Vegetable Grafting International Field Trip Report – Part I: Taiwan and Japan

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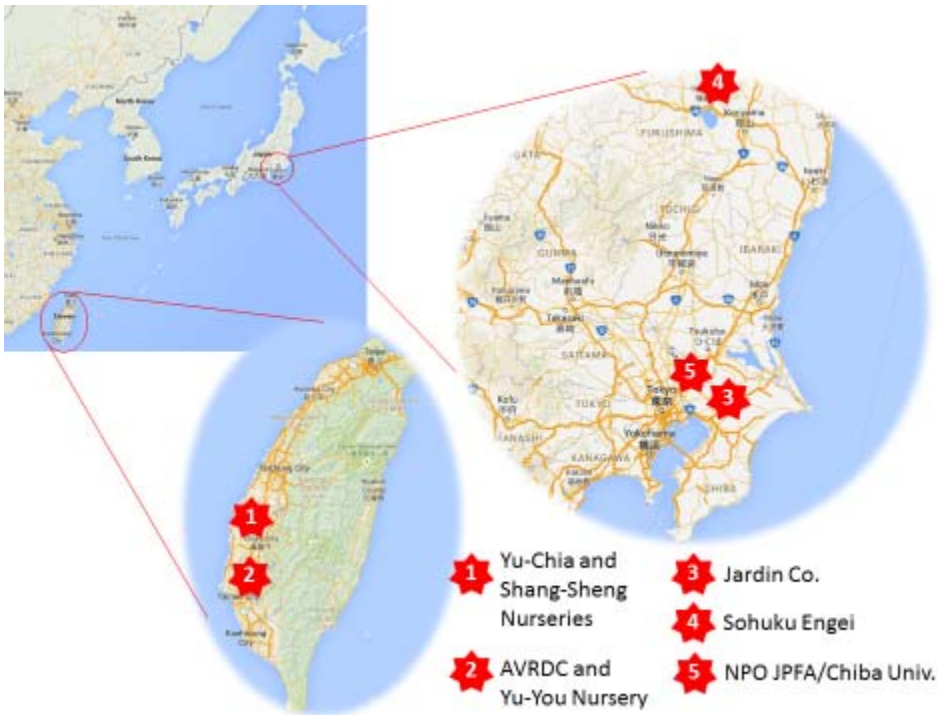

Introduction

Vegetable grafting is an IPM tool used to manage soil-borne diseases, pests and abiotic stresses problematic in production. As part of a Vegetable Grafting project funded by USDA Specialty Crop Research Initiative (SCRI), we organized international field trips for US stakeholders to visit selected nurseries to learn about commercial vegetable grafting worldwide. In 2015, our field trip went to Asia (Taiwan and Japan) during August 16 - 23 with 13 participants. The itinerary is shown in Table 1.

Table 1. 2015 field trip itinerary.

Date	Activity
Day 1 (8/16, Sun)	• Arrive in Taipei/Taoyuan International Airport (TPE), Taiwan
Day 2 (8/17, Mon)	• Visit Yu-Chia Nursery and Shang-Sheng Nursery producing grafted seedlings
Day 3 (8/18, Tue)	• Visit AVRDC (The World Vegetable Center) • Visit Yu-You Nursery
Day 4 (8/19, Wed)	• Fly from Taipei/Taoyuan (TPE) to Narita International Airport (NRT), Japan
Day 5 (8/20, Thur)	• Visit Jardin Co.
Day 6 (8/21, Fri)	• Visit Sohuku Engei
Day 7 (8/22, Sat)	• Visit NPO Japan Plant Factory Association • Visit Mirai commercial plant factory
Day 8 (8/23, Sun)	• Leave Japan

