Grafting of Vegetables

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Summary

The cultivation of grafted vegetable is one of the essential cultural techniques for certain vegetables in many parts of the world where intensive and successive cropping is routinely practiced. More than 95% of the watermelons and oriental melons in Japan, Korea, Taiwan are being grafted on squash and gourd rootstocks before transplanting. The number of vegetables being grafted is estimated to be 540 million seedlings per year in Korea and 750 million in Japan. The benefits of grafting are well recognized so that illustration on vegetable grafting has become the key portion of the crop production guide pamphlets published by the government. Even though several grafting robots have been introduced to Korea from Japan, none of them are used now for practical grafting, possibly because of several unexpected limitations. In addition, most of these robots are too big to be handled and too expensive to be purchased by individual growers. Reasonably priced and easy-to-handle grafting machines are also urgently needed for the individual growers. Growing highly uniform seedlings in tray is vital for efficient grafting operation, especially for grafting by robots. Research relevant to seed germination and ways to obtain fast and uniform seed germination should be conducted to maximize the efficiency of vegetable grafting.

Introduction

Vegetable grafting, first started by grafting watermelons to gourds to reduce the incidence of the soil-borne disease *Fusarium* in Japan and Korea, is now being practiced in many parts of the world and for many

Table 1. Metabolic and physiological responses associated with grafting (Chung et al., 1997; Friendlander et al., 1977; Hirata et al., 1986; Kim and Lee, 1989; Lee, 1994; Lee et al., 1998; Phatak and Wittwer, 1965, Stimart, 1983; Takesu et al., 1997; The Poinsettia Growers, 1995).

Direct responses	Indirect responses
Disease tolerance	Shoot growth promotion
Low temperature tolerance	Juvenile and adult factors
High temperature tolerance	Translocation studies of stimuli
Enhanced nutrient uptake	Sex expression
Salt tolerance	Hormonal regulation
Increasing fertilizer efficiency	Physiological changes (disorders)
Wet soil tolerance	Organic composition (nicotine, etc.)
Enhanced water uptake	Propagation and transformation
Root nodulation	Fruit yield and quality
Winter hardiness	Heritable changes or agent
Xylem sap composition	Ornamental value
Nematode resistance	Earliness (precocity or novelty)
	Size control
	Extended harvest period

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different purposes (Table 1). During the earlier years, growers used to encounter many problems associated with the growing of grafted vegetables such as the lack of suitable rootstocks, grafting and curing technique, poor quality of produce, and others (Lee, 1989, 1994). However, many of these problems have been solved or minimized and the cultivation of grafted vegetables has now become a very basic cultivation technique for many crops, especially cucurbitaceous and solanaceous vegetables. Recent rapid expansion of the vegetable nursery industry and commercial plug seedling production has stimulated research in developing efficient grafting machines to cut down the expense needed to produce grafted seedlings. Now there are many commercial nurseries specializing in the production of mostly grafted seedlings in Japan and Korea. The development of efficient and reasonably priced grafting robots will undoubtedly increase the commercial supply of grafted vegetables not only in Japan and Korea, but also in many other parts of the world. The physiological and metabolic changes associated with grafting are listed in Table 1. It is apparent that grafting can be practiced for so many other purposes in addition to the usual purpose of obtaining tolerances to diseases and other stress conditions.

Present Status of Grafting

Based on 1992 production statistics, Lee (1994) estimated the number of vegetables being grafted was about 336 million for Korea and 650 million for Japan. However, the number of seedlings being transplanted per greenhouse space has increased steadily along with

Table 2. Cultivation area of selected vegetables in Korea and grafted seedlings needed for the planting.

