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Present Status of Vegetable Grafting Systems

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Abstract

Recently, materials and machines for vegetable seedling production have been developed, for example grafting systems. Since grafted nursery plants which are essential for the cultivation of fruits and vegetables require precise techniques and careful management, grafting had so far been performed manually. However the development of grafting systems has enabled to perform this work mechanically. Currently, more than 10 companies are developing grafting systems. In this report, we classified representative grafting systems into their general configuration, object crop, seedling feeding method, grafting method and materials, and release of grafted nursery plants, and analyzed the functions of each system. Furthermore, we described the work performance of each grafting system and emphasized the importance of raising scions and stocks for mechanical grafting. Lastly, we indicated that the develop ment of new technologies such as automation of accessory operations, preparation of manuals for raising seedlings, seedling storage technology, and cultivation technology, is important for the development of grafting systems.

Discipline: Agricultural machinery/Horticulture
Additional key words: cucurbitaceous vegetables, nursery production, robotics, solanaceous vegetables

Introduction

Recently, vegetable seedlings have been increasingly produced by the use of mechanical equipment and sophisticated techniques such as virus-free nursery through tissue culture, plug nursery mass-production utilizing standardized multi-porous trays, and grafted nursery plants that require delicate manipulations.

Above all, grafted nursery plants are necessary to prevent injury by continuous cropping in the cultivation of fruits and vegetables. Although grafting of nursery plants can be performed manually, it requires precise techniques and is becoming increasingly difficult due to the advancing age of skilled workers. In addition, since fruits and vegetables are cultivated 2 or 3 times a year, laborious harvesting work conflicts with delicate raising of seedlings, resulting in a serious shortage of labor. Moreover, the employment of labor is also limited. Since it is becoming more difficult for individual farmers to produce grafted nursery plants due to the above-mentioned reasons, recently, a large number of farmers have been purchasing seedlings from nursery growers.

Under these circumstances, the BRAIN-IAM undertook research on mechanical grafting in 1986[3]. The results obtained were transferred to enterprises, and in October 1993, Iseki & Co., Ltd. succeeded in the commercialization of the world first semiautomatic grafting system, "a cucumber grafting robot." From 1993 onward, nursery growers, agricultural machinery manufacturers, and industrial machinery manufacturers started to develop grafting systems.

This report describes the present status of and prospects for the grafting systems developed in Japan.

Diffusion of grafted nursery plants

In grafting, a plant resistant to soil-borne diseases is used as the stock (resistant rootstock) and the target plant (scion) is joined to it. In cucumber grafting, for example, a pumpkin seedling is used

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Table 1. Specification and performance of grafting systems[a)]

Type	Semiautomatic				Fully automatic					
Manufacturer	Iseki	Iseki	Nasunix	Murata	Kagome	Kubota	Komatsu	Takii	Mitsubishi	Yanmar
Model	GR800-B	GR800T	G-710/G-720	MST771-2	-	KG-11	KGM0128	TS-1200	MGM600	AG1000
Object crops	Cucurbitaceous	Solanaceous	Cucurbitaceous Solanaceous	Cucurbitaceous Solanaceous	Cucurbitaceous Solanaceous	Solanaceous	Cucurbitaceous Solanaceous	Fruits and vegetables	Tomatoes	Solanaceous
Size: W-L-H (cm)	141-210-103	141-230-99	397-180-138	152-136-160	180-180-170	-	205-174-165	160-230-130	280-147-130	200-250-150
Weight (kg)	235	255	1800	150	-	750	200	-	420	750
Seedling feeding unit	Manual feeding	Manual feeding	Manual feeding	Manual feeding	Automatic feeding using 128-cell trays	Automatic feeding using 200-cell trays	Automatic feeding using 128-cell trays	Automatic feeding using trays	Automatic feeding using 13-cell single row trays	Automatic feeding using 72-cell trays
Clipping unit:										
Grafting method[b)]	c	a	a	c	a	b	b	d	a	a
No. of seedlings grafted simultaneously	1	1	1	1	1	1	8	10	1	6
Fixing tools[c)]	2	3	4	6	-	Instant glue	Instant glue	Pin	5	2
Grafted nursery plant releasing unit	Conveyor, Manual planting	Conveyor, Manual planting	72-cell tray, Automatic planting	Conveyor, Manual planting	128-cell tray, Automatic planting	200-cell tray, Automatic planting	128-cell tray, Field grafting	Tray, Field grafting	Tray, Field grafting	Tray, Automatic charging
No. of persons required	3 (2 for feeding seedlings)	3 (2 for feeding seedlings)	1 ~ 2	2 (for feeding seedlings)	1	1	1	1	1	1
Performance:										
Efficiency (seedlings/h)	800	800	750 ~ 850	600 ~ 700	180 ~ 250	1,200	1,000	1,000	400	1,000
Mechanical grafting success rate (%)	95	95	98	95	-	95	95	95	95	95
Agglutination rate (%)	90	90	98	-	90	-	85 (Solanaceous)	98	-	-