Taiwan

In Taiwan, watermelons and tomatoes have the largest acreage among grafted vegetables. Almost all the large-sized watermelon cultivars are grafted (Huang, 2014; Lee et al., 2000). The total acreage of grafted cucurbits including watermelons (*Citrullus lanatus*), cucumbers (*Cucumis sativus*), melons (*Cucumis melo*), and bitter melons (*Momordica charantia*) reached approximately 5,541 ha, while 1,138 ha was reported for production of grafted solanaceous vegetables including tomatoes, eggplants, and peppers (Lee et al., 2010). Grafted plants have also been used in Chinese okra (*Luffa acutangula*) production to overcome soil-borne diseases (Huang, 2014). Grafted vegetable production under protected culture has been increasing in recent years due to the problems associated with intensive continuous cropping systems. Manual grafting is employed by most nurseries in Taiwan, although grafting machines have been researched and developed by some universities since late 1990s. Asian Vegetable Research and Development Center (AVRDC), The World Vegetable Center (http://www.avrdc.org/) has played an important role in vegetable grafting technology development and utilization in Taiwan. AVRDC introduced open-pollinated rootstock cultivars and grafting to the vegetable industry in Taiwan in 1990s and since then AVRDC has been working actively to promote the use of vegetable grafting by smallholder farmers in Asia, Africa, and Oceania. Rootstocks released by AVRDC have been commonly used in tomato grafting in Taiwan, especially the eggplant-based rootstock with good disease resistance and tolerance to flooding. The tomato grafting technique using latex tubes developed by AVRDC is widely used by vegetable nurseries in Taiwan. With an emphasis on grafted tomato, AVRDC is currently launching a new grafting project for extensive selection and screening of Solanaceae rootstocks by exploring over 20,000 accessions in the AVRDC genebank, in order to provide improved rootstocks to cope with various biotic and abiotic stresses (Keatinge et al., 2014).

1. Yu-Chia Nursery and Shang-Sheng Nursery

Both nurseries are located in Chiayi County in southwestern part of Taiwan in the vegetable production region. Yu-Chia Nursery produces grafted tomato seedlings almost year-round (~1 million grafts per year) and Shang-Sheng nursery produces various grafted fruiting vegetable seedlings including tomato, pepper, chili pepper, and bitter melon (2 million grafted seedlings produced per year). Both nurseries ship their plants to all parts of Taiwan including low- and high-land production regions.

One unique aspect of grafting in Taiwan that the tour group found was the use of eggplant rootstock for tomato grafting (Fig. 1). AVRDC (World Vegetable Center) developed several eggplant rootstocks (http://avrdc.org/seed/improved-lines/rootstock/). EG203 is an open-pollinated eggplant originating from India and known to have resistance to saturated soils (flooding), fusarium wilt, bacterial wilt and root-knot nematode. Demand for the flooding resistance seems to be critical in tomato production in Taiwan where annual precipitation often exceeds 3,000 mm (118 inches).

Grafting is done manually in both nurseries using a low-cost grafting tube. This grafting tube is made of low-density rubber tubing, manufactured locally as a bicycle part (Fig. 2) (800 NT$ per kg of tubing or approximately 0.2 US cents per tube). Although the tubes do not have a slit, they naturally degrade and fall off as plants grow. Another unique feature we noticed for both nurseries was that graft union position is high, approximately 3-4 inches (8-10 cm) above the tray surface. Yu-Chia Nursery owner explained that farmers preferred high union position as they tend to plant the transplants deep in the soil bed and removing rootstock side shoots developed from the remaining axils was not problematic in Taiwan (presumably due to the small farm size). Average grafting speed is 250 grafts per hour. Timing of grafting for the plants we observed was 25 and 35 days after seeding for scion (tomato) and rootstock (eggplant), respectively. Rootstock seeds were produced by the nurseries themselves from a small number of seeds originally provided by AVRDC.

Healing is done in distinctly different systems in these two nurseries. Yu-Chia Nursery uses commercially available healing chambers equipped with ultra-sonic humidifier, temperature control and white fluorescent lamps (Fig. 3). They keep the plants for 3 days in near saturated humidity at 25°C in the chambers and then move them to shelving units placed in a shaded greenhouse for an additional 4 days to complete the healing process (Fig. 4). Shang-Sheng Nursery uses a healing system designed and constructed by themselves using a shipping container equipped with fluorescent lamps, temperature control and evaporative cooling system. In addition to grafted tomato plants, we saw well-healed grafted pepper seedlings at Shang-Sheng Nursery (Fig. 5).