Crop	Type	Cultivation area (ha)	Cultivation area of grafted seedling (ha)	No. of plants per ha (1000s)	Total seedlings needed (1000s)
Cucumber	Field	2,193	439	34	10,536
	Greenhouse	4,996	4746	30	142,380
Watermelc	Field	20,518	19492	7.5	146,190
	Greenhouse	18,752	17814	5.7	101,540
Oriental melon	Field	1,481	1481	9	13,329
	Greenhouse	9,198	9198	9	82,782
Melon	Field	0	0	24	0
	Greenhouse	419	82	24	1,968
Pumpkin	Field	4,454	0	9	0
	Greenhouse	2,805	281	9	2,529
Tomato	Field	216	0	30	0
	Greenhouse	3,828	383	30	11,490
Pepper	Field	90,762	0	30	0
	Greenhouse	4,767	238	30	7,140
Eggplants	Field	543	0	24	0
	Greenhouse	170	0	24	816
Total					520,700

the development of the growing technique, better growing environment, introduction of new cultivars, and others. The cultivation area of the vegetables and the number of seedlings being grafted in Korea are listed in Table 2. Watermelon is by far the most important vegetable being grafted in Korea. More than 95% of the watermelons are being grafted to gourd (*Lagenaria siceraria*) or squash (interspecific hybrid between *Cucurbita maxima* x *C. moschata*). Only about 20% of the field-grown cucumbers are being grafted whereas virtually all the cucumbers for greenhouse growing are grafted to figleaf gourd (*Cucurbita ficifolia*) or to squash. Some farmers are using bur-cucumber rootstock (*Sicyos angulatus*) to minimize the possible quality deterioration caused by the rootstocks (Lee et al., 1997). Almost all the Oriental melons (*Cucumis sativus* var. *makuwa* Makino) are being grafted to *Cucurbita* species. Furthermore, some farmers are now grafting

pumpkins (*Cucurbita moschata*) to figleaf gourd to promote growth and increase tolerances to environmental stress. Immature fruit of pumpkin (*Cucurbita moschata*), picked about 7–9 days after flowering, is one of the most popular vegetables among Koreans. The fruits have a very pleasant flavor and an excellent taste as compared to the zucchini-type. More studies are needed to clarify the effect of rootstocks on the quality of immature fruits of pumpkin and the fruit yield. Relatively lower percentages of tomato, pepper, and eggplants are being grafted in Korea in contrast to the fairly high percentages in Japan (Chung et al., 1995; Hwang et al., 1995; Lee, 1994). However, the percentage in Korea will increase rapidly because more and more farmers recognize the benefits of using grafted plants, especially under the unfavorable environmental conditions during the off-season.

The price of grafted watermelon (Table 3) is between

Table 3. Production and prices of grafted and normal vegetable seedlings in Korea.

Crop	Tray type	Price per grafted seedling ^z		Price per normal seedling ^y		Remarks
		Low	High	Low	High	
Watermelon	50 (~72) cells	400	500	120	180	Seedlings grown on other types of pots (not cell trays) are also being sold at similar prices.
Cucumber	50 (~72) cells	300	450	100	150	
Oriental melon	50 (~72) cells	400	450	120	180	
Pumpkin	50 (~72) cells	350	400	120	180	
Tomato	105 (~128) cells	300	350	120	150	
Pepper	105 (~128) cells	300	350	120	150	
Eggplant	105 (~128) cells	300	350	120	150	

^z One US dollar is 1,350 Korean Won as of June 25, 1998. Price varies mostly with the cultivar (watermelons and melons), final cell size, total number of order, and distance of transport.

^y Mostly for ordinary seedlings.

Fig. 1. Various grafting methods for vegetables. A: Hole-insertion (or plug-in) hypocotyl grafting, B: Modified hole-insertion grafting, C: Tongued approach grafting, D: Single cotyledon splice grafting, E: Single cotyledon double splice grafting, F: Hole insertion epicotyl grafting, G: Cleft grafting, H: Pin grafting, and I: Other grafting, respectively. See Table 4 for details.

400~500 Korean won (or 25~35 US cents) per seedling. The price usually varies with cultivars because the price of watermelon seeds (all hybrids) and, of course, the rootstock seeds vary greatly depending upon the cultivars. Intact or own-rooted seedlings are sold at much lower prices (8~12 US cents per seedling). Grafted seedlings of cucurbitaceous crops are usually grown in 50-cell trays by most commercial growers. Grafted seedlings have been exclusively produced based upon the direct order from the farmers. For grafted vegetables, 5,000~20,000 seedlings per order is the most common size requested. The price does not include the handling and shipping charges except for some large orders (100,000 seedlings or more per order).

