GRAFTING OF VEGETABLES TO IMPROVE GREENHOUSE PRODUCTION

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ABSTRACT

In vegetable production in greenhouses, most of the damage from continuous cropping is caused by soil-borne diseases and nematodes. As a countermeasure to the damage caused by soil-bone diseases such as Fusarium wilt, bacterial wilt and nematodes, grafting of fruit-bearing vegetables is popular in Japan. The proportion of the area producing grafted plants of watermelon, cucumber, melon, tomato and eggplant rose to 57% in 1980, and to 59% in 1990. Plants are grafted onto various rootstock species and varieties, by a range of grafting methods. Recently, the tube grafting method has been developed for plugs. This is popular in the manual grafting of tomato, eggplant and cucumber plants. Grafting robots and healing chambers have been developed, and are used in nurseries producing grafted plugs. Since grafting gives increased disease tolerance and vigor to crops, it will be useful in the low-input sustainable horticulture of the future.

DAMAGE FROM CONTINUOUS CROPPING

Continuous cropping is inevitable in greenhouses, but this reduces the yield and quality of produce. Takahashi (1984) reported that 68% of cases of failure in Japanese vegetable production under continuous cropping were caused by soil-borne diseases and nematodes (Table 1). Since soil sterilization can never be complete, grafting has become an essential technique for the production of repeated crops of fruit-bearing vegetables grown in greenhouses.

APPLICATION OF GRAFTING TO VEGETABLE PRODUCTION

The production of grafted plants first began in Japan and Korea in the late 1920s with watermelon (*Citrullus lanatus* Matsum. et Nakai) grafted onto gourd rootstock (Lee 1994). Eggplant was grafted onto scarlet eggplant (*Solanum integrifolium* Poir.) in the 1950s. Since then, the area of fruit-bearing vegetables based on grafted plants has increased. The proportion of the area in Japan producing grafted watermelon, cucumber, melon, tomato and eggplant reached 57% of the total production area in 1980, and 59% in 1990 (Oda 1993) (Table 2).

OBJECTIVES OF VEGETABLE GRAFTING

The main objective of grafting is to avoid soil-borne diseases such as Fusarium wilt in Cucurbitaceae (Cucumber, melon etc.) and bacterial wilt in Solanaceae (tomato, pepper etc.). Details of the objectives of grafting for each vegetable crop are shown in Table 3.

Keywords: acclimatization, grafting, greenhouse, Japan, nematode, plug, robot, rootstock, scion, soil-borne disease, vegetables

SPECIES AND VARIETIES FOR GRAFTING

Inter-generic grafting is used in the production of many fruit-bearing vegetables, i.e. cucumber (*Cucumis sativus* L.) grafted on pumpkin (*Cucurbita* spp.), watermelon (*Citrullus lanatus* Matsum. et Nakai), on bottle gourd (*Lagenaria siceraria* Standl.), melon (*Cucumis melo* L.) on white gourd (also known as wax gourd) (*Benicasa hispida* Cogn.). Inter-specific grafting is generally applied to eggplant (*Solanum melongena* L.). Scarlet eggplant (*S. integrifolium* Poir.) and *S. torvum* Swartz are popular rootstock for eggplant production. A large number of varieties for rootstock (Table 4) have been bred and released for use by growers in Japan.

GRAFTING METHODS FOR DIFFERENT TYPES OF FRUIT-BEARING VEGETABLE

Tomato plants are mainly grafted by conventional cleft grafting. Tube grafting has recently been developed for vegetable seedlings grown by plug culture.

Cleft Grafting

The seeds of the rootstock are sown five to seven days earlier than those of the scion (Fig. 1). The stem of the scion (at the fair-leaf stage), and the rootstock (at the four to five-leaf stage) are cut at right angles, each with 2-3 leaves remaining on the stem (Fig. 2). The stem of the scion is cut in a wedge, and the tapered end fitted into a cleft cut in the end of the rootstock. The graft is then held firm with a plastic clip.

