Growth and Yield of Eggplants Grafted by a Newly Developed Robot

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Abstract. Eggplant (*Solanum melongena* L.) at the two-leaf stage were grafted on scarlet eggplant (*Solanum integrifolium* Poir.) by hand or a newly developed robot. The scion and rootstock were fixed with an elastic tube for hand grafting or with an adhesive and a hardener for robotic grafting. After acclimatization, the grafted plants were planted at the three- or 11-leaf stage in a glasshouse. Plants grafted by the robot showed a higher percentage of survival, and attained the three- and 11-leaf stages 8 days earlier on average than those grafted by hand. Stems were longer, and shoot fresh mass and fruit yield of plants were higher for the three-leaf- than for the 11-leaf-stage planting, irrespective of the grafting method. Such vigorous growth and high yield by robotic grafting were absent for the 11-leaf-stage planting but obvious for the three-leaf-stage planting.

Failure of vegetable production associated with continuous cropping has been ascribed principally to the incidence of soilborne diseases and nematodes (Takahashi, 1984). To prevent the problems associated with soilborne diseases and nematodes, grafted plants have been extensively used for the production of certain fruit-bearing vegetables in Japan (Oda, 1995). Grafting should make it possible to successfully grow preferred cultivars that do not possess genetic resistance to soilborne diseases and nematodes.

However, grafting is extremely laborious and time-consuming, so growers were seeking a convenient grafting aid. Thus, attempts have been made to mechanize grafting operations since 1987 (Kobayashi et al., 1987). Itagi et al. (1990) grafted tomato (*Lycopersicon esculentum* Mill.) plants at the two-leaf stage using an elastic tube to support the scion and rootstock, which reduced the time required for grafting by one half. Morita (1988) and Oda and Nakajima (1992) applied an adhesive and a hardener to support the graft union in several crops.

We have simultaneously grafted five young tomato plants using grafting plates (Oda et al.,

1994), and further developed a grafting robot for plugs (Kurata, 1994; Oda et al., 1995). This robot has enabled eight plugs of tomato, eggplant, or pepper (*Capsicum annuum* L.) to be grafted simultaneously. Grafted plants are produced about 10 times faster by robotic grafting than by conventional hand grafting. Tomato plugs grafted by the robot produced fruits of similar mass to those grafted by the conventional method (Oda et al., 1995).

In our study, the growth and fruit yield of eggplants grafted on scarlet eggplants, a popular rootstock for eggplant, were examined to compare grafting methods and seedling stage at transplanting.

Materials and Methods

Structure and operation of the grafting robot. The structure and operation of the grafting robot we used have been detailed by Kurata (1994) and Oda et al. (1995). The design of the robot is based on the simultaneous grafting method using grafting plates (Oda et al., 1994) and the adhesive and hardener system (Morita, 1988; Oda and Nakajima, 1992). Briefly, eight scions and eight rootstocks are grasped by the robotic grafting plates and intermediate plates made of aluminum alloy. The hypocotyls of the scions and the rootstocks are cut with razor blades along the lower and upper surfaces of the intermediate plates, respectively. The grafting and intermediate plates holding the scions are placed on those holding the rootstocks by splicing the respective cut surfaces. Then, the intermediate plates are taken off, and the adhesive and hardener are applied around the graft union of the scions and rootstocks. The grafting plates are removed and the grafted plants are acclimatized. The resulting robotic grafting procedure is 10 times faster than hand grafting, which is 100 plants/h.

Growing conditions. Chitted seeds of the scarlet eggplant 'Akanasu' (Takii and Co.,

Kyoto, Japan) were sown on 6 Jan. 1995 in a 128-cell plug tray (24 mL/cell) that had been filled with Nippi no. 1 growth medium (Nippon Hiryo Co., Tokyo), mixed with the same volume of peat moss. The seeds of the eggplant 'Senryo No.2' (Takii and Co.) were sown on 13 Jan. 1995. The eggplant plugs were grown in a glasshouse with the air ranging from 15 to 35 °C.

On 13 Feb., when two true leaves had unfolded, the scion eggplants were grafted onto the scarlet eggplant rootstock by the robotic method or by hand. The hypocotyls of the scion and rootstock were cut at right angles, and the cut surfaces of the scion and rootstock were contacted with each other, followed by fixing them with an elastic tube (hand grafting; HG) or application of the adhesive and hardener (robotic grafting; RG) (Fig. 1). After 2 mL of water had been sprayed on the leaves of each scion with a hand sprayer, the plants were transferred to an acclimatization room maintained at 28 ± 2 °C and 95% or higher relative humidity (RH) under $100 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ photosynthetic photon flux light intensity (continuous lighting) provided by cool-white fluorescent lamps. After 3 d, RH was lowered daily by decreasing humidification; the rate of decrease was based on avoiding wilting of the plants. Acclimatization was finished on the 7th and 12th d for RG and HG, respectively.

