Basics & applications of vegetable grafting

Dr. Chieri Kubota
School of Plant Sciences
University of Arizona, USA
2014 Plug & Cutting Conference
September 23rd, 2014

Grafting

- Woody plants
- Vine crops
- As early as 1560 B.C. in China
- Benefit
  - Acquiring resistances for soil-borne diseases
  - Improving overall vigor
  - Increasing yields

Vegetable Grafting - A bit of history

- In China, vegetable grafting was used in the 5th Century for increasing fruit size of gourd.
- Use of grafting for controlling soil-borne diseases began in 1920s.
- Today over 90% of watermelon in Japan, Israel, Korea, Greece and southern Spain where crop rotation is difficult are grafted.
- Grafting is used for a wide range of fruiting vegetables.

Vegetable grafting (for fruit-producing vegetables such as tomato and melons)

Scion variety for better fruit yield and quality

Wild type based rootstock for vigorous root growth and soil-borne disease resistance

Grafted seedlings to produce higher yield and soil-borne disease resistances
Commercial nursery in Canada

Commercial nursery in Spain

Commercial nursery in Japan

Transplant factory in Japan

Worldwide use of grafted plants

<table>
<thead>
<tr>
<th>Country</th>
<th>Crop</th>
<th>Estimated number of grafts per year</th>
</tr>
</thead>
<tbody>
<tr>
<td>China*</td>
<td>Watermelon, cucumber, melon, tomato</td>
<td>700 million plants*</td>
</tr>
<tr>
<td>Korea*</td>
<td>Watermelon, cucumber, melon, tomato, pepper</td>
<td>700 million plants*</td>
</tr>
<tr>
<td>Japan*</td>
<td>Watermelon, cucumber, melon, tomato, pepper</td>
<td>700 million plants*</td>
</tr>
<tr>
<td>Spain***</td>
<td>Watermelon, tomato, eggplant</td>
<td>130 million plants***</td>
</tr>
<tr>
<td>Italy***</td>
<td>Watermelon, tomato, eggplant</td>
<td>60 million plants***</td>
</tr>
<tr>
<td>North America**</td>
<td>Tomato, watermelon</td>
<td>40 million plants**</td>
</tr>
</tbody>
</table>

*Lee et al. (2010); **Kubota et al. (2008); ***Personal communications (2012)

Studies are being conducted to advance grafting in vegetable production in US open fields

Photo by Dr. Josh Freeman (Virginia Tech)
Grafted plants yielded more than non-grafted or direct seeded plants.

<table>
<thead>
<tr>
<th>Plant type</th>
<th>Total harvestable number of fruit (fr/plant)</th>
<th>Total harvestable fruit yield (kg/plant)</th>
<th>ANOVA</th>
<th>71% yield increase (due to early establishment)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grafted plants</td>
<td>4.3a</td>
<td>6.5a</td>
<td>&lt;0.0001</td>
<td></td>
</tr>
<tr>
<td>Non-grafted plants</td>
<td>2.4b</td>
<td>3.9b</td>
<td>&lt;0.0001</td>
<td></td>
</tr>
<tr>
<td>Direct-seeded plants</td>
<td>2.5b</td>
<td>3.8b</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

ANOVA: <0.0001

Trade show exhibition of a seed company, demonstrating vigorous root development of rootstock compared with scion.

Rootstocks for tomato

<table>
<thead>
<tr>
<th>Type</th>
<th>Resistance</th>
<th>Other traits</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Interspecific hybrid</strong></td>
<td>Different for different rootstock varieties but generally include Fusarium, Verticillium wilt, root knot nematodes.</td>
<td>Very uniform growth. Less vigorous.</td>
</tr>
<tr>
<td><strong>Solanum lycopersicum x S. habrochaitae</strong></td>
<td>Vigorous. However, less uniformity in germination was noted.</td>
<td></td>
</tr>
<tr>
<td><strong>Intraspecific hybrid</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Solanum lycopersicum</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