Tube Grafting

Tube grafting makes it possible to graft small plants grown in plug trays two or three times faster than the conventional method. The smaller the plants, the more plants can be fitted into healing chambers or acclimation rooms. For this reason, tube grafting is popular among Japanese seedling producers.

The time schedule for tube grafting of tomato plugs is shown in Fig. 3. The optimum growth stage for grafting varies according to the kind of plug tray used. Plants in small cells must be grafted at an earlier growth stage, and require tubes with a smaller inside diameter.

First, the rootstock is cut at a slant. The scion is cut in the same way. Elastic tubes with a side-slit are placed onto the cut end of the rootstock. The cut ends of the scions are then inserted into the tube, splicing the cut surfaces of the scions and rootstock together (Fig. 4).

Eggplant

Eggplant is grafted mainly by cleft or tube grafting. The growth rate differs according to the species of rootstock used. The number of days from

Table 1. Cases of transplant failure in vegetable production

Cause	Ratio (%)	Details	Ratio (%)
Disease	72.0	Soil-borne diseases	60.9
		Other diseases	11.1
Disease-like phenomena	12.6		12.6
Pests	8.0	Nematodes	6.8
		Other pests	1.2
Causes other than diseases and pests	5.6	Physiological disorders	5.3
		Soil sickness	0.3
Unknown	1.8		1.8
Total	100.0		100.0

881 farmers responded to the questionnaire.

Source: Takahashi 1998

able 2. Ratio of the cultivation area using grafted plants to the total area producing fruit-bearing vegetables in Japan (1990)

Species	Type of cultivation	Cultivation area (ha) Surveyed	Grafted	Ratio of cultivation area using grafted plants (%)
Watermelon	Open & tunnel	15,474	14,181	91.7
	Plastic house	3,375	3,317	98.3
	Total	18,849	17,501	92.8
		(22,500)[b]		
Cucumber	Open & tunnel	9,551	5,253	55.0
	Plastic house	6,449	6,195	96.1
	Glasshouse	110	105	95.5
	Total	16,110	11,553	71.7
		(20,200)		
Melon (cv. Earl's favourite)	Plastic house	695	572	82.3
	Glasshouse	767	37	4.8
	Total	1,462[c)]	609	41.7
		(1,380)		
Melons for cultivation, mainly in plastic houses	Open & tunnel	4,485	1,888	42.1
	Plastic house	7,078	1,127	15.9
	Total	11,563	3,015	26.1
		(-[d)])		
Melons for cultivation/mainly in the open field	Open & tunnel	2,846	953	33.5
	Plastic house	794	640	80.6
	Total	3,640	1,593	43.8
		(16,700[e])		
Tomato	Open & tunnel	3,246	263	8.1
	Rain shelter[a)]	3,116	967	31.0
	Plastic house	4,430	2,027	45.8
	Glasshouse	416	277	66.6
	Total	11,208	3,534	31.5
		(14,200)		
Eggplant	Open & tunnel	10,669	4,576	42.9
	Plastic house	1,686	1,591	94.4
	Total	12,355	6,167	49.9
		(17,200)		
	Total	75,187	43,972	58.5
		(92,180)		

a): A simple, open-sided structure to protect plants from rain.
b): The total production area of each vegetable is indicated in the column.
c): The difference between surveyed and total area is caused by sampling error.
d): The figure is included in e).

Source: Oda 1993

Table 3. Objectives of grafting fruit-bearing vegetables

Species	Objective
Watermelo	Tolerance to Fusarium wilt (*F. oxysporum*), low temperatures, wilting due to physiological disorders, drought tolerance
Cucumber	Tolerance to *Fusarium* wilt, low temperatures, *Phytophthora melonis.*
Melon	Tolerance to *Fusarium* wilt (*F. oxysporum*), low temperatures, wilting due to physiological disorders, Phytophthora disease.
Tomato	Tolerance to bacterial wilt (*Pseudomonas solanacearum), Fusarium oxysporum, Pyrenochaeta lycopersici,* nematodes (*Meloidogyne* spp.) *Verticillium dahliae.*
Eggplant	Tolerance to bacterial wilt (*Pseudomonas solanacearum*), *Verticillium albo-atrum, Fusarium oxysporum,* low temperatures, nematodes. Greater vigor.