a): Prepared from catalogues, press releases, and other data.
b): Letter shows grafting method depicted in Fig. 1.
c): Numeral refers to fixing tool illustrated in Plate 3.
- denotes "None", "Unknown" or "No description".

as the stock and a cucumber seedling is used as the scion. Generally, both seedlings are joined with each other at the level of the hypocotyl both for the stock and scion. It is generally recognized that grafted nursery plants offer many advantages such as low/high temperature tolerance and increased yield as well as resistance to soil-borne diseases. Therefore, cultivation using grafted nursery plants enables to reduce the frequency of chemical sprays for pest control and thus can meet the consumers' requirement for safe foods and the need for reduced load on the environment. Furthermore, cucumbers without bloom can be produced using a particular type of stock which results in the increase of the value of the products. In this regard, grafting technology is indispensable for the cultivation of fruits and vegetables in Japan.

According to the survey performed by the National Research Institute of Vegetables, Ornamental Plants and Tea[5], the diffusion rate of grafted nursery plants in the area was 93% for watermelons, 72% for cucumbers, 44% for melons grown in open field, 42% for melons grown in greenhouses, 26% for melons grown in plastic film greenhouses, 50% for eggplants and 32% for tomatoes. Grafted nursery plants accounted for about 59% of the total fruit and vegetable seedlings. In greenhouse culture, the rate exceeded 90% in watermelons, cucumbers and eggplants.

Structure of the grafting system

Since 1996, more than 10 companies have developed grafting systems. However, since some of the systems were developed by nursery growers for their own production of grafting nursery plants, only 4 to 5 companies have marketed their systems. Table 1 gives a summary of the systems based on catalogues, etc.

1) Types of grafting systems

Grafting systems are classified as follows by their functions.

(1) Semiautomatic type, fully automatic type

Mechanical grafting work consists of 6 processes: (a) feeding of seedlings, (b) transfer of seedlings, (c) cutting off of unnecessary parts of seedlings, (d) feeding of fixing tools, (e) fixing of cut faces, and (f) removal of the grafted nursery plants and planting. Grafting systems include semiautomatic and fully automatic types. The difference between these 2 types depends on whether process (a) and process (f) are automated or not.

Plate 1 shows the world's first semiautomatic grafting system that was commercialized by Iseki & Co., Ltd. Feeding and planting of seedlings of the grafted nursery plants are performed manually. This system can be applied to the grafted nursery plants