For complete tomato rootstock table: www.graftedvegetables.org

Rootstocks for cucurbits

<table>
<thead>
<tr>
<th>Type</th>
<th>Resistance</th>
<th>Matching scions and other traits</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Interspecific hybrid squash</strong></td>
<td>Fusarium. Some also have vine decline, verticillium wilt and anthracnose.</td>
<td>For all cucurbits. Traits varied among different rootstock varieties (vigor, chilling heat or drought tolerance, etc.).</td>
</tr>
<tr>
<td><strong>Cucurbita maxima x C. moschata</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Bottle gourd</strong></td>
<td>Fusarium. Some also have vine decline, verticillium wilt and anthracnose.</td>
<td>For watermelon. Chilling tolerance.</td>
</tr>
<tr>
<td><strong>Lagenaria siceraria</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Watermelon or muskmelon</strong></td>
<td>Fusarium. Some also have anthracnose.</td>
<td>For watermelon or muskmelon</td>
</tr>
</tbody>
</table>

For complete cucurbit rootstock table: www.graftedvegetables.org

Propagation stages of vegetable grafting

- Germination
  - Scion and rootstock’s optimum germination temperatures may not necessarily the same.
- Preparation of Scion and rootstock seedlings
- Grafting
- Healing grafted seedlings
- Acclimatization
- Grow-on
- Hardening

Scheduling grafting

- Seeding scion: Duration varies depending on species and grafting method (18-24 days for tomato and 7-14 days for cucurbits)
- Seeding rootstock: Duration varies depending on species and grafting method (18-24 days for tomato and 7-14 days for cucurbits)
- Healing: (5-7 days)
- Finishing transplants: (1-3 weeks)
- Shipping and final transplanting
- Removal of grafted plants from healing chambers
Tomato grafting

- Almost all propagators use:
  - Tube grafting
- Some small growers use ‘approach grafting’ as it does not require sophisticated healing system despite of the slow grafting speed.

Tube grafting for tomato
(manual grafting 100 – 400 grafts/h)

Cucurbit grafting

- Several methods used commercially:
  - Approach grafting
  - One cotyledon grafting
  - Hole insertion grafting
- In North America, approach grafting is used by small growers, and one cotyledon grafting by commercial growers.

Approach grafting method

- High success rate without good healing system
- Time consuming (not suitable for mass production)

One cotyledon grafting method
(splice grafting)

- Originally developed for grafting robot
- Easy to learn for beginners.
- Suitable for mass production.
- Important that scion stem diameter similar to rootstock.

(Pictures from Lee, 2007)
Hole insertion method

- Suitable for mass production.
- Develop very strong grafted union
- More flexibility in size
- No clips or tubes required
- Needs more experience (success, internal rooting)
- Needs better healing system
- Rootstock may grow out if the axillary buds are not completely removed.

![Image of hole insertion method](image)

Commercial grafting methods for various crops in Japan (after NARO, 2010)

<table>
<thead>
<tr>
<th>Crop</th>
<th>Watermelon</th>
<th>Cucumber</th>
<th>Melon</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tomato</td>
<td>90%</td>
<td>10%</td>
<td>0%</td>
</tr>
<tr>
<td>Eggplant</td>
<td>0%</td>
<td>90%</td>
<td>10%</td>
</tr>
</tbody>
</table>

Most grafting operations are manual (number of workers = grafting capacity)
Automation for grafting

[Images of grafting machines]

900-1000 grafts per hour

http://www.isogroepmachinebouw.nl/index.html

Grafting tool

[Image of grafting tool being used]

Healing/welding
to form grafted union
The MOST critical step

[Diagram showing the process of healing/welding]

Vascular system
Callus bridge

Recommended healing conditions (= intensive care facility)

- **Relative humidity**: 95% or greater. Gradually decrease toward the end.
- **Air temperature**: 28-29°C (82-84°F) **INSIDE** the healing chamber. Gradually decrease to the end.
- **Light intensity**: Darkness for the first 24-48 hours and then turn the light on. Intensity = 50-100 micro-mol/m²/s (two fluorescent lamps over each shelf will create a similar level of light intensity.)
- **Duration**: 4-6 days for tomato, 7 days for cucurbits
- **Others**: Avoid too wet substrate for tomato rootstocks

Indoor healing facility using artificial light in multi-tiered system with overhead lighting in each tier (Tokushima, Japan)

Healing tent inside greenhouse equipped with shade cloth, heating, A/C unit (BC, Canada)
28-29°C (84°F), 95% RH, continuous lighting at 50 µmol/m²/s (Target)

Greenhouse-base healing system used in Almeria, Spain

Overhead shade to reduce light
- Dark shading cloth for the first 2-3 days

Plastic film for maintaining high RH

Plastics are removed at the end of healing process.