Source: Oda 1993

Table 4. Major varieties of rootstock used for fruiting crops in Japan

Scion	Rootstock	
	Species	Major variety in Japan
Watermelon	*Lagenaria siceraria*	Don K, Kachidoki No. 2, Aioi, FR 10, FR-Choju
	Cucurbita spp.	No. 8
	Benincasa hispida	Best
Cucumber	*Cucurbita* spp.	Hikari-Power*, Super-Unryu*, Kitora* Strong-Ikki*
	Cucurbita ficifolia	Kurodane
Greenhouse melons	*Cucumis melo*	Oi, Enken No. 2, Bernet Hill Favourite
	Benincasa hispida	Lion
	Cucurbita spp.	Unryu
	C. moschata x C. maxima	Shintosa
Melon grown in open field	*Cucurbita* spp.	Kongo
	C. moschata x C. maxima	Shintosa
	Cucumis melo	Enken No. 2, Kenkyaku
Tomato	*Lycopersicon esculentum*	Mate, Hawaii 7998, Joint, BF Okitsu No. 101, Helper M, PFNT No. 2, Sukuramu No. 2, Ancher T
Eggplant	*Solanum torvum*	Torvum Vigor
	Solanum integrifolium	Hiranasu
	Solanum melongena	Taibyo VF, Meet, Karehen, Assist