In summary, the prices of grafted seedlings are about 3 times more expensive than the non-grafted normal seedlings and the commercial nurseries are eager to sell grafted seedlings to earn a higher profit per unit seedling-production space. Furthermore, the quality of grafted seedlings produced by the commercial grower is usually superior to those produced by farmers in a small scale. Since only about 5% of the total grafted seedlings are being produced by the commercial growers in Korea, the role of commercial nurseries will become more and more important in the coming years.

Research in Grafting Methods

Considerable efforts have been made concerning grafting methods (Chung et al., 1987; Delves et al., 1986; Denna, 1962; Hamaguchi et al., 1997; Oda and Nakajima, 1993; Phatak and Wittwer, 1965; Seo et al., 1994). Grafting methods usually vary with the kind of crops being grafted and the growers' preferences. For example, 'hole insertion grafting' (or 'plug-in grafting')

is favored in watermelons (A in Fig. 1). In contrast, 'tongued approach grafting' is routinely practiced for cucumbers and pumpkins (C in Fig. 1). Melons and Oriental melons are being grafted by 'hole insertion grafting' or by 'tongued approach grafting' depending upon the farmers. In solanaceous crops, however, other grafting methods may be favored. Table 4 and Fig. 1 illustrate the various grafting methods developed so far by researchers and growers. The 'hole-insertion grafting method' (or plug-in method) is favored by many watermelon growers because it is simple and easy and does not require grafting clips or other aids. The diameter of stem being inserted into the rootstock should be smaller as compared to that of the rootstocks. The hole in the rootstock can be made by a gimlet, conical drill, or specially designed grafting apparatus (knife and drill), or by an ordinary toothpick. The holes should be made at a slant angle and the scion should also be inserted into the rootstock at slant angles to avoid the insertion into the hypocotyl cavity of the rootstocks and to assure close contact between the scion and the rootstock. The seeds of the rootstock should be sown several days earlier than the scion (watermelon) seeds (7~8 days for gourd and 3~4 days for squash rootstock) to assure the size differences in hypocotyl diameter for this type of grafting.

Some growers favor grafting with excised rootstock seedlings and then placing the grafted seedlings into cells (50-cell tray) containing ordinary substrate for healing and rooting. Even though more efficient and precise grafting can be made with this method, it requires a few more days for the rooting, thus subsequently extending the time required for producing salable grafted seedlings. It is generally believed that

Table 4. Various grafting methods for vegetables.

Grafting method	Grafting efficiency (plant/hr)	Days of special care	Grafting aid needed ^z	Vegetables being grafted
Hole insertion hypocotyl grafting (A)	80 – 160	5 – 7	None	Watermelon
Hole insertion hypoc. grafting+rooting (A')	80 – 160	5 – 8	None	Watermelon
Modified hole insertion grafting (B)	200 – 300	7 – 10	None	Cucurbits
Modified hole insertion grafting + rooting (B')	200 – 300	8 – 11	None	Cucurbits
Tongued approach grafting (C)	80 – 120	3 – 5	None	Cucurbits
Single cotyledon tongued approach grafting (C')	80 – 120	6 – 8	1	Cucurbits
Single cotyledon splice grafting (D)	80 – 120	6 – 8	1,2,3,4	Cucurbits
Single cotyledon splice grafting + Rooting (D')	80 – 120	8 – 10	1,2,3,4	Cucurbits
Single cotyledon double splice grafting (E,E')	60 – 80	6 – 8	1,2,3,4	Cucurbits
Hole insertion epicotyl grafting (F)	80 – 160	5 – 8	None	Solanaceous
Cleft grafting (G)	60 – 100	5 – 7	1	Solanaceous
Pin Grafting (H)	150 – 300	5 – 7	2	Cucurbits & Solanaceous
Other grafting (I)	— ^y	— ^y	1,2,3,4	Selected vegetables

^z 1: Normal grafting clip; 2: Grafting pins (ceramic on bamboo), 3: Silica rubber clip (Super Idol or Super Wiz) 4: Glue and hardener, and 5: Split tubes, respectively. ^y Data not available. Also see Fig. 1 for details.

rooted seedlings have a more vigorous root system than the intact seedlings having only the primary root system and subsequently grow much faster than the intact plant once the adventitious rooting has been completed.

