilst *S. macrocarpon* and *S. aethiopicum* genotypes which lacked the Mi gene performed better in graft combinations with *Solanum lycopersicum* "Pectomech".

P1-9

Changes of seedling quality of grafted cucumber transplants grown in cylindrical paper pot by different fertilizer concentrations and seedling growing days

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The objective of this study was to investigate the changes of seedling quality for grafted cucumber transplants grown in cylindrical paper pot by different fertilizer concentrations and seedling growing days. Three kinds of commercial cucumber scions, 'Joeunbaegdadagi', 'Hassalbaedadagi' and 'Daeseon', were grafted onto 'Sintojwa' and 'Heugjong'. After completing grafting union formation, the grafted cucumber transplants were cultivated by three different fertilizer levels (0.5, 1.0 and 2.0 standard nutrient solution), and top to root ratio and compactness were measured at 10, 17, 24 and 31 days. Plant height, leaf number, fresh weight and dry weight of grafted cucumber transplants were diverse over the growing days. According to seedling quality, compactness were decreased by 27 growing days but increased at 31 growing days, but top to root ratio was continuously increased as growing days increased. While compactness of the grafted seedlings affected by nutrient solutions showed significant difference at 10 growing days after grafting union formation, there were no significant differences at 17, 24 and 31 growing days. In addition, seedling compactness was significantly influenced by scion and rootstock cultivars. For the scion cultivars, compactness was significantly different at 17 and 24 growing days, respectably. For the rootstock cultivars, seedling compactness grafted onto 'Sintojwa' was higher than 'Heugjon' rootstock. Results indicated that seedling quality of grafted cucumber grown in cylindrical paper pot was highly affected by the growing days, fertilizer, and scion and rootstock cultivars.

P1-10

Evaluating fungicides and grafting to reduce Pythium disease in watermelon

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Eleven *Pythium* spp. isolated from cucurbits in South Carolina were screened in vitro against four concentrations of the fungicides mefenoxam and propamocarb. All 63 isolates were sensitive to both fungicides. *Pythium aphanidermatum* and *P. myriotylum,* the two most common species, were inoculated onto 16 cultivars of watermelon (*Citrullus lanatus*), citron (*Citrullus amarus*), bottlegourd (*Lagenaria siceraria*), and interspecific hybrid squash (*Cucurbita maxima* × *C. moschata*) in a growth chamber. Watermelon was more susceptible to both *Pythium* spp. than bottlegourd and interspecific hybrid squash at 20°C and 30°C. Twenty-one cultivars of the same hosts were transplanted into a field and inoculated with an equal blend of both *Pythium* spp. Interspecific hybrid squash was less susceptible to *Pythium* than bottlegourd and watermelon. Seedless watermelon 'Tri-X 313' was grafted to the citron rootstock 'Carolina Strongback', the bottlegourd rootstock 'Emphasis', and the interspecific hybrid squash rootstocks 'Camelforce', 'TZ148', and 'Super Shintosa'. Plants were inoculated with both *Pythium* spp. in the field. Mefenoxam, propamocarb, mefenoxam+ propamocarb, or water were drip applied after transplanting to evaluate *Pythium* spp. suppression in the field. Grafting to any interspecific hybrid squash rootstock reduced disease incidence compared to the non-grafted control. Disease incidence did not differ between fungicide and non-fungicide treatments. Marketable yield did not differ among grafting treatments. Interspecific hybrid squash was consistently resistant to *Pythium* in both field and growth chamber studies, demonstrating its utility as a rootstock in watermelon grafting.

P1-11

Developing tomato rootstock recommendations for high tunnel production and enhancing our understanding of the \`rhizobiome´

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Tomato grafting is being rapidly adopted by high tunnel growers, particularly those that utilize specialty cultivars and cater to local markets. Inter-specific hybrid rootstocks can confer resistance to many soil-borne pathogens and provide added vigor. However, it is unclear how they impact the microbial community that may exist in the root system and rhizosphere. The objectives of this project were to (1) identify rootstocks that improve crop productivity through on-farm and university research trials, (2) determine successful grafting methods for small-scale propagators; and (3) evaluate the effects of rootstock genotype on rhizosphere microbial communities (rhizobiome). High tunnel trials were conducted from 2013-2016 on three commercial farms (two organic) and at the Olathe Horticulture Center. Grafting with 'Arnold' and 'Maxifort' rootstocks significantly increased fruit yield whereas 'RST-04-106' and 'RT 1028' rootstocks provided no benefit under little disease pressure. We also investigated the formation of adventitious roots during the propagation of grafted plants. Leaf removal significantly decreased adventitious root formation, which leads to higher success rates and higher quality transplants. Finally, we profiled the root rhizobiome by sequencing bacterial 16s ribosomal rRNA and fungal ITS regions from the rhizosphere and within plant roots from the trial sites. The majority of observed microbial taxa were shared; however, a small percentage (less than 3%, $P < 0.05$) were associated with genotype. Interestingly, a more diverse community was observed on 'Maxifort' rootstock. The results of this project identify certain rootstocks that lead to higher productivity for organic and conventional high tunnel tomato growers and show that the rhizobiome of grafted plants is somewhat different than non-grafted tomato.

P1-12

Application of grafting technology for the control of tomato verticillium wilt caused by *Verticillium dahlia*

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Verticillium dahliae is a fungal vascular wilt pathogen that infects many agriculturally valuable crops including tomato. As a soil borne pathogen, *V. dahliae* enters tomato roots and travels through the xylem causing stunted growth with wilting and drying of leaves within a few weeks. Many commercial tomato cultivars possess the *Ve1* gene, which provides resistance against race 1 strains of *V. dahliae*. However, the majority of isolates in North Carolina, USA were found to be non race1 strains and did not contain an avirulent effector, *VdAve1*, thus resistance provided by *Ve1* is not effective resulting in verticillium wilt being a major threat to tomato production. Soil fumigation was the major way to control this disease but due to costs and restricted use because of safety concerns, alternative solutions are being sought. The use of grafted materials using robust rootstocks is a host-based approach for enhancing marketable quality of fruit as well as for disease control. In this study, we evaluated pathogen progress and symptom development as impacted by the *Ve1*gene in response to challenge with race 1 and race 2 (non-race 1) isolates on commercial lines as well as isogenic lines. We also evaluated disease progress in grafted plants using a combination of resistant or susceptible rootstock and scions. Results will be presented and discussed in the context of enhancing host resistance and managing this important disease.

P1-13

Cost estimates for grafted, non-grafted, and direct seeded cantaloupes

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Stem grafting can be argued to not only increase yields under certain conditions but also increase the marketability of yields produced. We estimate the break-even prices for size 12 cantaloupes using 4 years (two years each for fall and spring trials) of trials for grafted, non-grafted, and direct seeded cantaloupes, accounting for the different sizes of melons harvested and their relative price differences. Size 9 was the most common melon harvested throughout but the next smaller size 12 has more consistent price quotes across USDA/AMS's reporting wholesale market prices. Some of the larger cost items that vary between these production methods include the cost of grafted transplants ($.60/transplant and 5,600 transplants per acre), extra planting and management costs for both non-grafted and grafted transplants of near $700/acre and harvest costs that are driven by the marketable cantaloupes harvested. Because the trials are replicated, we present an overall mean break-even price along with a range in break-even prices using the standard error associated with all replications for a given year. Some trials were also root-knot-nematode inoculated so that chemical fumigation costs (over $100/acre) associated with treatments could also be compared with the cost of grafted transplants. In general, we found direct seeded cantaloupes to have the lowest mean break-even cost of production but we sometimes found less variation or uncertainty with the non-grafted transplants and to a lesser degree the grafted transplants. Although the field trials for this analysis were done in 2007 to 2010, this relative cost of production information has not been compiled and published somewhere as the grower did not want the entities that they sell to have any access to their current per unit costs of production.

P1-14

Rootstocks affect response of grafted cucumbers to silicon supplementation

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Bloom formation on fruit surface of cucumber depends on absorption and allocation of silicon in plants to some extent. To investigate the effects of rootstocks on silicon absorption and allocation, cucumber (*Cucumis sativus* L) cultivar 'Shannong No 5' was grafted onto 'Yunnan Figleaf Gourd' (*Cucurbita ficifolia* Bouche) and 'Huangchenggen No. 2' (*C. moschata* Duch. × *C. moschata* Duch.), two rootstocks with different capacities of removing fruit bloom, and all plants were simultaneously grown in Yamazaki's cucumber nutrient solution with two silicon concentrations (1.7mM and 8.7×10-4 mM). The results showed that: Silicon contents in organs of non-grafted cucumber or grafted cucumber on 'Yunnan figleaf gourd' were significantly increased by silicon supplementation, and much higher than those in grafted cucumbers on 'Huangchenggen No 2', in which silicon contents just slightly increased; The expressions of CmLsi1, CmLsi2-1, CmLsi2-2 and CmLsi3 in roots of cucumbers grafted on 'Yunnan figleaf gourd' were higher than those on 'Huangchenggen No. 2'; With the prolongation of silicon supplementation, expressions of silicon transporter genes in roots of cucumbers grafted on both 'Yunnan figleaf gourd' and 'Huangchenggen No. 2' were down-regulated.