Price for grafted tomato seedlings was 7.00-7.50 NT$ (without seed costs, ~25 US cents per plant), approximately three times more expensive than non-grafted tomato seedlings (2.00-2.50 NT$ without seed costs). Hourly wage for grafting workers is 110 NT$ (~US$3.67). Together with the low material costs (such as grafting tubes), Taiwan growers have access to low cost grafted seedlings. However, the labor issue is still problematic as the Taiwan government does not allow agricultural sectors to hire immigrant workers from Southeast Asia.

2. Yu-You Nursery

The third nursery we visited in Taiwan is located in Tainan City, and specialized in cucurbit seedling production (watermelon, melon, and winter melon (*Benincasa hispida*)). Grafted watermelon is the majority of production, reflecting the high percentage of use of grafted watermelon in Taiwan. At the peak season, they graft as many as 50,000 plants per day.

We observed watermelon grafting with squash rootstock. Grafting is done manually using the hole insertion method at a speed of approximately 200 grafts per hour. Squash rootstock plants were grown in 50-cell trays. The unique procedure we noticed was their preparation of scion plants. Etiolated scion (watermelon) seedlings (sprouts) germinated in flats filled with river sand (500 seeds per flat) and grown in a warm and dark chamber for 2-3 days were used for grafting (Fig. 6). The nursery developed their own grafting tools (knives and piercing tool, Fig. 7). Their grafting process was: 1) pinch to remove rootstock shoot tip, 2) pierce a hole on the top of rootstock seedling between the two cotyledons, leaving the piercing tool attached, 3) make one angle cut on a scion seedling, and 4) remove the piercing tool and insert the scion into the hole.

Trays of grafted seedlings are placed inside opaque plastic containers stacked in the warehouse building for a few hours in summer before moving into low-tunnel healing chambers in the field (Fig. 8). In winter time, these containers will be placed in a heated shipping container (30°C) overnight before moving into the low tunnels. For low tunnels, they adjust the covering materials and layers for different stages, increasing the light by reducing the shade towards the end of healing process. Over the healing period, axillary shoots tend to grow out on the rootstocks, and workers remove them during the several inspections which are carried out before shipping.

Price for grafted watermelon seedlings is 6.50-7.00 NT$ per seedling including seeds (22-23 US cents). For expensive specialty cultivars, they would have to add 4.00 NT$ (12 US cents) to cover the seed expense. Watermelon cultivars grown in Taiwan are mostly seeded types. One task ahead might be modification of the propagation process for seedless cultivars as seedless watermelon becomes more popular in the future.

3. AVRDC

AVRDC (Asian Vegetable Research and Development Center) was founded in 1971 with a focus on tropical East Asia, and now the World Vegetable Center is working on various projects to support developing countries worldwide. The tour group visited the headquarters and the research station located in Tainan, Taiwan. AVRDC's achievements include the development of solanaceous rootstocks suitable for tropical climate and international outreach activities (http://avrdc.org/seed/improved-

lines/rootstock/). These rootstocks are open pollinated (Fig. 9) and therefore the seed costs can be many times lower than for commercial hybrid rootstocks. The seeds are available through AVRDC's gene bank, whose collection (439 species and over 61,000 accessions) is world renown. The tour group had the opportunity to visit the gene bank facilities, visit the demonstration field (Fig. 9), and exchanged information with the scientists.