'Modified hole insertion grafting' (B in Fig. 1) was developed and patented by a commercial grower in Korea. The grafting is very simple and the grafting speed can be markedly accelerated. It also has an amazing advantage in that almost any rootstock seedling can be used for grafting. However, since the rootstock has no cotyledons remaining, it requires a longer period to attain suitable size for distribution. Fully or partially etiolated young scions preferably having unfolded cotyledons should be inserted into the rootstock to obtain fast healing.

'Tongued-approach grafting' is favorably practiced by beginners because it does not need several days of special care or a curing room with high moisture and temperature with artificial lighting or partial or full shading. The grafting operation is slow and tedious (about 800–1000 seedlings/day/woman), but a reasonably priced grafting machine has been developed and widely used for this kind of grafting in Korea. The outstanding advantage of this type of grafting is the complete control of sucker growth from the growing point since the cotyledons and the entire epicotyl are removed after the healing of the graft union (8–10 days after grafting) so that there is no need to rigorously remove the suckers or axillary shoots growing out from the rootstocks. Even though this type of grafting is widely used for cucumbers, other crops such as watermelons, pumpkins, and melons, and even some solanaceous and cruciferous crops can be successfully grafted by this method (Seo et al., 1994). Usually the fusion of only 2–4 vascular bundles among the 6 bundles takes place initially depending upon the depth of incision so that the speed of healing and early growth is rather slow.

'Single cotyledon splice grafting + rooting' (Table 4 and D in Fig. 1) is now the most widely used method among the large, experienced commercial growers in Korea. Since the scion and rootstock are cut at a slant angle and placed tightly together with a cheap, reusable grafting clip, the healing of the grafting union takes place much faster than most other methods and all the 6 vascular bundles could be fused together much sooner, which is vital for the vigorous early growth after grafting since the excised rootstock seedlings are used for grafting. It requires a somewhat longer period for complete healing and rooting as compared to some other methods and this is the major disadvantage.

The 'pin grafting method' has been temporarily used by some growers (H and I in Fig. 1). Ceramic pins developed by Takii Seed Company (15 x 0.5 mm diameter with hexagonal cross section) and bamboo pins developed by Naju Nursery in Korea (18 x 0.7 mm diameter with rectangular cross-section) are being used. However, this ceramic pin method was not very popular among commercial growers in Korea because of the higher price of the ceramic pins (30 Korean won or 2 US cents per each disposable pin) and the difficult post-graft care. The price of bamboo pins is much cheaper (5–7 won or 0.7 US cents per each) than the ceramic pins and more convenient to use.

Development of Grafting Robots and Grafting Machine

Grafting robots are being tested and manufactured for commercial use exclusively in Japan (Hartmann et al., 1997; Honami et al., 1992; Kurata, 1994; Oda et al., 1994) and Korea (Hwang et al., 1995). Table 5 shows some of the grafting robots and some grafting machines developed so far. The grafting robots being developed recently are usually designed to graft several plants at

once (plants in one row of a tray or a whole tray at once). Since seedlings are mostly grafted using cuttings, a special conditioning chamber is vital for post-graft care. Various grafting aids such as several types of grafting clips, grafting tubes, pins, glues, and others are being used. Several grafting robots equipped with self-clipping devices, were imported to Korea from Japan or were developed in Korea, but unfortunately none of these expensive robots are being used by commercial growers. A reasonably priced plug-in type grafting robot has also been developed and has been used by several growers successfully on an experimental basis in Korea.

