Current Situation of Grafted Vegetable Seedling Industry and Its Mechanization Development in Taiwan

Hsueh-Shih Lin, Chin-Yuan Chang, Chang-Sheng Chien, Shih-Fang Chen, Wei-Ling Chen, Yung-Chu Chu, Ai-Hua Yang, Yu-Kuang Hseuh, Sheng-Chih Chang

Taichung District Agricultural Research and Extension Station (TCDARES)
Tainan District Agricultural Research and Extension Station (TNDARES)
Taiwan Seed Improvement and Propagation Station (TSIPS)
Council of Agriculture (COA), Executive Yuan, Taiwan

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Why do we use grafted seedling?

- soil borne disease, pest – biotic stresses
- Chilling, Flooding, Salt stress – abiotic stresses
- Increase vigor, yields, quality (http://cals.arizona.edu/grafting/)

Left: Grafted Tomatoes,
Right: Non grafted tomatoes infected by *Fus.*#3

http://www.graftingveg.com/why-grafting/

Flooding
First started by grafting watermelons to gourds to reduce the incidence of the soil-borne disease *Fusarium* in Japan during the 1920s.

First eggplant (*Solanum melongena* L.) grafted on scarlet eggplant (*Solanum integrifolium* Poir.) in the 1950s.

Grafting tomato (*Lycopersicon esculentum* Mill.) was introduced commercially in the 1960s.

The first commercial model of a grafting robot (GR800 series, Iseki & Co. Ltd., Matsuyama, Japan) in 1993.

(Kubota et al., 2008)
Table 1. Estimation of grafted vegetables used in some Asian countries and the USA.

<table>
<thead>
<tr>
<th>Crop</th>
<th>Japan</th>
<th>Korea</th>
<th>China</th>
<th>Taiwan</th>
<th>USA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Watermelon</td>
<td>92%</td>
<td>95%</td>
<td>20%</td>
<td>35%</td>
<td>NA</td>
</tr>
<tr>
<td>Cucumber</td>
<td>75%</td>
<td>75%</td>
<td>30%</td>
<td>11%</td>
<td>NA</td>
</tr>
<tr>
<td>Melons</td>
<td>30%</td>
<td>90%</td>
<td>5%</td>
<td>0.1%</td>
<td>NA</td>
</tr>
<tr>
<td>Bitter melon</td>
<td>NA</td>
<td>NA</td>
<td>2%</td>
<td>30%</td>
<td>NA</td>
</tr>
<tr>
<td>Pickling melon</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Tomato</td>
<td>40%</td>
<td>25%</td>
<td>1%</td>
<td>25%</td>
<td>70%</td>
</tr>
<tr>
<td>Eggplant</td>
<td>55%</td>
<td>20%</td>
<td>1%</td>
<td>1.3%</td>
<td>NA</td>
</tr>
<tr>
<td>Pepper</td>
<td>5%</td>
<td>10%</td>
<td>1%</td>
<td>2.5%</td>
<td>NA</td>
</tr>
</tbody>
</table>

(Článek et al., 2010)
Table 2. Estimation of grafted vegetables used in some European countries.

<table>
<thead>
<tr>
<th>Crop</th>
<th>Spain</th>
<th>Italy</th>
<th>France</th>
<th>Netherlands</th>
</tr>
</thead>
<tbody>
<tr>
<td>Watermelon</td>
<td>43%</td>
<td>12%</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Melons</td>
<td>1%</td>
<td>3%</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Cucumber</td>
<td>0.3%</td>
<td>1.5%</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Tomato</td>
<td>53%</td>
<td>0.5%</td>
<td>50%</td>
<td>75%</td>
</tr>
<tr>
<td>Eggplant</td>
<td>4%</td>
<td>7.3%</td>
<td>65%</td>
<td>75%</td>
</tr>
<tr>
<td>Pepper</td>
<td>0.1%</td>
<td>0.3%</td>
<td>NA</td>
<td>NA</td>
</tr>
</tbody>
</table>

