CURRENT SITUATION OF GRAFTED VEGETABLE SEEDLING INDUSTRY AND ITS MECHANIZATION DEVELOPMENT IN TAIWAN

Hsueh-Shih Lin1, Chin-Yuan Chang1, Chang-Sheng Chien1, Shih-Fang Chen1, Wei-Ling Chen1, Yung-Chu Chu2, Ai-Hua Yang2, Yu-Kuang Hseuh3, Sheng-Chih Chang3

1Director, Assistant, Assistant, Associate, and Associate Researcher, Taichung District Agricultural Research and Extension Station (TDARES), Council of Agriculture, Executive (COA) Yuan, Changhua, Taiwan
2Assistant researcher and Researcher, Tainan District Agricultural Research and Extension Station (Tainan-DARES), COA, Executive Yuan, Tainan, Taiwan
3Assistant researcher and Assistant researcher, Taiwan Seed Improvement and Propagation Station (TSIPS), COA, Executive Yuan, Taichung, Taiwan

Corresponding Author: Chin-Yuan Chang (changcy@tdais.gov.tw)

ABSTRACT

The production of grafted seedlings in Taiwan is mainly done manually at present. Therefore, in order to help the owners of grafting farms improve their efficiency and reduce the loading of the workers, it is recommended to use the automatic grafting machine; this article illustrates the current status of the development of fruit and vegetable grafting machine in Taiwan as well as those abroad. There were eight countries that invented grafting machines and 15 commercial models with different operations are now available. However, the grafting farms have to consider the machine's price, grafting successful rate, working efficiency, and industrial scale to make appropriate choice. In addition, standardized nursery for uniform rootstock and scion is also needed for mechanization followed by healing and acclimation procedures.

Keywords: Grafting, Rootstock, Scion, Mechanization

INTRODUCTION

Soil transmitted diseases damage the growth of crops seriously due to intensive farming and soil degradation. Thus, more and more farmers tend to use grafting seedlings in agricultural production. According to the annual report of Taiwan Council of Agriculture (COA), tomato, pepper, watermelon, bitter gourd, cantaloupe, and cucumber are the most common crops which use grafting in production. In 2013, 140 million grafted seedlings generated a total of one billion output values were used in tomato for 2,471 hectares and bitter gourd for 1,569 hectares. The grafted seedlings producers also indicate that there has been a dramatic increase in the demand for grafted seedlings.

However, due to the aging and deficiency of agri-workers, mechanization and automation of grafting operations are necessary to develop the increasing work efficiency and productivity thus enhancing the competitiveness of the seedling industry. This article illustrates the current status of the development of fruit and vegetable grafting machines in Taiwan as well as those abroad. It expects to provide some information for the plant graft industry.
CURRENT APPLICATION OF GRAFTED TECHNOLOGY FOR VEGETABLE SEEDLING

History of grafting

Grafting of vegetable seedlings is a traditional plant propagation technology which is popular in Asia. It mainly overcomes the limitations of farming caused by abiotic factors such as soil-borne diseases *Fusarium* and *Ralstonia* as well as biotic stresses included chilling, flooding, and salt stress. It can also increase growth vigor, yield, and quality of crops. This technology was introduced to Europe and other countries in the late 20th century and since then, has become a commercial industry. The first record of interspecific, herbaceous grafting as a yield increase and pest/disease control strategy was for watermelon (*Citrullus lanatus* (Thunb.) Matsum. & Nakai), using a squash (*Cucurbita moschata* Duch.) as rootstock, reportedly developed by a watermelon farmer in Japan (Tateishi, 1927).

Grafting technology developed rapidly, and expanded to other crops, the first record for Solanaceae was for eggplant (*Solanum melongena* L.) which was grafted onto scarlet eggplant (*Solanum integrifolium* Poir.) in the 1950s (Oda, 1999). Grafted tomato (*Lycopersicon esculentum* Mill.) was introduced commercially in the 1960s (Lee and Oda, 2003). Until 1993, Japan developed the first commercially grafting robot (GR800 series, Iseki & Co. Ltd., Matsuyama, Japan) for cucurbits that initiated automated production of grafted vegetable seedlings (Kubota et al., 2008).

