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New Grafting Methods for Fruit-Bearing Vegetables in Japan

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Abstract
Vegetable production using grafted plants was first initiated in Japan and Korea in the late 1920s. Grafting has become popular especially in fruit-bearing vegetables grown in greenhouses. In 1990, the area using grafted plants accounted for 59% of the production area of watermelons, cucumbers, eggplants, tomatoes and melons. Grafting is very effective to control soil-borne diseases and nematodes, but it is laborious and requires time, space and materials. Recently, production of grafted plants has become difficult for farmers due to the aging of farmers and labor shortage. Therefore, studies on the development of a rapid method and of instruments for grafting began in 1987 in Japan, and various grafting methods and instruments were released. Acclimation of the grafts has been studied and survival rate of the plants grafted by the new grafting methods or instruments has increased.

Discipline: Horticulture
Additional key words: mechanization, nematode. plug, seedling, soil-borne disease

Introduction

Grafting has been a very popular technique for propagation in pomology from time immemorial. As for vegetables, grafting was applied to fruit-bearing vegetables early in this century and has become a major technique for the production of fruit-bearing vegetables. The effect of grafting is clearly observed in the control of soil-borne diseases and nematodes. At present, grafted plants account for more than half of the total production area of main fruit-bearing vegetables. However, grafting requires time, space and materials and is laborious[11]. To alleviate these shortcomings, grafting techniques have been improved in Japan. In this paper, various aspects related to the grafting of fruit-bearing vegetables are described.

History and present state of grafting

The origin of grafting can be traced back to ancient times. There is evidence that the Chinese were familiar with the art of grafting trees at least as early as 1,000 B.C. Aristotle (384-322 B.C.) and Theophrastus (372-287 B.C.) discussed grafting in their writings with considerable expertise in the Grecian era[1].

Vegetable production using grafted plants was first initiated in Japan and Korea in the late 1920s by grafting watermelons (*Citrullus lanatus*) onto gourd rootstocks[8]. Eggplants were grafted onto scarlet eggplant (*Solanum integrifolium*) in the 1950s[22]. Since then, the production area of fruit-bearing vegetables using grafted plants has increased. Now, grafting is a major technique in Japan for sustainable production of fruit-bearing vegetables, which are cultivated mainly in greenhouses where continuous cropping is common. Failure of vegetable production associated with continuous cropping, which appeared since the 1970s, was ascribed in 68% of the cases to the incidence of soil-borne diseases and nematodes (Table 1). To alleviate these shortcomings, grafted plants have been used for the production of fruit-bearing vegetables. The ratio of the production area using grafted plants to the total production area in Japan is 93% for watermelons, 72% for cucumbers (*Cucumis sativus*), 50% for eggplants, 32% for tomatoes (*Lycopersicon esculentum*) and 30% for all types of melons (*Cucumis melo*) in 1990 (Table 2). Generally, the area where grafted plants were used accounted for 59% of the production area of these fruit-bearing vegetables.

Table 1. Causes of replant failure in vegetable production[21)]

Cause	Ratio (%)	Detail	Ratio (%)
Diseases	72.0	Soil-borne diseases	60.9
		Others	11.1
Disease-like phenomena	12.6		12.6
Pests	8.0	Nematodes	6.8
		Others	1.2
Except diseases and pests	5.6	Physiological disorders	5.3
		Soil sickness	0.3
Unknown	1.8		1.8
Total	100.0		100.0

Questionnaire consisted of 881 samples.