Perhaps one of the most extensively used grafting machines among Korean farmers is the 'Yupoong' grafting machine (or robot) developed by Yupoong Company in Korea. The machine requires one operator all the time and grafts the scion and rootstock seedlings with a full root system by tongued approach grafting (C in Fig. 1) method. The machine can graft 400 seedlings per hour (4~5 times more efficient than a grafting expert). The angle and the cutting depth can be easily adjusted. An advanced model with a self-clipping device is also available, but at a higher price. Even though some grafting robots are now available in Japan and Korea, the price of the robot appears to be the major factor for wide distribution.

Research on Rootstocks

Earlier research has been focused on the graft compatibility and disease resistance. However, it has been widely reported that the fruit quality can be greatly

influenced by the rootstock in many crops (Chung, 1995; Lee, 1989; Lee et al., 1997b; Takesu et al., 1997). Extensive searches for suitable rootstocks have been persistently attempted to provide suitable rootstocks for different types of growing, growing season, growing environments, and even for specific scion cultivars. For example, the Takii Seed Company developed several rootstocks specifically for a very popular tomato cultivar, 'Momotaro' exclusively (Vegetable Catalog of Takii, 1995). Chung et al. (1997) also examined the seedling growth and disease infection in 'Momotaro' tomatoes as influenced by the rootstocks. The grafting was made with pin-grafting method and the plants were transplanted to the field soil severely infested with *Fusarium* wilt disease. Significant differences in seedling growth, days to the first flowering, photosynthesis rate, and disease infection rate were recognized depending upon not only the rootstocks but also the tomato cultivars.

Seo et al. (1994) reported a fairly good compatibility between Chinese cabbage (scion) and radish (rootstock). Even though they failed to obtain satisfactory yields of both the Chinese cabbage and radish from the same plant, the grafted plants showed an almost normal growth even after the transplanting to the field. Oda and Nakajima (1992) succeeded in growing Chinese cabbages grafted onto turnip root by using instant glue as the grafting aid. In addition, there are other reports on intergeneric or interspecific grafting (Chung et al., 1997; Dawson, 1942; Lee et al., 1997a; Oda et al., 1992). Sakata et al. (1996) evaluated the resistance to bacterial wilt and *Verticillium* wilt in 60 accessions of eggplants

Table 5. Grafting machines or grafting robots being developed in Japan and Korea (Kurata, 1994; Hwang et al., 1995).

Grafting machine	Company (Country)	Crops	Efficiency	Others
Grafting robot GR 800B	Iseki Co. (Japan)	Cucurbits	880/hr	Single cotyledon remaining
Super Angel G-710	Nasmix Co. (Japan)	Cucurbits	600-800/hr	Super Idol 31 silica rubber split tube for fixing
Super Angel G-720	Nasmix Co. (Japan)	Salanaceous	600-800/hr	Same as above.
Grafting Robot AG 1000	Yanma (Japan)	Salanaceous	1000/hr	
TGR ² grafting robot	Technical Grafting Res. Institute (Japan)	Cucurbits & Solanaceous	800/hr	Instant glue is used and all 128 seedlings in a tray can be grafted at once.
Pin grafting robot	Takii (Japan)	Solanaceous	— ^y	Ceramic pins are used.
Plug-in grafting robot (- machine)	Osaka Prefecture Univ. (Japan)	— ^y	— ^y	Plug-in method without other grafting clips or glue.
Grafting robot/Korea (Plug-in type)	Kyungpuk Univ. (Korea)	Solanaceous & cucurbits	700/hr	Being developed as of Feb., 1998
Pin-grafting robot	RDA (Korea)	Solanaceous	— ^y	Being developed.
Semi-automatic grafting machine	Yupoong (Korea)	Cucurbits	400/hr	One operator is needed per machine.

² Technical Grafting Research Institute. ^y Data not available

Table 6. Effects of rootstocks on juice acidity, electric conductivity (EC), soluble solids and sugar contents in 'Eunsung Baekdadagi' cucumber^z.