Introduction of grafting industry for vegetables in the world

Grafting has been commercially produced for several decades and its technology gained the attention of the world. Japan and South Korea is by far the leading Asian countries in the grafting industry. Grafted watermelon in Japan was most widely used with a utilization rate up of up to 92% followed by 75% in cucumber, 55% in eggplant and 40% in tomato. In Korea, grafting industry focused on the *Cucurbitaceae* like watermelon with 95%, melon with 90% and cucumber with 75%. Tomato, on the other hand, only registered 25%. In comparison, China’s grafting industry started relatively late, with grafted cucumber as the most widely used (about 30%), followed by watermelon, 20%. The number of vegetables being grafted is estimated to be 540 million seedlings per year in Korea and 750 million in Japan (Lee et al., 1998). Until 2008, over 700 million grafted seedlings have been produced and is increasing year by year in Korea and Japan. References showed that in 2009, about 200 million grafted seedlings can be produced in China, compared with South Korea and Japan, although the figures have also been increasing on a yearly basis (Lee et al., 2010).

The grafting industry in European countries is in its developing stage, the main producing countries are Spain, Italy, France and the Netherlands, where Spain is the most developed. In Spain, grafted watermelon and tomato are the main crops which occupy about 43% and 53% respectively (Lee et al., 2010). References showed about 129 million grafted seedlings were produced in 2009 (Hoyos Echeverria, 2010). In Italy, grafted watermelon and eggplant are the main crops which occupy about 12% and 7.3%. About 47 million grafted seedlings were used per year (Morra and Bilotto, 2009). Similarly, France and the Netherlands grafting industry also had grafted tomato and eggplant as the main crops, with over than 50% of the seedlings used were grafted. About 28 million grafted seedlings were produced per year in France (Lee et al., 2010).

Grafted seedlings can increase vigor, yield as well as resistance to soil-borne diseases and nematodes, which attract interest from both greenhouse growers and organic producers in the US. Mexico and Canada are the leading countries in terms of plant grafting. Grafted tomato was the main crop with 40 million grafted seedlings applied per year (Kubota et al., 2008). Around 75% of tomatoes in the US are grafted and is a rising trend (Lee et al., 2010). In conclusion, the above information shows that grafting has gained the world's attention where growers are committed to the development of important technologies.

Current situation of grafted fruit-vegetable seedling in Taiwan

Due to the high cost of seedlings, the grafted seedling industry were mainly applied for fruit-vegetables, such as watermelon, tomato and bitter gourd, occupying between 25% and 35% of the seedlings in Taiwan (Lee et al., 2010). The estimated grafted seedlings produced per year was about 42 million including 20 million for watermelon, 20 million for tomato, 1.5 million for cucumber, 1 million for bitter melon (Table 1).
Table 1. Current status of the estimated use of grafted vegetables in Taiwan

<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, bottle gourd, watermelon</td>
<td>hole insertion grafting, tongue approach grafting</td>
</tr>
<tr>
<td>Bitter melon</td>
<td>1 million</td>
<td>sponge gourd, pumpkin</td>
<td>cleft grafting, tongue approach grafting</td>
</tr>
<tr>
<td>Tomato</td>
<td>20 million</td>
<td>eggplant, tomato</td>
<td>tube grafting, splice grafting</td>
</tr>
<tr>
<td>Cucumber</td>
<td>1.5 million</td>
<td>pumpkin, bottle gourd</td>
<td>tongue approach grafting</td>
</tr>
</tbody>
</table>

The following is a brief introduction of Taiwan’s main grafted fruit-vegetables:

**Watermelon**
Growers of grafted watermelon usually choose gourd or wild watermelon as their rootstock. When cultivated in low temperature, pumpkins are chosen. Grafted watermelon is used to prevent *Fusarium* wilt, and nematodes. It can increase growth and tolerance to chilling and drought. The main grafting methods used are hole insertion grafting or tongue approach grafting (Chou *et al.*, 2008).

**Tomato**
In Taiwan, (unlike Europe) wild tomato is used as rootstock, while grafted tomato usually use eggplant as rootstock. EG203 and EG213 were the main varieties of eggplant rootstock that are selected in the germplasm of AVRDC-The World Vegetable Center. Grafted tomato is used for increasing the tolerance for bacterial wilt and flooding while Europe and America use it to increase yield, the main grafting methods used is tube grafting (Chou *et al.*, 2008).

**Bitter gourd**
Bitter gourd has good heat tolerance but is not resistant to flooding. During the cultivation process, it is also easily infected by *Fusarium* wilt. Even with the use of pesticides, it is generally difficult to control. Therefore, in recent years, growers of bitter gourd usually choose pumpkin or sponge gourd as their rootstock to prevent *Fusarium* disease, prolong productive period, increase yield, and raise chilling and flooding resistance. Main grafting methods used are cleft grafting or tongue approach (Chou *et al.*, 2008).