* Rootstock for bloomless fruit.
Source: Oda 1993

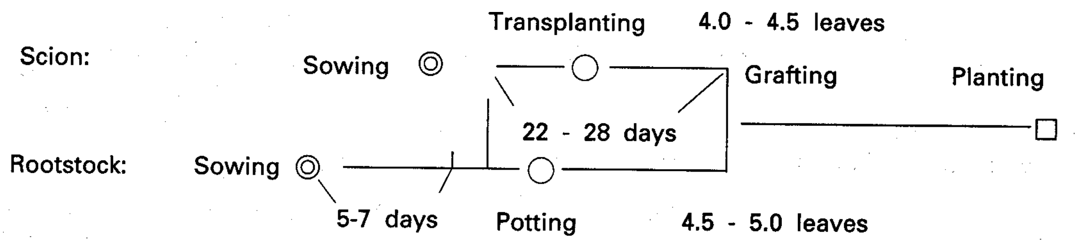

Fig. 1. Time schedule of cleft grafting for tomato plants

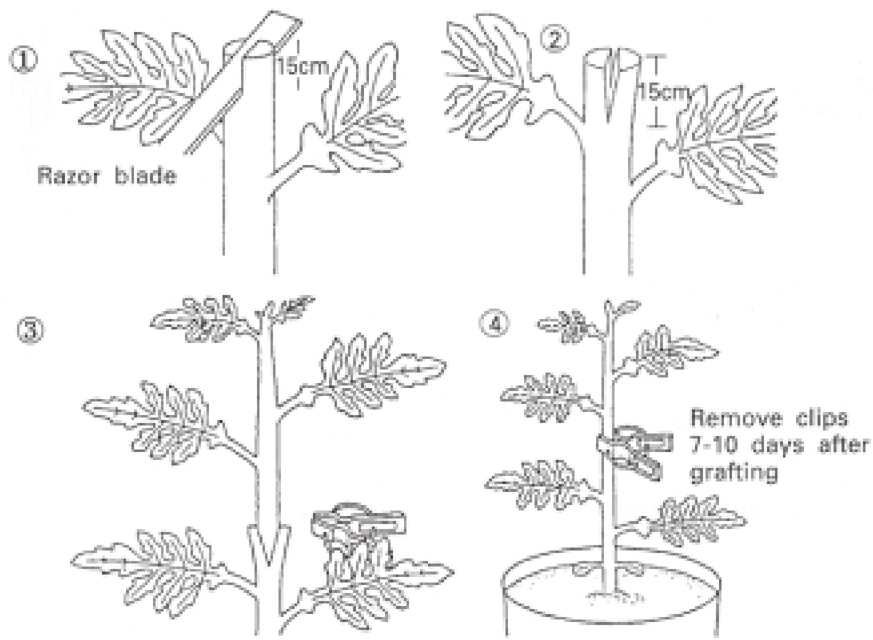

Fig. 2. Schematic diagram of cleft grafting
(By K. Ito)

sowing to grafting varies accordingly.

Cleft Grafting

Cleft grafting of eggplant is a similar process to that done for tomato. The time schedule for cleft grafting of eggplant is shown in Fig. 5.

Tube Grafting

The time schedule and grafting methods for tube grafting of cucumber are similar to those used for tomato plants. However, the seeds of *S. torvum* must be sown a few days earlier than those of the other rootstock species.

Cucumber

Tongue Approach Grafting

The survival ratio of grafted Cucurbitaceae plants is higher if tongue approach grafting is used. This is because the root of the scion remains until the formation of the graft union. In this method, seeds of cucumber are sown 10 - 13 days before grafting, and pumpkin seeds 7 - 10 days before grafting, to ensure uniformity in the diameter of the hypocotyls of the scion and rootstock (Fig. 6). The shoot apex of the rootstock is removed so that the shoot cannot grow. The hypocotyls of the scion

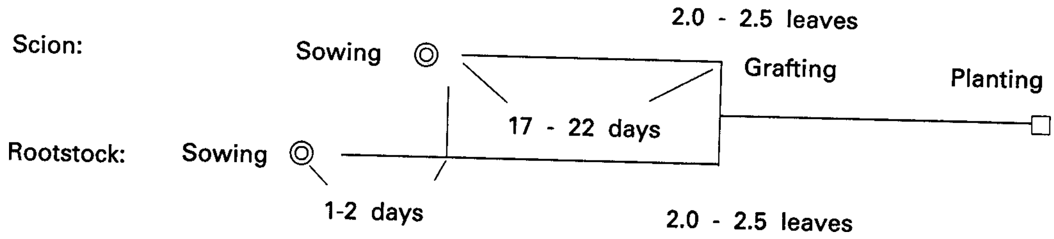

Fig. 3. Time schedule for tube grafting of tomato plugs (128-cell tray).

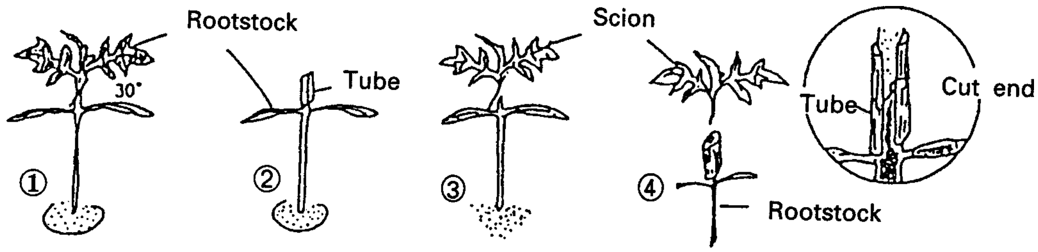

Fig. 4. Schematic diagram of tube grafting for tomato plugs on plug tray (By T. Itagi)