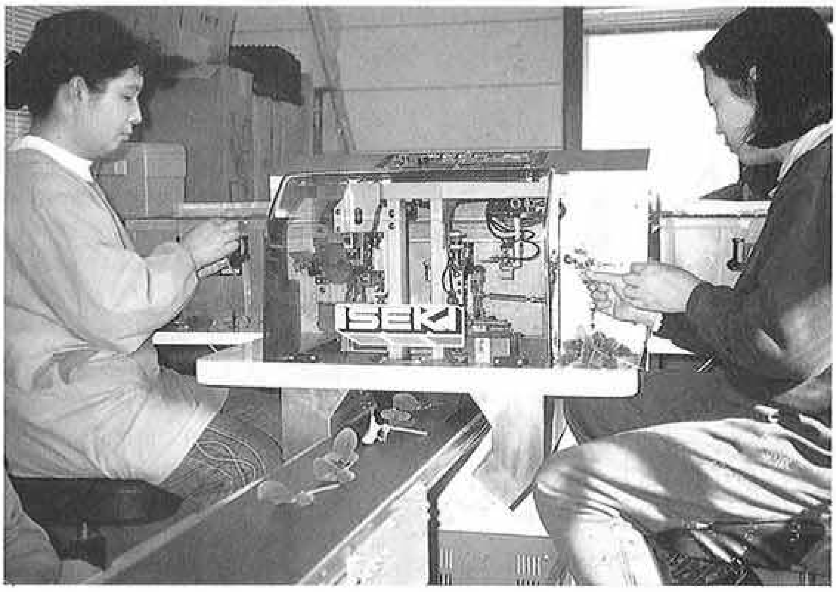

Plate 1. Semiautomatic grafting system and grafting operation Stocks (left) and scions (right) are fed by 2 persons. Grafted nursery plants are released on the belt conveyor.

of cucurbitaceous vegetables. Systems for solanaceous vegetables, which have different parts such as the nursery gripping hands, etc., are also being marketed by Iseki & Co., Ltd.

Plate 2 (a) to (c) shows fully automatic grafting systems which are suitable for grafting tomatoes. Scions and stocks grown in cell-trays are fed to the system.

(2) Seedling feeding unit

In the case of a semiautomatic system, seedlings with or without roots are fed by workers. In the case of a fully automatic system, however, seedlings are fed by gripping hands from trays on a belt conveyor. Trays with 72 cells or 128 cells are used. Furthermore, in a system, special trays which have 13 cells can be used (see Plate 2(c)).

(3) Clipping unit

a) Grafting method: Fig. 1 shows some representative grafting methods. In solanaceous vegetables, the scion and stock are clipped after the hypocotyl is cut aslant (Fig. 1, a) or by cutting the hypocotyls at a right angle to the axis (Fig. 1, b). In the grafting systems for cucurbitaceous vegetables, one cotyledon and the growing point of the stock are cut and then the scion's hypocotyl is cut aslant and the cut surfaces are fixed with a clip (Fig. 1, c). The joining portion on the stock is the hypocotyl above or below the cotyledon for solanaceous vegetables and the joint of cotyledons to hypocotyl or the hypocotyl for cucurbitaceous vegetables. The joining portion on the scion is below the cotyledons for solanaceous vegetables and cucurbitaceous vegetables.

b) Number of seedlings grafted simultaneously:

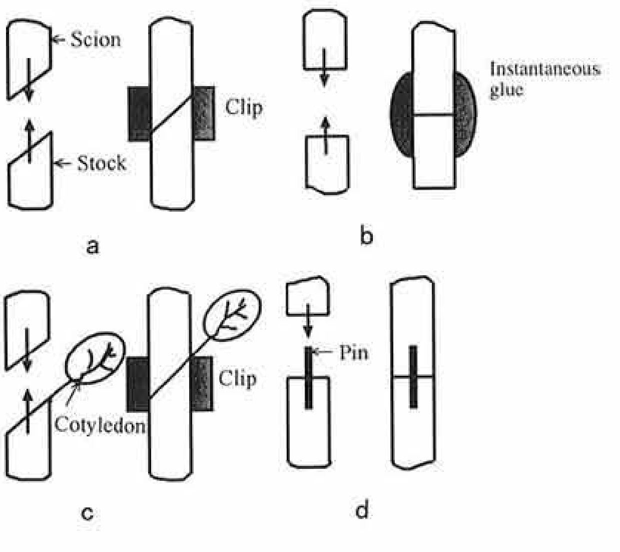

Fig. 1. Grafting methods using various grafting systems

There are 2 types of grafting methods, "single grafting", where one single seedling is grafted at a time and "multiple grafting", where 6 or 8 couples of seedlings are grafted simultaneously. Although seedlings are fed manually or automatically in single grafting, smaller plants and/or non-plant cells are detected while feeding.