Japan

Commercial grafting nurseries in Japan have developed since the 1980s (before then, farmers were grafting by themselves, instead of buying grafted plants). To support the increasing demand for grafted plants, supporting technologies were also developed during the 1980s, and included tube grafting for tomato and eggplant (Itagi et al., 1990), automation such as grafting robots (Kurata, 1994), and healing chambers using electric lighting and multi-shelving units. In the 1990s to early 2000s, nursery technologies and systems to produce uniform scion and rootstock seedlings were developed and commercialized (Kubota and Chun, 2000). Today many large grafting nurseries use the 'Closed-type Plant Production System' (CPPS) especially for tomato and eggplant seedlings. Commercial grafting nurseries have been established for cucumber, tomato and eggplant, and they also graft watermelon and muskmelon but at a much lesser extent (as farmers usually graft these crops themselves). Use of grafted plants is exceeding 90% (production area basis) for watermelon and cucumber, 79% for eggplant and 58% for tomato per the survey reported by the Japanese government in 2011 (NARO, 2011). Japanese grafting nurseries today use 342 scion cultivars and 85 rootstocks for tomato and 230 scion cultivars and 51 rootstocks for cucumber (T. Itagi, personal communication). Large nurseries use advanced technologies such as controlled environment chambers for healing or growing plants under electric lighting. However, usage of automated grafting is not common as the successful use requires good knowledge of mechanics as well as techniques to grow uniform plants that meet the machine specifications. The tour selected two nurseries to see advanced grafting technologies, and also visited the university and the organization that had a pivotal role in this technology development.

1. Jardin Co., Ltd.

Established in December 1979, Jardin Co., Ltd. (http://www.jsjardin.co.jp/) produces vegetable and ornamental seedlings and containerized plants for both home gardeners and commercial growers. Its headquarter office is located in Takefukuro Inzai, Chiba Prefecture. With 8 production sites (total of about 14 ha greenhouses/fields), Jardin has an annual production capacity of approximately 50 million seedlings, among these are 6 million grafted vegetable plants including tomato (the largest number), eggplant, pepper, watermelon, and melon. Indoor facilities are used for grafted seedling production, and include indoor growth rooms equipped with fluorescent lamps (CPPS) for growing scion and rootstock plants (Fig. 10) and healing rooms for grafted plants. There are 20 grafters employed year-round in the grafted vegetable department, while an additional 80 grafters may be needed during the busy seasons. Manual grafting can achieve 150-200 grafts per hour on average. Growers can specify the rootstocks needed when placing an order for grafted plants, and grafting compatibility will be checked with new scion-rootstock combinations at the nursery, typically using 100 seedlings. The price of grafted plants is about $0.90 excluding the seed cost. It may be increased by up to 20% for larger grafted plants.

Only tomato grafting was being conducted when we toured the facilities (Fig. 11). About 25% of the grafted tomato plants are pinched to force the plants to develop two leaders; pinched plants are used by growers primarily due to the high cost of tomato seeds. Pinching is performed 9 days after grafting (healing for 5 days and another 4 days in the growth room), and plants can be shipped 12 days after pinching (Fig. 12). A walk-in shipping container is modified for use as a healing chamber which can accommodate 12 nursery carts with each cart holding 25 200-cell trays of grafted tomato plants (Fig.

13). Plant carts are rotated once a day inside the healing chamber to optimize plant exposure to uniform light and humidity. The healing conditions used for grafted tomato plants are specified as follows: 27 ^{o}C, an hourly cycle of 45 min light (fluorescent lamps; approximately 30 μmol m^{-2} s^{-1} photosynthetic photon flux over the plant canopy) and 15 min darkness, 90% RH (dry fog system) for the first 3-4 days then reduced to 70%. Grafted plants stay in the healing chamber for 4-5 days depending upon the cultivars used.

Although we did not see cucurbit grafting during our visit, we learned about the healing conditions used for grafted cucurbits at Jardin. The one-cotyledon method is used for grafting watermelon, melon, and cucumber. Grafted watermelon and melon are kept in the healing chamber for 7 days with 90% RH gradually reduced to 60-70%, while grafted cucumber are kept for 5-6 days at 95% RH. Healing temperature is maintained at 25-27 ^{o}C and 26-28 ^{o}C for winter and summer season, respectively. Different from grafted tomato, a 12-hr light and 12-hr dark cycle is used for healing grafted watermelon. Leaf wetness should be avoided to minimize disease problems in grafted watermelon and is achieved through air circulation, which is also critical for healing grafted cucumber seedlings.