**Cucumber**
Cucumber can be planted all-year round, but midday withering in summer and growth retardation in winter can easily occur in Taiwan. Growers usually choose pumpkin or bottle gourd as their rootstock. Grafted seedling is used to prevent soil-borne diseases, prolong productive period, increase yield, quality, and chilling tolerance. The main grafting methods used are hole insertion grafting or tongue approach (Chou *et al.*, 2008).

![Fig 1. Major grafting methods in Cucurbitaceae and Solanaceae vegetables. Hole insertion grafting (A and B); tongue approach grafting (C); splice grafting (D, E and J); cleft grafting (F, G); pin grafting (H and I). (Lee *et al.*, 2010)](image-url)
Grafting procedures and precautions

Grafted process can be divided into four main stages, namely nursery, grafting, healing and acclimation. The primary objective of the nursery stage is to choose a suitable cultivar with scion and rootstock. The rootstock and scion compatibility and objective must always be considered, together with the arranged timing of planting, making sure that there is consistency in stem diameter with scion and rootstock. Cultivated temperature and light intensity are two key factors that can adjust growth in scion and rootstock.

In the grafting stage workers should pay attention to grafting methods and grafting timing, each crop’s suitable method for grafting as described above. Grafting timing is required to avoid high temperature of operation. Healing stage follows grafting. In order to accelerate the connection between scion and rootstock’s vascular bundle, controlling the healing chamber with optimal temperature, humidity, and light intensity is the most effective method. Previous study showed that the recommended temperature are 25 to 30°C, 85 to 95% relative humidity, dark or low light in healing chamber (Rivard and Louws, 2006). That condition is similar to the healing in Taiwan’s producer (Qiu et al., 2007). In the acclimation stage, there is a need to keep the air humidity to reduce water loss. Semi-shade environment makes grafted seedlings gradually adapted to the outdoor environment until transplanting takes place in the field.

Research and development of grafted industry

In order to improve grafted seedling industry in Taiwan, six agricultural research institutes (Fig.2.), Taiwan Seed Improvement and Propagation Station (TSIPS) ,Taiwan Agricultural Research Institute (TARI) ,Taichung District Agricultural Research and Extension Station (TDARES),Tainan District Agricultural Research and Extension Station (Tainan-DARES), Feng-Shan Tropical Horticultural Experiment Branch (TARI-FTHEB), The World Vegetable Center (AVRDC) had cooperated as a team for vegetable grafting research since 2015.

The team had taken the grafted tomato seedlings for research and included five research topics: grafting mechanization, seedling’s planting and healing, breeding for stress resistance of rootstock, grafting compatibility, and graft industry investigation.

The production of grafting seedlings in Taiwan is mainly done manually at present. Tomato grafted with eggplant as rootstock is used in splice grafting and holding with rubber tube. Other crops like Cucurbitaceae use top cleft grafting and holding with clip. The grafting worker required to be highly skilled with intensive use of the eyes that are oftentimes difficult for the elder workers. In 2013, Directorate General of Budget, Accounting and Statistics (DGBAS) had an investigation of the age distribution of vegetable planting managers and workers. The study showed that 24.7% of the managers and workers are over 65 year-old in Taiwan. It means that owners of grafting farms will find it hard to hire young workers in the future. Therefore, introducing grafting machines is one of the methods to solve the problem.
Mechanization of grafting

Grafting machines were invented in eight countries including the Netherlands, Spain, Italy, Israel, Japan, Korea, China, and Taiwan with 15 available commercial models. Among them, the Netherlands, Spain, Italy and Israel had invented the grafting machine mainly for solanaceous vegetables while Japan, Korea and China had invented for Cucurbitaceae. In Taiwan, the grafting machine for passion fruit was invented in 2001, the rubber-tube type grafting machine for tomato seedlings was invented in 2004, while the grafting machine GR800-B was introduced from Japan in 1999 (Hseuh et al., 2005).

Grafting machine for passion fruit seedling in Taiwan

Passion fruit grafting machine was invented by scientists of the National Chung-Hsing University, National Chia-Yi University and TDARES. The grafting method used is cleft grafting holding with PE grafting clip. The working efficiency is about 200 grafts per hour with 91% average success rate which is equivalent to three workers. It only needed one worker to assist the machine and is easy to operate. However, due to the small demand in the Taiwan market the machine is not commercially available.

Grafting machine for tomato seedling in Taiwan

Taiwan’s tubing-grafting system was invented by scientists of the National I-Lan University, National Taiwan University and Tainan-DARES. It is suitable for tomato as scion and eggplant as rootstock. The grafting method used is splice grafting. It holds with tube and produces 327 grafts per hour (Chen et al., 2010; Chung et al., 2005). It needs one worker to assist the machine. TSIPS has a restart study for the tubing-grafting automatic system in 2016 for increasing its grafting efficiency such as speed and successful rate. The results show that the grafting speed is 200–250 grafts per hour with 92–97% successful rate. Besides, grafted seedling had 90–96% recovery rate.

