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An Experimental Study on the Effect of Cutting Angle on the Growth of Grafted Watermelon Seedlings Using the One-Cotyledon Grafting Method

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Abstract: The labor-efficient automation of grafting has been recognized as a key factor in the wider adoption of grafting. In growing cucurbits, the root pruned one-cotyledon grafting method is the most commonly used method with grafting machines. The cutting angle, which affects the matching of the rootstock and scion, is key to the survival of the graft seedling. In the production of cucurbit graft seedlings, the cutting parameters are established based on experience, leading to low grafting success. To determine accurate cutting parameters, the watermelon cv. 'Zaojia84-24′ was used as the scion and the pumpkin cv. 'Zhenzhuang' was used as rootstock, and two one-way experiments investigating the cutting angle of the watermelon scion and the rootstock as factors were conducted. The cutting angle of the rootstock and scion had no significant effect on the xylem reconnection rate or the grafting survival rate. A larger cutting angle for the rootstock and scion led to a delay in the reconnection of the phloem. Different cutting angles for the scion significantly affected the growth of the scion after grafting. Compared with a scion graft cutting angle of 10° (SL), graft cutting angles of 14° (SM) and 20° (SS) led to significantly greater scion dry weights, with increases of 16.00% and 18.61%, respectively. Different cutting angles of the rootstock significantly affected the growth of roots after grafting. Compared with a rootstock graft cutting angle of 10° (RL), graft cutting angles of 17° (RM) and 27° (RS) led to significantly greater root dry weights, with increases of 29.33% and 22.54%, respectively. The results of this study can provide a reference for the design of cutting mechanisms for cucurbit grafting robots, improving the cutting precision of grafting robots.

Keywords: watermelon; one-cotyledon grafting; cutting angle; survival rate; grafting robot; healing

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1. Introduction

Grafting has become a common practice in watermelon (*Citrullus lanatus* (Thunb.) Matsum and Nakai) production in China, Japan, Korea, Italy, France, and the USA, as it provides the ability to control soil-borne diseases caused by bacteria, fungi, oomycetes, viruses, and root-knot nematodes [1–3]. Moreover, it can overcome the obstacles of continuous cropping and improve yield, quality, and stress resistance [4–6]. The manual grafting method with top hole insertion is the most widely used method for watermelon grafting in China [7–9]. However, manual grafting is labor-intensive. With the increasing demand for grafted watermelon transplanting, manual grafting has gradually become unable to meet the needs of large-scale production [10]. In addition, with the population aging in rural China and the upsurge in the cost of manpower, the availability of skilled grafting laborers has decreased. Automatic grafting is one of the keys to solving this problem [11].

In automatic grafting, a grafting machine or a grafting robot is needed. Cucurbit grafting machines are being developed in Japan, Korea, China, and other places [12–15]. The grafting method generally used by these machines is the one-cotyledon grafting method. In the one-cotyledon grafting technique [16], one cotyledon is removed from the rootstock and the other cotyledon is left intact and firmly attached to the rootstock stem. The scion shoot is then bevel cut. The two cut stem surfaces are joined and held together with a grafting clip.

Cutting is one of the main links in the mechanized grafting of seedlings [17]. During cutting operations, the cutter interacts with the plant. First, the plant is compressed by the cutter. Second, according to the working parameters, the cutter cuts the stem. Third, the stem is cut off and transferred to the next grafting stage. Then, the cycle is repeated until the plant stem is cut.

The cutting angle is a key working parameter of the cutter. Boydas et al. [18] found that the shear stress value at the bevel angle of 28° was lower than the shear stress value at the bevel angle of 0° when the red bean stem was cut by the cutter. Allameh et al. [19] found that the best specific cutting energy was obtained when the cutting angle was 30°. The effects of the average cutting speed, the sliding angle, the cutting edge angle, and the cutter clearance on the cutting force were studied by Lu et al. [20]. The results showed that the optimal cutting combination parameters were an average cutting speed of 532.17 mm/s, a sliding angle of 39.53°, a cutting edge angle of 25.15°, and a cutter clearance of 1.37 mm. Jiang et al. [21,22] designed the cutting mechanism of a vegetable grafting robot and proposed that in the cutting of rootstock, the robot should avoid cutting through the pith cavity, and cutting should be carried out after the scion stems are straightened, which can improve the success rate of seedling cutting. Xu et al. [23] studied the limited cutting angle range for rootstock. The test results showed that the range of the ultimate cutting angle for rootstock seedlings (*Cucurbita moschata*) was 18.21° ± 1.92°; the cutting angles of the rootstock (*Cucurbita moschata*) and scion seedlings (watermelon) were 22° and 19.68°. Bausher et al. [24] found that an increase in graft angle resulted in greater survival of grafted plants. Pardo-Alonso et al. [25] investigated the combined influence of the cutting angle and different random diameters on grafting success. The optimal cutting angle range for tomatoes was 50°–70° using the splicing grafting method. Limited studies are available regarding the effect of grafting techniques on the physical attributes of watermelon. In grafted watermelon seedling production, the cutting parameters are set according to experience, leading to low grafting success.

