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Development of Prototype Automatic Grafting System for Fruit-bearing Vegetables†

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적 요

우리나라의 경우 각종 장해와 주년 수요의 증가에 따른 불시재배의 증가로 인하여 저온신장성, 병해저항성 등과 같이 작물의 내성증진을 목적으로 접목묘의 이용이 급속도로 신장되고 있다. 특히 연작장해가 심한 박과형 채소류는 대부분 접목재배가 필요한 실정이다. 그러나 국내의 경우, 접목작업은 거의 수작업으로 행해지며 세밀한 조작과 숙련성 그리고 많은 노력을 필요로 한다. 따라서, 접목 생산성을 높일 수 있는 저가의 자동화 시스템 개발이 요구된다. 다양한 접목법들 중 현재 농가에서 가장 광범위하게 이용되고 있는 호접은 삽접 및 절단접에 비하여 자동화가 어렵고 활착 후 절단작업이 부가적으로 필요하나 접목 후 순화공정이 간단하고 활착률이 높다. 본 논문에서는 호접과 삽접에 대하여 접목 후의 활착률 및 접목에 소요되는 작업시간을 비교하였고, 호접법에 의거하여 작업공정을 생력화한 육묘 자동접목 시작기를 개발하였다. 시작기는 농가조합 및 중규모 육묘장의 설비를 지향하여, 묘판 및 접목묘의 취급을 제외하고 1인 접목작업 형태의 자동화 시스템으로 개발하였다. 시작기는 크게 버퍼기능을 부착한 배치형 육묘장착부, 2세트의 공압 매니퓰레이터, 대목과 접수의 원할한 접목을 위해 설계한 특수 그리퍼, 각도 조절형 절단부, 진동형 클립공급부 그리고 자동 클립 장착장치로 구성하였다. 접목 작업시간은 대략 4초 정도이나 작업시간의 조정이 가능하도록 하였다. 실험실에서 수행한 간이접목 시험 결과, 절단날이 대목과 접수의 접촉부위를 관통할 때 접촉면이 서로 어긋나는 경우가 발생하였으나 육묘들이 호접에 적정한 기하학적 물성 요건을 갖춘다면 80% 이상의 접목 성공률을 예상하고 있다. 향후, 현장적용을 위하여 대목과 접수의 접촉면 어긋남을 방지하는 기구부 보완 및 육묘의 기하학적 물성에 따른 체계적인 접목시험이 필요하다.

주요용어(Key Words): 자동접목(Automatic Grafting), 호접(Inarching), 박과 채소(Fruit-bearing Vegetables) 기하학적 물성(Geometric Property)

1. INTRODUCTION

In the production of horticultural crops, the preparation of seedling is essential to produce the high quality product and to increase the amount of the harvest. Grafting seedlings of fruit-bearing vegetables is very critical to reduce the damages caused by the low temperature, disease, and successive planting. In Korea,

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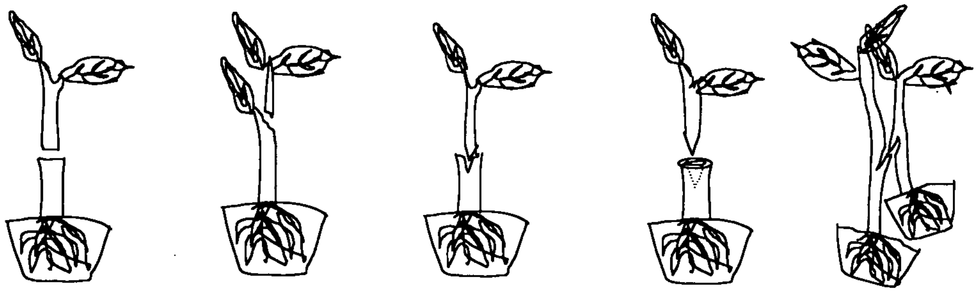
cultivation using the grafted nursery plants is very popular and the amount of demand for the grafted nursery plants has rapidly increased. More than 70% of watermelons, greenhouse cucumbers, tomatoes, melons, and eggplants have been cultivated using grafted seedlings. Domestic report showed the estimated number of grafted seedlings for fruit-bearing vegetable cultivation was more than 5.6 hundred millions, which covered about 60% of total seedlings.