Bottom heating to maintain the temperature inside the healing chamber.

Mist system under the bench to humidify the chamber.

**Keys for success**

- Developing a good healing system
  - Temperature, humidity and light
- Scheduling scion and rootstock seeding dates
- Good grafting skills – good eyes
**Vegetable grafting in North America (commercial use)**

<table>
<thead>
<tr>
<th>Country</th>
<th>Production (plants per year)</th>
<th>Use (plants per year)</th>
<th>Crop species (commercial use)</th>
</tr>
</thead>
<tbody>
<tr>
<td>U.S.A.</td>
<td>~0.2 million</td>
<td>~10 million</td>
<td>Tomato (Greenhouse)</td>
</tr>
<tr>
<td>Canada</td>
<td>~20 million</td>
<td>~10 million</td>
<td>Tomato (Greenhouse)</td>
</tr>
<tr>
<td>Mexico</td>
<td>&gt;20 million</td>
<td>&gt;7 million</td>
<td>Tomato (Greenhouse)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Watermelon (Open-field)</td>
</tr>
</tbody>
</table>

✓ US greenhouse growers are buying millions of grafted plants from Canada.
✓ Main purpose of using grafted plants in greenhouse is to increase yield.

**Home Gardening: Growing market for vegetable grafting**

- Increasing worldwide
- Unique product lines
- Varieties of crops
  - Tomato (heirlooms)
  - Melons
  - Eggplant
  - Cucumber
  - Sweet pepper

**Grafting heirloom tomato**

- Heirloom varieties can be grafted on commercial rootstock varieties to acquire vigor and disease resistances.
- However, in some cases, ToMV compatibility becomes an issue. On-going research at USDA ARS in FL (Rosskopf et al., 2013).

**Current grafting propagation technology in North America**

- Typical systems used in nurseries for **greenhouse seedlings** include:
  - High-tech greenhouses (including cooling, heating and supplemental lighting)
  - Rockwool plugs/cubes as substrates
  - Various automation
  - Sub-irrigation
- Seedling price range (grafted):
  - Tomato: 40 cents – 1.50 dollars per plant
- Transportation:
  - Long distance with refrigerated trucks
  - International transportation

**Current grafting propagation technology in North America**

- Typical systems used in nurseries for **home gardeners and other production systems**
  - Low- to medium-tech greenhouses (plastics covered, without/with heating/cooling)
  - Substrate mix in plug trays (1020 or injection molded)
  - Sub-irrigation (recommended)
- Seedling price range (grafted):
  - Commercial market: ???
  - Retail market: ???
- Transportation:
  - Long distance with commercial freight (e.g., FedEx)
  - International shipment

In North America, millions of grafted tomato seedlings are transported for long distance (2-4 days) in trailers.
Grafting nursery in the US

Vertical grafting nursery in the US

Slide by Grafted Growers

Challenges in US

- Need more propagators to supply grafted seedlings to high tunnels, open fields, as well as greenhouses.
- Reducing the propagation costs.
- High tunnels and open fields have regionally limited planting seasons.
- Labor and capital intensive, logistically complex production.
- Automation and long distance transportation is a key.

Unrooted grafted cuttings

Unrooted grafted cuttings: our study objectives

- Two major questions:
  - For long distance transportation, when is the best timing to harvest grafted cuttings to ship them?
  - Would refrigeration be necessary for transportation of grafted cuttings? (i.e., watermelon is sensitive to low temperature)
Effect of temperature on the visual quality of unrooted cuttings

- Lower temperature maintained the cutting turgidity and prevented bending the scion.
- Similar loss of turgidity occurred in tomato at 20°C compared with 10°C.

Effect of temperature on the visual quality of rooted cuttings

- Grafted cuttings can be harvested after 3 days in healing for tomato.
- Tomato did not show notable difference in quality of finished plants affected by temperature.

Cuttings were harvested after 5 days in healing.

Cuttings were harvested after 7 days in healing.

Vegetable Grafting Information Website
(http://cals.arizona.edu/grafting)

www.vegetablegrafting.org

Any questions?

E-mail: ckubota@email.arizona.edu