In multiple grafting, since scions and stocks grown in trays must be sound, removal of non-plant cells and smaller plants and supply of sound seedlings are required. Furthermore, before feeding, the upper part of stocks is cut off to avoid any mechanical trouble.

c) Fixing tools: Some representative fixing tools are shown in Plate 3. No. 1 is used for manual grafting and the others for mechanical grafting. No. 2 and 3 were modified from No. 1, No. 4 and 5 are one-piece types made of resin, and No. 6 is a split-type clip. In addition, instant glue and ceramic pins are also used. Although No. 2 and 3 must be removed manually before the planting, No. 4, 5, 6, and adhesives naturally fall as the plant grows. Ceramic pin (Fig. 1, d) remains in the hypocotyl during cultivation.

(4) Processing of grafted nursery plants

Grafted nursery plants are either fed onto a belt conveyor or planted on a tray. In the former case, grafted nursery plants are manually planted in a pot or tray. In the latter, 3 methods can be applied: (a) stocks without roots are grafted and planted to another tray, (b) stocks with a root ball are grafted after being removed from the tray, and are planted on another tray of the same size, and (c) grafting is carried out on the tray, without moving the stocks (field-grafting).

2) Performance of the grafting systems

(1) Grafting capacity

Grafting capacity is represented by the number of grafted plants per hour. Although the grafting capacity of the semiautomatic system (see Plate 1) depends on the capacity of the seedling supplier, based on the results of tests conducted at horticulture experimental stations in both Iwate and Saitama Prefectures, 750 seedlings per hour can be grafted. Although in other systems no official test data are available, grafting capacity described in the catalogue amounts to 600 to 850 seedlings per hour. The values of the grafting capacity of fully automatic systems are all described in the catalogues and 180 to 1,200 seedlings can be grafted per hour in the single grafting system and 1,000 seedlings per hour in the case

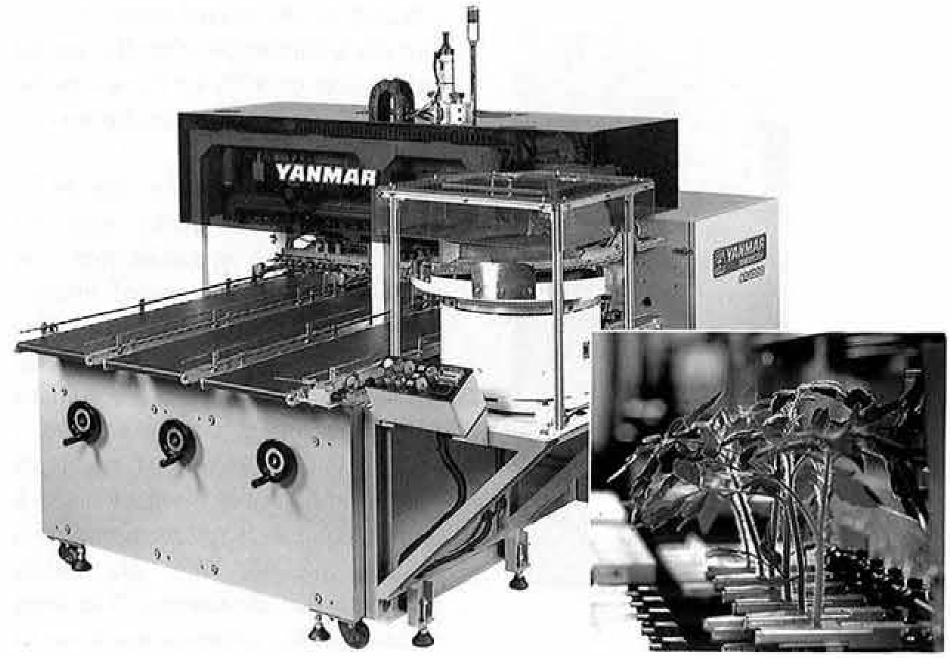

Plate 2(a). Fully automatic grafting system (1)
Multiple seedlings are grafted simultaneously. There are 3 belt conveyors; left conveyor is for scions and central one is for stocks. Scions and stocks are grafted after being removed from their trays. The grafted nursery plants with root balls are transferred in the trays mounted on the right conveyor.