Table 2. Ratio of the cultivation areas using grafted plants to the areas producing fruit-bearing vegetables in Japan (1990)[13)]

Species	Type of cultivation	Cultivation area (ha)		Ratio of cultivation area using grafted plants (%)
		Surveyed	Grafted	
Watermelon	Open & tunnel	15,474	14,181	91.7
	Plastic house	3,375	3,317	98.3
	Sum	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
	Sum	16,110	11,553	71.7
		(20,200)		
Melon (cv. Earl's favourite)	Plastic house	695	572	82.3
	Glasshouse	767	37	4.8
	Sum	1,462[c)]	609	41.7
		(1,380)		
Melons for cultivation mainly in plastic house	Open & tunnel	4,485	1,888	42.1
	Plastic house	7,078	1,127	15.9
	Sum	11,563	3,015	26.1
		(–[d)])		
Melons for cultivation mainly in open field	Open & tunnel	2,846	953	33.5
	Plastic house	794	640	80.6
	Sum	3,640	1,593	43.8
		(16,700[e)])		
Tomato	Open & tunnel	3,246	263	8.1
	Rain sheltering house[a)]	3,116	967	31.0
	Plastic house	4,430	2,027	45.8
	Glasshouse	416	277	66.6
	Sum	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
	Sum	12,355	6,167	49.9
		(17,200)		
	Sum	75,187	43,972	58.5
		(92,180)		

a): A simple, open-side structure to protect plants from rain.
b): 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).

Advantages and disadvantages of grafting

1) Advantages

Grafting offers various advantages as follows: (1) reduction of incidence of soil-borne diseases caused by pathogens such as *Fusarium oxysporum*; (2) increase of tolerance to low temperature, to soil salinity or waterlogging; (3) enhancement of water and nutrient uptake; (4) increase of plant vigor and extension of the duration of economic harvest time; and (5) shortening of the breeding period by limiting the breeding objective for resistance to soil-borne diseases and nematodes in rootstock.

Melons of all kinds and watermelons are grafted to control *Fusarium* wilt and to increase low temperature tolerance (Table 3). Cucumber plants are grafted to eliminate bloom on the fruit surface by grafting onto bloomless rootstock. In tomato and eggplant, bacterial wilt is controlled by grafting onto a resistant rootstock.

For these purposes, inter-generic grafting has been applied to the production of fruit-bearing vegetables. Cucumbers are grafted onto pumpkin (*Cucurbita moschata*) to confer resistance to *Fusarium* wilt and onto figleaf gourd (*Cucurbita ficifolia*) to confer low temperature tolerance. High temperature tolerance is conferred through grafting cucumber onto 'Shintosa' pumpkin. Watermelons are grafted onto bottle gourd (*Lagenaria siceraria*) and seldom onto

Table 3. Objectives for grafting in fruit-bearing vegetables in Japan[13)]

Species	Objective
Watermelon	*Fusarium* wilt (*F. oxysporum*), low temp. tolerance, wilting due to physiological disorders, drought tolerance
Cucumber	Bloomless fruit, *Fusarium* wilt, low temp. tolerance, vigor, *Phytophthora melonis*
Melon	*Fusarium* wilt (*F. oxysporum*), low temp. tolerance, wilting due to physiological disorders, *Phytophthora* disease
Tomato	Bacterial wilt (*Pseudomonas solanacearum*), *Fusarium oxysporum*, *Pyrenochaeta lycopersici*, nematodes (*Meloidogyne* spp.) *Verticillium dahliae*
Eggplant	Bacterial wilt (*Pseudomonas solanacearum*), *Verticillium albo-atrum*, *Fusarium oxysporum*, low temp. tolerance, nematodes, vigor

Table 4. Major varieties of rootstocks for fruit-bearing vegetables in Japan[13)]

Scion	Rootstock	
	Species	Major variety
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
Melons for greenhouse	*Cucumis melo*	Oi, Enken No. 2, Bernet hill favourite
	Benincasa hispida	Lion
	Cucurbita spp.	Unryu
	C. moschata × *C. maxima*	Shintosa
Melons for open field	*Cucurbita* spp.	Kongo
	C. moschata × *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.

pumpkin. Melons are grafted onto the same species but very rarely onto white gourd (*Benincasa hispida*) and pumpkin. The shape and taste of the fruits of the plants grafted onto pumpkin show a remarkable deterioration in watermelons and melons. Interspecific grafting is generally applied to eggplants. Scarlet eggplant (*Solanum integrifolium*) and *Solanum torvum* are popular rootstocks for eggplant (*Solanum melongena*) to confer resistance mainly to *Fusarium oxysporum* f. sp. *melongena* and bacterial wilt (*Pseudomonas solanacearum*), respectively. Tomatoes are grafted onto the same species bred to acquired resistance to bacterial wilt in summer and *Fusarium* wilt in winter. A large number of cultivars for rootstocks have been bred and released for practical use by many seed companies. The major varieties of rootstocks are listed in Table 4.

