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DEVELOPMENT OF THE GRAFTING ROBOT FOR CUCUMBER SEEDLINGS

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ABSTRACT

With the object of doing mechanical grafting of cucurbitaceous vegetables, the grafting robot was developed in 1989. This robot consists of the following components; feeding wheels, grippers, conveying wheels, cutters, fixing clipper, discharger, controller and power supply. One cycle time to produce a grafted plant is about 3 seconds. Results of some cucumber grafting tests; successful grafting rate of 98 percent and after acclimation, a successful agglutination rate of 95 percent.

These techniques are now transferring to the private company. The commercial robot will come into the market in this year.

INTRODUCTION

Grafting means a series of several operations which comprises: Cutting off the roots of an objective plant (scion) at its hypocotyl, Fixing scion on the hypocotyl of another plant (stock), Adhering scion and stock together and Curing or Acclimatizing them.

The aims of grafting is to stabilize the production and to increase the yield through the prevention of injury by successive plantings. In Japan, 57 percent of cucumbers, watermelons, melons, eggplants and tomatoes were grown by grafting. In greenhouse culture, the ratio of grafted seedlings reached about 70 percent.

Grafting is performed manually. Farmers usually perform the grafting in cooperation with neighbour farmers, but recently, with the increase of senior farmers, many farmers complain of wearied eyes, stiffness of shoulders after works. This fact leads to the new tendency that farmers who want to purchase grafted seedlings are in increase. On the other hand, the nursery companies rely on the manual labour of part-time workers. How to secure abundant skilled helps is a vital problem for these companies.

This article outlines the present status of our efforts to develop grafting robot for cucurbitaceous vegetables, chiefly cucumbers .

1. ANALYSIS OF TRADITIONAL GRAFTING WORK

Before starting the development activities of grafting units, we conducted a survey on the traditional grafting work as was used by farmers. Table 1 shows one example of the survey results. In this case, the grafting work was carried out by the group-work system. One farmer was in charge of pulling of seedlings and disbudding (removal of the growing points of the stocks), three to five fixing, and one planting of grafted plants in pots. The method of 'approach grafting' was adopted, and the farmers took six hours to graft about 3000 plants. The work efficiency was about 100 plants per farmer per hour, and about 70 percent of the time was spent for fixing work.

2. ELEMENT TECHNIQUES FOR DESIGNING OF GRAFTING ROBOT

2.1 METHOD OF GRAFTING

The several methods of grafting were investigated from the view point of mechanization. From the results of this investigation, we concluded that 'Cutting-a-Cotyledon-off-Grafting' method ('CCG', hereafter. Not authorized term) is suitable for mechanization. CCG comprises three major procedures:

(a) From the seedling of pumpkin, one of its cotyledons and the growing point are cut off. (stock)

(b) From the seedling of cucumber, its root is cut off at the middle of its hypocotyl. (scion)

(c) The stock and scion are fixed together. (grafted seedling)

These procedure are illustrated in Fig.1.

2.2 LOCATION OF CUTTING

Because one of the cotyledons and the growth point of the stock plant are cut off simultaneously in CCG, precise locating of cutting is required, and hence some standard point or dimension of seedlings has to be chosen. Dimensions which change or vary widely with the growth of the plant, such as the length of hypocotyl or the angle between cotyledons, cannot be adopted as a standard for locating. We observed that the joint of cotyledons to hypocotyl meets the request of standard point of locating, and we decided to hung plants at this point.

2.3 EFFECT OF GRIPPING FORCE ON THE GROWTH OF SEEDLINGS

To determine the gripping force of fingers, the effect the strain of the compressed hypocotyls on the growth of seedlings was tested. If the compression strain of the diameter of hypocotyl does not exceeds 30 percent just after loading, no unfavourable effects were observed. But when it exceeds 50 percent, bending of seedlings at the loaded point and cracks in the hypocotyl occur. It was thought to be reasonable to restrain the compression strain under 30 percent.

2.4 CUTTING METHOD

The effects of cutting speed and angle necessary to cut off hypocotyls were investigated. As the cutting knives, blades for safety razors were selected because of their availability, sharpness and smooth cutting plain. The cutting speed over 2.5 m/s and cutting angle of 30 degrees for stocks, and the cutting speed over 4 m/s and cutting angle of 10 degrees for scions were found to be favourable.

2.5 SELECTION OF FIXING TOOLS

Adhesive tapes and instantaneous or medical adhesive agents were examined. Adhesive tapes incurred poor successful unions, had disadvantages in their poor elasticity and airing, and required troublesome labour to peel them off afterwards. Glues incurred poor ratio of successful unions of as low as 4.2 percent. Thus the intention to adopt these materials was abandoned and conventional ' grafting clips' as shown in Fig.2 were selected. These are widely used in manual grafting and are easily available and can be used many time over.