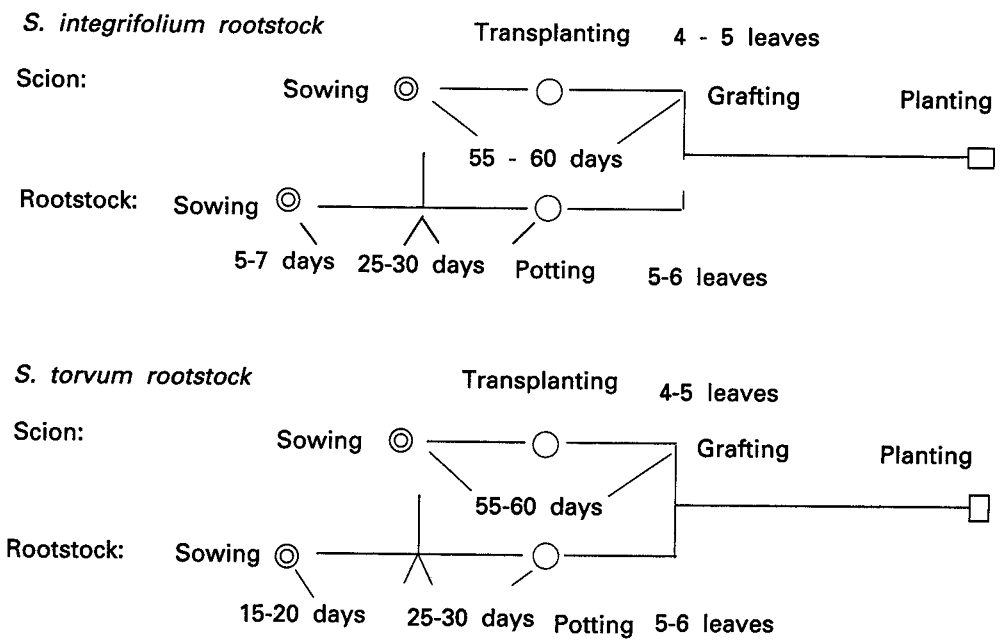

Fig. 5. Time schedule of cleft grafting for tomato plants

and rootstock are cut in such a way that they tongue into each other (Fig. 7), and the graft is secured with a plastic clip. The hypocotyl of the scion is left to heal for 3 - 4 days and then crushed between the fingers. The hypocotyl is cut off with a razor blade three or four days after being crushed (Fig. 7).

Slant-cut grafting is easy to do, and has recently become popular. Stages at which the scions and rootstock should be grafted are the same as those shown in Fig. 6. This grafting method was developed for robotic grafting. It is important to remove the 1st leaf and lateral buds when a cotyledon of rootstock is cut on a slant (Fig. 8).

Planting Watermelon

Cut grafting is popular for watermelon. The time schedule for cut grafting varies according to the species of rootstock used (Fig. 9). A schematic diagram of cut grafting is shown in Fig. 10.

Melon

Melon plants are mainly grafted by tongue approach grafting. The time schedule for tongue approach grafting of melon plants is shown in Fig. 11. Tongue approach grafting for melon is similar to that used for cucumber plants, shown in Fig. 7.