P1-15

Grafted pepper fruits retain similar market quality to those harvested from their own-rooted counterparts across a range of rootstock and scion genotypes

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Experiments (Exps.) were conducted in Egypt and the US to determine if pepper fruit market quality is affected by rootstock genotype. In Egypt (Exp. 1), mature fruit from high tunnel-grown scions of blocky-fruited 'Toronto' and 'Zedinca', and elongate-fruited 'Kurtovszka Kapia' and 'Eigman' grafted to cultivars 'Budai csipős' and 'Nourdine', to commercial rootstocks 52-03 RZ and Tan Tan (No: 12G076), to breeding line CCA-4758, or grown as self-grafted or ungrafted controls were examined for their morphological features (weight, shape index and carpel wall thickness) and chemical characteristics (titratable acidity and soluble solids). In the US (Exp. 2), mature green fruit from field-grown 'Aristotle' (blocky-fruited) scions produced on 'Black Pearl', 'Ghost', 'Carolina Wonder' or appropriate controls were appraised similarly. In Exp. 3, US field-grown mature green fruit of 'Aristotle' and 'Carolina Wonder' grafted to 'Anaheim' and 'Jalapeno' were evaluated by consumer sensory panels using discriminatory, hedonic and preference tests. In Exps. 1 and 2 mean fruit weights across all rootstock-scion combinations was 134 ± 2 g and 252 ± 8 g respectively, whereas wall thickness means were found to be 6.8 ± 0.1 and 7.9 ± 0.3 mm, respectively. Shape indices ranged from 0.96 to 1.10 for all blocky-fruited scions and 3.47 to 5.00 for elongate-fruited scions. Fruit from Exp 1 and 2 rootstock-scion combinations averaged 6.3 ± 0.3 % and 0.10 ± 0.00 % respectively for soluble solids and titratable acidity. All values meet USDA crop grading standards or reported literature ranges for sweet peppers. All rootstocks used except 'Carolina Wonder' were pungent-fruited genotypes that had little or no effect on the capsinoid or capsaisinoid levels in scion fruit as determined by HPLC. Consumers failed to distinguish between fruit from own-rooted and grafted plants nor did they prefer one over the other; hedonic scores were nearly identical (Exp. 3).

P1-16

Exploring the use of Cucurbita rootstocks for early spring planting of seedless watermelon in North Florida

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Interspecific hybrid squash rootstocks (*Cucurbita maxima* × *C. moschata*) used in grafted watermelon production for managing Fusarium wilt are also known for their tolerance to low temperatures. There is a growing interest in grafted watermelon production among growers in Florida for disease management, along with a trend of early spring season planting of watermelons to target premium price despite the spring frost risk; however, little research has been conducted regarding the feasibility of early planting of seedless watermelon using squash rootstocks. Thus, the overall objective of this project is to assess the impact of *Cucurbita* rootstocks on early production of seedless watermelon during the spring season. A greenhouse rootstock screening experiment was conducted by exposing grafted and non-grafted 'Fascination' watermelon plants to night temperature at 9 ^{o}C for 11 hours during a 6-day period, to examine plant growth. Field performance of grafted watermelon plants when exposed to early season chilling temperatures was further assessed in two locations (Citra and Live Oak) in North Florida. Five commercially available *Cucurbita* rootstocks, including 'Flexifort', 'RST-04-109-MW', 'Super Shintosa', 'Strong Man', and 'No. 1' were evaluated using 'Fascination' as the seedless watermelon scion in comparison with non-grafted watermelon plants. Three transplanting dates were included in the field studies, i.e., late Feb., mid Mar., and early Apr. Plant growth parameters were measured to assess crop establishment after transplanting along with fruit yield components and fruit quality attributes (e.g., soluble solids content, titratable acidity, pH, lycopene content) for each planting. Preliminary results showed that early planting resulted in significantly higher total marketable fruit yields compared with later plantings at both locations. Some interesting interaction effects of planting date and rootstock on fruit yields were observed. The impacts of planting date and grafting on plant growth and fruit quality parameters will also be discussed.

P1-17

Screening rootstocks to mitigate the supra-thermal stress of bell pepper crops

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Supra-thermal stress in greenhouses is a limitation for high yields and quality of pepper crops during the warm parts of the season, and could be even great in the global warming scenario. Our hypothesis was to confirm if grafting on to adequate rootstocks can help the scion to overcome the negative impact of the very high temperatures on yields and quality of bell pepper under greenhouses. We also wanted to know how the physiological parameters related to this stress are modified by the rootstock, if any. For this, several genotypes were evaluated as rootstocks of the California-type pepper cultivar 'Maestral' in greenhouses with two climatic conditions: thermal stress and control. Net photosynthesis, stomatal conductance, sub-stomatal CO_2concentration, instantaneous carboxylation efficiency, fluorescence parameters, cell membrane permeability and total phenol content in leaves were analyzed. The grafted plants subjected to thermal stress, obtained, in general, lower photosynthetic rates and instantaneous carboxylation efficiency. The fluorescence parameters and the amount of total phenolic compounds did not show clear differences between environments. An increase in cell membrane permeability was also measured in plants subjected to thermal stress, observing differences between rootstocks. Yields were significantly lower under thermal stress conditions, without differences between rootstocks.

P1-18

Screening World Vegetable Center eggplant and pepper rootstocks for resistance to verticillium wilt

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Verticillium wilt (caused by *Verticillium dahliae*) is a fungal soil-borne disease that affects health and productivity of eggplant and pepper crops. Grafting can help manage the disease effectively, but the lack of resistant commercially available rootstocks prevents growers from adopting the technique. This experiment comprised two studies designed to test the verticillium wilt resistance of eggplant and pepper rootstocks publically available from the World Vegetable Center (WVC, Taiwan, Tainan). The studies were carried out at Washington State University Northwestern Washington Research and Extension Center, Mount Vernon, WA. Eggplant cv. Millionaire was used as the scion for the 14 eggplant rootstocks tested in one study, and in the second study, pepper cv. Ace was used as the scion for three pepper rootstocks. The grafted plants plus a non-grafted control were transplanted into a field naturally infested with *V. dahliae* at 7 $cfu \cdot g^{-1}$ soil, and also inoculated with microsclerotia (104 cfu per planting hole) to ensure infection by the pathogen. For grafted and non-grafted eggplant, there were no significant differences among treatments for disease severity, date of flowering and number of *V. dahliae* colonies recovered from the stem. Plant height was improved only for 'Millionaire'/VI042738 combination. Among pepper plants, rootstocks VI037556 and VI014995 reduced plant height, but date of flowering did not differ significantly among any of the treatments. The pepper plants did not exhibit symptoms of disease, and the lack of infection was confirmed by no colonies of *V. dahliae* present in stems from any of the treatments. Grafting eggplant was not able to provide a benefit against verticillium wilt at the disease level in this study. The peppers tested in this study were resistant to *V. dahliae* at this location and could be used as a rotation crop in fields in the region where *V. dahliae* is present.

P1-19

Grafting for open-field production of heirloom tomatoes in California

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Heirloom tomatoes (*Solanum lycopersicum* L.) are a high-value crop with an important niche market for organic vegetable growers in the Northern Sacramento Valley. In these operations, tomatoes are often a cornerstone crop, significant in both income and acreage. Heirloom varieties, however, can be challenging due to minimal disease resistance and low yields compared to modern varieties. Grafting offers a potential pathway for more productive and disease resistant heirloom tomato plants by pairing heirloom fruit genetics with the desired disease resistance package of a rootstock. In this two-year study, six rootstocks, Fortamino, Estamino, Espartano, Multifort, Maxifort and DRO138TX, were evaluated for two heirloom tomato varieties, Cherokee Purple and Brandywine. A commercial nursery in California specializing in vegetable grafting supplied all plants. In a replicated complete block design with a non-grafted scion control for each scion variety, seedlings were transplanted into open-field conditions, staked and trellised, drip irrigated and harvested over approximately seven weeks. Weeds were managed by hand and crop nutrition was supplied from OMRI-approved products. In 2017, both non-grafted scion varieties outperformed all grafted combinations for the respective scion. Most varieties yielded significantly lower than the non-grafted control, from 28%-88% yield decrease. In 2018, Espartano, Multifort, Maxifort and DRO138TX increased yield for both scions compared to the non-grafted plants. Yield ranged from an 86% increase to a 58% decrease, compared to the non-grafted variety. In addition to yield, impacts to fruit size depended on the specific rootstock/scion combination. Sources for the inconsistency between the two years is unclear, but could be environmental effects (extreme heat in 2017) or scion inconsistency as is typical with heirlooms varieties. In conclusion, inconsistent performance in two years supports the need for continued work, currently underway, to determine whether rootstocks can be a reliable tool for increasing heirloom tomato production in open-field conditions in California.

P1-20

Performance of grafted hybrid tomatoes within a Midwestern United States high tunnel in the absence of soil-borne disease pressure

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Prior work in Iowa, USA indicated tomatoes grafted to hybrid rootstock 'RST-04-106-T' have a minimal yield increase in the absence of soil-borne disease pressure. This result drove the need for additional localized rootstock performance research within an Iowa high tunnel in 2017 and 2018. We hypothesized that alternative rootstocks would outperform non-grafted plants even without the effect of soil-borne disease pressure. Our research objectives were to assess marketable yield, fruit quality (soluble solids, titratable acids, and firmness), and plant growth characteristics (SPAD, plant height, stem diameter, petiole-sap, and biomass) of eight different hybrid tomato rootstocks compared to a self-grafted and non-grafted control. 'BHN 589', a determinate hybrid tomato, was grafted to

all rootstocks in addition to non-grafted and self-grafted controls. The rootstock treatments included 'Arnold', 'Beaufort', 'DRO141TX', 'Estamino',' Maxifort',' RST-04-106-T', and two trial rootstocks, '946 TRS' and '980 TRS'. This research took place 21 Apr. – 28 Sept., 2017 and 20 Apr. – 25 Sept., 2018 in a 9.1 × 29.2 m single-poly high tunnel. There were five plants per plot in a randomized complete block design with five replications. Harvest took place thirteen times each season from Jul. – Sept. Harvest data showed 'Arnold', 'Beaufort', 'DRO141TX', 'Estamino', and 'Maxifort' significantly increased the average number (P < .0001) and weight of marketable fruit per plant (P = 0.0004) as compared to the all other treatments. There were no differences in fruit quality as indicated by SSC, TTA, or the SSC:TTA ratio. The same five high-yielding rootstock treatments grew the largest in the field with an average height ranging from 191.4-206.3 cm. Overall, the results of this study indicate that 'Arnold', 'Beaufort', 'DRO141TX', 'Estamino', and 'Maxifort' rootstocks should improve plant growth and fruit yield when grafted to a hybrid tomato cultivar in typical Midwestern United States high tunnel production systems.