Scion/rootstock	pH	EC (mS/cm)	Soluble solids contents (%)	Sugar content ^y (%)		
				Fructose	Glucose	Total
Cucumber intact	5.98 c ^x	5.86 a	4.17 a	0.90 a	1.55 a	2.45 a
Cucumber/'Andong' ^w	6.12 a	4.67 b	4.16 a	0.81 b	1.49 a	2.30 b
Cucumber/'Heukjong'	6.05 b	4.57 b	3.66 b	0.65 c	1.33 b	1.98 c

^z Sucrose was not found or may be present only in trace amounts.^y Mean separation by Duncan's multiple range test at 5% level.^x Variety of bur cucumber (*Sicyos angulatus*).^w Samples of varying size from 3 growers in the same area for each graft combination were measured.

collected in Malaysia and reported that only one accession was resistant to *Verticillium* wilt whereas two accessions were resistant to *Fusarium* wilt. A worldwide search for suitable rootstocks should be performed on a larger scale.

The kind of rootstock varies with the kind of crops, growing season, and purpose. Hirata et al. (1986) reported the inheritance of graft-induced changes in eggplants and Yagishita (1961) also reported that the changes in pepper fruit shape induced by grafting were inherited for 3 generations. Dole and Wilkins (1992) also made similar reports on branching habits of poinsettia for 3 generations. Similar reports are available for other crops (Gomi and Masuda, 1981; Kato and Lou, 1989; Lee et al., 1997b; Kim and Lee, 1989). Numerous poinsettia cultivars have been developed by utilizing graft-induced permanent changes in the scion (The Poinsettia Grower Assoc., 1995; Stimart, 1983).

A considerable number of reports are available on the effects of rootstocks on fruit quality (Takesu et al., 1997; Chung, 1995). A higher fruit yield may be obtained by grafting scions on vigorous rootstocks, but the fruit quality is always better in intact or non-grafted plants. Lee et al. (1997) found significant reductions in the quality of cucumber fruits harvested from the plants grafted onto 'Heukjong' (*Cucurbita ficifolia*) rootstock. Significant reductions in mineral ion concentrations in fruit juice, soluble solids contents in fruits, and sugar contents in fruit juice were obtained in cucumber fruits collected from many growers in cucumber growing areas using different rootstocks (Table 6). Interestingly, however, the quality reduction can be minimized by using different rootstock, 'Andong' (*Sicyos angulatus*). Other quality measures such as fruit flesh firmness and shelf-life were also better in fruits from 'Andong' as compared to the fruits from 'Heukjong' rootstock.

Matsuzoe et al. (1996) evaluated fruit quality of 'Momotaro' tomatoes as influenced by 3 different rootstocks of *Solanum* species, *S. sisymbriifolium*, *S. torvum*, and *S. toxicarium*. They concluded that the fruit quality of the tomato plants grafted on other *Solanum* species was not different from that of tomato on its own roots.

The amount of reducing sugars and organic acids in fruit varied only slightly with the rootstocks, cropping season, and the amount of fertilizer applied. In oriental melons (*Cucumis melo* var. *makuwa* Makino), fruit quality deterioration and the incidence of some physiological disorder (internal decay) appeared to be closely associated with the rootstock. Vigorous rootstocks, such as interspecific hybrids between *Cucurbita maxima* x *C. moschata* tended to absorb more nitrogen fertilizers and less calcium into the fruits, thus causing severe incidence of premature internal decay in 'Keumssaragi' oriental melons (Chung et al., 1997). The benefits and effects of grafting can be clearly recognized in many vegetables and automation of grafting operation will undoubtedly stimulate the large-scaled commercial production of grafted seedlings for sale at reasonable prices in many parts of the world. However, the following problems should be solved or minimized in order to facilitate the above-mentioned global trend for the worldwide utilization of grafted vegetables as in fruit trees. First, methods to obtain fast and uniform germination of rootstock and scion seeds in tray cells should be thoroughly investigated for robot or machine grafting (Song and Lee, 1996; Yoo et al., 1996). Recent development in seed processing technology will undoubtedly contribute in this regard. Secondly, easy-to-use grafting machines or robots should be available at reasonable prices even to the individual farmers. Thirdly, a search for rootstocks for better performance should be thoroughly conducted using worldwide germplasm. Finally, ways to minimize the quality reduction, if any, caused by rootstocks should be thoroughly investigated.

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