A system to produce grafted nurseries consists of a preparation of seedlings, a readiness of scion and stock, grafting of scion and stock, and acclimation of grafted seedling. Amongst of processes in grafted nursery production, grafting itself is one of the most important processes. Though various grafting methods have been developed as shown in Fig. 1, grafting has been done manually by skilled workers. An inarching graftage is widely used for most fruit-bearing vegetables except eggplants and more than 60% of melons and cucumbers are cultivated through this grafting. An insertion grafting is mainly used for watermelons, and an ordinary splice grafting for most eggplants. Currently, as shown in Fig. 1, a variant of ordinary splice grafting which cuts a cotyledon off(Onoda 1992) and the plug-in grafting[Honami 1992, Nishiura 1995] have been investigated.

Methods of grafting and physical properties of seedlings to be grafted have great effects on the system design of grafted nursery production and implementation. As a result of many years of research and development efforts to automate the grafting process, several automatic grafting machines have been developed(Yamada 1995, Nishiura 1995) and some are commercially available. And those systems were developed mostly in Japan and adopted a splice or similar kinds of grafting in the matter of eliminating root of the scion and upper stem of the stock.

A splice grafting is known to be easier to automate the process itself and better to construct the fully automatic system by interfacing tray feeding units compared with an inarching method. However, it requires an additional incubator system for acclimation to maintain the proper graft-taking rate because of the inherent grafting characteristics. An inarching graftage is difficult to automate and is not proper in a sense of full-scale automation because of an extra cutting process after grafting. An inarching graftage, however, has been widely used in manual grafting for most fruit-bearing vegetable plants because of its vitality without the additional incubator system for acclimation.

In a case of splice grafting, to realize the fully automatic system for nursery production while ma-



[a] Splic [b] Variant of splice [c] Insertion [d] Plug-in [e] Inarching

Fig. 1 Various methods of grafting.

ximizing the profit of automation, a grafting machine, acclimation system, and auto-feeding units for seedlings before and after grafting should be considered in its implementation. As a result, it requires lots of facility investment. The grafting machine based on the inarching method can be more economical and productive in a certain scale of nursery production system. Developing a labor saving and economical automatic grafting system was the major motivation of adopting the inarching graftage in this research.

In this paper, automatic grafting system operated by one person was developed based on the process of inarching, pre-specified functional requirements of grafting process, and geometrical properties of scion and stock. And performance of the system including each component was tested and presented.

2. MATERIALS AND METHOD

Since geometrical properties of scion and stock are crucial in mechanizing grafting processes and they were closely related to the success of grafting task itself and the rate of graft-taking, plant height, length and thickness of hypocotyl, and length and width of cotyledon were measured. The thickness of each seedling was measured in two ways along the direction of cotyledon and its traverse direction. And the properties of 10 days old scions after sowing were measured for 12 varieties of watermelons(*Citrullus vulgaris* S.), 9 varieties of melons(*Cucumis melo* L.), and 19 varieties of cucumbers(*Cucumis sativus* L.). The soil temperature of the seedbed was kept 25℃ before germination and 23℃ after germination. Air temperature was kept around 25℃ in the daytime and around 15℃ at night.

Required labor and graft-taking rates of manual inarching and insertion grafting were investigated and compared. Maturity status of grafted and non-grafted seedlings was also investigated. When grafted nursery bore the third true leaf, it was counted as being matured. Watermelon as scion and pumpkin as stock were used for the experiment.

An inarching graftage was chosen considering the popularity of grafting methods for various fruit-bearing vegetables in Korea, experimental results of graft-taking rate, and the system requirement for grafting methods. A semi-automatic grafting system was developed based on the processes of the inarching graftage and geometrical properties of scion and stock. And the grafting capability was set to produce more than 900 grafted nurseries per hour resulting in less than 4 seconds cycle time per grafting. Following functional specifications were set in developing automatic grafting system based on the inarching graftage.

(1) stock and scion loading unit

- manual loading with buffer function
- feeding automatically loaded stocks and scions with variable speeds
- feeding one by one to the initial grafting position and checking the state of feeding

(2) stock and scion handling unit

- secure gripping without damaging to seedling
- designing gripper appropriate to the inarching sequence
- automatic feeding to grafting stage
- setting proper actuating sequence for successful inarching

(3) cutting and grafting unit

• designing a penetrating cutter with variable angular edge position

(4) feeding clip and discharging grafted nursery

• secure clipping without damaging to the grafted nursery

• continuous feeding of clip

• secure discharge and auto-feeding of the grafted seedlings to the operator

3. RESULTS AND DISCUSSION

A. Geometric properties of scion and stock

Geometric properties of 13 varieties of pumpkin (*Cucurbita moschata* spp.) as a stock seedling were measured. The plant heights of pumpkin varied 7.9~13.3cm and the lengths of hypocotyls varied 3.5~11.1 cm. The thickness of hypocotyl along the cotyledon was usually thinner than the one along its traverse direction. The thicknesses were 1.8~4.0mm along the cotyledon and 2.6~4.6mm along the traverse direction. The lengths and widths of cotyledon were 4.4~9.4cm and 2.9~5.1cm, respectively.