Jardin Co. is currently enhancing its grafting capacity by introducing automated grafting because of increasing difficulty to secure needed number of grafting workers. They collaborate with ISO Group in the Netherlands and recently became a Japanese distributor for their machines (http://www.isogroepmachinebouw.nl /en/home.html). ISO has two models of grafting machines available at present including ISO Graft 1100 which requires two operators and ISO Graft 1200 which needs only one operator (Fig. 14). Both models can graft up to 1050 plants per hour. A plant sorting machine (6000-7000 plants per hour) is also recommended for maximizing grafting efficiency, and it sorts newly emerged seedlings by cotyledon size (Fig. 15).

2. Sohuku Engei Nursery

This family-owned nursery grows flowers and vegetable seedlings and is located in Fukushima Prefecture. They specialize in grafting cucurbits especially cucumber, with all the plants produced by semi-automated grafting (ISEKI, Japan). Sohuku Engei has an annual grafting capacity of approximately 1 million plants and produces 4 million seedlings in total. Another unique aspect of their grafting operation is the re-rooting of grafted plants which takes place during graft healing. The re-rooting practice is well adapted to machine grafting as the rootstock roots are removed prior to grafting thus allowing for a clean operation with high efficiency by the machine. In addition, the re-rooted grafted seedlings tend to have stronger root systems, as perceived by many cucurbit growers in Japan (Fig. 16).

A vacuum seeding machine is used to plant seeds of cucumber scions and squash rootstocks. Approximately 20-24 cucumber cultivars and 10-12 rootstock cultivars are currently used by cucumber growers for which Sohuku Engei Nursery serves. The seed trays are kept in the germination room for 2 and 3 days for scion and rootstock plants, respectively, and then moved to the greenhouse for transplant production. The machine severs rootstock and scion plants from their hypocotyls and then performs the grafting (using the one cotyledon grafting method). The semi-automated grafting machine (manufactured 30 years ago) is operated by 2 people and can graft 600 plants per hour (Fig. 17). For each machine, there is also one additional person who checks the graft union and sometimes redoes jointing/clipping when the machine fails to make the grafts properly. The nursery uses 9 machines in their grafting operation. Sohuku Engei also has 3 fully-automated grafting machines that can achieve 800 grafts per hour (Fig. 18). Fully-automated machines are not used in summer propagation as it is more challenging to meet the seedling size to the specifics required for fully-automated machine grafting. Semi-automated machines are more flexible in terms of workable seedling size. The nursery does not use manual grafting at all.

Grafted cucumber plants (without roots) are then inserted into seedling pots with growing media (made at the nursery by mixing purchased compost and peat moss) and roots are regenerated

during the healing process (Fig. 19). Inside the greenhouse, a low tunnel structure constructed on the ground is used for healing grafted cucumber plants (Fig. 20). The healing structures are covered by 4 layers including plastic sheeting, thermal sheeting, and a silver shade cloth which are used to control temperature and RH and adjust air circulation during healing. Using the different covering layers helps modify environmental conditions inside the healing structure with more convenience and flexibility. A floor heating system is used as needed to maintain the inside temperature around 27 ^{o}C. The nursery grower pointed out that watering of scion and rootstock seedlings should be limited right before grafting to ensure good graft survival. Pesticides are not used on plants ready for grafting to protect workers' safety.

The prices of semi- and fully-automated grafting machines are approximately $60,000 and $80,000, respectively. The selling price of grafted cucumber seedlings produced at Sohuku Engei is about $1.60 per plant with the costs of seeds and shipping included, which account for 40% of the total cost of grafted plants. Grafted plants are used in more than 95% of the cucumber production acreage in Japan, and primarily employ squash rootstocks that help with disease control, "bloomless" fruit production, and cold tolerance. Bloomless fruit means little or no deposition of silicon crystals over the fruit and therefore fruit surface becomes more glossy. Some squash rootstocks are known as "bloomless" rootstocks for cucumber. In Fukushima Prefecture, half of the cucumber production acreage is under protected culture.