P1-21

Vegetable grafting workshops participation in the Delaware region

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Several workshops on tomato grafting and one on melon grafting, have been provided through Delaware State University, Cooperative Extension, Small Farms Program, in the Delaware region. Gauging from the events from 2014 to 2018, we conclude that, interest in 'Vegetable Grafting' is gaining traction in Delaware. Tomatoes and watermelons are among the fresh vegetables, largely grown in Delaware. This poster presentation captures the perspective of one vegetable-grafting expert in the Delaware region from demonstrations which mainly consisted of tomato grafting. Participants included; members of an organized 'Green Thumb' group, Master gardeners, High Tunnel growers, Farm school clientele, large farms hire, and horticulture students. The sites of grafting demonstrations included Delaware State University Greenhouses and Smyrna Outreach and Research Center, University of Maryland, Eastern-Shore, and Ocean City, Maryland. Surveys collected data during these events by using interactive digital clicker response activities embedded in presentations, sometimes coupled with short 'before and after' paper surveys. Five most popular reasons for the interest in learning the vegetable grafting skill emerged. Growers want to grow their valued heirloom varieties while taking care of soil-borne diseases with minimal use of pesticides. The imminent salt build-up in high tunnels confers the quest of grafting heirlooms onto salt tolerant rootstocks. Gardening hobbyists seek to grow multiple tomato varieties or solanaceous crops on a single plant. Some students participated to satisfy course of study requirements. Growers would like to graft to control fusarium wilt in watermelons. The challenges cited involve; the ability to choose and find an adequate rootstock for appropriate use; and ability to synchronize the starting of seeds of the scion and the rootstock to attain the proper stem diameter for successful grafting. Most of the participants preferred tube grafting to cleft grafting or tongue approach grafting.

P1-22

Weed competitiveness and herbicide tolerance in grafted tomato

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Critical period for weed control (CPWC) is the period during the cropping season when weeds must be controlled to prevent yield and quality reductions in a crop. Aggressive cultivars have a shorter CPWC than less aggressive cultivars. Grafted plants have shown more vigorous growth and produce higher biomass compared to non-grafted plants. In addition, several herbicides are registered for tomato, however information regarding herbicide tolerance of grafted tomato does not exist. Therefore, the goal of this research was to provide growers information related to herbicide safety and adequate timing of weed control in grafted tomato. Field studies were conducted to determine CPWC of grafted and non-grafted tomato. Tomato plants included non-grafted 'Amelia' and Amelia grafted onto 'Maxifort' tomato rootstock. In the establishment study, weeds were transplanted at 1, 2, 3, 4, 5, 6, and 12 wk after transplanting (WAT) and remained until tomato harvest. In the removal study, weeds were transplanted on the same day of tomato transplanting and removed at 2, 3, 4, 5, 6, 8, and 12 WAT. Each planting hole contained one grafted or non-grafted tomato plant and six weed seedlings (2 yellow nutsedge, 2 common purslane, and 2 large crabgrass). In both grafted and non-grafted, tomato plant biomass increased as establishment of weeds was delayed, and plant biomass decreased when removal of weeds was delayed. In both grafted and non-grafted plants, the delay in establishment and removal of weeds resulted in weed biomass decrease and increase of the same magnitude, respectively. To avoid 5% yield loss, predicted CPWC ranged from 2.2 to 4.5 WAT in grafted tomato and from 3.3 to 5.8 WAT in nongrafted tomato. The length (2.3 or 2.5 wk) of the CPWC in fresh market tomato was not affected by grafting; however, the CPWC management began and ended 1 week earlier in grafted tomato than in nongrafted tomato. Field studies were conducted to determine the effect of herbicides on grafted tomato. Grafting treatments included non-grafted Amelia and Amelia scion grafted onto 'AnchorT', 'Beaufort', or 'Maxifort' tomato rootstocks. Herbicide treatments included nontreated, and preemergence *S*-metolachlor (0.8 and 1.06 kg ai/ha), fomesafen (0.28 and 0.42 kg ai/ha), metribuzin (0.28 and 0.55 kg ai/ha), napropamide (1.12 and 2.24 kg ai/ha), halosulfuron (0.039 and 0.052 kg ai/ha), and trifluralin (0.56 and 0.84 kg ai/ha) applied one day before transplanting. In 2012, at 1 and 2 WAT injury was greater in grafted plants regardless of rootstock type (AnchorT, Beaufort, Maxifort) than in non-grafted for halosulfuron, fomesafen, and metribuzin. However, by 4 WAT no injury was observed in grafted or non-grafted plants. In 2013, no injury was observed regardless of rootstock and herbicide treatment. Herbicide treatment had no effect on total and marketable fruit yield. Grafted tomato exhibited similar tolerance as nongrafted tomato for all herbicides applied pretransplant. Overall, results from these studies show that weed management of grafted tomato is similar to non-grafted tomato.

P1-23

Grafting tomato as a tool to manage *Fusarium solani* in greenhouses

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Greenhouse tomato is a significant and profitable crop in Southern Israel. In the last three years, the soil borne fungal pathogen *Fusarium solani* is often being involved with a late wilting phenomenon that affects both cherry and round tomatoes. Managing *F. solani* in greenhouses usually involves an intensive fungicide application which is expensive and harmful to the environment. Nevertheless, the potential use of resistant and tolerant rootstocks may provide much more sustainable management tool against this disease. During 2019 a set of rootstocks from the genetic background Monsanto (Dynafort, Balancefort Beaufort), Syngenta (Arnold 503682, so4109, Taurino), Rootility (Negev16) and Hazera (RS-5) was tested in 25ºC controlled environment chambers using artificial inoculation with *F. solani*. Rootstocks from the genetic background of Arnold, Negev16, Beaufort showed lower mortality rate and weaker disease symptoms. The results were verified with an additional experiment that involved grafting of susceptible cherry tomato CV. Shiran on the latter rootstocks and have yielded similar results. The rootstocks' resistance level against *F. solani* did not correlate with their resistance against *F. oxysporum* f. sp. *radicis-lycopersici* or *Fusarium oxysporum* f. sp. *lycopersici* race 1, 2 or 3. The results of the study demonstrate the potential of the rootstock as a promising component of *F. solani* management.

P2-1

The study on the effect of five cucurbit rootstocks on growth, development and active substances content of medicinal pumpkin (*Cucurbita pepo subsp. pepo var. Styriaca*)

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In this research five cucurbit (Code #11, 21, 36, 42, 45) was used as rootstocks for grafting (Splice type) of naked-seed pumpkin (*Cucurbita pepo subsp. Pepo* var. Styriaca) during 2016 and growth and fruiting behavior of medicinal pumpkin was evaluated. Naked-seed pumpkin was used as control. The study was conducted on the basis of Complete Randomized Block Design (RCBD) with three replications and three grafted vines in each replication. Rootstock seeds cultivated seven days earlier than scion seeds in greenhouse and grafting was done at two-leaf stage. After grafting all plants moved in dark condition (1-3 days) at 27-28 °C with 90-95 relative humidity. After successful grafting the plants was transfer to the filed with 150×50 cm apart. During the growth periods grafting regions was checked for inhibiting of rootstock adventitious shoots. Then rootstock and scion diameter at grafting region, lateral shoots/vine, no of fruit/vine, no of seeds/fruit, fresh and dry seeds/fruit, 1000 seed weight, root length, and weight were evaluated. Seed oil quality and quantity of all grafted plants also evaluated. Analysis of variance of the data showed that root parameters was significantly different among different rootstocks but there is no significant different among the rootstock for no of fruit/vine. Different rootstock affect 1000 seed weight and the lowest 1000 seed weight

(85.5 g) was recorded in rootstock #11 but the highest (159.8 g) was produced in rootstock # 21. The highest difference in diameter of scion-rootstock junction region (as a sign of incompatibility) was significant in rootstock #42 and the lowest difference was recorded in rootstock #45. The highest seed oil (37.51 %v/w) was determined in rootstock #11 and the lowest seed oil content (19.32% V/W) was measured in rootstock # 21. With respect to the highest seed weight/fruits and also the highest 1000 seed weight in rootstock # this rootstock was superior to the other evaluated rootstock. In conclusion the best compatibility for medicinal pumpkin was shown with rootstock # 21 and 45.

P2-2

Histological and transcriptomic reveal the healing mechanism at graft junction of cucumber grafted onto squash heterografts

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Heterograft is widely practiced in the production of economically important crops, and also used to study the long-distance movement of molecules in science. Unfortunately, the molecular mechanism of graft union formation is poorly understood. Here, grafted cucumber-pumpkin were used to study the development of graft union, and genome-wide tempo-spatial gene expressions at the graft interface were investigated comprehensively. Histological analysis suggested that both phloem and xylem are reconnected, the scion and rootstock start to develop markedly, and scion was observed obvious morphological changes compared with rootstock 3 days after grafting. A total of 4,269 and 8,634 differentially expressed genes in cucumber and pumpkin, respectively, were identified. The percentages of DEGs were significantly higher in pumpkin than cucumber at 3d after grafting, but this value is similar in cucumber and pumpkin at 6d, 9d after grafting, respectively. We found significant asymmetry between scion and rootstock was applied to genes related in cambium development, cell cycle, and sugar metabolism. GO and KEGG analysis showed that sugar relative metabolic and plant hormone signal transduction were simultaneously enriched in cucumber and pumpkin at the 3d after grafting, and few enriched terms was overlap between scion and rootstock during graft union healing. Additionally, gene involved in cambium development and cell cycle were activated, such as *PXY*, *WOX4*, *ANT*, *HCA2*, *HTR2*, and also showed asymmetry between cucumber and pumpkin. However, sugar perception response was symmetric in cucumber and pumpkin at 3d after grafting, and this correlate with the sucrose content at the graft junction. Although the genes expression pattern of key enzymes in the raffinose family oligosaccharides (RFOs), sucrose and starch metabolism were also asymmetry between scion and rootstock, *SnRK1*were activated and symmetry in the scion and rootstock during graft union healing. Overall, our results demonstrate there are different healing mechanism at the graft interface in scion and rootstock of heterograft, and sugar metabolic may paly critical roles during heterograft union formation.