Geometric properties of watermelon, melon, and cucumber as seedlings for a scion were measured. Plant heights of watermelon varied 4.8~8.4cm and lengths of hypocotyl varied 2.9~5.5cm. Thickness of hypocotyl along the cotyledon was usually thinner than the one along its traverse direction. The thicknesses were 2.1~2.6mm along the cotyledon and 2.6~4.0mm along the traverse direction. The lengths and widths of cotyledon were 3.0~4.5cm and 1.9~2.6cm, respectively. Plant heights of melon varied 5.1~7.1cm and lengths of hypocotyl varied 2.2~4.1cm. Thickness of hypocotyl along the cotyledon was almost same as the one along its traverse direction and thickness ranged 1.8~2.3mm. The lengths and widths of cotyledon were 2.9~3.4cm and 1.8~2.1cm, respectively. Plant heights of cucumber varied 4.8~7.6cm and lengths of hypocotyl varied 3.6~6.7cm. Thickness of hypocotyl along the cotyledon was almost same as the one along its traverse direction. Thicknesses were 1.6~2.4mm along the cotyledon and 1.7~2.2mm along the traverse direction. The lengths and widths of cotyledon were 4.5~5.8cm and 2.5~3.2cm, respectively.

Amongst of geometrical properties of scion and stock, the length and thickness of hypocotyl were especially important in inarching grafting because of holding, fitting, and penetrating cut of seedlings. According to the geometric properties of scion and stock, the hypocotyl length was assumed to be 6~7cm and thickness of scion and stock was assumed to be 2.0~2.5mm and 3.5~4.0mm, respectively. In a case of manual grafting via inarching method, almost equal hypocotyl lengths of both scion and stock allowed the manual inarching job to be easy.

B. Comparison between manual inarching and insertion grafting

In manual inarching and insertion grafting, the total required times to produce 100 grafted nursery plants were around 77min and 53min for inarching and insertion respectively, which resulted into around 46sec and 32sec per each respectively. In a case of inarching grafting, extra labor of cutting hypocotyl of stock and scion and removing clip after being grafted was required compared with insertion grafting. Average time required for each stage of grafting to produce one grafted seedling as shown in Table 1. It took most of time in grafting scion and stock, 25.5sec for insertion

Table 1 Average labor time to produce one grafted nursery plant (scion : watermelon, stock : pumpkin)

Grafting Methods	Seedling Preparation	Grafting	Transplanting	Cutting Hypocotyl	Clip Removal	Total
Inarching	2.6sec	30.0sec	4.3sec	4.8sec	4.3sec	46.0sec
Insertion	2.7sec	25.5sec	3.7sec	–	–	31.9sec

Table 2 Status of average maturity at the time of 3 weeks after grafting (scion : watermelon, stock : pumpkin)

Grafting Methods	Plant Height (cm)	Number of Leaves	Leaf Area (cm^2)	Fresh Weight (gram / seedling)		Dry Weight (gram / seedling)	
				Scion	Root of Stock	Scion	Root of Stock
Inarching	16.7	6.4	124.9	5.49	1.42	0.52	0.16
Insertion	15.5	5.7	123.7	5.36	1.41	0.50	0.14
Non-grafting	14.2	5.5	111.6	5.02	0.42	0.49	0.08

and 30sec for inarching, respectively.

Rates of graft-taking for 100 grafted seedlings at the time of 3 weeks after grafting were 89.9% for inarching and 82.3% for insertion. Higher graft-taking rate of inarching method was due to the fact that non-elimination of roots allowed better supplies of moisture and nutrients than the insertion method during the period of graft-taking. A Result of average status of maturity per seedling was shown in Table 2. Seedlings grafted by the inarching method showed the best status of maturity.