In order to provide basic documented information on the suitable cut surface for grafting machines, using the watermelon cv. 'Zaojia 84-24′ as a scion and the pumpkin cv. 'Zhenzhuang' as a rootstock, two one-way experiments examining the incision lengths of the watermelon scion and rootstock as factors were performed. This experiment was conducted to study the influence of the cutting angle of the rootstock and scion on the survival rate of grafting and the later growth of grafted seedlings, which provided a reference for determining the appropriate section length of the grafting machine.

2. Materials and Methods

2.1. Seedling Production

The watermelon cv. 'Zaojia84-24′ (*C. lanatus*, Xinjiang Seed Co., Ltd., Urumchi, China) was used as the scion, and the interspecific pumpkin cv. 'Zhenzhuang' (Jingyan Yinong, Seed Sci-Tech Co., Ltd., Beijing, China) was used as the rootstock. All the experiments were carried out in a greenhouse (with an air temperature of 20 °C to 35 °C) in 2022 at the Wuhan Agricultural Academy, Central China (30°27′ N, 114°20′ E, and an altitude of 22 m above sea level). The scion and rootstock seeds were sown into 98- and 72-cell trays, respectively, with one seed in one cell filled with mixed seedling substrate (peat moss and pearlite at a volume ratio of 3:1). The rootstock and scion were sown on the same day to meet the requirements for grafting experiments [26]. Plants were fertilized with a water-soluble fertilizer (Product Model: 20-10-20 + TE, 1000 times liquid, Shanghai Yongtong chemical Co., Ltd., Shanghai, China).

2.2. The Cutting Device and Usage

The cutting device was developed by the Beijing Academy of Agriculture and Forestry Sciences to ensure the accuracy of the cutting angle required for each treatment. The cutting device was composed of a fixed plate, laser, rotary regulator, support, cutting tool, moving parts, base, etc., as shown in Figure 1. The rotating regulator (Product Model: HGMMA20, accuracy: ±1°) was mounted on the base parallel to the support, and the laser was installed in the center of the rotating regulator. Through the use of the rotating regulator, the laser can be driven to rotate and a red cross-shaped cursor can be displayed on the fixed plate to assist in the positioning of seedlings. The fixing plate was provided with a slot, the cutting tool was installed on the fixing plate through the moving parts, the cutting tool was placed in the slot, and the moving parts were pushed by hand to achieve the reciprocating movement of the cutting tool in the slot to complete the operation of cutting seedlings.

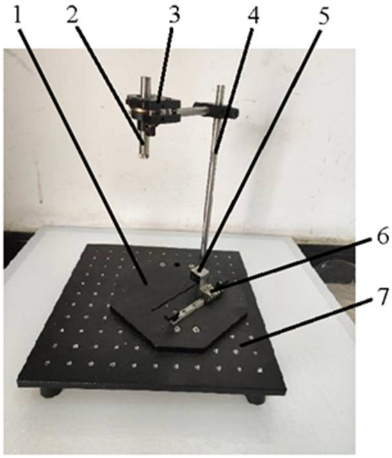

Figure 1. The cutting device. Components: (1) Fixing plate. (2) Laser. (3) Rotary regulator. (4) Support. (5) Cutting tool. (6) Moving parts. (7) Base.

Cutting process (Figure 2): (1) Firstly, the cutting angle was set. The angle between the vertical direction of the cross cursor and the tool slot was set by rotating the regulator, namely the cutting angle of the seedling. (2) The rootstock seedlings were placed on the fixed plate so that the stalk overlapped with the vertical direction of the cursor, and the cotyledon and the true leaf were overlapped with the center of the knife groove. (3) We pushed the moving parts from top to bottom, so that the cutter cut off a cotyledon and a true leaf, to complete the cutting operation of the rootstock seedling. Scion cutting was mainly controlled based on the cutting height of seedling stem, and other cutting processes were the same as that of the rootstock.