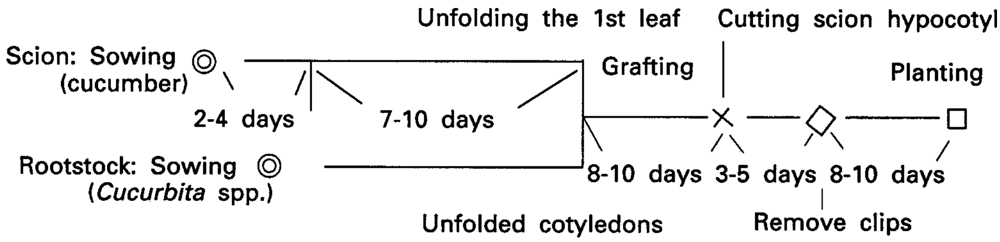

Fig. 6. Time schedule of tongue approach grafting for cucumber plants

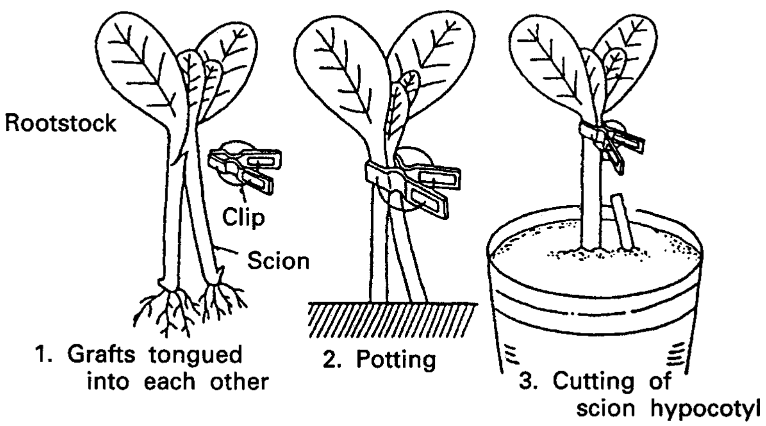

Fig. 7. Schematic diagram of tongue approach grafting for cucumber plants. The scion hypocotyl is cut after a healing period. (By K. Ito).

HEALING AND ACCLIMATIZATION

Grafting should be carried out in a shady place sheltered from the wind, to avoid wilting of the grafted plants.

Grafted plants are usually healed and acclimated in a plastic tunnel (Fig. 12). The healing and acclimatization are very important for grafted plants to survive. The tunnel is covered with materials which provide shade and maintain inside humidity: silver/white cheese-cloth (outside) and transparent film (inside). During acclimatization, it is recommended to keep light levels at about 3 to 5 klx.

Before grafting:

- Expose the scion and rootstock to sunshine for two to three days;
- Withhold water from the plants to avoid spindly growth, *and*
- Make sure that the scions and rootstock have stems of a similar diameter (Oda *et al.* 1993).

All these will improve the survival rate of grafted plants. When grafting is performed, it is important to increase the chances for vascular bundles of the scion and rootstock to come into contact (Oda *et al.* 1994b), by maximizing the area of the cut surfaces that are spliced together, and by pressing the spliced cut surfaces together. The cut surfaces should not be allowed to dry out. After grafting, keeping the grafted plants at about 30°C

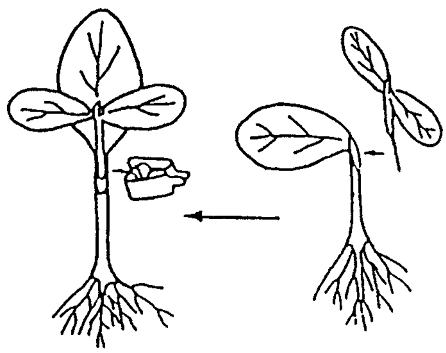

Fig. 8. Slant-cut grafting for Cucurbit plants (By K. Kobayashi)