C. Automatic grafting system

The actuating mechanism of the developed grafting system was built with 4 independent units such that a unit for stock and scion loading, a unit for stock and scion handling, a unit for cutting and grafting, and a unit for clip feeding and unloading. The scion and stock loading unit was built with sprockets and chains driven by two sets of variable speed DC motor and attached with a series of seedling holder brackets. One set of bracket was for scion loading and another for stock loading. Each bracket had upper and lower holder attached 4cm distance apart and each holder had an open round hole. The spring plate was mounted inside the upper hole to hold the seedlings securely. A guide rod was mounted between the upper and lower plates along the sidetrack of chain feeder to feed seedlings securely.

Each chain feeder was designed to have 4 brackets moving straight in front of the operator so that operator may insert seedlings easily. Four brackets per each chain feeder worked as a buffer unit so that operator could control the speed of inserting 4 scions and 4 stocks within 12 to 16 seconds. Each bracket passed with a stop interval of 3 to 4 seconds depending on the specified grafting cycle. Two sets of reflective type optical switches were used at each bracket feeder to check passing of each bracket and to check the existence of the seedling at the initial stage of the grafting unit. Each chain driven bracket feeder was continuously moved until the reflective sensor had a signal from the seedling in the bracket holder.

Two sets of electro-pneumatic manipulators were built to handle the stock and scion. A gripper was specially designed to make inarching process easy. Each manipulator was composed of a horizontal arm actuated by linear cylinder, a trunk actuated by a rotary cylinder, and a parallel chuck. Manipulator handling a stock seedling had an additional vertical cylinder for inarching process. A gripper was attached to the parallel chuck. Two magnetic lead switches and speed control valves were mounted to each cylinder.

A gripper was built as shown in Fig. 2 and a round pin was attached at the end of the tip of upper and lower fingers. While gripping, fingers were sled along the pin. When the gripper approached a seedling, the seedling was bent as shown in Fig. 2-[a]. Hypocotyl of each seedling should be bent before being cut by the piercing cutter. Tension induced by the bending caused the clearance of the tissue when the piercing cutter cut seedlings. And the clearance caused by bent enabled inarching of two seedlings to be possible. Adjusting the travel distance of horizontal arm, i.e. the push distance of pin, controlled the amount of bent. Physical properties of seedlings related to the bending moment, shear and compressive forces, and recoverable limit of tissue damage by compression were under taken. However, in this experiment, the soft sponge pad was simply attached to the finger to grip the seedlings. Tips of gripper fingers were designed to self-align and to assure the close contact of the scion and stock seedling as shown in Fig. 2-[b]. Seedling existence signals from both reflective optic sensors initiated both manipulators to actuate from the initial reset position.

Once scion and stock were in close contact as shown in Fig. 3-[a], a clip guide with "U" shaped edge approached to hold both seedlings as shown in Fig. 3-[b]. Then the piercing cutter moved forward to cut the hypocotyl of scion and stock as shown in fig. 3-[c]. The edge angle of piercing cutter was about 35o with respect to the vertical line. The orientation of the cutter edge was manually adjusted and could be varied easily by rotating actuator body. Then the finger gripping a stock moved upward to inarch scion and stock. The cutter acted as a guide during inarching process as shown in fig. 3-[d]. After inarching, the cutter moved back to the initial position and a clip was fed to fix the inarched part.

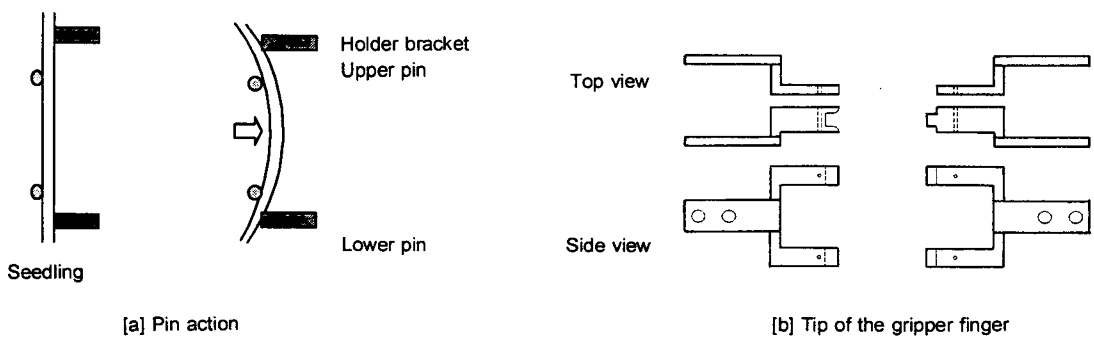


Fig. 2 Bent of seedling and gripper finger.