Spain’s tomato grafting machine

The number of cultivated tomatoes increased in Taiwan. The owners of grafting farms want to use grafting machines to solve the shortage in manual labor. Therefore, TDARES had introduced Spain’s Conic-System EMP-300 grafting machine in 2016. It is suitable for solanaceous plants by using splice grafting and holding with tube clips. It can adjust the miter angle as 20°, 30°, and 40°; producing 300–500 grafts per hour with 90–95% success rate. It only takes one worker to assist the machine. It is easy to operate and only takes 5–30 minutes to train a new worker.

The first grafting process of this machine is feeding the scion and rootstock into the system, then the machine automatically chucks and cuts the plant followed by the manual removal of peat-moss. It moves the plant to grafting position and holds the rootstock and scion with tube clip automatic, then it finally chucks the grafted seedlings to the conveyor through the machine’s arm. The test results are shown in Table 2. The grafting machine can produce 480 grafts per hour which is twice the result compared to manual grafting.

During the testing process, we found that the key for success of mechanical grafting is the specifications and quality of the rootstock and scion, such as the bud scale scars, node, stem diameter, texture, and uniformity etc.
Table 2. The experimental results for the capability of Spain Conic-System EMP-300 grafting machine

<table>
<thead>
<tr>
<th>Grafting</th>
<th>Manual</th>
<th>Semi-Automatic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Rate per hour</td>
<td>15~20 Sec</td>
<td>7.5~12 Sec</td>
</tr>
<tr>
<td></td>
<td>240~180 Plants</td>
<td>480~300 Plants</td>
</tr>
</tbody>
</table>

**Spain’s simple grafting machine**

Spain Agrupamex INJESTAR is a simple grafting machine used to help the workers to cut the scion and rootstock with a uniform cut angle and use tube clips for grafting. It is suitable for the solanaceous plants which are splice grafted. The working rate is about 450 grafts per hour and only needs one worker to assist the machine. This model can significantly increase the efficiency of the manual grafting, and its price is inexpensive and suitable for Taiwan’s grafting farms. However, it is not yet commercially available.
The Netherlands’s tomato grafting machine
Netherlands ISO-Group had invented three models of tomato grafting machines (ISO Graft 1000, 1100, 1200). The grafting process of Graft 1200 is cutting the rootstocks and putting the plug tray into the machine first, then manually putting the scion one at a time. In order to determine the position and angle of the cut, the rootstock and scion are moved closer, are cut at the same time and are held with plastic PU clip. This model needs one worker to assist the machine. Graft 1100, (unlike Graft 1200), manually puts the rootstock into the machine that needs two workers to assist. Graft 1000 uses a special tube with three fins which is similar to the tube used during manual grafting in Taiwan. The machine will pull the three fins and insert the scion and rootstock into the tube then the graft is finished. It needs one to two workers to assist the machine. The efficiency of these three models is about 1000 grafts per hour.

Italy’s tomato grafting machine
Italy’s Atlantic Man. s.r.l., model type GR 300/3 is suitable for cucurbits and solanaceous plants (1.2–4 mm in diameter). The grafting method used is splice grafting and holds with clip for the cucubits and clips for the solanaceous plants, respectively. The producing rate is 600 grafts per hour with one worker to assist the machine. It is manually fed and uses a machine to cut and transport the scion and rootstock. Unfortunately, it needs workers to support the scion or the rootstock while holding the seedlings.
Israel’s tomato grafting machine
Israel’s Virentes Plant-Grafting Robot is a prototype of grafted machine suitable for solanaceous and cucurbit plants. It is manually fed with a plug tray. The grafting method used is splice grafting and holds with tube clips. It grafts five seedlings at a time and produces about 840 grafts per hour with only one worker assisting the machine.

The Cucurbitaceae grafting seedlings are more popular than the Solanaceae in Asia. Therefore, Japan, Korea and China all had been involved in developing grafting machines for the Cucurbitaceae plants. Taiwan had introduced a grafting machine (GR800-B) from Japan in 1999 and developed a circular grafting robotic system for watermelon seedlings in 2010 (Chiu et al, 2010).