3. EXPERIMENTAL GRAFTING ROBOTS

The first prototype grafting robot was designed in 1987, which proved the possibility of the mechanized grafting. On this basis, in 1989 the second prototype model named G892 was developed.

3.1 STRUCTURAL UNITS

Grafting robot G892 is shown in Fig.3. The robot comprises:

(a) Feeding wheel units (b) Gripping and conveying units
(c) Cutting units (d) Clip feeding unit
(e) Clip Fixing unit (f) Discharge unit
(g) Control unit (h) Power unit

3.1.1 FEEDING WHEEL UNITS : There are two units : one for stocks and the other for scions. The feeding wheels have twenty slots at an even spacing on their circumference. For stocks, seedlings are hunged as the direction of cotyledons coincides with the radial direction of the wheel. For scions, the direction of cotyledons are set in tangential directions of the wheel. Both wheels were rotated every 1/20 rotation intermittently by stepping motors.

3.1.2 GRIPPING AND CONVEYING UNITS : One for stocks and one for scions. Fingers on the unit are opened and shut by means of a cam mechanism. Conveying units, both for stocks and scions, are disc shaped with three grippers on their circumference at an even spacing. The units are driven by stepping motors. Both units are arranged so that the grippers of the both discs face opposite to each other at the position of fixing. The discs rotate every 120 degrees intermittently.

3.1.3 CUTTING UNITS : a) For stocks: The arm with a blade on its tip rotates 360 degrees and cuts off one of the cotyledons and the growth point in a rotation. As the cotyledons are aligned to the radial direction of disc, the locus of the blade goes along from the lower point of the joint of a cotyledon to the upper part of the petiole(leaf stalk) of the other cotyledon. b) For scions: Fundamental structure is similar to that for stocks. The blade on the arm cuts off root at a given point of the hypocotyl.

3.1.4 CLIP FEEDING UNIT : Clips are installed on the feeding wheel at its 40 slots on the circumference. The feeding wheel is driven intermittently.

3.1.5 CLIP FIXING UNIT : This is composed of a cam trough and a push rod.

The push rod pushes a clip out of the feeding wheel into the cam trough, and while a clip is pushed forward to the fixing position in the trough, the mouth of the clip is opened till it arrives at the fixing point. When it arrives at the fixing point, the clip comes out of the trough, and pinches the hypocotyls of the stock and scion together. After the fixing, the cam trough and push rod go back to the initial position to be ready to fed with the next clip.

3.1.6 CONTROL UNIT : Sequence control is used by means of a programmable controller.

3.1.7 POWER UNIT : This robot applies stepping motors for rotating mechanisms and air cylinders for reciprocating parts. An air compressor is installed inside the frame of the robot.

3.2 SEQUENCE OF OPERATIONS

(a) Preparation works : Seedlings are hunged on the feeding wheels in the way above mentioned. Clip are also inserted in the slots of the feeding wheel.

(b) Feeding of seedlings and Gripping : At first the gripping and conveying units begin to rotate, then the feeding wheels begin to turn. Gripping fingers grip seedlings. This operation is performed for both stocks and scions simultaneously.

(c) Conveying: The seedlings are conveyed to the cutting point.

(d) For stocks, one of the cotyledons and the growth point are cut off, and its section is upward aslant. For scions, roots are cuts off, and its section is downward aslant. These are shown in Fig.4.

(e) Conveyance and section alignment: After cutting, the stock and scion come in opposite position to each other.

(f) Clipping : A clip is fed to the cam trough and at the fixing point the stock and scion are fixed together by it. The clipping in detail are shown in Fig.5.

(g) Discharging: After clipping, the grippers open to allow the grafted seedlings to come on the discharging belt conveyor.

(h) Potting(manual): Grafted seedlings are planted in pots and brought to the acclimatization room.

4. PERFORMANCE OF G892

Table 2 shows the results of the grafting tests on G892. The G892 showed a high accuracy: it's mechanical grafting success rate was 98 percent, successful grafting agglutination rate after acclimation 95 percent, and successful union rate 87 percent. The mechanical grafting success rate also reached 97 percent when we used bloomless stocks, which have rapidly been introduced in recent years.

As discussed above, we were able to confirm the possibility of applying a machine to grafting work by using G892. Our future task is to raise the mechanical accuracy of the unit's parts further in order to obtain stably successful union rates higher than 90 percent.

To identify the possible problems of growing mechanically grafted plants, we carried out in the controlled greenhouse and forcing culture of cucumbers using manually grafted plants as controls, and compared the crops in terms of growth, yield, quality and other factors. The results of the controlled greenhouse culture are summarized in Table 3, and no significant difference was observed among the plots.