2) Disadvantages

Grafting is laborious or requires time, space and materials. Moreover, a high expertise is required for grafting, healing and acclimation. Depending on the combination of scions and rootstocks, grafting incompatibility and a decrease in the quality of fruits may appear, and the grafted plants often require improved cultivation methods.

In tomato plants, there are three kinds of resistance genes, Tm, Tm-2, Tm-2^a, to tobacco mosaic virus (TMV), and the genes in the scion and rootstock should be matched with each other. When the gene types of the scion and rootstock are different and the grafted plant is infected with TMV, grafting is generally successful but problems appear later.

The other problems associated with grafting are listed in Table 5.

Grafting methods

The main grafting methods include tongue approach grafting (Fig. 1-a) in cucumbers and melons of all kinds, cleft grafting (Fig. 1-b) in eggplants, tongue approach grafting and cleft grafting in tomatoes and cut grafting (Fig. 1-c) in watermelons[13]. Slant-cut grafting (Fig. 1-d) and horizontal-cut grafting (Fig. 1-e) on plug trays at a young stage have been developed and are being disseminated now.

Table 5. Problems associated with grafting and cultivated grafted plants[8]

Factors	Category	Measures for alleviation
Labor	Grafting operation	Specifically designed knives, grafting apparatus, grafting machines, grafting robots
	Postgraft care	Experience needed and postgraft conditioning chamber may be required for automation
Techniques	Rootstocks	Judicious selection of rootstock suitable for type of crops and cultivars
Management	Fertilizer application	Differences in field management, in particular reduced fertilizer application
Compatibility	Uneven senescence	Proper timing of growing season and rootstock type and selection
Growth	Excessive vegetative growth	Reduced fertilizer application and soil moisture
	Physiological disorders	Judicious selection of rootstocks to reduce excessive water and nutrient uptake
Fruit quality	Size and shape	Partly controlled with rootstocks
	Appearance	Proper cultural management
	Insipid taste	Cultivar and rootstock selection
	Soluble solid	Proper soil moisture control
	Yellow band in flesh	May appear in red flesh of watermelon
	Internal decay	Foliar Ca application and reduced N
Expense	Rootstock seeds	Inexpensive rootstock seeds (domestic or imported)
Scion rooting	External rooting	Careful management during seedling stage and at transplanting
	Internal or fused rooting	Different grafting methods to avoid scion root development through internal cavity of rootstock hypocotyl, which often cannot be recognized externally

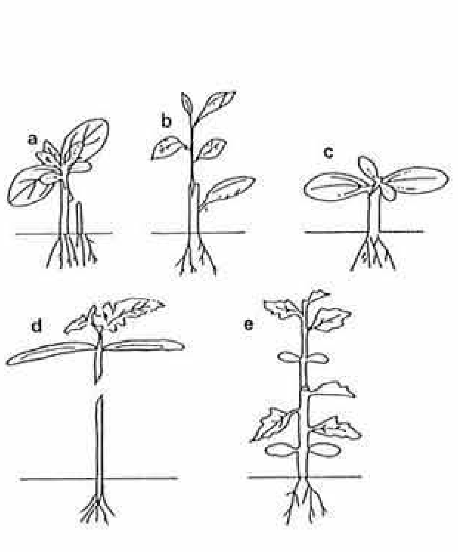

Fig. 1. Various grafting methods
a: Tongue approach grafting, b: Cleft grafting, c: Cut grafting, d: Slant-cut grafting, e: Horizontal-cut grafting[22].