Japan’s Cucurbitaceae grafting machine
Japan ISEKI had invented two models of grafted machines. The GRF800-U needs one worker feeding the scion and rootstock with the plug tray into the system, and the machine grafts the seedlings automatically while the GRF803-U needs two workers. Those two models have many structures to adjust the seedlings position to increase its success rate. They use one cotyledon grafting method and the shearing blade cuts the cotyledon with an arc-shaped. However, farmers in Taiwan dislike using one cotyledon grafting method, therefore this kind of model is difficult to commercialize in Taiwan.

Korea’s Cucurbitaceae grafting machine
Korea Helper Robotech, model typeGR600C-S, is suitable for the cucurbits as well as solanaceous plants. Its grafting method is splice grafting and holds with tube clips. The working efficiency is 650 grafts per hour with two to three workers to assist the machine. This model needs two workers feeding the scion and rootstock, the machine automatically cuts (arc) and grafts the seedlings. Then it still needs one worker taking the grafting seedling from the conveyor.
China’s Cucurbitaceae grafting machine
China had invented two models of el type of grafted machines. 2JC-600B needs two workers to feed the scion and rootstock manually. It pokes the leaf of the rootstock and punctures a hole on the rootstock, then automatically inserts the scion to the rootstock. It does not take tube or clip to hold the grafted seedling. Model type 2JC-1000A needs one worker to feed the scion and rootstock, and then automatically grafts five seedlings at one time which is similar to Japan and Israel’s machines.

Investigation of grafting industry
Taiwan has both small and large grafting farms. Analyzing the structure of Taiwan’s grafting industry, the results showed that the farms with an annual production (referring to seedling number) of 2000k, 1500k, 1000k, 500k, and 100k was accounted for 13%, 22%, 8%, 22%, and 35% respectively. The distribution of industrial production is close. In recent years, the government is encouraging young farmers to engage in agriculture. Therefore, with more and more farmers involved in tomato production, the development of the graft industry started to increase.

Fig. 14. China’s 2JC-600B grafting machine
Fig. 15. China’s 2JC-1000B grafting machine

Fig. 16. Investigation for the yield extent of the graft industry
(Grafting Seedling / Tomato / Thousand / Year)
For analyzing the production cost of the grafting industry, six of Taiwan’s grafting farms (those specialized in the production of tomato grafted seedlings) were chosen. It contains the variable costs of materials, labor, other management and marketing costs. It also contains the fixed costs of land rent and equipment costs (Table 3).

Table 3. Graft industry production cost investigation Items

<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><strong>Staff</strong></td>
</tr>
<tr>
<td><strong>Others</strong></td>
</tr>
<tr>
<td><strong>Fixed Cost</strong></td>
</tr>
<tr>
<td><strong>Depreciation</strong></td>
</tr>
</tbody>
</table>

The results showed that the production costs are staff 13%, others 3%, land 1%, depreciation 5%, and material 78%, respectively (Fig. 17). Further analysis of the cost of materials, other materials account for 20%, while pesticide 1%, fuel 3%, electricity 5%, water 1%, fertilizer 1%, rootstock 11%, and scion 58%. Among them, the scion is the main cost, especially for cherry tomato ‘Jade Girl’ which has thin peel, high sweetness and good flavor.

![Pie Chart](image.png)

Fig. 17. Investigation for production cost of the grafted industry
CONCLUSION

The production of grafted seedlings in Taiwan is mainly done manually. However, due to the long working hours, the workers are oftentimes tired and their efficiency is significantly reduced. Generally, one worker can graft about 200 tomato grafted seedlings per hour manually.

To improve grafting efficiency and reduce the burden of the workers, over the past years, Taiwan has worked on the research and development of grafting machines. We also introduced some models from other countries including Japan’s grafting machine GR800-B for the Cucurbitaceae plants by TSIPS. Besides, TDARES had developed the passion fruit grafting machine, and the Tainan-DARES had invented the rubber tube type grafting machine for tomato seedlings. These two machines represent the grafting machine technologies of Taiwan. In 2016, Spain’s tomato grafting machine was introduced by TDARES to make grafting mechanization in Taiwan more competitive.

Based on the above illustrations, there are many forms of grafting machines. They usually need one to two workers and have two ways for scion and rootstock feeding. One is manual feeding with one seedling at a time; the other way is through feeding with the automatic plug tray by machine. Gripping the seedling and holding the scion as well as rootstock can be manual or automatic. Cutting and holding of the rootstock and scion are the key factors for mechanical grafting. Each grafting machine has different operation modes, the more automatic the more expensive. Therefore grafting farm needs to consider grafting machines’ price, grafting successful rate, working efficiency, as well as their industrial scale and other factors in selecting the appropriate grafting machine. Keeping the research and development work for grafting machines is still a necessary endeavor in the future.
REFERENCES


Webpages