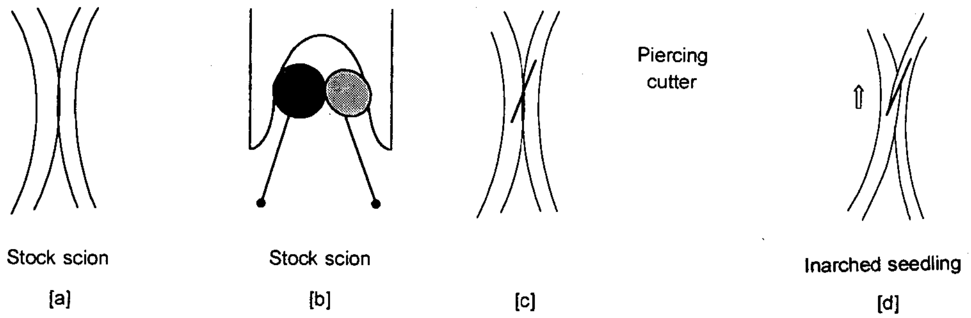


Fig. 3 Sequence of inarching grafting of the developed system.

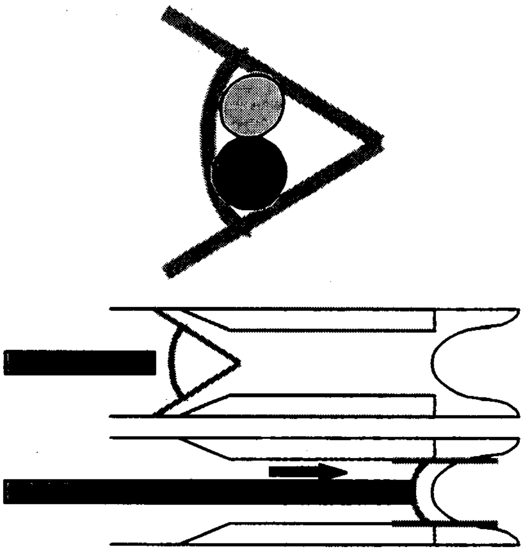


Fig. 4 Specially designed clip and clip feeder.

Fig. 5 Automatic grafting system.

A polyurethane clip was specially designed for the inarching process as shown in Fig. 4. Clip was fed automatically to the feeding mechanism from the vibrating bowel feeder along the guide chute. The feeding mechanism was composed of two linear actuators and clip feeding was done through two stages. First, the clip guide with "U" shaped edge approached seedlings and then a clip was pushed through the guide. While the clip was fed forward, clip guide automatically made clip open and close as shown in Fig. 4. Grafted nursery was pushed onto the conveyor and returned to the operator site to be relocated.

One-chip microprocessor(NEC V40) based controller including I/O interface and driver board was built to control the actuating sequence of the system. One main operator with a helper who delivers seedling trays and grafted plants were required to operate the system. The success rate of grafting was expected more than 80% after testing. The failure of grafting was mainly caused by the non-uniform size of seedlings. Variation of the thickness of hypocotly resulted into the error in orienting the piercing cutter and the loose contact between the scion and stock seedling. Fig. 5 showed the prototype of the grafting system developed in the laboratory. The system is still under modification to improve the success rate of grafting.

4. CONCLUSION

An automatic grafting machine for fruit-bearing vegetables was developed. It could be applied for Cucurbitaceae species like watermelons, melons, and cucumbers. Average 4 seconds of loading time for scion and stock were required to maximize system capacity. Excepting the labor for preparing plugged seedlings and relocating grafted seedlings, the grafting performance was about 900 seedlings per hour with an operator.

According to the temporary results of the grafting test done at the laboratory, unfitting of contact surfaces of scion and stock occurred sometimes during the piercing cut process of the knife. However, this mis-grafting can be reduced if seedlings with proper physical properties are supplied. Though the success rate of grafting of the developed prototype was expected more than 80%, the additional modification of the mechanism should be done to prevent from unfitting of contact surfaces during the piercing cut process. Since the success rate of grafting depended much on the state of seedlings, it was important to raise seedlings in order to have consistent geometric properties.

If seedlings could be raised uniformly around 7~9 cm of hypocotyl length and 2.5~3.0mm and 3.5~4.0 mm of hypocotyl thicknesses for scion and stock respectively and the proper holding mechanism of seedlings during the process of piercing cut is added, the developed system could be utilized with a higher success rate. For the further research, the systematic grafting experiment should be performed based on the geometric properties of seedlings to assure the on-site practice.

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