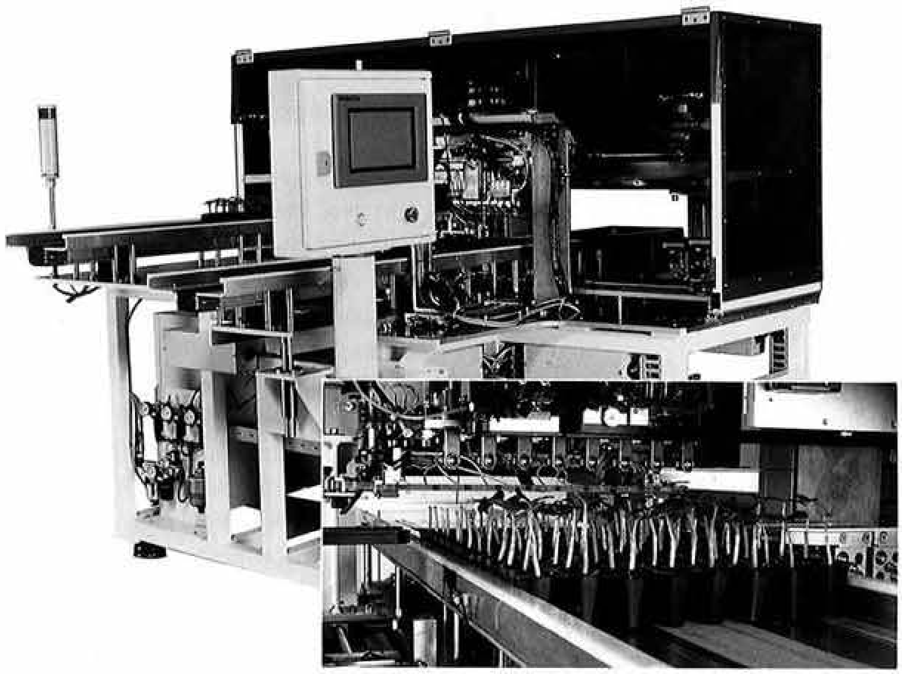

Plate 2(b). Fully automatic grafting system (2)
Seedlings are grafted simultaneously. When the trays of scions and stocks are mounted on the conveyor, the plate guides and grasps the seedlings. Stocks and scions are cut along the plate, cut faces are joined with glue, and the glue is hardened by a curing agent.

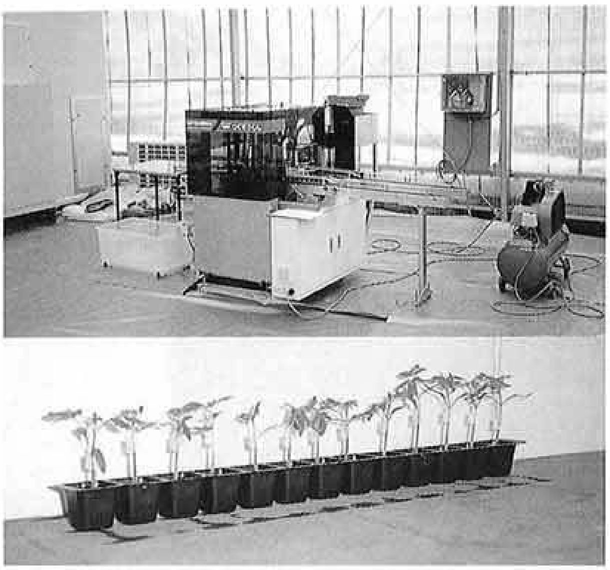

Plate 2(c). Fully automatic grafting system (3)
A single seedling is grafted. Scions and stocks are arranged in 13 cells per row on a belt conveyor. The stock is cut at a fixed position after the position of the cotyledons is detected, and the scion is carried and joined to the stock with a clip.

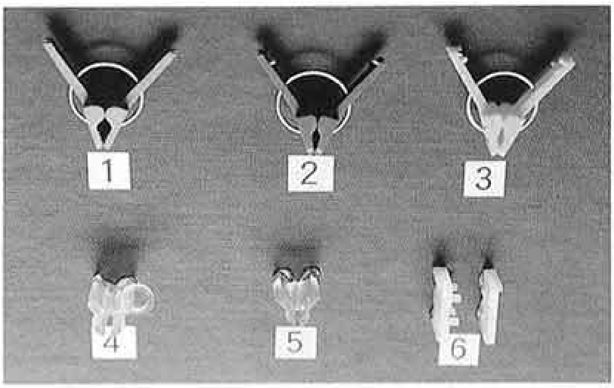

Plate 3. Fixing tools used for grafting systems

of multiple grafting.