2.3. The Cutting Angle Design

The cutting technology of rootstock seedlings requires the cutting of a cotyledon and growth point. We measured the section lengths of rootstock seedlings with cutting angles of 10°, 17°, 24°, 27°, 34°, 41°, 48°, 55°, and 62°. Twenty-five plants were measured at each cutting angle, as shown in Figure 3. The analysis showed that when the cutting angle was greater than 34°, the section length decreased to 3.84 mm, and there was no significant difference between different cutting angles. Therefore, the selection of the cutting angle was less than 34°. Among the five angles of 10°, 17°, 24°, 27°, and 34°, the difference between the treatments of 10°, 17°, and 27° was more obvious, so the three cutting angles were selected.

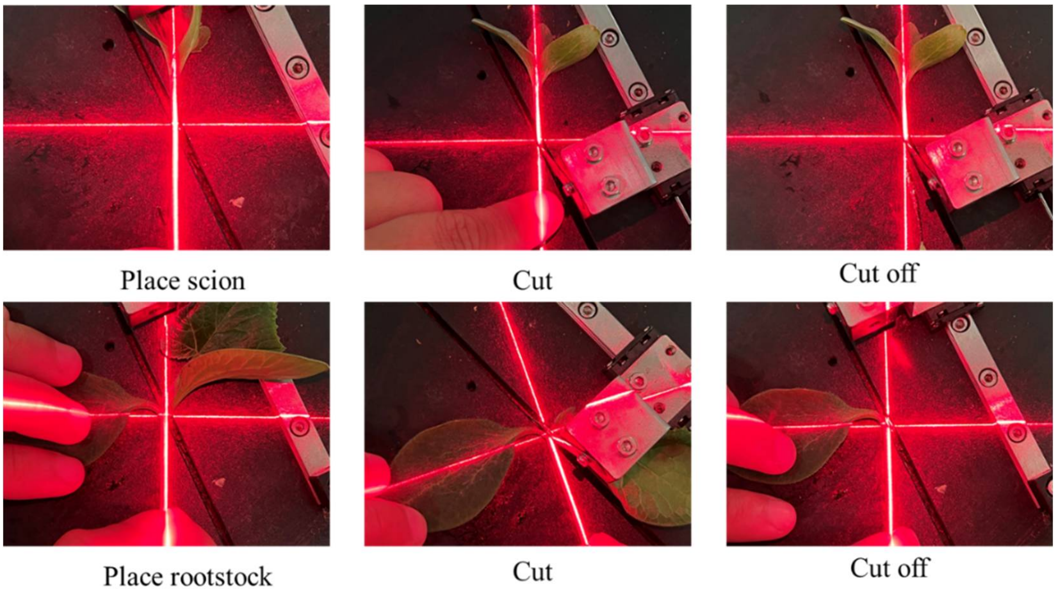
Place scion
Cut
Cut off
Place rootstock
Cut
Cut off

Figure 2. The procedure of cutting the scion and rootstock.

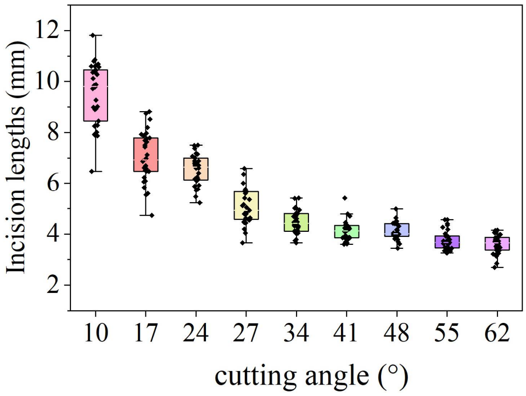

Figure 3. Incision lengths of rootstock using different cutting angles.

Randomly selecting 75 plants for scion seedlings, we measured the width of seedling stems in the direction of cotyledon development, and the calculated average value was 1.61 mm. We set the target incision lengths of scion seedlings as 8 mm, 6 mm, and 4 mm; therefore, the cutting angle of the scion was calculated to be 10°, 14°, and 20°, respectively. In each group of experiments, 25 rootstocks and scions were cut, and the measurement results were averaged. The test results are shown in Table 1.