5. FUTURE TASKS AND OUTLOOK

As the trend of farmers buying grafted seedlings is gradually increasing, there have been more cases where agricultural cooperatives and seed and seedling growers mass-produce and sell these plants.

We are transferring our knowhow obtained during the development research to private companies. The commercial robot for cucumber seedlings as shown in Fig.6 will come into the market in this year. This robot will require two operators to supply the feeding units the cucumber for scion and the pumpkin for stock.

At present, we are developing the third type grafting robot. This robot will automate the supply of seedlings and fixing clips, thus realizing a fully-automatic grafting work.

CONCLUSION

With the object of doing mechanical grafting of cucumber seedlings, the experimental model of grafting robot was developed and tested.

(1) This robot consists of the following units : Feeding wheels, Grippers and conveyers, Cutters, Clip Feeder, Fixing clipper, Discharger, Controller and Power supply.

(2) One cycle time from feeding nursery plants to discharge a grafted plant is about 3 seconds.

(3) The ratio of successful fixing of stocks and scions (mechanical success) was 98 % and after acclimation , a successful agglutination rate of 95 %.

(4) No differences of the growth was observed between the seedlings grafted by robot and those by manual.

(5) The technical transfer to the private company was done. The commercial grafting robot for cucumber seedlings will come into the market in this year.

REFERENCES

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Table 1 Time needed for grafting operation (in term of 1,000 grafted plants)

Process	Time-needed (man.hour)	Ratio (%)
Pulling of seedlings	0.45	4.6
Disbudding	1.05	10.8
Fixing	6.88	70.8
Planting	1.34	13.8
Total	9.72	100.0

Table 2 Performance of G892

Vegetable	Cucumber	
	Stock A	Stock B
Mechanical grafting success rate (%)	98	97
Successful agglutination rate (%)	95	88
Successful union rate (%)	87	83

note: Varieties used : Stock A : *Shintosa* Stock
Stock B : *Kitora* Stock

Table 3 Results of controlled greenhouse culture of cucumbers

Plot	Yield per plant			Yield
	No. of cucumbers	Weight (g)	Ratio of good quality (%)	per are (kg)
Robot grafted plant	22.9	3352	83.3	553
Manually grafted plant	24.6	3479	78.4	574

note: No. of cucumbers and weight are those per plant.

