Overview of Vegetable Grafting in the United States

Chieri Kubota & SCRI-Grafting PIs
Overview of Vegetable Grafting in the U.S.

• A bit of history
• Current status, opportunities, and challenges
  – Greenhouses
  – High tunnels
  – Open fields
  – Retail
  – Costs and economics
Vegetable grafting timeline

**Gourd grafting for large fruit production in China**
- Discovery as IPM tool for fusarium in watermelon (Japan)
- Farmers began to use grafting for intensive cultivation (Korea/Japan)

500s

1920s-1930s

1940s

**Technology development of plant breeding for disease resistance**
- Globalization of seed market and supply
- Grafting technology adopted in Israel and Europe

1950s-1980s

1990s

1990s


**U.S. researchers in SE promoted grafting tomato onto jimson weed (Datura spp.) for RKN**

**1940s**

**1990s**

**1990s**

**1990s**

**2000s**

**2010s**

**Tomato grafting in hydroponic greenhouse in Holland**

**Tomato grafting in hydroponic greenhouse in Canada**

**Tomato grafting in hydroponic greenhouse in US and Mexico**

**Vegetable grafting for retail market in US**

**Vegetable grafting in various production systems in Mexico (and US)**
US vegetable production

Diversity in climates, soil, systems, etc...
## Commercial production and use of grafted vegetable plants in North America

### Table. Estimate in 2012

<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>&lt; 0.1 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, &gt;7 million</td>
<td>&gt;20 million, &gt;7 million</td>
<td>Tomato (Greenhouse), 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.
## Use of grafted vegetable plants in the U.S. (all sectors)

### Table. 2015 estimate (USA usage)

<table>
<thead>
<tr>
<th>Use</th>
<th>Tomato</th>
<th>Watermelon</th>
<th>Other crops grafted</th>
<th>Sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>Greenhouses</td>
<td>~10 million</td>
<td>None</td>
<td>cucumber</td>
<td>Canada, Mexico, US</td>
</tr>
<tr>
<td>High tunnels</td>
<td>~1 million?</td>
<td>None</td>
<td>melon, eggplant</td>
<td>US, Canada</td>
</tr>
<tr>
<td>Open fields</td>
<td>~6 million</td>
<td>~200K?</td>
<td>melon, eggplant</td>
<td>US, Canada, Israel</td>
</tr>
<tr>
<td>Retail</td>
<td>~1 million</td>
<td>None</td>
<td>eggplant, pepper, potato</td>
<td>US</td>
</tr>
</tbody>
</table>
Greenhouses
Vegetable grafting in US Greenhouses

- **Hydroponic/soilless tomato**
- Introduced by Dutch/Canadian growers in early 2000s.
- Use of strong rootstocks (interspecific hybrid) for **vigor** to support long cultivation cycle (10-12 months)
- Typical yield increase: 10-20% (increase by 5-10 kg/m² or 22-44 ton/acre)
- Use of two-headed grafted plants to reduce the plant costs (12000 → 6000 plants/acre)
- ~10 million grafted plants used (estimate as of 2012)
One double-head (twin leader) plant can yield the same as two-single head plants

- NG/2
- G/2
- G/1
- NG/1

Grafted plants (single or double headed)

Non-grafted plants (single)

Non-grafted plants (double)

Error bars are +/- cumulative SE

(Data by Pat Rorabaugh, 2004)
Commercial nurseries in Canada

Technology-rich propagation
Transplant types used in US Greenhouses

• Substrate (Rockwool)
• Young seedling plugs ($0.50-$1.00 per plant)
• Mature 1-ft plants at flowering stage (~$1.50 per plant)
• Use of two-headed (twin leader) grafted plants to reduce the plant costs
• Low grafting (close to substrate surface)
Trade show exhibition of a seed company, demonstrating vigorous root development of rootstock compared with scion.
Importation of tomato plants in US

- Importation ban of tomato plants due to ToTV and ToSLCV (APHIS, 2009)
- Exempt: Canada
- Importation of tomato plants growing in *soilless medium* from Mexico to US greenhouses is approved (APHIS, 2015)
High Tunnels

Photo by Cary Rivard
Vegetable grafting in US high tunnels

- Unheated or minimally heated structure, typically with soil
- 4600 acres (estimated in 2009)
- High Tunnel System Initiative (USDA NRCS)
- Rapidly increasing sector of US vegetable industry
- Strong support for locally grown fresh vegetables
- Intensive cultivation
- Early adaptors of grafting technologies (tomato, eggplant and melon)
Typical objectives of grafting in HTs

• Disease and pest management due to the intensive cultivation (without rotations)
• Abiotic stress tolerance for season extension (cold soil temperature)
• Vigor for less vigorous cultivars (e.g., heirloom)
Heirloom tomatoes

- Old tomato cultivars maintained for many generations in North America and Europe
- Specialized market
- Low productivity
- Little or no resistance to soil-borne disease
- *Emerging ToMV compatibility issue in grafting* (Rosskopf, 2013)

Photos by Seed Savers Exchange (http://www.seedsavers.org)
Fig. 1. Mean southern blight incidence on non-grafted and self-grafted tomato cultivar Cherokee Purple as well as Cherokee Purple grafted onto rootstock cultivars Beaufort and Maxifort at the Alamance County location in 2007 and 2008.
Vegetable grafting in US retail (for home gardening)
Unique product lines for retail market

Log House Plants

Photo by Hishtil

Photo by Alice Doyle

You Can Grow Me! Veg-ease™

Grafted Celebrity

All America Selections winner! Heavy yields of tasty tomatoes.