Table 1. Incision lengths of rootstocks and scions with different cutting angles.

Treatment	**Cutting Angle of Scion (°)**			**Cutting Angle of Rootstock (°)**		
	10	**14**	**20**	**10**	**17**	**27**
Incision lengths (mm)	7.65 ± 0.80	5.48 ± 0.75	3.74 ± 0.47	8.75 ± 0.30	6.46 ± 0.42	4.92 ± 0.43

The experiments were set up as one-way experiments with three replicates, and each replicate had 150 plants. Experiment 1 was carried out with 10° (SL), 14° (SM), and 20° (SS) of scion (Figure 4), the rootstock cutting angle of the three treatments were 27°. Experiment 2 was carried out with 10° (RL), 17° (RM), and 27° (RS) cutting angles for the rootstock (Figure 5), the scion cutting angle of the three treatments were 14°.

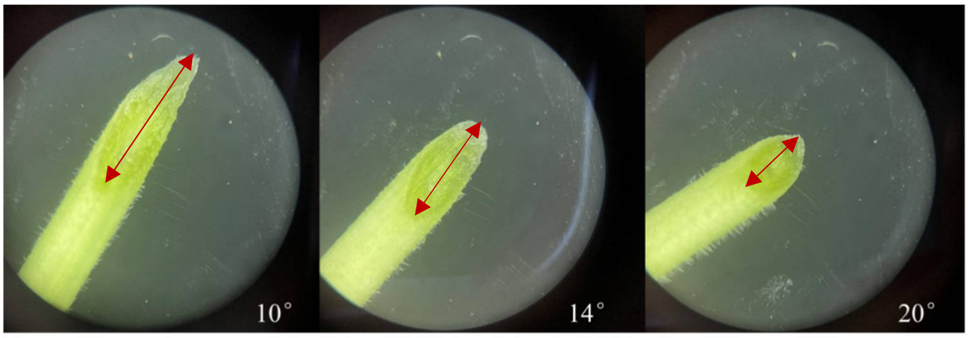

Figure 4. Cutting angle of the scion. The red arrows represent for the incision lengths.

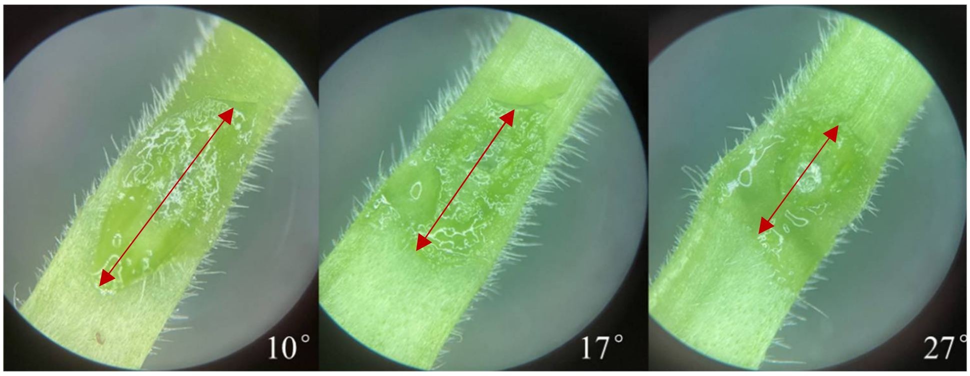

Figure 5. Cutting angle of the rootstock. The red arrows represent for the incision lengths.

2.4. Grafting and Healing

Grafting was performed after the first true leaf developed in the rootstock and scion, and for the root excision the one-cotyledon splicing grafting method was used [27]. In the nursery, the plants were cultivated from sowing until 10 to 15 days. This variability of days was determined based on the growth rate, which was directly related to the climatic conditions of the month of growing.

The plants were considered mature and ready for grafting when they had one true leaf, as shown in Figure 6. The diameters in the area close to the cut varied from 1.28 to 1.89 mm for the scion and 2.25 to 3.15 mm for the rootstock.

Figure 6. The morphological properties of the rootstock and scion at the time of grafting.