(Lee et al., 2010)
Current situation of Grafted seedling - Asia

- In 1998 was estimated to be **540 million** transplants in Korea and **750 million** in Japan. (Lee et al., 1998)

- More than **700 million** grafted seedlings were estimated to be produced in 2008 in Korea and Japan. (Lee et al., 2010)

- In 2009 was estimated that about **200 million** seedlings be used in China. (Lee et al., 2010)
Current situation of Grafted seedling - Europe

- Spain is by far the leading country in Europe by using grafted vegetables, which was about 129.8 million in 2009. (Hoyos Echeverría, 2010)
- Italy about 47.1 million (Morra and Bilotto, 2009)
- France about 28 million (Lee et al., 2010)
Current situation of Grafted seedling - America

- A survey conducted at the University of Arizona in 2002 and 2006 showed that the total number of grafted seedlings utilized in North America was 30 to 40 million seedlings. (http://cals.arizona.edu/grafting/)
Current situation of Grafted seedling - Taiwan

- More than 80% of watermelon grafted seedling was used in Taiwan.
- Over 10 million tomato plants were grafted in Taiwan in 2002. (Chiu et al., 2007)

- Vegetable grafting is becoming increasingly popular worldwide.
Current status of grafted vegetables used in Taiwan estimated

<table>
<thead>
<tr>
<th>Crop</th>
<th>No. of grafted seedlings</th>
<th>Rootstock</th>
<th>Grafting methods</th>
</tr>
</thead>
<tbody>
<tr>
<td>Watermelon</td>
<td>20 million</td>
<td>■ Pumpkin</td>
<td>■ hole insertion grafting</td>
</tr>
<tr>
<td></td>
<td></td>
<td>■ bottle gourd</td>
<td>■ tongue approach grafting</td>
</tr>
<tr>
<td></td>
<td></td>
<td>■ Watermelon</td>
<td></td>
</tr>
<tr>
<td>Bitter melon</td>
<td>1 million</td>
<td>■ sponge gourd</td>
<td>■ cleft grafting</td>
</tr>
<tr>
<td></td>
<td></td>
<td>■ Pumpkin</td>
<td>■ tongue approach grafting</td>
</tr>
<tr>
<td>Tomato</td>
<td>20 million</td>
<td>■ eggplant</td>
<td>■ tube grafting</td>
</tr>
<tr>
<td></td>
<td></td>
<td>■ tomato</td>
<td>■ splice grafting</td>
</tr>
<tr>
<td>Cucumber</td>
<td>1.5 million</td>
<td>■ pumpkin</td>
<td>■ tongue approach grafting</td>
</tr>
<tr>
<td></td>
<td></td>
<td>■ bottle gourd</td>
<td></td>
</tr>
</tbody>
</table>
**Watermelon**

hole insertion grafting

process:
A. remove apical bud and make a hole on top of bottle gourd seedling as a rootstock
B. cut the end of watermelon hypocotyl to V-shaped as a scion
C. put scion into the hole of rootstock
D. completed

(Chiu et al., 2007)
Bitter melon
cleft grafting

Process:
A. rootstock was mitered in downward direction
B. scion was mitered to make a tapered wedge
C. placing the scion into the split on rootstock, and combined with a clip.
D. completed

http://net.1nongjing.com/a/201510/117809.html
Tomato

✓ rootstock and scion are mitered with the same angle.
✓ put the rootstock into soft rubber tube and combine with scion
Cucumber — tongue approach grafting

- Rootstock is cut downward to slant angle.
- Scion is cut to slant angle of inverse.
- Place the scion into the split on rootstock, combined with clip.
Team project (from 2015....) Upgrading graft technology on important vegetable crops (Tomato)