An all-purpose variety with superb flavor, disease resistance and heavy yield on determinate plants. Crack-resistant fruits average 7 oz.

Why GRAFTED?: Grafting is a natural art that joins the top of one plant to the root of another creating a stronger plant with high yields of great tasting fruit.

www.graftedgrowers.com
Grafting workshops for home gardeners

- Grafting workshops are very popular programs for master gardeners

Photo by Carol Miles
Open Fields
Trial introduction of grafting to open-fields
Grafted cantaloupe seedlings prepared in Texas for Arizona trials (2007-2010)
Grafting trial for bacterial wilt

Grafted plants

Non Grafted plants

Photo by Dr. Josh Freeman (Univ. of FL)
### Watermelon grafting trial (2015, AZ)

#### Cumulative Total Yield (Kg m\(^2\))

<table>
<thead>
<tr>
<th>Type</th>
<th>Treatment</th>
<th>N</th>
<th># fruit / plant</th>
<th>SE</th>
<th>HSD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grafted</td>
<td>Covered</td>
<td>4</td>
<td>3.5</td>
<td>0.39</td>
<td>A</td>
</tr>
<tr>
<td>Grafted</td>
<td>Non-covered</td>
<td>4</td>
<td>3.2</td>
<td>0.32</td>
<td>A,B</td>
</tr>
<tr>
<td>Non-grafted Covered</td>
<td></td>
<td>4</td>
<td>2.1</td>
<td>0.12</td>
<td>B</td>
</tr>
<tr>
<td>Non-grafted Non-covered</td>
<td></td>
<td>4</td>
<td>2.0</td>
<td>0.21</td>
<td>B</td>
</tr>
</tbody>
</table>

\[0.0053\]

<table>
<thead>
<tr>
<th>Type</th>
<th>Treatment</th>
<th>N</th>
<th>Fruit size Kg</th>
<th>SE</th>
<th>HSD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grafted</td>
<td>Covered</td>
<td>4</td>
<td>8.2</td>
<td>0.24</td>
<td>A,B</td>
</tr>
<tr>
<td>Grafted</td>
<td>Non-covered</td>
<td>4</td>
<td>8.4</td>
<td>0.31</td>
<td>A</td>
</tr>
<tr>
<td>Non-grafted Covered</td>
<td></td>
<td>4</td>
<td>6.9</td>
<td>0.25</td>
<td>C</td>
</tr>
<tr>
<td>Non-grafted Non-covered</td>
<td></td>
<td>4</td>
<td>7.1</td>
<td>0.36</td>
<td>B,C</td>
</tr>
</tbody>
</table>

\[0.0069\]

**1800 plants per acre**

**50 ton/acre**

**Harvest Date**

- 5/21/2015
- 5/28/2015
- 6/4/2015
- 6/11/2015
- 6/18/2015
- 6/25/2015
- 7/2/2015
- 7/9/2015
**Muskmelon grafting trial (2010, AZ)**

- Grafted plants yielded more than non-grafted or direct seeded plants.

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

5606 plants per acre
Grafting effect on fruit quality - watermelon

Fruit firmness (kgf) as affected by grafting (Data by Richard Hassell)
Dynamic market of US grafted tomato seedlings in North America

Canadian nurseries sell grafted seedlings to all three countries.

US nurseries are rapidly developing propagation capability (all scales, all technology levels, GH to indoor).

Grafting capacity is well developed in Mexico. Exportation to US GH began in 2015.
Grafting for processing tomato

Emerging application
Grafting for processing tomato

Emerging application

5.5 million plant production using semi-automated grafting machines over 3 months (processing tomato grafting trials in California)

AgriVest 2015 –Part-6-Rootility
https://www.youtube.com/watch?v=koXNA3Qkdp4
Promotional factors for open fields

- Prolonged drought
- Lack of lands for rotation
- Limited fumigation tools
- New rootstocks (for biotic and abiotic stress management)
- Vigor and more yield in marginal lands

Photo by Carol Miles
Challenges

A few as example, but more...