Immediately after grafting, the plants were placed under a plastic film with a day/night cycle at 28 °C/18 °C and more than 90% humidity under low light intensity (75 umol·m^{-2}·s^{-1}, 12/12 h photoperiod). The grafted plants were exposed to the air 1–3 h per day until the scions were alive and normally grown after 8 days. After 10 days, the grafted seedlings were transferred to a greenhouse, following common practice.

2.5. Assays of Phloem and Xylem Connectivity

Phloem and xylem connectivity [28] were measured on days 5, 7, and 9 after grafting based on the movement of esculin and acid fuchsin across the graft union, respectively. To assay the phloem connection, 0.4 g esculin was dissolved in 20 mL of 60% methyl cyanide. The cotyledon center of the scion was gently scraped with a sharp single-edged razor to create a small opening for the esculin to enter. Next, 2 uL of esculin solution was added per cotyledon, and the fluorescence in the rootstock hypocotyls was measured after 2 h of incubation. For xylem connections, plant roots were incubated in a solution of 0.1% acid fuchsin, and the watermelon scion hypocotyls were examined after 2 h.

Phloem and xylem reconnection rate were investigated using the formula.

$$\text{Phloem reconnection rate (\%)} = (\text{phloem reconnected grafts}/\text{total test grafts}) \times 100\%.$$
$$\text{Xylem reconnection rate (\%)} = (\text{xylem reconnected grafts}/\text{total test grafts}) \times 100\%.$$

2.6. Calculation of Adhesion Force

The graft adhesion force of the graft union was measured with a digital force gauge (product model: ZTS-1-HPO.15, IMADA Co., Ltd., Aichi, Japan) [29], set on a measuring stand (MX-10 N, IMADA). It was measured with a dynamometer and expressed in Newtons (N). Twenty plant grafting seedlings were tested for each treatment, and this was repeated three times.

2.7. Grafted Survival Measurement

Survival of the grafted plants was assessed at day 15 after grafting using the formula presented below [30]. The grafted plants were considered alive and as having survived if the scion leaves and the rootstock stems were turgid, whereas severely wilted scion leaves and stems of both the scion and the rootstock were considered as graft failures.

$$\text{Survival rate (\%)} = (\text{Survival number}/\text{total number of grafted plants}) \times 100\%.$$

2.8. Measurement of Morphological Index

Plants were sampled at day 15 after grafting. Scion height was measured using a ruler from the scion cotyledon node to the growth point and the stem diameter was measured with a digital caliper 1 cm below the cotyledon base of the watermelon scion. The fresh samples of watermelon scion above the cotyledon node and root were placed into a forced-air oven (product model: 101-3AB, Tianjin Taisite Instrument Co., Ltd., Tianjin, China) at 105 °C for 30 min and then at 70 °C for 3 days to determine their dry weights.

2.9. Data Analyses

The figures were developed using Origin 2019b. Significant differences were determined based on Duncan's tests using SAS 9.0.2 software.

3. Results

3.1. Measurement of Phloem and Xylem Connectivity Rate of Rootstock and Scion Cutting with Different Angles on Different Days after Grafting

The beginning of the exchange of materials between the scion and rootstock was marked by the reconnection of vascular bundles. We applied esculin to cotyledons of 20 plants and examined the number of plants which exhibited fluorescent signals 5 days, 7 days, and 9 days after grafting. The phloem reconnection rate showed significant differences among the three cutting angles of the scion and rootstock (Figure 7A,C). The phloem reconnection rate with cutting angles of 10° (SL) and 14° (SM) of the scion were 100% and 97.78% at 9 days after grafting, respectively, whereas the value in the 20° (SS) treatment decreased to 85.86%. Compared with the 27° (RS) treatment, the phloem reconnection rates with an angle of 10° (RL) for rootstock were 1.91-fold, 1.86-fold, and 1.35-fold 5 days, 7 days, and 9 days after grafting, respectively. The results showed that the phloem reconnection occurred earlier with a small cutting angle than with a large cutting angle.