3. NPO Japan Plant Factory Association

The NPO Japan Plant Factory Association (JPFA, http://npoplantfactory.org/) and their research facility are located on the Kashiwanoha campus of Chiba University in Chiba Prefecture and specializes in indoor plant production and vertical farming. The JPFA provides industry with R&D facilities and support. Dr. Toyoki Kozai, Chief Director of JPFA and Professor Emeritus of Chiba University, presented an introduction to the development of CPPS for maximizing resource use efficiency. As of April 2015, CPPS has been used in 250 sites throughout Japan. Tomato, lettuce and other leafy green vegetables, and their seedlings are the main types of plants grown in CPPS. Many commercial nurseries (including Jardin Co. we visited) have adopted CPPS for producing high quality transplants. High planting density is often used in CPPS, while good air circulation and temperature control are provided to control plant height. CPPS can produce highly uniform plants, reduce floor area by 90% as compared with regular greenhouse production, and achieve 97% water use efficiency by using dehumidifier water. Vegetable transplants produced in CPPS are also found to have enhanced tolerance to environmental stress conditions.

Per JPFA, the largest grafting nursery in Japan is Berg Earth Co. Ltd, who produces uniform scion and rootstock seedlings used for grafting using CPPS. The nursery has an annual grafting capacity of 36 million plants. Grafted cuttings that are not fully healed are shipped to growers and other nurseries for re-rooting and complete healing.

The initial investment in commercial CPPS can be expensive. A 15 m^2 unit of CPPS holding 96 200-cell trays is an all-in-one system commercially available and may cost $65,000. The current model of CPPS was developed in the early 2000s and employs lighting system based on high frequency white fluorescent lamps. Many nurseries are examining LEDs as a way to reduce the electricity costs; but experienced issues such as intumescence (chlorotic hypertrophic growths developed over leaf surface) for tomato. The sensitivity to develop intumescence is known as species and cultivar specific. Scientists in Chiba University and University of Arizona work on this physiological disorder in transplant production.

The JPFA serves many private industries through providing R&D support and professional education in controlled environment agriculture. In addition to grafting related technologies, we had opportunities to visit hydroponic greenhouse facilities examining high-density limited-truss tomato production and plant factory research facilities for leafy green production on the Kashiwanoha campus.

Mirai Co. is one such company which has a research facility on campus and we visited their production facility near the campus as described in the following section.

4. Mirai Co., Ltd. commercial plant factory

CPPS technology is also applied to plant factories that produce leafy vegetables under electric lighting. JPFA defines a plant factory as an "Indoor Vertical Farming System for Efficient Quality Food Production" that helps "offset the threats that unusual weather and shortages of land and natural resources bring to the food supply." Per Dr. Kozai, among all the plant factories in Japan using CPPS, 30% of them are profitable, whereas 60% are breakeven and 10% of the operations are having financial problems.

Established in 2004, Mirai (http://miraigroup.jp/en/) has been successfully implementing the plant factory CPPS technology in year-round commercial production and marketing of leafy vegetables (Fig. 21). They grow approximately 40 different types of leafy greens such as lettuce, basil, kale, mustard green, and watercress, with lettuce as their specialty (production capacity: 10,000 lettuce heads per day). Mirai currently has two plant factory rooms and employs 20 workers. Each of the 500-m^2 rooms has 6-meter tall production system using the floating system. The growing cycle is 35 days for lettuce from seeding to harvest. By controlling temperature, light (fluorescent lamps and LED light used), and airflow, disease and pest pressure is at a minimum and pesticides are not used. As drinking water is used in growing the plants inside a highly sanitized environment, vegetables are packed right after they are harvested in the same room without rinsing, and the products are considered ready-to-eat. The criteria for crop selection used at Mirai include: plants complete their growth cycle within about one month; plants grow up to 30 cm high; and at least 85% of the plant parts are harvestable. They work to continuously improve the plant factory technology and have developed technology software for those interested in commercializing the plant factory system for vegetable production. Mirai markets most of their produce directly to restaurants.

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Fig. 1. Tomato grafting using eggplant rootstock at Shang-Sheng Nursery in Taiwan: tomato scion (left) seedlings and eggplant rootstock (right) seedlings are grown in 128-cell trays in greenhouse.