1) Tongue approach grafting

Survival rate of grafted plants is higher by this grafting method in *Cucurbitaceae*, because the root of the scion remains until the formation of graft union. Seeds of cucumber and pumpkin are sown 10-13 and 7-10 days before grafting, respectively, to ensure uniformity in the diameter of the hypocotyls of the scion and rootstock. The shoot apex of the rootstock is removed to avoid shoot elongation. The hypocotyls of the scion and rootstock are cut up and down, respectively, to tongue with each other, followed by clipping. Grafted plants are covered with a shading material that intercepts sunlight by about half. The hypocotyl of the scion is crushed with fingers and cut with a sharp razor blade 3 and 7 days after grafting, respectively. The shading material is removed 10 days after grafting.

2) Cleft grafting

This method is most popular for grafting *Solanaceae*. The seeds of the rootstock are sown 5-7 days earlier than those of the scion. The scion at the 4 or 5-leaf stage is grafted onto the rootstock at the 5 or 6-leaf stage. Stems of scion and rootstock are cut with 2 to 3 leaves remaining on the scion and rootstock. The tapered stem end of the scion is placed into the cleft of the cut end of the rootstock, followed by clipping. The grafts are then placed in a container or a tunnel in which the inside humidity is kept at more than 95% RH and at a low light intensity of 3-5 klx. Three days after grafting, the shading materials and plastic film are removed in the morning and evening and the exposure period is gradually increased. Acclimation is completed from 7 to 10 days after grafting.

3) Cut grafting

This method is used for the grafting of *Cucurbitaceae* in seasons besides summer when the survival rate of grafted plants tends to be low. This method requires precise control of acclimation conditions, but grafting clips are not necessary.

First, the apical meristem of the rootstock (ex. *Cucurbita* spp.) is removed and a hole about 2 mm in diameter is made at the top of the rootstock hypocotyl with a stick. Second, the hypocotyl of the scion (ex. cucumber) is slantly cut at 45°. The cut hypocotyl of the scion is then inserted into the hole of the rootstock. Finally, the grafted plant is sprayed with water.

Recent studies for efficient grafting

Grafting is so laborious and time-consuming that farmers and growers aim at the development of a grafting instrument to reduce labor and time. For rapid grafting, Itagi (1990)[3] manually grafted tomato plants at the 2-leaf stage in a plug tray using the supporting-tube method, which reduced the time required for grafting to 1/3. Morita (1988)[9] used an adhesive and a hardener for the grafting of cucumbers, eggplants and grape. Chinese cabbage was grafted onto turnip using an adhesive and a hardener[15]. Watermelon, tomato and eggplant were mechanically homografted by the plug-in method[2]. Onoda et al. (1992)[20] have developed an instrument for grafting cucumbers onto *Cucurbita* spp. Oda et al. (1992)[14] evaluated possible combinations of scions and rootstocks in *Cruciferae*, assuming that small plants could be grafted simultaneously using a grafting instrument in the future. A model for the mechanical grafting of plugs was developed[17] and the growth and yield of the plugs grafted with an instrument based on the model were studied[19]. Oda (1992)[12] and Kurata (1994)[7] introduced patents and robots related to grafting, respectively. Though a grafting instrument would be suitable for sustained production of vegetables, there are few studies on mechanical grafting except for those listed above.

New and future grafting methods

1) Tube grafting of plugs

This manual grafting method was developed by

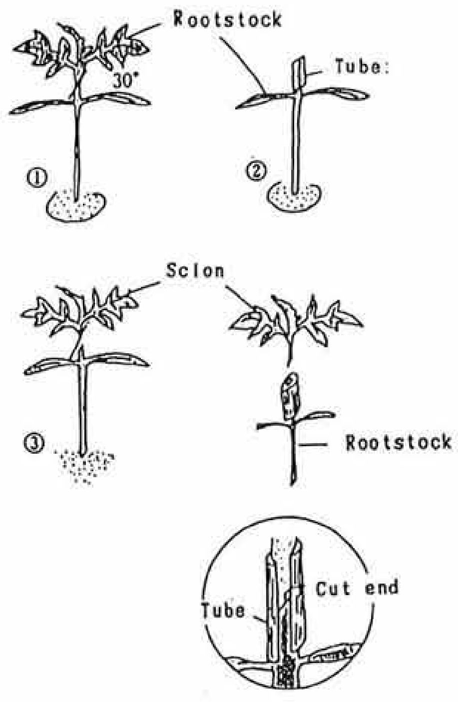

Fig. 2. Tube grafting for plugs[3]