P2-3

Grafted combinations affect tomato root growth and water permeability

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Grafting is widely established in agriculture and provides practical advantages for vegetable production. We investigated physiological differences between the grafted combinations of tomato cultivars. Plants were grown hydroponically until the flowers on the first truss bloomed, and the following parameters were measured: fresh weight of the aerial parts, root surface area, root permeability by using a pressure chamber, and water potential of exudates by using an isopiestic psychrometer. The 'Starbuck' /'Maxifort' combination had higher values of the aerial part weight, root surface area, and root permeability than 'Reiyo' /'Receive', whereas 'Reiyo' /'Maxifort' tended to have higher values of these parameters than 'Reiyo' /'Receive'. 'Maxifort' had a significantly larger root surface area than 'Receive', but root permeability was not significantly different. In 'Reiyo' /'Maxifort' and 'Starbuck' /'Receive', these parameters were not significantly different except for a single comparison of root permeability. Thus, root permeability and root surface area may depend not only on the rootstock but be also affected by scion in grafted plants. Water potential of exudates was similar in most combinations and experiment. This shows that two rootstock cultivars provided similar nutrient concentrations even with different scions.

P2-4

Grafting watermelon onto pumpkin improves the nitrogen uptake and nitrogen use efficiency

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Nitrogen (N) is a macronutrient, essential for plant growth and development. The improvement of nitrogen uptake and nitrogen use efficiency (NUE) in crops is an important consideration of plant biologist. In fruit vegetables such as watermelon, rootstocks are often utilized to control soil borne diseases and improve plant performance to a range of abiotic stresses. Our study was aimed to investigate how pumpkin grafting improves NUE of watermelon. A commercial watermelon cultivar "Zaojia 8424" [*Citrullus lanatus* (Thunb.) Matsum. and Nakai.] was self-grafted and grafted onto pumpkin (*Cucurbita maxima* × *C. moschata*) rootstock cv. Qingyan Zhenmu No.1. The grafted plants were grown under hydroponic conditions and exposed to 9 mM and 0.2 mM nitrogen. The grafted plants were harvested at days 11 and 22 after low nitrogen treatment. Pumpkin grafting improved the NUE of watermelon through the vigorous root system of pumpkin rootstock that enhanced the uptake and accumulation of nitrogen and other ions such as phosphorous, potassium, calcium, magnesium, boron, and manganese. Additionally, pumpkin grafting improved nitrogen assimilation by regulating gene expression. The expressions of nitrate reductase (*Cla002787*, *Cla002791*, and *Cla023145*) and nitrite reductase (*Cla013062*) genes were apparently increased in pumpkin grafted watermelon leaves compared with self-grafted watermelon. Furthermore, pumpkin rootstock also enhanced the supply of zeatine riboside (ZR) and isopentenyl adenosine (iPA) in the leaves, promoting shoot growth. Pumpkin grafting modified the leaf structure by improving the mesophyll thickness and SPAD index (relative chlorophyll content). All these events lead towards improved plant growth and nitrogen use efficiency of pumpkin rootstock-grafted watermelon plants.

P2-5

Effects of shade treatment on bioactive compounds in the fruit of pepper plants grown under high light intensity stress during summer

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Variations in light intensity due to abnormal weather conditions affect the growth and development of vegetable crops grown in open fields and greenhouses. In Korea, pepper plants are mostly cultivated in open fields, but in recent years, they are grown in plastic greenhouse systems. However, high light intensity during summer in plastic greenhouse systems significantly influences the growth characteristics of pepper plant. The objective of this study was to collect basic data on changes in the bioactive compounds of pepper fruit due to shade treatment under high light intensity stress. The pepper cultivar used was 'Nokkwang'. Pepper seedlings were divided into two groups, namely, the control group (one-layer vinyl greenhouse) and shade-treatment group (two-layer vinyl greenhouse). The content of β-carotene, vitamin C, capsaicin, and dihydrocapsaicin was measured in green and red pepper fruits harvested 87 d after planting. The content of 2,2-diphenyl-1-picrylhydrazyl (DPPH) and 2,2′-azino-bis(3-ethylbenzothiazoline-6-sulphonic acid (ABTS) and ferric reducing antioxidant power (FRAP) were measured in green and red pepper fruits harvested 99 d after planting. The content of β-carotene, capsaicin, and dihydrocapsaicin was higher in the red pepper fruit than in the green pepper fruit, and the opposite was observed for vitamin C content. Furthermore, the effect of shade treatment was observed only on β-carotene. The DPPH content in red peppers of the shade-treatment group was higher than that in red peppers of the control group and green peppers of the shade treatment group. The ABTS content was higher in peppers of the shade treatment group than in those of the control group, but it was higher in green peppers than in red peppers of the shade treatment group. The FRAP was the highest in red peppers of the shade treatment group. In this study, we investigated the effect of shade treatment on the bioactive compounds of pepper fruits, and further research is required to establish a cultivation technique for pepper under high light intensity stress.

P2-6

Growth of grafted tomato seedlings as affected by N and P contents in a nutrient solution during cultivation after graft union formation

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Cultivation conditions after grafting affect quality of grafted seedlings such as plant height, number of leaves, and the first flowering node, and high quality of grafted seedlings leads to higher productivity and quality at harvest. In this study, we investigated the effect of N and P contents in the nutrient solution during cultivation after grafted union formation on growth of grafted tomato seedlings. The grafted tomato seedlings healed for 5 days under red and blue LEDs were used for the experiment. They were cultivated for 12 days in a plant factory using white LED as a light source, and sub-irrigated once a day using nutrient solutions with different concentrations of N and P. The growth of grafted tomato seedlings was not increased by increasing N content in the nutrient solution, but decreasing N content in the nutrient solution reduced the growth of seedlings. Control of P content of the nutrient solution significantly affected the shoot growth, especially, an increase of the height of scion promoted with increasing P content. From the results, we can adjust the cultivation period after grafted union formation or the plant height of grafted tomato seedlings depending on the consumer demand by control of P content in the nutrient solution.

P2-7

Non-destructive characterization of grafted tomato root systems using the mini-horhizotron

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Root system morphological and architectural characteristics play a critical role in a plants ability to utilize substrate resources. Unfortunately, viewing and quantifying root system activity in potted plants is exceedingly difficult and traditionally done through destructive harvests. This method only allows for a snapshot of the plant root system at the time of harvest and gives no inference on the rate of root growth. Furthermore, this method can be highly destructive to the root system itself; many of the fine, high absorptive-capacity roots are lost during the cleaning process. The following study utilized the newly developed mini-horhizotron to non-destructively characterize root system morphology and architecture in grafted tomato (*Solanum lycopersicum* [L.]). Root tip density, speed of horizontal root growth, and total root length in the commercially available tomato scion ('Tribute') and two rootstock cultivars ('Maxifort' and 'RST-106') were compared. The study was conducted and repeated twice in a heated greenhouse during the months of February and March, 2014. A total of eight grafted treatments were compared: Non-grafted 'Tribute', 'RST-106', and 'Maxifort'; self-grafted 'Tribute', 'RST-106', and 'Maxifort'; and 'Tribute' grafted onto 'RST-106' and 'Maxifort'. The 'Maxifort' rootstock produced root systems with up to 80% higher root tip density, 25% faster rate of horizontal root growth, and 35% increase in total root length compared to 'Tribute', with 'RST-106' rootstock being intermediate to the two. These observed differences in 'Maxifort' root systems may correlate to the increased yield and vegetative vigor reported in the literature when this rootstock is used in greenhouse and field production. Furthermore, results from this study indicate that the mini-horhizotron allows for sensitive and robust non-destructive data collection on root system traits.

P2-8

The use of supplementary lighting enhances the quality of grafted watermelon seedlings

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Research on the use of supplementary lighting has intensified over the last decade in the production process of grafted vegetable seedlings and can be differentiated into three stages: A) Growing of seedlings used for scion and rootstock into greenhouse, B) Healing of grafted seedlings in a growth chamber and C) Growing grafted seedlings into greenhouse. The aim of the present study was to study the necessity of supplementary lighting during greenhouse stages during the production of grafted watermelon seedlings. Watermelon seedlings used for scion and rootstock as well as grafted seedlings after healing were grown into greenhouse with or without supplementary lighting (high pressure sodium lamps) while during healing for 6 days in the growth chamber, fluorescent (FL) lamps were used. The evaluated parameters were: Shoot length and diameter, shoot and root fresh and dry weight, leaf thickness, leaf and cotyledon area, relative chlorophyll content and leaf color. Seedlings used for scion developed thicker stems (+23%) and leaves (+50%), larger leaves and cotyledons (+220% and +18%, respectively) and greater shoot and root biomass (+82% and +89%, respectively) when grown under supplementary lighting. Grafted seedlings exposed to supplementary lighting after the healing chamber had thicker (+18%) and greener (+42% chlorophyll) leaves as well as greater fresh and dry root weight (+14% and +18%, respectively) compared to seedlings exposed to natural light. During the healing in the growth chamber, the relatively low percentage of optimum to just acceptable marketable seedlings was not satisfactory for the production of high quality grafted watermelon seedlings. It is concluded that supplementary lighting is necessary in the greenhouse for growing of seedlings used for scion and grafted seedlings while FL lamps are not as efficient as needed during the healing stage.