Taiwan Seed Improvement and Propagation Station (TSIPS)
Taiwan Agricultural Research Institute (TARI)
Taichung District Agricultural Research and Extension Station (TCDARES)
Tainan District Agricultural Research and Extension Station (TNDARES)
Fengshan Tropical Horticural Experiment Branch (TARI-FTHEB)
The World Vegetable Center (AVRDC)
Content of the team project

1. Grafting mechanization
2. Healing techniques for grafted plants
3. Breeding of stress resistant rootstocks
4. Compatibility study between rootstock and scion
5. Survey of vegetable grafting industry
Tomato: Manual Grafting

Eggplant Rootstock + Tomato Scion = grafted seedling

Soft rubber tube
Scion-rootstock combining accessory

- Rubber tube
  Solanaceae
  Miter Grafting

- Grafting clip
  Cucurbitaceae
  Top Cleft Grafting

- Tube clip
  Solanaceae
  Miter Grafting
A typical schedule for grafting.

(Rivard and Louws, 2006)
Nursery stage

- Uniformity
- Size of stems
- Timing for grafting
Healing stage

After rootstock and scion are grafted together, both vascular tissues must be reconnected so that water and nutrients supplied could continue. This process should be processed in a semi-enclosed chamber where humidity, light, and temperature can be controlled.

- **Temperature**: 25 °C ~ 30 °C
- **Humidity**: 85% ~ 95%
- **Light**: Dark, two to four days
  Partial, three days after dark
Healing chamber: Plastic tunnel
(Traditional, cheap)

(Chiu et al., 2007)
Healing chamber: Growth chamber (artificial environment, expensive)
Acclimation stage

- Temperature: 30 ℃
- Humidity: Controlled with water pad
- Light: 50% Shading
Although grafting is a simple process, it requires careful attention to rootstock selection, seeding dates, healing, and planting in the field.

- Choose the best combination of scion and rootstock cultivars
- Uniformity is key factor
- Construct a healing chamber
- Choose the best time and methods to graft
- Acclimation
- Transplanting process

(Rivard and Louws, 2006)
Why use grafting machine??

Hyper-aged workers

Grafting worker needs: Eyesight, skilful

<table>
<thead>
<tr>
<th>Job</th>
<th>Total</th>
<th>15~24</th>
<th>25~44</th>
<th>45~64</th>
<th>65~over</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vegetables Planting</td>
<td>23,879</td>
<td>36</td>
<td>2,990</td>
<td>14,953</td>
<td>5,900</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.15%</td>
<td>12.5%</td>
<td>62.6%</td>
<td>24.7%</td>
</tr>
</tbody>
</table>

2013, Directorate-General of Budget, Accounting and Statistics, Taiwan

Unit: Person
<table>
<thead>
<tr>
<th>Country</th>
<th>Mechanical</th>
<th>Crop</th>
</tr>
</thead>
<tbody>
<tr>
<td>Taiwan</td>
<td><strong>Tubing-Grafting Robotic System</strong></td>
<td><strong>Solanaceae</strong></td>
</tr>
<tr>
<td></td>
<td><strong>Passion Fruit Grafting Machine</strong></td>
<td><strong>Passion fruit</strong></td>
</tr>
<tr>
<td>Netherlands</td>
<td>ISO Graft 1000, 1100, 1200</td>
<td></td>
</tr>
<tr>
<td>Spain</td>
<td>EMP-300, INJESTAR</td>
<td><strong>Solanaceae</strong></td>
</tr>
<tr>
<td>Italy</td>
<td>GR 300/3</td>
<td></td>
</tr>
<tr>
<td>Israel</td>
<td>Plant-Grafting Robot (Prototype)</td>
<td></td>
</tr>
<tr>
<td>Japan</td>
<td>GRF800-U, GRF803-U, GR800-B</td>
<td></td>
</tr>
<tr>
<td>Korea</td>
<td>GR600C-S</td>
<td><strong>Cucurbitaceae</strong></td>
</tr>
<tr>
<td>China</td>
<td>2JC-600B, 2JC-1000A</td>
<td></td>
</tr>
</tbody>
</table>