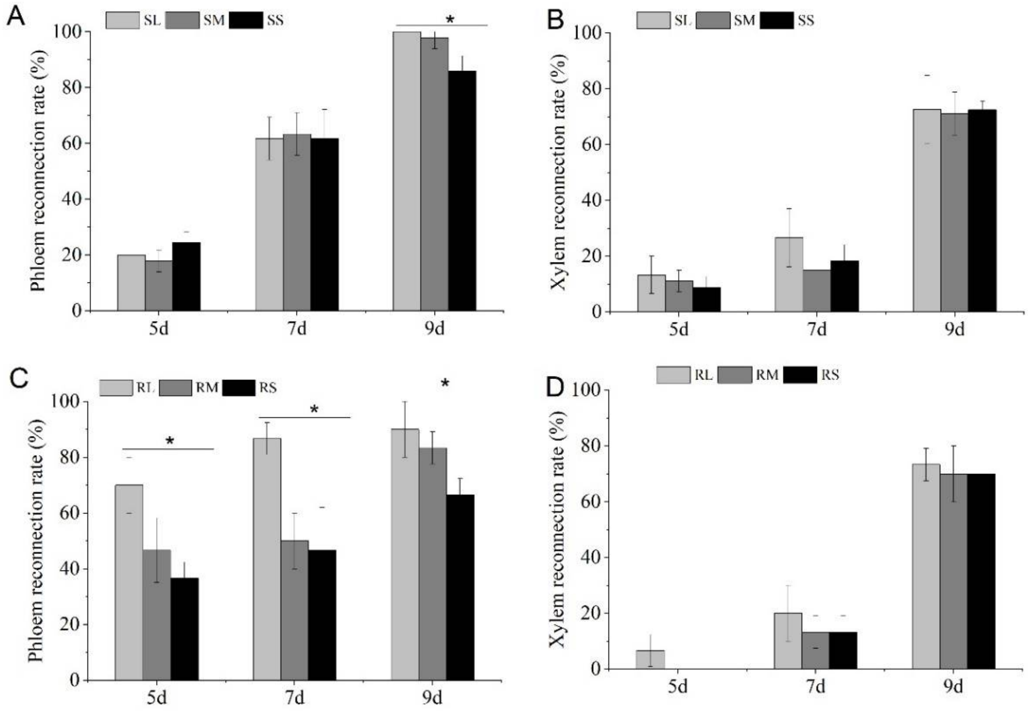

Figure 7. Phloem reconnection rate (**A**,**C**) and xylem reconnection rates (**B**,**D**) after cutting the scion and rootstock at different angles 3 days, 5 days, and 9 days after grafting. Data for each time point was collected from three treatments with 20 seedlings per treatment and presented as means ± SE. SL, SM, and SS indicate scion cutting angles of 10°, 14°, and 20°, respectively. RL, RM, and RS indicate rootstock cutting angles of 10°, 17°, and 27°, respectively. * indicates significant differences at the $p < 0.05$ level.

The acid fuchsin assay was used to monitor the xylem reconnection (Figure 7B,D). The xylem reconnection rate at 5 days, 7 days, and 9 days after grafting showed no significant differences between the different cutting angles of the scion, the results for the rootstock were similar to those obtained for the scion.

3.2. Measurement of the Adhesion Force of Grafting Unions Cut at Different Angles on Different Days after Grafting

The adhesion forces of grafting unions cut at different angles were significantly different (Figure 8). The adhesion force observed for the cutting angle of 10° (SL) of the scion 3 days, 5 days, and 9 days after grafting were 2.55 N, 4.51 N, and 6.23 N, respectively, representing increases of 22.33%, 62.84%, and 31.30%, respectively, compared with the 20° (SS) treatment. The adhesion force observed for the cutting angle of 10° (RL) of the rootstock 3 days, 5 days, and 9 days after grafting were 5.41 N, 5.47 N, and 6.11 N, respectively, representing increases of 62.31%, 42.78%, and 25.78%, respectively, compared with the 27° (RS) treatment. The result showed that the smaller the cutting angle, the larger the adhesion force.