P2-9

Growth change after grafting of root pruning splice grafted cucumber seedling grown in different media

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When producing grafted seedlings, root pruning splice grafting is used on watermelon and cucumber in the Republic of Korea. Growing medium is one of the important factors for rooting of transplanted plants. This study was conducted to investigate the effect of different media on rooting of root prune splice grafted cucumber seedling. Cucumber (*Cucumis sativus* **L. '**Shindong') seedlings as scion were grafted on to the bottle gourd (*Lagenaria siceraria* Stanld. 'Shingiwon') seedling as rootstock using root pruning one cotyledon splice grafting. The grafted seedlings were transplanted in five media as follows: commercial plug seedling medium (control), rockwool (RW), LC grow foam (LC), RC grow foam (RC), and terra-plug (TP). The seedlings were placed in a healing chamber during five days after grafting, and environmental conditions of the healing chamber were 24±1°C temperature, 98**±**1% relative humidity, 16/8 h (light/dark) photoperiod, and 130±5 $\mu mol \cdot m^{-2} \cdot s^{-1}$ **PPFD light intensity using LED (**red:blue = 30:70). The connection of scion and rootstock, plant height, stem diameters of scion and rootstock, and dry weights of scion and rootstock were not significantly different among media types. However, the root morphological characteristics were significantly influenced by all five different media. The total root length, total root surface, and total root volume were significantly greater in TP and lower in LC than in other media. On the contrary, the average root diameter was the thinnest in TP and the thickest in LC. These results showed that using the TP medium has an advantage to rootlet development and rooting of cucumber that grafted as root prune grafting with bottle gourd.

P2-10

A conceptual model of smart grafted transplant production system

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The aim of this study was to develop a conceptual model of smart vegetable grafted transplants production system. With the emergence of the fourth industrial revolution, smart farming has been an important key issue to improve plant production effectiveness and efficiency in horticulture. Since the production of grafted transplants is considered as one of the most complex production processes in the horticulture sector, application of smart farming technology could be most suitable. One of big complexities for the vegetable grafted seedling production business is the proper control of grafting work schedule with optimizing workforce and plant surplus. Hence, the conceptual model suggested a smart data-based grafted transplant production system to enhance productivity and quality considering whole process from seedling, germination, scion/ rootstock cultivation, grafting, grafting union formation and quality selection to shipment. Also, the conceptual model composed of interrelated smart farming hardware in terms of an image-based seedling growth information gathering, RFID gated system for production traceability, a closed transplant production system, a grafting robot and an image-based seedling quality selection. In addition, the conceptual model suggested a cloud-based production management application to manage order shipment, growing space, environmental conditions and the smart farming hardware.

P2-11

Short-term mechanisms of grafted pepper using NIBER rootstock, tolerant to salinity

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Improving abiotic stress tolerance is crucial in order to preserve future food, since climate change is nowadays a reality that is causing important losses in production and quality of crops. There are some techniques in order to overcome abiotic stress; among all of them grafting sensitive plants onto tolerant rootstocks is one of the most used between horticulture crops. Recently in our group we have registered a new hybrid pepper rootstock, called NIBER, which is tolerant to salt stress under an agronomic point of view, but the physiology of this tolerance is not still studied. As consequence, in this experiment we measured ABA concentration, ions concentration in leaves and roots and photosynthesis parameters after 10 days of treatment in three different pepper combinations: Adige variety without grafting (A), self-grafted (A/A) and grafted onto NIBER rootstock (A/NB). Respect to Na^+/K^+, the combination with the highest decrease, meaning an improved selectivity of K^+ onto Na^+, was A/NB in both roots and leaves. On the other side, in An/Ci coefficient there were significant differences between pepper plant combinations, being A/NB the one with the highest value under salinity, meaning a better photosynthetic efficiency and as, consequence, a better use of carbon. Finally, respect to ABA concentration in leaves and roots, we observed a decrease of this hormone in A/NB in both organs, meaning a lower degree of stress. As consequence, we could conclude that plants grafted onto this new rootstock (NIBER) increased photosynthetic parameters and decreased toxicity to salt, which caused a less degree of stress. This favorable behavior in physiological parameters was reflected in higher yield under salinity conditions. This work has been financed by INIA (Spain) through the project RTA2017-00030-C02-00 and the European Regional Development Fund (ERDF). López-Serrano L. is beneficiary of a doctoral fellowship (FPI-INIA).

P2-12

The role of ethylene in long-distance transportation of grafted vegetable seedlings

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Although many growers worldwide are utilizing grafted transplants, there is still a limited availability of grafted transplants in North America. The ability to ship grafted transplants long distances could allow nurseries to expand the market of high-quality seedlings to diverse U.S. growing regions. Furthermore, propagators that are currently shipping may encounter problems that may occur during transportation. Our recent survey results indicate that buyers of grafted vegetable seedlings have obersved the following symptoms upon receiving the plants after shipment: stem elongation, wilted leaves, leaf yellowing, chilling/freezing damage, and intumescence/oedema. Ethylene may be involved in the presentation of these symptoms. Investigating the ethylene response in tomato seedlings will allow for better understanding of how ethylene may be contributing to these symptoms during transportation. Ethylene sensitivity was evaluated by exposing shipment-ready grafted and non-grafted tomato seedlings to 0, 0.1, 1, and 10 $\mu L \cdot L^{-1}$ of ethylene for four days in sealed plexiglass chambers. 'Cherokee Purple' was use for the non-grafted seedlings and 'Cherokee Purple' grafted on 'Maxifort' rootstock was used for the grafted seedlings. Transplants were monitored during the four-day treatment event by evaluating: visual quality, leaf epinasty, stem length, chlorophyll fluorescence, and leaf color. Each concentration included 25 replications of grafted and non-grafted seedlings. The experiment was performed twice, and each experiment represented one block. A complimentary greenhouse experiment was conducted to evaluate how ethylene exposure may affect seedling growth and quality. Seedlings were transplanted into 6" pots and arranged on the greenhouse bench in a complete randomized design. Plants were destructively measured on days 0, 7, 14, and 21. Growth measurements included leaf area, shoot and root biomass, plant height, stem caliper, and flower count. Understanding how ethylene exposure contributes to transplant quality and growth will allow for more informed shipment recommendations and provide useful information for producers of grafted transplants and tomato growers.

P2-13

Molecular marker-assistant selection of pumpkin rootstocks for powdery mildew resistance and blooming capacity

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As an important agronomic technique to enhance resistance and yield, grafting is widely used in watermelon, melon and cucumber production. Pumpkin is the main rootstock type of melon crop grafting. At present, powdery mildew is common in melon vegetables, and often starts on rootstocks and then spreads to scions, resulting in serious economic losses. Therefore, breeding of resistant rootstocks is one of the most effective methods to reduce losses. Based on this, we carried out the identification of molecular maker linked to powdery mildew resistance using mapping populations (BC_6F_2). The resistance gene (*Pm-1*) was successfully mapped to a small genomic interval of 157 kb on LG 10 and a SSR marker (SSR023) inside this interval was developed to facilitate marker-assisted selection. The verification results showed that the accuracy of the molecular marker was up to 96.40%. Then we transmitted the powdery mildew resistance into pumpkin rootstocks by marker-assisted selection. In addition, the bloom is one of the important characters affecting the commodity property of cucumber. Bloomless cucumber can be produced by grafting cucumber on specific pumpkin cultivars. Therefore, blooming capacity is an important character of pumpkin rootstocks in China, Japan and other countries. However, *Cucurbita moschata* **resources with blooming capacity are scarce and need to be further developed. Based on this, we developed a SNP marker of rootstock cultivar for blooming capacity by using bloom and bloomless pumpkin rootstocks. The verification results showed that the accuracy of the molecular marker was up to 95.60%. So far, we have created more than a dozen of** *Cucurbita moschata* germplasms with powdery mildew resistance and blooming capacity, providing material basis for grafting rootstock breeding. The molecular makers identified in this study are useful in marker-assisted selection in rootstock breeding.

P2-14

Grafting bell peppers onto pepper and tomato rootstocks, and the effects on yield and plant morphology

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The implementation of rootstocks for bell pepper production could provide increased yield and/or disease resistance for vegetable production in the United States. The adoption of grafting for pepper production occurs worldwide, but it is unclear whether rootstocks can provide a significant yield advantage over the use of nongrafted plants in the U.S. Solanaceous rootstocks could increase plant vigor and disease resistance, but there are conflicting reports in the literature regarding the compatibility of intergeneric *Capsicum*/*Solanum* grafts. The objectives of this study were to identify commercially-available pepper rootstocks that improve crop productivity and determine the viability of using solanaceous rootstocks for bell pepper production. We conducted five trials in 2016 and 2017 that utilized a randomized complete block design. 'Karisma' was the nongrafted control and was used as scion for three *Capsicum* rootstocks ('Scarface', 'Yaocali', and 'Meeting') in addition to two *Solanum* rootstocks ('Maxifort' and 'Sweetie'). We found that 'Scarface' rootstock significantly improved yield ($P < 0.05$) and plants grafted with 'Scarface' had 32% greater marketable yield, 15%-18% larger fruit, and 9-12% higher marketability than the nongrafted 'Karisma' plants. Plants grafted with 'Yaocali' showed similar results, but were less consistent. 'Meeting' rootstock did not have any significant effects on yield, but may be beneficial for managing specific diseases or abiotic stressors. We also observed significant correlations between plant biomass and yield, indicating that future development of high-yielding pepper rootstocks should consider the use of highly vegetative rootstocks. The *Solanum* rootstocks, 'Maxifort' and 'Sweetie', displayed symptoms of delayed incompatibility when grafted with 'Karisma' scions, including significant (78% to 89%) reductions in yield and 59% to 93% less plant biomass. Based on our results, *Solanum* rootstocks were not suitable for bell pepper, but the utilization of capsicum rootstocks, 'Scarface' and 'Yaocali' may be useful for growers that want to increase crop productivity.