Itagi et al. (1990)[3]. Tube grafting enables the grafting of small plants on plug trays at a rate three times faster than the conventional grafting method. The axes of scions and rootstocks are cut at a slant (Fig. 2). Elastic tubes are placed onto the cut ends of the rootstocks, and the cut ends of the scions are inserted into the holes of the tube, resulting in the splicing of the cut surfaces of the scions and

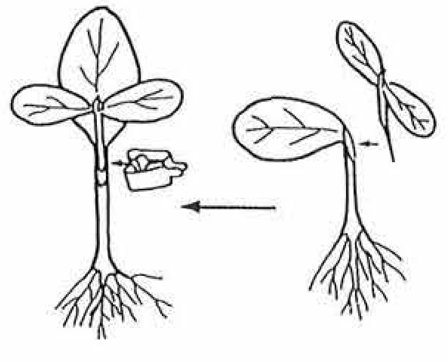

Fig. 3. Slant-cut grafting developed for mechanical grafting of *Cucurbitaceae*[4]

rootstocks. The tube grafting method has some advantages, i.e. low cost, simplicity and rapidity of grafting, high survival ratio and high adaptability to small plants. However, the acclimation conditions have to be precisely controlled.

2) Grafting instrument for Cucurbitaceae

Kobayashi et al.[4–6] started the development of a grafting instrument for *Cucurbitaceae* in 1987 and it was completed by Onoda et al. (1992)[20]. One cotyledon and apical meristem of pumpkin rootstock are cut off at a slant, leaving the other cotyledon (Fig. 3). The cut end of the hypocotyl of the cucumber scion is then spliced with the cut end of the rootstock and clipped. Such grafting procedures require about 3 s using the grafting instrument. A company has been marketing practical grafting instruments since 1993.

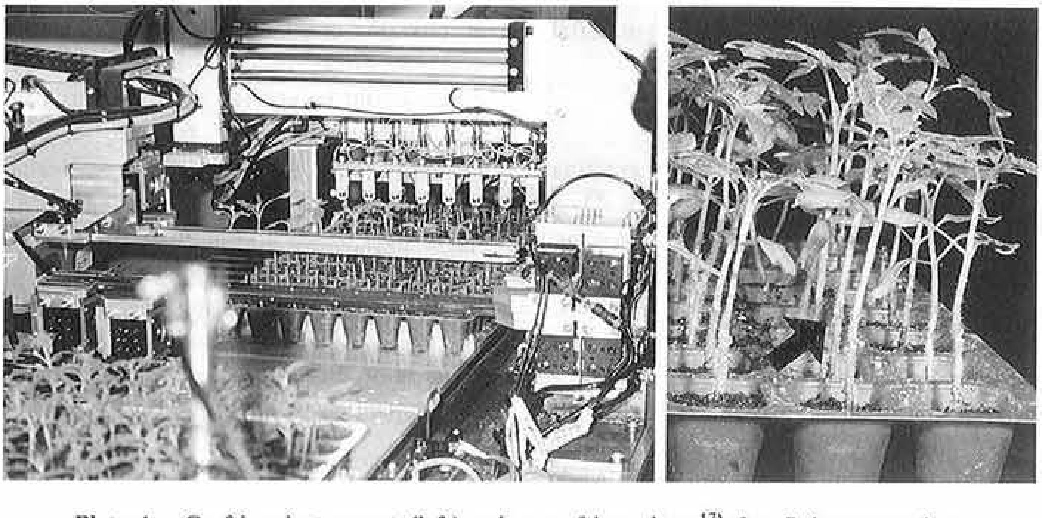

Plate 1. Grafting instrument (left) using grafting plates[17] for *Solanaceae* plugs Scions and rootstocks of tomato plugs (right) grafted with the instrument are held with an adhesive (arrow)[9,15].