**8 Country, 15 Mechanical**
Grafting Machine - Taiwan


Passion Fruit Grafting Machine (2001)
Scion-rootstock combining types

Chen et al., 2010
Passion Fruit Grafting Machine

- **Chung Hsing**, Chiayi University, TCDARES
- **Crop**: Passion Fruit
- **Method**: Cleft Grafting
- **Fixed**: Grafting Clip (PE)
- **Capability**: 200 Plants /hr
- **Staff**: Single operator
- **Feeding**: Manual
- **Grafting**: Automatic
Passion Fruit Grafting Machine

- Scion
- Wedge Cut
- Locate
- Grafting Clips
- Select
- Array
- Feeding
- Rootstock
- Cut
- V-Shaped
- Grafting
- Clamping
- Grafting Seeding
Tubing-Grafting Robotic System

National Ilan, Taiwan University, and TNDARES
Tubing-Grafting Robotic System

- **Crop**: Tomato scion & eggplant rootstock
- **Method**: Splice Grafting
- **Fixed**: Rubber tube
- **Capability**: 327 plants/hr
- **Staff**: Single operator
- **Feeding**: Manual
- **Grafting**: Automatic

(Chen et al., 2010; Chung et al., 2005)
Grafted Seedlings

Rootstock

Scion

Tubing-Grafting Robotic System
Tubing-Grafting Robotic System

Rootscock Chucking

Rootscock Cutting

Fixed Tube

Grafted Seedlings

Scion Chucking

Scion Cutting
Grafting Mechanize (TSIPS)

- Restart the Tubing-Grafting Robotic System
- Study for grafting efficiency of the Roboter
  - Grafting speed: 200~250 plants/hr
  - Successful rate: 92-97%
  - Grafted seedling had 90-96% recovered
Grafting Mechanize (TCDARES)

- **Type:** Spain Conic-System EMP-300
- **Crop:** Solanaceae, Cucurbitaceae
- **Method:** Splice Grafting, Angle (20°, 30°, 40°)
- **Fixed:** Tube Clips
- **Capability:** 300~500 plants/hr
- **Staff:** Single operator
- **Feeding:** Manual
- **Grafting:** Automatic
Feeding by workers: the scion and rootstock

Automatic chucking the plant ➔ Cut ➔ Moving the plant to grafting position ➔ Held the rootstock and scion with tube clip ➔ Chucking the grafting seedling to conveyor by a machine arm
Grafting Mechanize (TCDARES)

<table>
<thead>
<tr>
<th>Item</th>
<th>Manual</th>
<th>Semi-Automatic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average rate</td>
<td>15~20 Sec</td>
<td>7.5~12 Sec</td>
</tr>
<tr>
<td>Capability</td>
<td>240~180 plants/hr</td>
<td>480~300 plants/hr</td>
</tr>
</tbody>
</table>
Advantage: Less professional, Easy use, Easy training (5~30min).
Key for a successful grafting

Rootstock & Scion
- Stem size
- Seedling quality
- Age of seedlings
- Uniformity
- Cultural medium
- etc…
Spain Agrupamex

- **Type:** INJESTAR
- **Crop:** Solanaceae
- **Grafting:** Splice grafting
- **Fixed:** Tube Clips
- **Capability:** 450 plants/hr
- **Staff:** Single operator
- **Feeding:** Manual
- **Grafting:** Automatic
◆ Machine can cut the scion and rootstock, and use tube clips to graft, but need worker to operate.
◆ Reduce the burden of workers.
◆ Grafting capability: 10 seconds/plant.
◆ Uniform cut angle.
# Netherlands ISO-Group