Fig. 2. Rubber based grafting tubes used widely in Taiwan for grafting solanaceous plants; the estimated cost per tube is approximately 0.2 US cents. (Photo taken at Yu-Chia Nursery, Taiwan)

Fig. 3. Indoor healing chamber with electric lighting (white fluorescent lamps) and ultrasonic humidification system. (Photo taken at Yu-Chia Nursery, Taiwan)

Fig. 4. Grafted tomato plants (with eggplant rootstock) are moved from the indoor healing chamber 3 days after grafting to a shaded greenhouse for an additional 4 days to complete the healing process. (Photo taken at Yu-Chia Nursery, Taiwan)

Fig. 5. Well-healed grafted pepper seedlings in the greenhouse. (Photo taken at Shang-Sheng Nursery, Taiwan)

Fig. 6. Watermelon grafting in Taiwan where the hole-insertion grafting method is used to graft squash rootstock grown in 50-cell trays and watermelon scion (Left); watermelon seeds are germinated for a few days in darkness so that scions are etiolated. A woman preparing bundles of scion seedlings (Right). (Photos taken at Yu-You Nursery, Taiwan).

Fig. 7. Tools developed and used at Yu-You Nursery in Taiwan; the left tool is to make the angle-cut for scion, and the right tool is to pierce a hole in the rootstock seedlings.

Fig. 8. Outdoor low-tunnel healing chambers used in grafted watermelon transplant production at Yu-You Nursery, Taiwan (left); well-healed grafted watermelon seedlings inside the healing chamber (right).

Fig. 9. Simple outdoor healing structure for grafted vegetable seedlings suitable for developing countries (left) and eggplant rootstocks in the demonstration plots at AVRDC in Taiwan.

Fig. 10. Growth rooms (CPPS) used to grow tomato scion and rootstock seedlings at Jardin Co., Japan, with controlled light (12-14 hr photoperiod), temperature, and RH (<70%); an ebb and flow irrigation system is used, and CO_2 enrichment is applied at 1000 ppm.

Fig. 11. Tomato grafting at Jardin Co. where temperature is maintained at 26 ^{o}C and there is not control of RH. A: Tomato rootstock seedlings are placed and cut on the grafting table; B: Tomato scion seedlings are cut from the tray and shaped on the grafting table; C: Grafts are made using the tube grafting method; D: Completed tomato grafts are placed in the tray. (Photos taken at Jardin Co., Japan)

Fig. 12. Well-healed grafted tomato plants are pinched to develop two leaders. (Photo taken at Jardin Co., Japan)

Fig. 13. Walk-in shipping container equipped with fluorescent lamps and temperature and RH control with dry-fogging is used as healing room for grafted tomato plants at Jardin Co. in Japan. The healing room can accommodate 12 carts with each cart holding 25 200-cell trays.

Fig. 14. Grafting machine (manufactured by ISO Group) used for tomato grafting at Jardin Co., Japan.

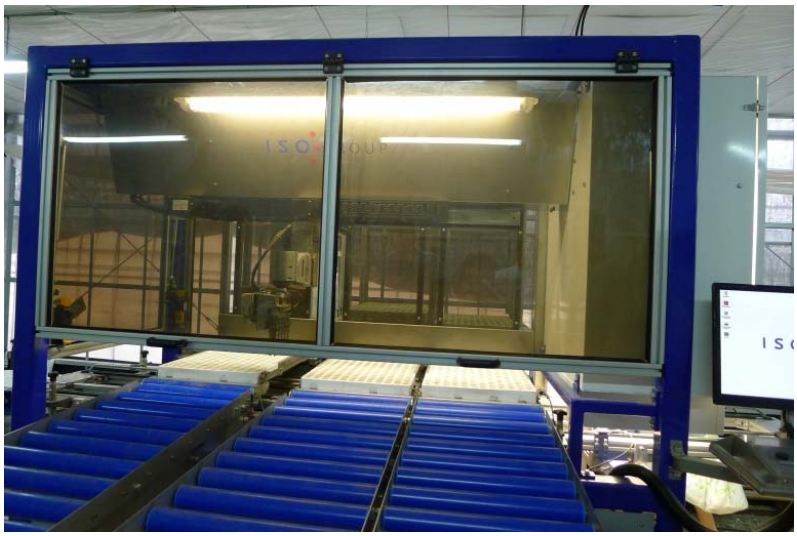

Fig. 15. Plant sorting machine (manufactured by ISO Group) used for making uniform rootstock seedling trays for tomato grafting at Jardin Co. It can sort 6000-7000 seedlings per hour.