(2) Mechanical grafting success rate

Mechanical grafting success rate depends on the percentage of physically connected plants. The plants whose cut surfaces are not aligned with each other are not included in grafted nursery plants even though they are connected. The mechanical grafting success rate of any type of system is 95% or more.

(3) Agglutination rate

Agglutination rate refers to the percentage of physiologically agglutinated seedlings. This rate will be affected by the performance of the grafting system and the acclimation after the grafting. An agglutination rate of 90% or more can be obtained under specified acclimation conditions.

3) Artificial acclimation system[4)]

Grafted nursery plants require special management referred to as acclimation. Acclimation is the process whereby the joined tissues are able to agglutinate and whereby a smooth transition to the subsequent normal management of seedlings is secured. Acclimation is a prerequisite for the success or failure of agglutination (Plate 4).

The basic principle of acclimation is to enable the joined tissues of the stock and scion to agglutinate with minimum energy consumption by sprinkling and dousing and not allow the seedlings to wilt even under normal conditions. The artificial acclimation system enables to secure optimum humidity, temperature, light, and wind velocity conditions. In many cases, a grafting system is introduced together with an artificial acclimation system.

After being acclimated by this system for several days, grafted nursery plants are put on the raising shelf in the greenhouse, and at first exposed to weak light. Lighting hours are gradually increased in order to accustom the seedlings to natural conditions. Dousing of curtains, water sprinkling, and temperature control are performed manually because this process requires a certain degree of skill.

Seedlings suitable for the grafting system

The grafting system can not always be applied to any kinds of seedlings. With regard to the size of seedlings, scions and stocks with a certain range of values for the hypocotyl length and diameter and expansion of leaves are suitable for the grafting system. Furthermore, slightly harder seedlings raised with little sprinkling lead to a higher mechanical grafting rate and to agglutination after the grafting.

The methods of raising scions and stocks are very important to enhance the efficiency of grafting work as a whole. For that purpose, seeds with a high germination percentage and germination rate and a bed soil with good physical and chemical characteristics are used. A system that can secure optimum conditions and a high level of skill for the raising of seedlings are required. Obviously, the success or failure of grafting depends on the method of raising scions and stocks.

Plate 4. Grafting systems introduced in a seedling production plant
Four systems are arranged on both sides of the belt conveyor.
Artificial acclimation systems are seen on both sides.

Future prospects for grafting systems[1,2]

First generation grafting systems are currently in use, and it will become necessary to develop improved systems suitable for a wider range of seedling conditions and affording a high working accuracy and work rate.

A wide range of uses for other crops is also required because the production of grafted nursery plants for fruits and vegetables is seasonal and consequently the operation rate of the system decreases. If the same system could be used to produce grafted nursery plants for flowering trees and shrubs as well as fruit trees, the operation rate of the seedling production plant as a whole as well as the system itself could be raised, resulting in the reduction of the production cost.

The production of grafted nursery plants involves many processes ranging from the preparation of bed soil to planting. During this period, no error in management should take place. Since the grafting system saves labor only in the whole process of grafting work, overall labor saving cannot be achieved without automating the processes before and after grafting and developing good interrelations with them. Automation of accessory operations such as handling of the bed soil and trays, sowing systems for large seeds, and environmental control of the seedling raising room, are necessary.

For the efficient production of seedlings through the division of labor, from the view point of transport cost for distributing the seedlings, and ease of handling, trays will be utilized over the whole process, ranging from the raising of scions and stocks and shipment of grafted nursery plants to planting in the field. To raise scions and stocks suitable for mechanical grafting on trays and to obtain grafted nursery plants that are homogeneous, as well as of high-quality and high-grade, expertise in the determination of the lighting regime and water content in the soil, as well as temperature control is necessary. Standardization of these techniques is required.

The technology for storing seedlings is also important. If the seedlings can be stored, systematic production can be achieved. This technology is also useful for maintaining the quality of seedlings during transportation.

As a result of the development of grafting systems, new technologies must be developed in the field of seeds, production and distribution of seedlings, as well as cultivation.

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