<table>
<thead>
<tr>
<th>Type</th>
<th>ISO Graft 1000</th>
<th>ISO Graft 1100</th>
<th>ISO Graft 1200</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crop</td>
<td>Tomato</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Method</td>
<td>Splice Grafting (Miter Cut or Cutting)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fixed</td>
<td>Fin Tube</td>
<td>Tube Clip</td>
<td></td>
</tr>
<tr>
<td>Capability</td>
<td>1000</td>
<td>1,050</td>
<td></td>
</tr>
<tr>
<td>Staff</td>
<td>1</td>
<td>2</td>
<td>&gt;1</td>
</tr>
<tr>
<td>Feeding</td>
<td>Semi-Automatic</td>
<td>Manual</td>
<td>Semi-Automatic</td>
</tr>
</tbody>
</table>
Netherlands  ISO-Group 1000

<table>
<thead>
<tr>
<th>Type</th>
<th>1000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fixed</td>
<td>Fin Tube</td>
</tr>
<tr>
<td>Feeding</td>
<td>Semi-Automatic 5 Seedling</td>
</tr>
<tr>
<td>Grafting</td>
<td>Vertical Cut Automatic</td>
</tr>
</tbody>
</table>

电影
Netherlands ISO-Group 1100

<table>
<thead>
<tr>
<th>Type</th>
<th>1100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fixed</td>
<td>Tube Clips</td>
</tr>
<tr>
<td>Feeding</td>
<td>Manual</td>
</tr>
<tr>
<td>Grafting</td>
<td>Vertical Cut</td>
</tr>
</tbody>
</table>

movie
Netherlands ISO-Group 1200

<table>
<thead>
<tr>
<th>Type</th>
<th>1200</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fixed</td>
<td>Tube Clips</td>
</tr>
<tr>
<td>Feeding</td>
<td>Semi-Automatic 5 Seedling</td>
</tr>
<tr>
<td>Grafting</td>
<td>Vertical Cut</td>
</tr>
</tbody>
</table>

[Movie]
Netherlands  ISO-Group feature

- Fins can help to open the tube, and easy to graft and match.
- The capability is 1000 plants/hr, and need two workers, therefore the capability is 500 plants/hr/worker.
- Feeding with hole tray ➔ more efficient with plant auto-chucking unit ➔ more expensive with high-quality seedling and uniform size.
Italy Atlantic Man. s.r.l.

- **Type:** GR 300/3
- **Crop:** (1.2~4mm) Cucurbitaceae, Solanaceae
- **Method:** Splice Grafting
- **Fixed:** Grafting clip or Tube clip
- **Capability:** 600 seedlings/hr
- **Staff:** Single operator
- **Feeding:** Manual
- **Grafting:** Manual
◆ Machine cut and transport the scion and rootstock.
◆ While held the seedling and rootstock need workers to support the seedling.
Israel Virentes

- **Type:** Plant-Grafting Robot (Prototype)
- **Crop:** Solanaceae & Cucurbitaceae
- **Method:** Splice grafting
- **Fixed:** Tube clip
- **Capability:** 840 plants/hr
- **Staff:** Single operator
- **Feeding:** Plug, Manual
## Japan - ISEKI

<table>
<thead>
<tr>
<th>Type</th>
<th>GRF803-U</th>
<th>GRF800-U</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crop</td>
<td>Cucurbitaceae</td>
<td></td>
</tr>
<tr>
<td>Method</td>
<td>Splice Grafting</td>
<td></td>
</tr>
<tr>
<td>Fixed</td>
<td>Grafting Clip</td>
<td></td>
</tr>
<tr>
<td>Capability (hr)</td>
<td>900</td>
<td>800</td>
</tr>
<tr>
<td>Staff</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Feeding</td>
<td>Manually</td>
<td>Semi-automatic</td>
</tr>
<tr>
<td>Grafting</td>
<td>Automatic</td>
<td></td>
</tr>
</tbody>
</table>
- Worker puts the hole tray into machine, then the machine grafting seedlings automatically.
- The support device improve the success of grafting.
- Rootstock keeps a single leaf.
- The rootstock had root cut.
Korea Helper Robotech

- **Type**: GR600C-S
- **Crop**: Cucurbitaceae, Solanaceae
- **Method**: Splice Grafting
- **Fixed**: Grafting Clip
- **Capability**: 650 Seedlings/hr
- **Staff**: 2~3 Operator
- **Feeding**: Manually
- **Grafting**: Automatic
Korea Helper Robotech

- 2 workers feeding the scion and rootstock.
- Automatic cut (Arc) and grafting.
- 1 worker take the grafting seedling from the conveyor.