P2-15

Environmental conditions affect silicon absorption and bloom formation on fruit surface of grafted and non-grafted cucumbers

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The degree of bloom on fruit surface of cucumber is an important indicator of fruit quality, which was closely related to the rootstock types and growth environments. To reveal the mechanism of environmental conditions affecting bloom formation in cucumber fruits, cucumber (*Cucumis sativus L*) cultivar 'Shannong No 5' and two rootstock cultivars with different capacities of removing fruit bloom, 'Yunnan Figleaf Gourd' (*Cucurbita ficifolia Bouche*) and 'Huangchenggen No. 2' (*C.moschata Duch*. × *C.moschata Duch*.), were used for growing season (winter-spring crop; autumn-winter crop) experiments in solar greenhouse and controlled environment (air temperature 28℃/18℃, light intensity 600 μmol·m^{-2}·s^{-1}, relative humidity 55/65%; air temperature 22℃/12℃, light intensity 300 μmol·m^{-2}·s^{-1}, relative humidity 85/95%) experiments in artificial climate chambers, and bloom formation and silicon absorption in cucumber were investigated. The results showed that: The bloom on marketable mature fruits from winter-spring cropping in solar greenhouse was significantly more than that from autumn-winter crop, especially in grafted cucumber on 'Yunnan Figleaf Gourd'; In the same growing season, grafted cucumber on 'Yunnan Figleaf Gourd' had the largest amount of bloom, followed by non-grafted cucumber, and grafted cucumber on 'Huangchenggen No 2' had the least; Silicon content in plant organs showed similar changes. High temperature, strong light and low humidity conditions in artificial climate chamber promoted silicon absorption of both grafted and non-grafted cucumber seedlings, and as a result increased silicon content in different organs, grafted cucumber on 'Yunnan Figleaf Gourd' showing the highest and that on 'Huangchenggen No 2' being the lowest; The expression characteristics of silicon transporter genes in both leaves and roots changed accordingly. These results indicated that environmental conditions affected the formation of bloom on surface of cucumber fruits by changing the absorption and distribution of silicon in plants.

P2-16

Exploring chamberless healing for small-scale production of grafted tomato transplants

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Growing interest exists among small-scale local growers in grafting tomato plants for improved crop productivity. Oftentimes, setting up healing chambers and graft healing management are major challenges that limit graft survival. Here, we demonstrate a "chamberless healing" strategy for grafted tomato plants using regular indoor conditions compared with covered seedling trays as a simple means for graft healing. The tomato scion 'Tribute' was grafted onto 'Estamino' rootstock using the splice method. After grafting, plants were placed in uncovered seedling trays (chamberless) for healing or in plastic dome covered seedling trays as the healing chamber. A beaker with 25 mL of DI water was put in every tray to help maintain humidity and the plants were sprayed daily. A complete block design with 3 replications of 5 plants was used. Six different levels of humidity management for the covered tray were also assessed by manipulating the duration of tray covering and opening. All the seedling trays were placed inside an air-conditioned room at 23 °C and around 45% relative humidity with 8 h per day fluorescent lighting. There was no significant difference in survival rate between different healing treatments 21 days after grafting, and the "chamberless" healing reached a 93% survival rate. Similar plant height and stem diameter among treatments were observed. Adventitious roots from the graft union developed around 5-6 days after grafting in covered seedling trays but only one in fifteen plants showed adventitious roots in the "chamberless" treatment. Although some extra management is required during healing to prevent water loss (like spraying water to create a moist microclimate), the "chamberless" system assessed in this study exhibited great potential to facilitate small-scale graft healing under regular room conditions without sophisticated setup of the healing environment. More studies are underway to further validate the "chamberless" healing approach.

P2-17

Pathogenic races and putative fungal effectors in *Fusarium oxysporum* f. sp. *lycopersic*i from greenhouse tomato in North Carolina

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Fusarium oxysporum **f. sp.** *lycopersici* (FOL) causes Fusarium wilt in tomatoes. Although the disease has been detected in various areas in the United States, knowledge about the genetic and pathogenic variability of FOL from greenhouse tomato is very limited. In this study, 40 isolates of FOL collected from different greenhouse-grown tomatoes were characterized by race typing using four differential cultivars, polymerase chain reaction (PCR)-based race specific primers, and mating type loci. Isolate sequences were analyzed to determine the correlation of three housekeeping genes and twenty-seven fungal effector genes with wilt symptoms. Race 3 was commonly detected and suggested that its introduction into greenhouses was through contaminated propagative material. Isolate sequences were analyzed to determine the correlation of three housekeeping genes and twenty-seven fungal effector genes with wilt symptoms. FOL isolates are genetically highly diverse and contain several virulence effector genes. Additional collections and monitoring of FOL races are necessary to search for resistant rootstocks and deploy new tomato varieties with multiple disease resistance genes for Fusarium wilt management. Assessing the population structure of this important pathogen informs recommendations and decisions to use the best rootstock where grafting is used as an IPM tool.

P2-18

Effect of supplemental lighting source combined with intensity on quality of grafted tomato plug seedlings

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Insufficient amount of light, especially in winter seasons, may result in lower quality and longer production period of grafted tomato (*Solanum lycopersicum* L.) plug seedlings in greenhouses. Supplemental artificial lighting to grafted plug seedlings may be a feasible solution to such problems. The objective of this study was to assess the influence of light source and intensity on the growth and development of two tomato cultivars 'Super Sunload' and 'Super Dotaerang' grafted onto the 'B-Blocking' rootstock. Grafted seedlings were grown for 10 days in a glasshouse with an average daily light intensity of 346 μmol·m^{-2}·s^{-1} photosynthetic photon flux density (PPFD) coming from the sun without (the control) or with 8 h per day of supplemental lighting provided at a light intensity of 50, 100 or 150 μmol·m^{-2}·s^{-1} PPFD from high pressure sodium (HPS), metal halide (MH), or mixed light emitting diode (LED-mix). The culture environment had a set point of 23℃/17℃ day/night temperatures, 75±5% relative humidity, and a natural photoperiod of 12 h. Both cultivars grown in the LED-mix with 150 μmol·m^{-2}·s^{-1} PPFD (LED 150) had the greatest stem diameter and dry weight of the scion. Leaf area, ratio of scion dry weight to plant height, specific leaf weight, and dry weight of the root were also the largest in the LED 150. A rank analysis of growth and developmental parameters showed that LED 150 had the best effects on seedling quality for both cultivars, followed by HPS 150 and MH 150.

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P2-19

A meta-analysis of the effects of watermelon grafting on yield and fruit quality

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With more stringent regulations on using agrochemicals for controlling diseases, pests, and weeds in vegetable production globally, grafting practices and research have been expanding accordingly. Watermelon grafting has been in practice since the late 1920s and is currently most common in China, Turkey, the United States, and Mexico. Although the benefit of watermelon grafting has been documented extensively in the literature, the adoption rate of this technology varies significantly by country. The key driving factor and barrier of grafting adoption among growers is the perceived economic benefit, which depends heavily on fruit yield and quality. With a focus on fruit yield and quality, this study assessed watermelon grafting studies from eighteen countries reported in English, Spanish, and Korean. The 58 studies included in our analysis had used ninety totally different rootstocks. The results showed that despite differences in regions and rootstocks, watermelon grafting on average results in a 40.3% increase in yield, a 28.3% increase in average fruit weight, and an 18.1% increase in fruit number per plant. However, no significant differences were evident in soluble solids content. 'Jumbo', 'Nun', and 'Ojakkyo' were the three rootstocks with the most beneficial results on increased fruit quality of grafted watermelon. The results also demonstrated that studies conducted in other regions of the world were more likely to show the greater performance of grafted watermelon than non-grafted compared with the studies in the United States. This could potentially be a consequence of a short history of grafting research in the States. Results of this study would provide comprehensive information regarding the benefits of watermelon grafting from a global perspective, which may guide future research on watermelon grafting. It also provides essential information to growers who are interested in adopting watermelon grafting in their production.

P2-20

Functional characterization and expression analysis of influx silicon transporter LSi1 in pumpkin rootstocks and cucumber scion during bloom accumulation on cucumber fruits

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Pumpkin is a common rootstock for cucumber grafting. Grafting is not only can improve the plant's resistance and yield, some pumpkin rootstocks also can reduce the bloom content on the surface of cucumber, and then improve the fruit's commodity. It has been reported that the content of bloom on the surface of cucumber fruits is related to the silicon content and the function of silicon transporter LSi1. However, what roles of *CmLSi1* and *CsLSi1* play in pumpkin rootstock and cucumber scion respectively during the accumulation of bloom on cucumber fruits, and how they are regulated between the rootstock and scion is not clear until now. In this research, 12 bloomless pumpkin rootstocks and 12 bloom pumpkin rootstocks were used to analyze the expression and sequence structure of *CmLSi1* gene in roots and stems of different rootstocks. The results showed that there was no significant difference in the expression of *CmLSi1* between different rootstocks, but all bloomless rootstocks have the same amino acid mutation at position 242 compare to the bloom rootstocks and cucumber scion. The mutation resulted in the loss of transport activity of LSi1, thus affecting the transport of silicon to scions. In addition, we also found that the silicon content and the expression level of *CsLSi1* in the skin and flesh of bloomless cucumber fruit were significantly lower than that in the bloom cucumber fruit. This indicates that the change of silicon content may provide a feedback regulating effect on *CsLSi1* in scion fruits and then down-regulating the expression of *CsLSi1* in bloomless cucumber fruits. These results indicated that the function of LSi1 was closely related to the content of bloom on the surface of cucumber fruit.