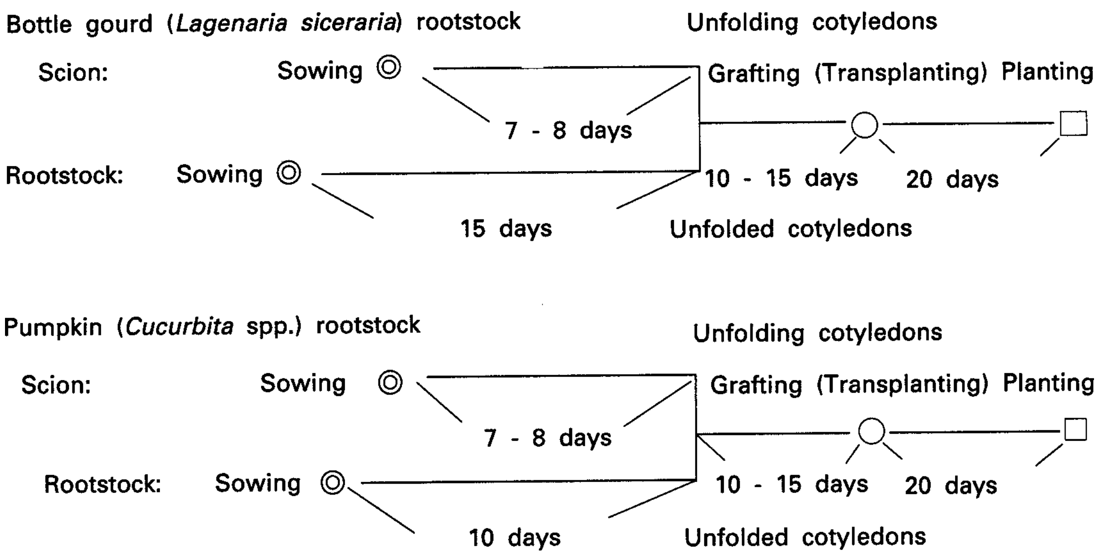

Fig. 9. Time schedule of cut grafting for watermelon

and with more than 95% relative humidity for three days of healing promotes the survival ratio. Gradually, the relative humidity is then lowered and the light intensity increased. During healing and acclimatization, it is important to keep a constant air temperature in the tunnel, in order to maintain high humidity. If wilting is observed, foliar spraying of grafted plants with water is effective in helping them survive. The shading materials and films should be adjusted according to the daily weather, with more shade on a fine day.

FUTURE PROSPECTS

Grafting is extremely laborious and time-consuming, and growers are trying to reduce the labor input required. Attempts have been made to mechanize grafting operations since 1987. Tube grafting was developed as a manual operation for small plugs by Itagi *et al.* (1990), and reduced the time required for manual grafting by at least one-half. Morita (1988) and Oda and Nakajima (1992) have applied an adhesive and a hardener to support the graft union in several crops. With the adhesive, five tomato plugs at a two-leaf stage were grafted at the same

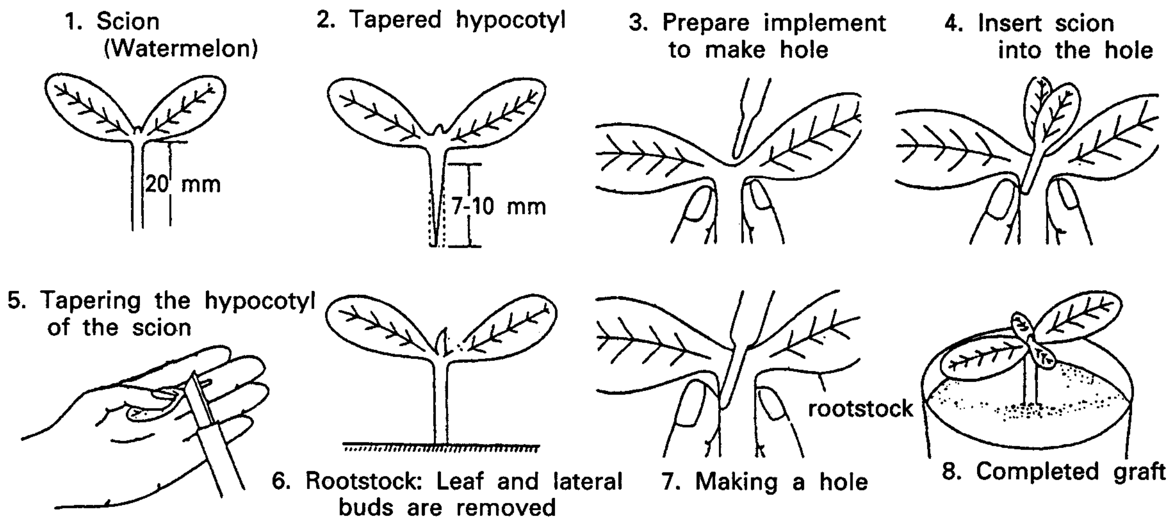

Fig. 10. Schematic diagram of cut grafting for watermelon plants. (By K. Ito)