(movie)
### China

<table>
<thead>
<tr>
<th></th>
<th>2JC-600B</th>
<th>2JC-1000B</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Type</strong></td>
<td>2JC-600B</td>
<td>2JC-1000B</td>
</tr>
<tr>
<td><strong>Crop</strong></td>
<td>Cucurbitaceae</td>
<td></td>
</tr>
<tr>
<td><strong>Method</strong></td>
<td>Top plug-in grafting</td>
<td></td>
</tr>
<tr>
<td><strong>Capability (plants/hr)</strong></td>
<td>600</td>
<td>1,125</td>
</tr>
<tr>
<td><strong>Staff</strong></td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td><strong>Feeding</strong></td>
<td>Operator action</td>
<td>Semi-automatic</td>
</tr>
<tr>
<td><strong>Grafting</strong></td>
<td>Automatic</td>
<td></td>
</tr>
</tbody>
</table>
Two workers feeding the scion and rootstock.

Hand poke leaf and puncture hole the scion.
China  2JC-1000A

◆ Automatic take 5 seedling.
◆ Similar to japan machine.
Grafted tomato industry survey - Taiwan
(TNDARES, TSIPS, TCDARES)

Numbers of grafted seedlings/year

- 2,000 k (13%)
- 1,500 k (22%)
- 1,000 k (8%)
- 500 k (22%)
- 100 k (35%)
Analysis of productive cost for grafted seedling

- Graft Industry
- 6 Nursery
- Operating Investigation
- Ex: Tomato grafted Seedlings
Grafted industry survey (tomato) - Taiwan

<table>
<thead>
<tr>
<th>Investigated items of productive cost in grafting industry</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Variable cost</strong></td>
</tr>
<tr>
<td>Material</td>
</tr>
<tr>
<td>Seed, Fertilizer, Water, Electricity, Fuel, Pesticide, Agricultural materials</td>
</tr>
<tr>
<td>Staff</td>
</tr>
<tr>
<td>Grafting workers</td>
</tr>
<tr>
<td>Others</td>
</tr>
<tr>
<td>Management and marketing</td>
</tr>
<tr>
<td><strong>Fixed cost</strong></td>
</tr>
<tr>
<td>Land</td>
</tr>
<tr>
<td>Land rent, Capital interest</td>
</tr>
<tr>
<td>Depreciation</td>
</tr>
<tr>
<td>Farm machinery, Agro-facilities, Delivery vehicle</td>
</tr>
</tbody>
</table>

(TNDARES, TSIPS, TCDARES)
Grafted industry survey (tomato) - Taiwan

Production cost

- Material: 78%
- Staff: 13%
- Others: 3%
- Land: 1%
- Depreciation: 5%

(TNDARES, TSIPS, TCDARES)
Materials cost

- Scion: 58%
- Other Material: 20%
- Rootstock: 11%
- Fertilizer: 1%
- Water: 1%
- Electricity: 5%
- Fuel: 3%
- Pesticide: 1%

(TNDARES, TSIPS, TCDARES)
Future perspectives

-Short term
  ◆ Investigation: Scion and rootstock relationship
  ◆ Extension: Adopt automatic grafting machine in grafted vegetable industry

-Long term
  ◆ Machinery: Develop grafting machine for Taiwan graft industry
  ◆ Breeding: stress resistant tomato rootstock
rootstock EG203 (eggplant plant)
AVRDC

Known-you seed Co., Taiwan

Enza Zaden Netherlands
Thanks for your attention......