If the hypocotyl of the rootstock is cut and thrust into the soil in the plug trays, cutting of the grafted plants into plug trays becomes easy. Growth after cutting is so satisfactory that the method can be applied for growing cucumber plugs grafted with the grafting instrument.

3) Mechanical grafting of plugs

Seedlings are grafted by cutting the axis horizontally. In horizontal-cut grafting, the cut is made at a right angle to the hypocotyls of the scion and rootstock. Cotyledons on the rootstock are lost by cutting the hypocotyl. The surfaces of the cut ends are then spliced, followed by holding the scion and rootstock together with grafting plates.

Five young tomato plants were simultaneously grafted using grafting plates which can be used for both scions and rootstocks[17]. The grafting plates consist of a hollowed plate and a driving plate. The hollowed plate has several V-shaped hollows on the inner side. The axes of scions and rootstocks can be held easily in a definite area by joining the driving plate with the hollowed plate.

A practical grafting instrument with this model has been developed by a company (Plate 1), combining an adhesive and hardener system for supporting the scion and rootstock together. This instrument is applicable to *Solanaceae*.

How to obtain a high survival rate in grafting

Acclimation is very important for grafted plants to survive. Space-saving grafted plugs are suitable for acclimation under artificial conditions because the cost per plant is comparatively low. Such an artificial acclimation system has been marketed by an agricultural cooperative and companies, and also a low-cost acclimation system using agricultural materials (Fig. 4) has been developed[10].

Before grafting, ① irradiation of sunlight on the scions and rootstocks for 2 to 3 days before grafting, ② drying of the potted soil where the scion and rootstock grow by controlled watering to avoid spindly growth, and ③ application of axes of scion and rootstock with similar diameters are important to increase the survival ratio[16]. When grafting is performed, it is important to: ① increase the chance for vascular bundles of the scion and rootstock to come into contact[18] by increasing the area of spliced cut surfaces and by appropriate pressure to the spliced cut surfaces together, and ② not to dry the spliced cut surfaces. After grafting,① keeping a 100% RH for 3 days and then proceed to gradual drying, and ② keeping the light intensity at 3–5 klx promote the survival ratio.

Distribution of grafted vegetables

The grafting of vegetables is extremely popular in Japan, and the technique has been developed in recent years. Mechanical grafting has been studied and some grafting instruments have been marketed by some Japanese companies. Recent advances in mechanical grafting on plug trays may accelerate the use of grafted plants by farmers all over the world, if the cost were to decrease. In the future, grafted plants will find other applications in addition to their use as horticultural crops. We intend to find new combinations for practical grafting based on studies on grafting incompatibility.

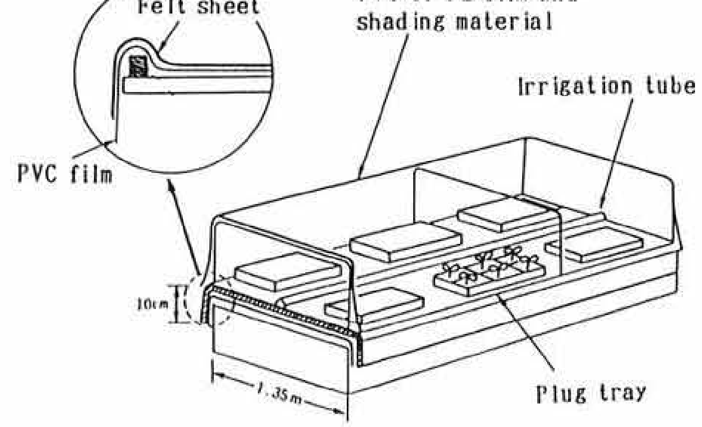

Fig. 4. Acclimation tunnel constructed with agricultural materials[10]

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