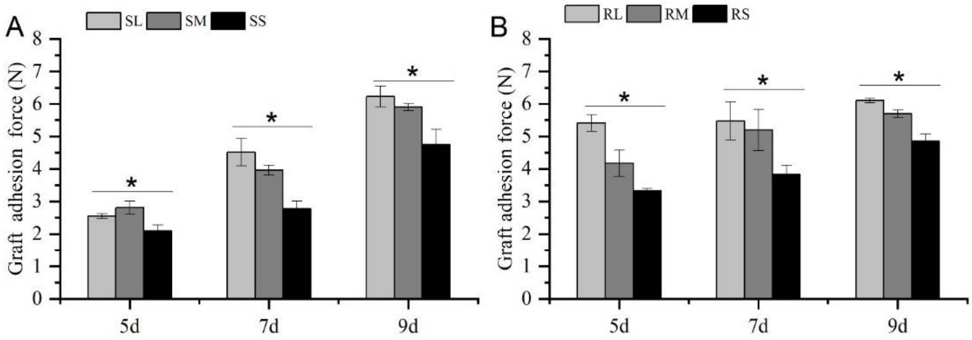

Figure 8. The adhesion force observed for scions and rootstocks cut at different angles 3 days, 5 days, and 9 days after grafting. (**A**) represent for the adhesion force for three cutting angles of the scion. SL, SM, and SS indicate scion cutting angles of 10°, 14°, and 20°, respectively. (**B**) represent for the adhesion force for three cutting angles of rootstocks. RL, RM, and RS represent rootstock cutting angles of 10°, 17°, and 27°, respectively. * indicates significant differences at the $p < 0.05$ level.

3.3. Survival Rates of Grafting Seedlings Cut at Different Angles

There was no significant difference in the graft survival rates among the three cutting angles for the scion and rootstock (Figure 9), both of which were 100%.

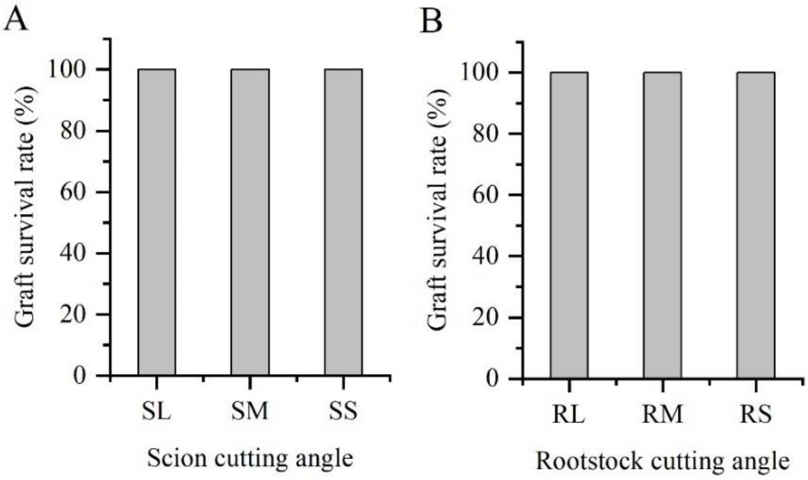

Figure 9. Graft survival rates observed 15 days after grafting. (**A**) represents the survival rate of grafting seedlings using three cutting angles of the scion. SL, SM, and SS indicate scion cutting angles of 10°, 14°, and 20°, respectively. (**B**) represents the survival rate of grafting seedlings using three cutting angles of rootstocks. RL, RM, and RS represent rootstock cutting angles of 10°, 17°, and 27°, respectively. SL, SM, and SS indicate scion cutting angles of 10°, 14°, and 20°, respectively. RL, RM, and RS, indicate rootstock cutting angles of 10°, 17°, and 27°, respectively.

3.4. Graft Seedling Growth by Morphological Parameters

The morphology parameters of grafted watermelon seedlings using different cutting angles for the scion and rootstock are shown in Table 2. The shoot dry weight observed with a cutting angle of 10° (SL) for the scion was 86.36 mg·plant^{-1}, representing increases of 16.00% and 18.61% compared with the values for cutting angles of 14° (SM) and 20° (SS) of the scion, respectively. The root dry weight with a cutting angle of 10° (RL) for the rootstock was 9.05 mg·plant^{-1}, representing increases of 29.33% and 22.54% compared with the values for cutting angles of 17° (RM) and 27° (RS) of the scion, respectively. There were no significant differences in the plant height, stem diameter, or root length between different cutting angles of the scion and rootstock.

Table 2. The morphology parameters of watermelon seedlings grafted using different cutting angles of the scion and rootstock. SL, SM, and SS indicate scion cutting angles of 10°, 14°, and 20°, respectively. RL, RM, and RS indicate rootstock cutting angles of 10°, 17°, and 27°, respectively. The different small letters indicate significant differences at the $p < 0.05$ level.