The grafted plants were transferred to the glasshouse and were divided into two groups, one for planting at the three-leaf and the other at the 11-leaf stage. On 2 Mar., when three leaves had unfolded, half of the plugs grafted by the robot were directly planted into ground beds in the glasshouse, and the other half were transplanted into 500-mL pots. The potted plants were grown in the same glasshouse and planted into ground beds on 6 Apr. when 11 leaves had unfolded. Plants grafted by hand needed 8 d more to reach the same growth stages for transplanting when compared to those grafted by the robot.

A slow-release granular fertilizer had been broadcast and incorporated into the ground beds, with N, P, and K each at 28, 28, and 24 g·m⁻² before transplanting. The experiment was arranged in a randomized block with three replications, each consisting of four plants. The grafted plants were placed 60 cm apart within rows and 150 cm between the rows. Three stems were trained on each plant. The air in the glasshouse after planting ranged from 14 to 40 °C. The experiment was terminated on 11 July 1995.

Results and Discussion

The average period of acclimation was 7 and 12 d for RG and HG plants, respectively. Since 7 to 10 d are generally required for acclimatization after grafting, regardless of the method, graft union formation appeared to be delayed by HG in this experiment. Of the 128 grafted plants in a plug tray, 98 (77%) and 122 (95%) plants survived after HG and RG, respectively. The adhesive and hardener that were applied for RG was not phytotoxic to plants (Morita, 1988; Oda and Nakajima,

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Fig. 1. Methods for supporting the scion and rootstock in hand (left) and robotic grafting (right). (S) scion, (R) rootstock, (T) side-slit elastic tube, (A) adhesive plus hardener.

Table 1. Effects of grafting method and stage at transplanting on growth of eggplants.^z

Grafting method	Leaf-stage at transplanting	Stem length ^y (cm)		Shoot fresh mass ^x (kg/plant)
		10 May	13 June	
Hand	3	164 b ^w	347 b	2.51 a
	11	127 c	302 c	1.69 c
Robot	3	226 a	400 a	2.07 b
	11	135 c	310 c	1.46 c

^zPlants grafted by the robot were transplanted at the three- or 11-leaf stage on 2 Mar. and 6 Apr., respectively. Plants grafted by hand were transplanted 8 d later than those grafted by the robot at each planting stage.

^yTotal length of three trained stems.

^xTotal mass of stems and leaves during cultivation.

^wMean separation within columns by Duncan's multiple range test at $P \leq 0.05$.

Fig. 2 Fruit yield of eggplants as influenced by grafting method and stage at transplanting. (▲) hand grafting (HG) and three-leaf-stage transplanting (3P), (△) HG and 11-leaf-stage transplanting (11P), (●) robotic grafting (RG) and 3P, (○) RG11P. Mean separation by Duncan's multiple range test at $P \leq 0.05$.

1992). Meanwhile, scion and rootstock were fixed loosely with elastic tube used in HG. Union of the scion and rootstock was delayed as a result of the elastic tube used in HG when compared with the adhesive and hardener used in RG. Thus, transplanting was delayed 8 d for

plants grafted by HG compared to those grafted by RG.

Seedlings planted at the three-leaf-stage (3P) had longer stems than those planted at the 11-leaf-stage (11P), irrespective of the grafting method (Table 1). The longest average

stem length was obtained in RG plants transplanted at 3P. Shoot fresh mass was higher for 3P than for 11P.

Fruit yield was higher for 3P than for 11P, irrespective of the grafting method (Fig. 2). For the 3P, fruit yield was higher for RG than for HG, but no such difference existed for 11P. The lower fruit yield in 11P was most likely attributable to growth suppression before transplanting into the ground beds, because of the relatively small pots (500 mL) in which plants were raised from the four- to 11-leaf stage.

Before 1990, transplants of eggplants in Japan were produced in 500- to 1000-mL pots. Since then, plugs grafted manually with tubes (Itagi et al., 1990) have become popular among the growers. Our results make clear that planting at an earlier growth stage, such as the plug stage, is advantageous for increasing the production of fruits in eggplants. In a previous study (Oda et al., 1995), the growth and fruit yield of tomato plants were not affected by grafting method and transplanting stage, whereas RG eggplants grew more vigorously and produced more fruits than HG plants when young seedlings were transplanted.

The results obtained in this study indicate that eggplant plugs grafted simultaneously with the newly developed robot can be safely used for production of grafted transplants on a commercial scale.

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