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Herbicide tolerance of grafted eggplant on tomato rootstock

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Interspecific grafting using rootstock and scion from different species is a common practice in solanaceous crop production to address many abiotic and biotic stresses, including drought/waterlogging, insects, and diseases. Tomato rootstocks have been successfully used for eggplant production. However, the safety of tomato herbicides has not been tested on grafted eggplant which is combination of two plants, tomato rootstock and eggplant scion. Greenhouse and field studies were conducted to determine the response of grafted eggplant to napropamide, metribuzin, halosulfuron, trifluralin, S-metolachlor and fomesafen herbicides which are registered in tomato. The greenhouse study treatments included metribuzin pretransplant (PRE) or posttransplant (POST) at 0.14 and 0.28 kg ai/ha, S-metolachlor PRE at 0.4, and 0.8 kg ai/ha, and halosulfuron POST at 0.018, and 0.036 kg ai/ha. The field study was conducted at Mountain Research Station, Waynesville, NC and at Horticultural Crops Research Station, Clinton, NC. Herbicide treatments included PRE S-metolachlor (0.8 and 1.06 kg ai/ha), fomesafen (0.28 and 0.42 kg ai/ha), metribuzin (0.28 and 0.55 kg ai/ha), napropamide (1.12 and 2.24 kg ai/ha), halosulfuron (0.039 and 0.052 kg ai/ha), and trifluralin (0.56 and 0.84 kg ai/ha). The eggplant cultivar 'Santana' was used as scion and non-grafted control, while two hybrid tomatoes 'DP106' and 'Maxifort' were used as rootstocks for grafted plants. No differences were observed in grafted and non-grafted eggplant for herbicide injury in greenhouse and field studies. Injury from metribuzin POST at 0.14 and 0.28 kg/ha at 4 WAT was 94 and 100% for grafted and non-grafted eggplant, respectively. In field studies, pretransplant fomesafen, napropamide, S-metolachlor, and trifluralin caused less than 10% injury and no yield reduction in grafted and nongrafted eggplant. However, metribuzin caused severe injury and yield reduction in both grafted and non-grafted eggplant. Metribuzin at 0.55 kg/ha caused 60 and 81% plant stand loss in 2013 and 2014, respectively. Halosulfuron PRE caused 24% yield reduction in grafted and non-grafted eggplant compared to nontreated control during 2013 but was not injurious in 2014. PRE napropamide, S-metolachlor, fomesafen and trifluralin can be considered safe for weed control in grafted eggplant on tomato rootstock.

P2-22

Critical period of control of a mixed weed population in grafted triploid watermelon

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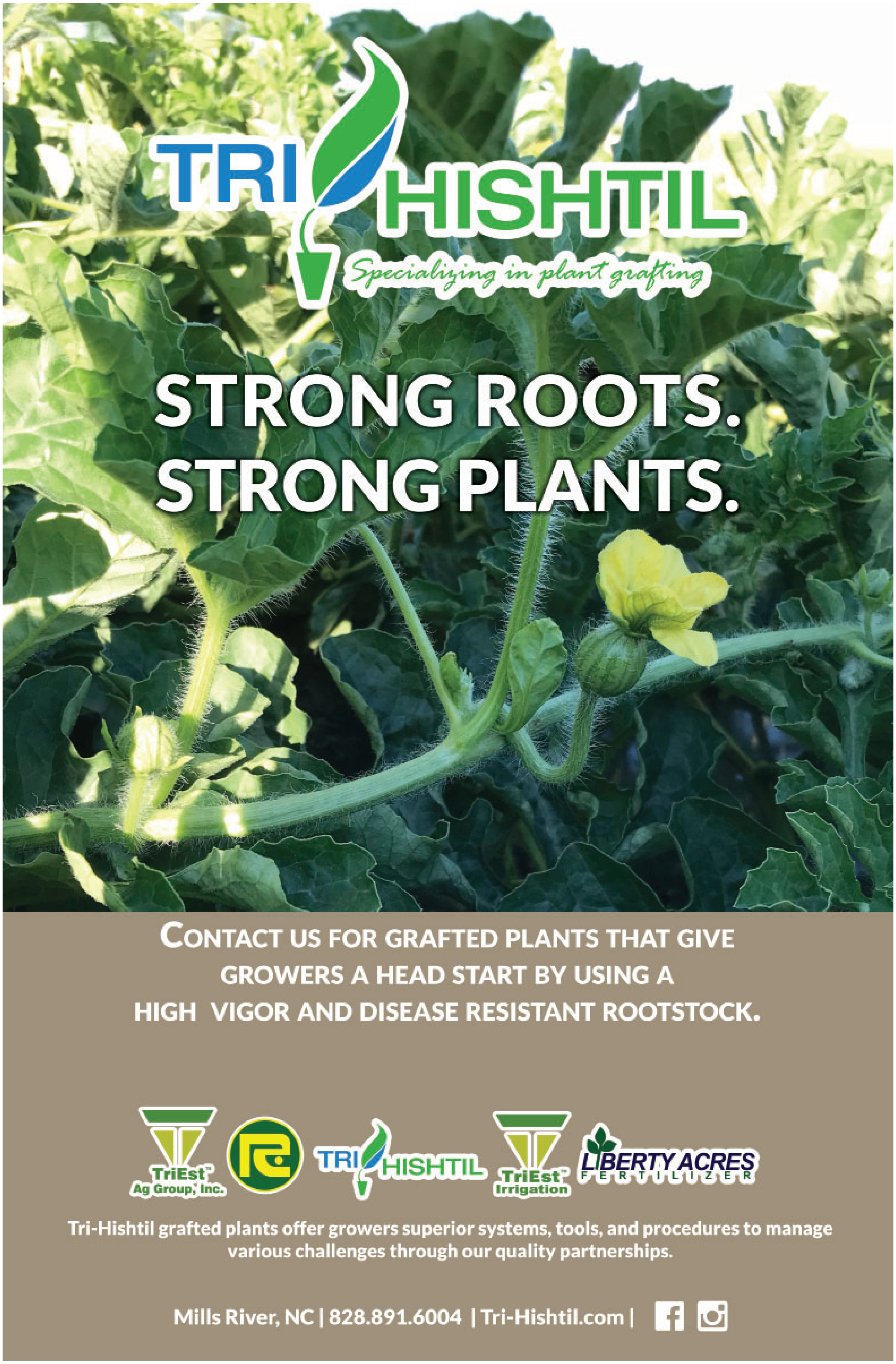
Field studies were conducted to determine the critical period for weed control (CPWC) in grafted and nongrafted watermelon produced in plasticulture. 'Exclamation' seedless watermelon was used as the nongrafted control and grafted onto 'Carnivor' and 'Kazako' rootstocks (interspecific hybrid squash). Establishment treatments included weeds (yellow nutsedge, large crabgrass, and common purslane) transplanted at 0, 2, 3, 4, and 6 weeks after watermelon transplanting. Weeds remained through watermelon harvest. The removal treatments included the same weeds transplanted on the day of watermelon transplanting and then they were removed 2, 3, 4, 6, or 11 weeks after watermelon transplanting. Season long weedy and weed-free checks were included for comparison. Foliar biomass of weeds decreased as weed establishment was delayed and increased as weed removal was delayed. For nongrafted 'Exclamation' and grafted 'Exclamation' on 'Carnivor' rootstock the predicted CPWC was a single weed removal between 2.3 and 2.5 weeks after transplanting and 1.9 to 2.6 weeks after transplanting, respectively. The predicted CPWC for 'Kazako' rootstock ranged from 0.3 to 2.6 weeks after transplanting.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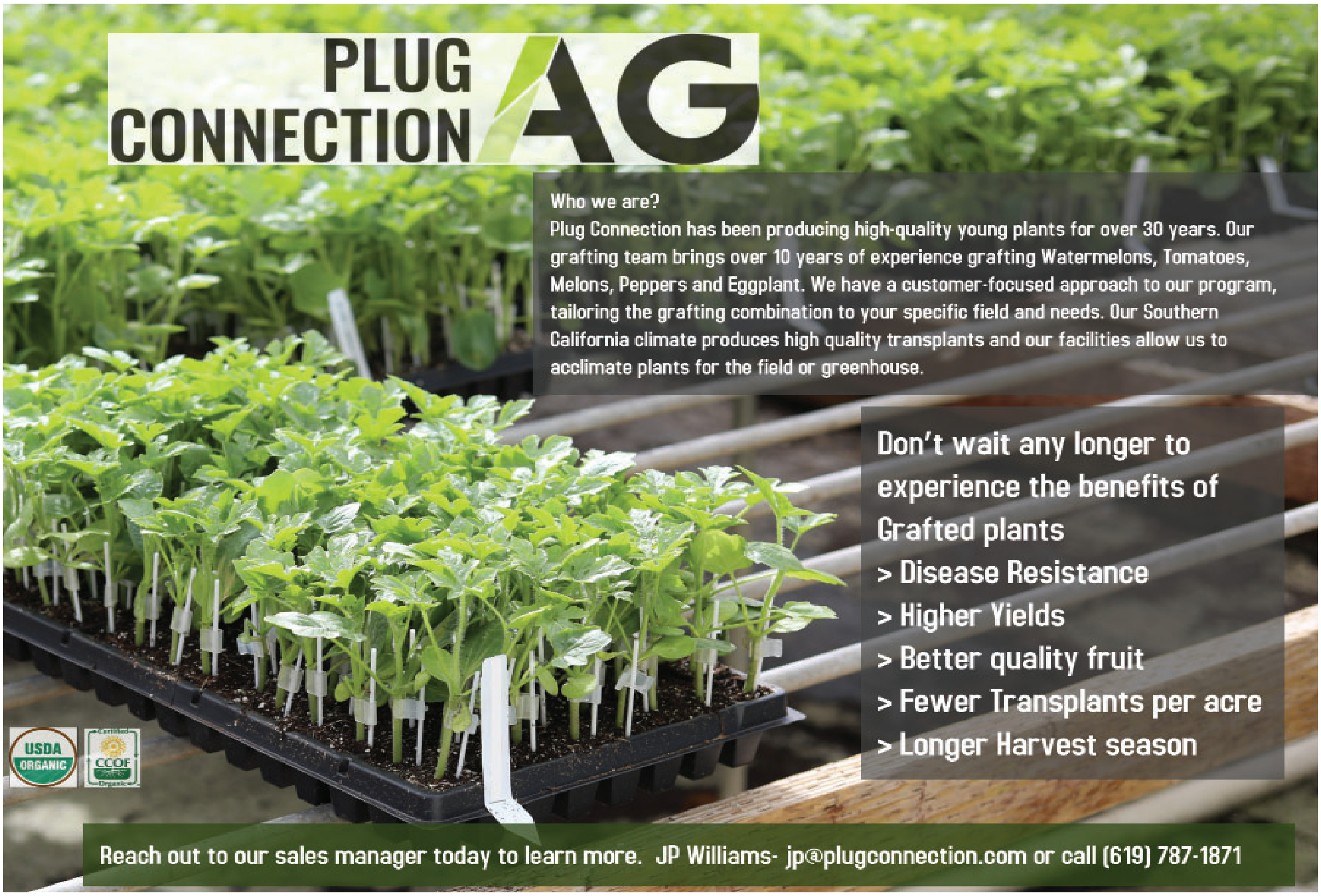
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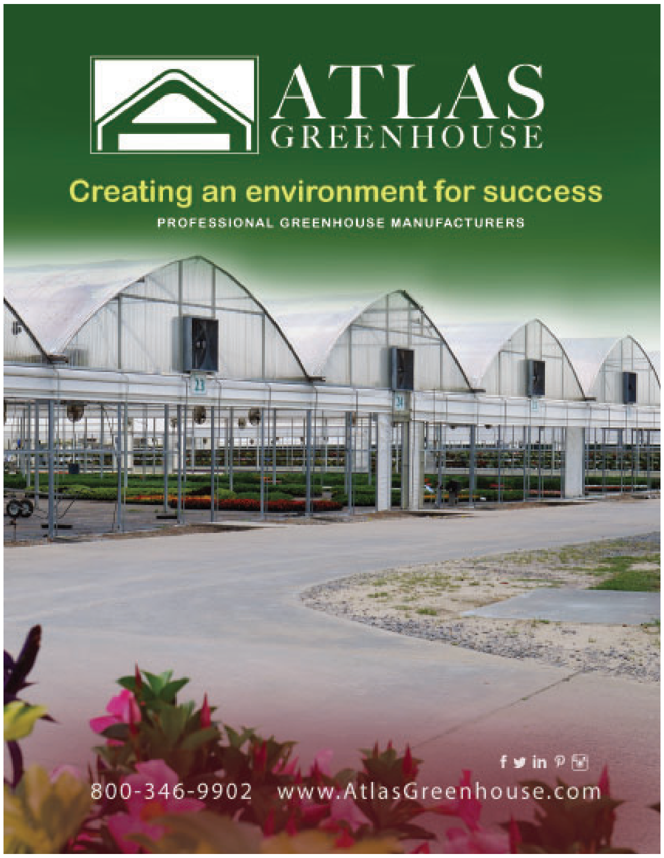
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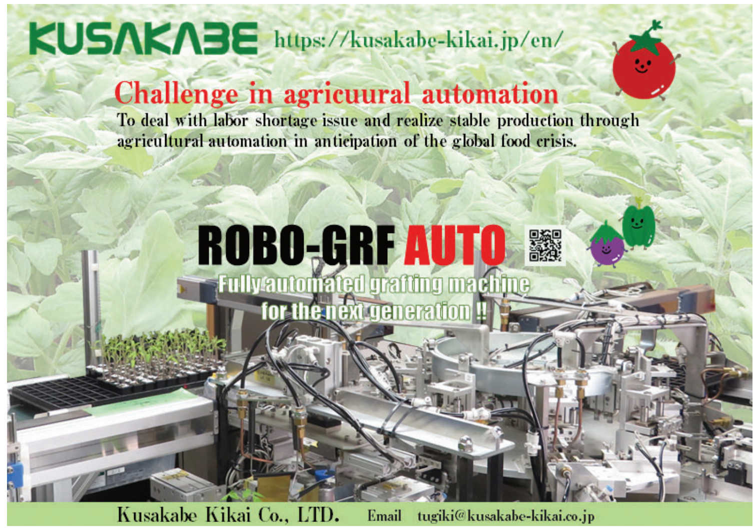