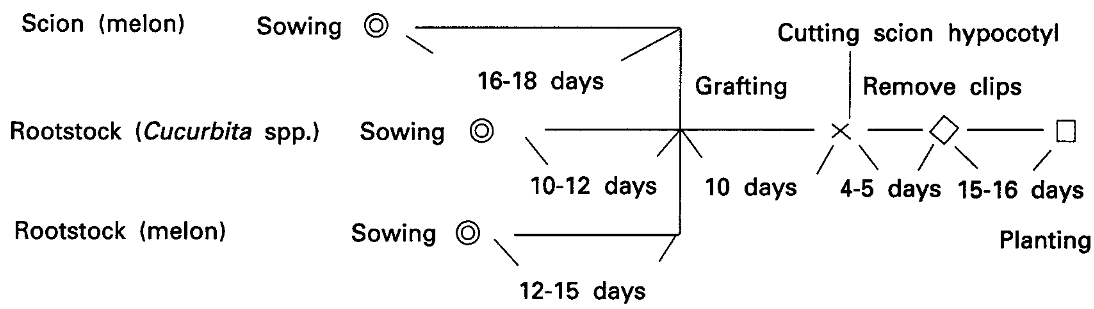

Fig. 11. Time schedule for tongue approach grafting of melon.

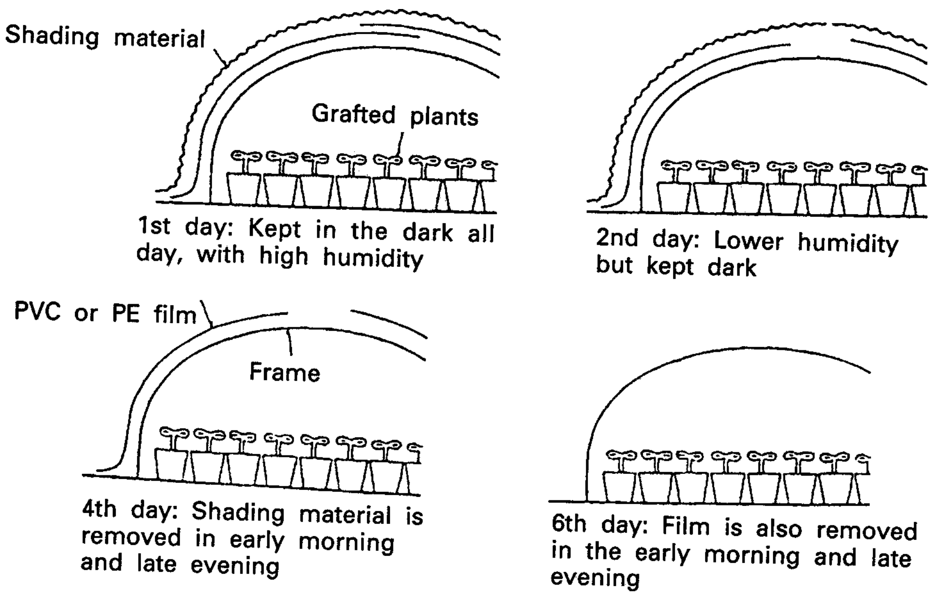

Fig. 12. Structure of acclimatization tunnel and how to acclimatize grafted plants. (by K. Ito)

time, using grafting plates (Oda *et al* 1994a). Grafting robots for plugs have also been developed, by combining the adhesive and grafting plates (Kurata 1994, Oda 1995). This robot makes it possible for eight plugs of tomato, eggplant, or pepper to be grafted simultaneously. Robotic grafting is about ten times faster than conventional hand grafting. Tomato (Oda *et al.* 1995) and eggplant (Oda *et al.* 1997) grafted by robot produced a yield of fruit similar to that of plants grafted by conventional methods.

Healing has also been mechanized. The survival ratio is consistently high when the newly developed healing chambers are used. Healing chambers in which the environment is artificially controlled are now being used by many nurseries which produce grafted plugs.

As grafting operations and the healing of grafted plants become easier, grafted vegetable crops may become popular all over the world. Since plants gain disease tolerance and vigor by grafting, grafting of vegetables may be useful in the low-input, sustainable horticulture of the future.

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