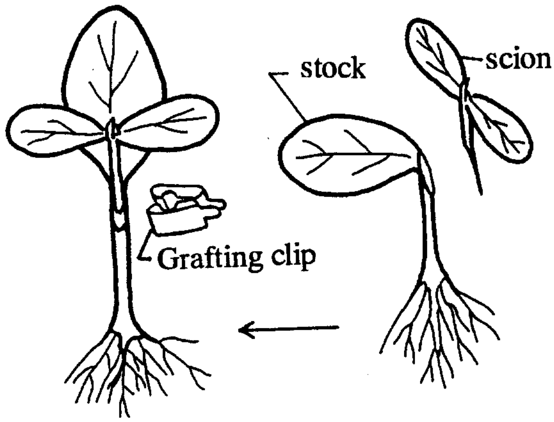

Fig.1 The Method of CCG

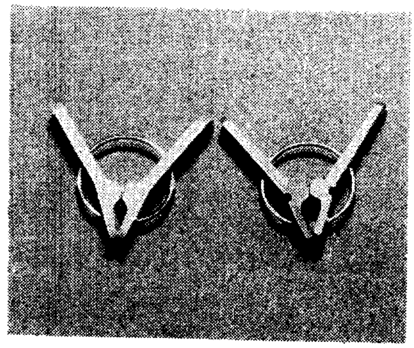

Fig.2 Grafting clip

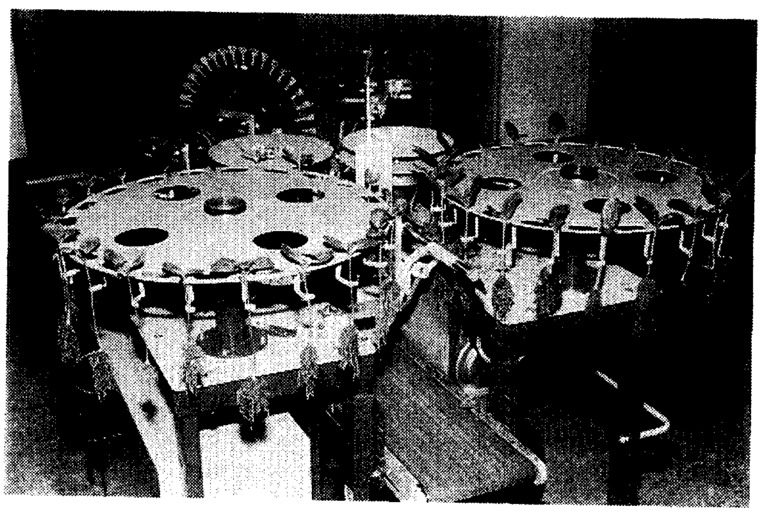

Fig.3 Grafting robot G892

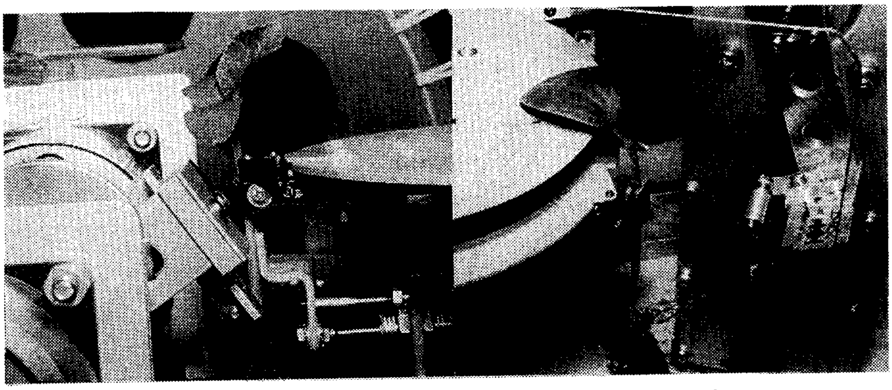

Fig.4 Cutting unit(Left:Scion Right:Stock)

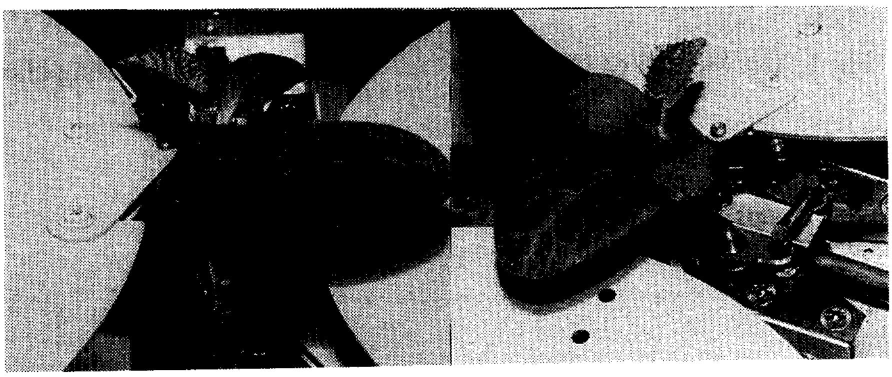

Fig.5 Close-up view at the clipping unit

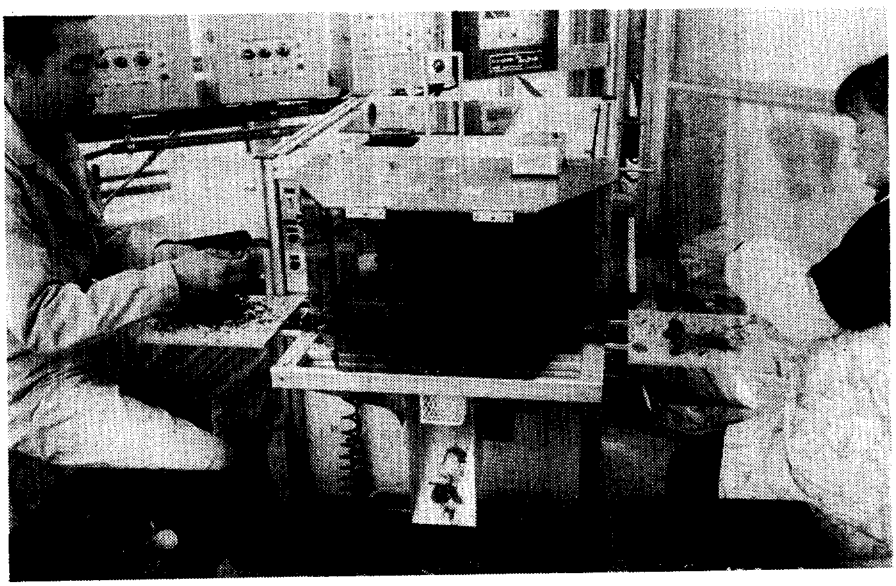

Fig.6 The Commercial model of grafting robot for cucumber