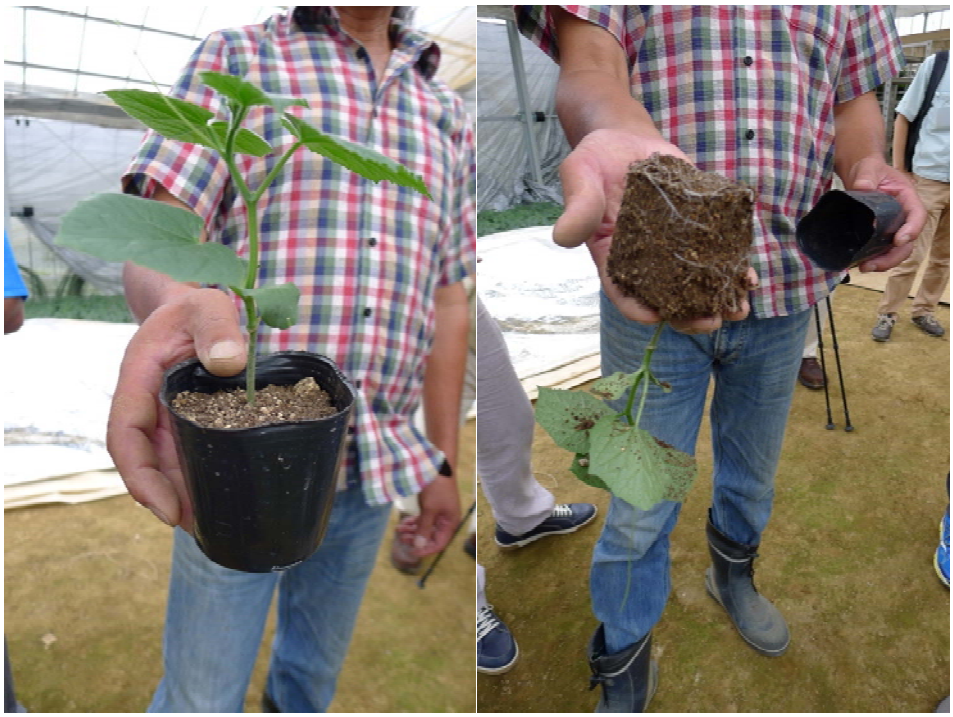

Fig. 16. Owner of Sohuku Engei, Japan demonstrates the well-healed grafted cucumber plant and its regenerated root system.

Fig. 17. Semi-automated grafting machines used at Sohuku Engei Nursery in Japan for grafting cucumber seedlings. Each machine is operated by 3 people for feeding scion and rootstock plants to the machine, respectively, as well as checking the quality of grafts.

Fig. 18. Fully-automated grafting machine displayed at Sohuku Engei Nursery, Japan.

Fig. 19. Owner of Sohuku Engei in Japan demonstrates the newly machine-grafted cucumber seedling with the rootstock roots removed. The rootstock hypocotyl is inserted into the growing media at 2-3 cm deep to regenerate the root system.

Fig. 20. Healing system used in the greenhouse at Sohuku Engei Nursery in Japan for grafted cucumber seedlings with the rootstock roots removed. It is a low tunnel structure covered by 4 layers of plastic films, thermal blanket and silver shade cloth. Opening of different covering layers helps control temperature and RH during healing and adjust air circulation. A floor heating system is also used on the ground as needed to maintain inside temperature around 27 ^{o}C.

Fig. 21. A commercial plant factory room for growing lettuce, basil and other leaf greens at Mirai Co. in Japan. Vegetable production and packaging take place in the same room.