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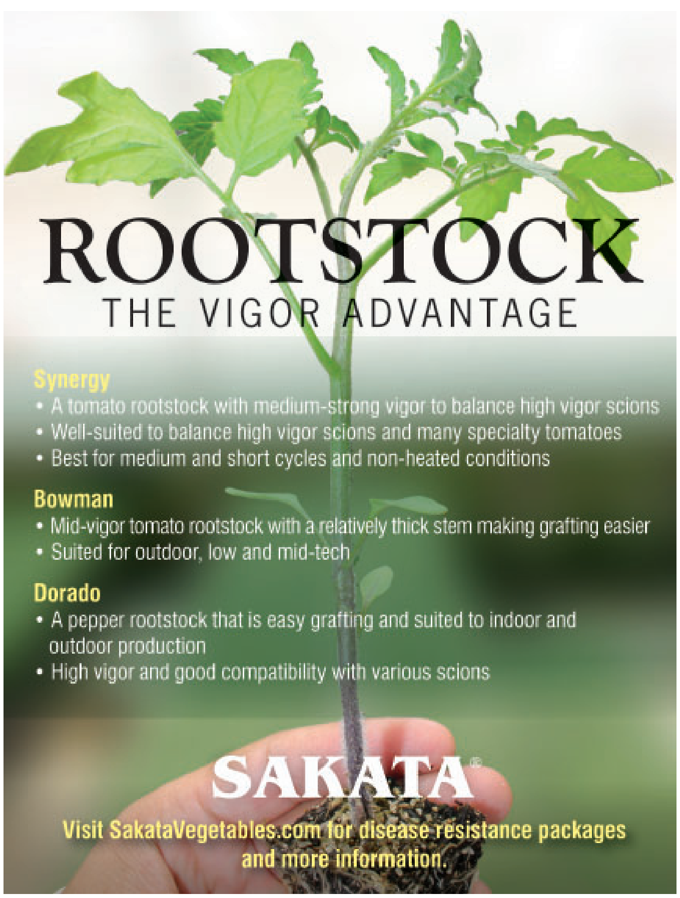

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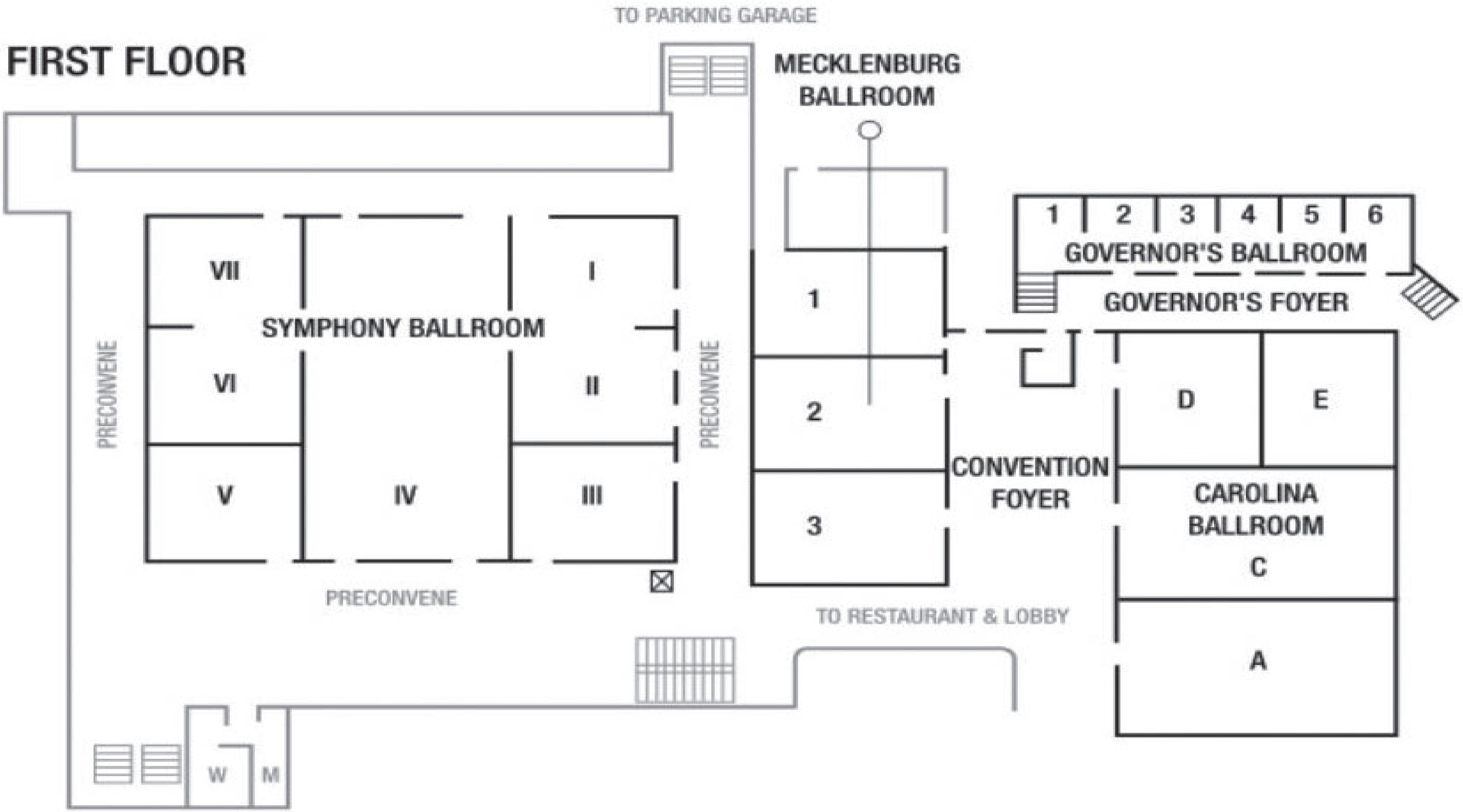

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