Labor

Integrating into existing technology

Wind damage

Rootstock grow-out
Key technology – transportation and distribution
Cost analysis for grafting propagation

- Proportion of added costs
  - e.g. seed costs (%) = \(\frac{\text{SEED}_{\text{graft}} - \text{SEED}_{\text{non}}}{\text{TOTAL}_{\text{graft}} - \text{TOTAL}_{\text{non}}}\)

\(\text{NC location:}\)

- Seed: 52%
- Misc. materials: 14%
- Heating: 5%
- Transplant labor: 5%
- Chamber / clips: 24%
- Grafting labor: <1%

\(\text{PA location:}\)

- Seed: 33%
- Misc. materials: 7%
- Heating: 7%
- Transplant labor: 12%
- Chamber / clips: 13%
- Grafting labor: 24%

\$0.46 / plant \quad \text{vs.} \quad \$0.74 / plant = \text{Added cost}  
\phantom{\text{(Rivard et al., 2010)}}
Cost analysis for grafting propagation

Scenario-based theoretical analysis

Variable costs per plant for low and high volume tomato grafting in FL

<table>
<thead>
<tr>
<th>Item</th>
<th>Low Vol - Manual</th>
<th>High Vol - Automation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>20,000 plants/week</td>
<td>2,000,000 plants/week</td>
</tr>
<tr>
<td>Depreciation</td>
<td>$0.008 5.5%</td>
<td>$0.030 25.3%</td>
</tr>
<tr>
<td>Materials</td>
<td>$0.031 20.9%</td>
<td>$0.019 16.3%</td>
</tr>
<tr>
<td>Utilities</td>
<td>$0.049 33.5%</td>
<td>$0.050 42.9%</td>
</tr>
<tr>
<td>Labor</td>
<td>$0.059 40.1%</td>
<td>$0.018 15.4%</td>
</tr>
<tr>
<td>Variable Cost / plant (not including seeds)</td>
<td>$0.148</td>
<td>$0.116</td>
</tr>
</tbody>
</table>

Grafting speed = 300/h

Grafting speed = 1000/h

Lewis et al. (2014)
## Cost analysis for grafting propagation

**Scenario-based theoretical analysis**

### Variable costs per plant for low and high volume watermelon grafting in FL

<table>
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<tr>
<th>Item</th>
<th>Low Vol - Manual</th>
<th>High Vol - Automation</th>
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<td></td>
<td>20,000 plants/week</td>
<td>2,000,000 plants/week</td>
</tr>
<tr>
<td>Depreciation</td>
<td>$0.009 4.4%</td>
<td>$0.022 22.6%</td>
</tr>
<tr>
<td>Materials</td>
<td>$0.037 19.0%</td>
<td>$0.022 24.2%</td>
</tr>
<tr>
<td>Utilities</td>
<td>$0.032 16.3%</td>
<td>$0.032 35.3%</td>
</tr>
<tr>
<td>Labor</td>
<td>$0.118 60.4%</td>
<td>$0.016 17.8%</td>
</tr>
<tr>
<td><strong>Variable Cost / plant (not including seeds)</strong></td>
<td><strong>$0.195</strong></td>
<td><strong>$0.089</strong></td>
</tr>
</tbody>
</table>

Grafting speed = 150/h  
Grafting speed = 800/h  
Lewis et al. (2014)
Cost analysis for use of grafted plants

Added yield per plant (lb) needed to compensate for higher transplant prices - tomato

<table>
<thead>
<tr>
<th>Transplant price premium</th>
<th>$ 0.40</th>
<th>$ 0.80</th>
<th>$ 0.80</th>
<th>$ 1.60</th>
<th>$ 2.00</th>
<th>$ 2.40</th>
<th>$ 2.80</th>
</tr>
</thead>
<tbody>
<tr>
<td>$ 0.50</td>
<td>1.79</td>
<td>0.74</td>
<td>0.46</td>
<td>0.34</td>
<td>0.27</td>
<td>0.22</td>
<td>0.19</td>
</tr>
<tr>
<td>$ 0.75</td>
<td>2.68</td>
<td>1.10</td>
<td>0.69</td>
<td>0.51</td>
<td>0.40</td>
<td>0.33</td>
<td>0.28</td>
</tr>
<tr>
<td>$ 1.00</td>
<td>3.57</td>
<td>1.47</td>
<td>0.93</td>
<td>0.68</td>
<td>0.53</td>
<td>0.44</td>
<td>0.37</td>
</tr>
</tbody>
</table>

Transplant price premium = Price grafted – Price non-grafted
A baseline yield = 9.3 lb/plant

Data by Olya Rysin (NCSU)
Figure 1. Estimated profit given different yields of grafted seedless watermelon.

Baseline non grafted yield = 25 tons/acre

Figure 2. Estimated profit given different prices of grafted watermelon transplants.

Source: Non-grafted and Grafted Seedless Watermelon Transplants: Comparative Economic Feasibility Analysis
Galinato et al. 2015, Washington State University Extension Publication TB08E
More grafting innovation needed!

- Automation for seedless watermelon
- Rootstocks for abiotic stress management (drought, salinity, heat)
- “Postharvest” technologies for seedling transportation
- Integration with other farm management technologies
- Value added crop production with enhanced quality

http://www.rikou.ryukoku.ac.jp/~nomura/HRS2012/
Thank you!
(www.vegetablegrafting.org)