Treatment	Plant Height (mm)	Stem Diameter (mm)	Root Length (mm)	Shoot Dry Weight (mg·Plant^{-1})	Root Dry Weight (mg·Plant^{-1})
SL	21.10 ± 3.05 a	2.58 ± 0.14 a	124.20 ± 2.16 a	86.36 ± 2.67 b	7.52 ± 0.26 a
SM	20.71 ± 4.71 a	2.59 ± 0.23 a	124.62 ± 3.46 a	100.18 ± 2.29 a	7.24 ± 0.20 a
SS	23.33 ± 3.06 a	2.53 ± 0.15 a	116.41 ± 0.68 a	102.43 ± 6.43 a	7.51 ± 0.40 a
RL	28.65 ± 0.36 a	3.02 ± 0.13 a	127.00 ± 7.14 a	114.98 ± 3.60 a	9.05 ± 0.55 b
RM	29.20 ± 0.51 a	2.97 ± 0.08 a	126.53 ± 0.88 a	120.52 ± 3.47 a	11.70 ± 0.85 a
RS	28.79 ± 0.53 a	3.26 ± 0.13 a	129.09 ± 5.25 a	121.92 ± 4.97 a	11.09 ± 1.00 ab

4. Discussion

There are more than 3000 large seedling enterprises in China at present. Grafting mostly relies on the work of skilled laborers. The mechanization of grafting can reduce the labor intensity and improve the efficiency of grafting, and it is a hotspot in the research on horticultural production. Researchers have conducted a large quantity of research on vegetable grafting robots [31–33]. The grafting speed is being continuously improved. Lacking grafting seedling production technology for grafting robots is one main insufficiency. The grafting parameters, such as cutting angle and the aging of scion and rootstock, are not clear.

The cutting angles used for the scion and rootstock during grafting are based completely on experience, resulting in instability in grafting survival rates and healing. Furthermore, cutting parameters determine the working track of the cutter, providing the basis for precise cutting. It is necessary to investigate how to set the cutting parameters of the grafting machine before grafting, instead of relying on the experience of an operator to slowly adjust these settings. Additionally, the cutting parameters determine the incision lengths of the scion and rootstock and the cutting accuracy. Many researchers have analyzed the efficacy of different cutting angles. Limited literature is available related to the effect of cutting parameters on the growth of grafted seedlings.

In this study, we used the cutting angle as the dependent variable to investigate the grafting survival rate and the later growth of grafted seedlings, and the results can provide a reference for setting cutting parameters in machine grafting. In the study, the graft survival rate (100%) was high. Because the one cotyledon grafting method was easily performed by hand, the optimum age of the rootstock and scion seedlings were studied before, and the healing environment was stable and suitable [8,26,34]. Moreover, the cutting device was used to complete the cutting of seedlings, and the notch consistency was good, and the rootstock and scion fixed by skilled workers made the join of the cut surface good.

Grafting success is dependent on the development of vascular tissue (xylem and phloem) and reconnection between rootstock and scion [35]. The process of graft union formation was obviously different with a healing environment and grafted plant species. Yang et al. showed that the vascular bridges were connected 5 days after grafting at a night temperature of 18 °C using watermelon grafted onto bottle gourd rootstock [36]. Xu et al. found that the new vascular bundle formation occurred 9 days after grafting using oriental melon grafted onto squash [37]. The phloem junction occurs at the graft union before the xylem [38,39]. The results also showed that the phloem reconnections occurred earlier than xylem, and the xylem reconnection occurred at 5 days after grafting. The area of contact surface increases, thus increasing the probability of vascular reconnection [40]. Bausher et al. supports that seedlings should have similar diameters in the cutting zone [24]. However, the stem of the watermelon scion was slender. When clipping the graft union, the cut area of scion becomes flat and enlarge. If the cutting zone was similar before clipping, the cut area of scion is larger than that of rootstock after clipping. In addition, when the grafting machine was in operation, scion cutting angles of less than 10° were difficult to accomplish. The stem of the rootstock was stocky. However, it was difficult not only to maintain cotyledon integrity, but also to completely remove the growing point to ensure a lower rootstock regrowth rate after grafting. In this study, a cutting angle of about 14° for the scion and a cutting angle of about 17° for the rootstock was better. In this situation, the incision lengths of rootstocks and scions were 6.46 mm and 5.48 mm, respectively.

The blade is the only cutting tool for manual grafting, and there is no special grafting cutter for melon seedlings. In China and Japan, there are grafting cutters for solanaceous crops [41]. However, the cutting angle cannot be adjusted, and the operation is only executed at a fixed cutting angle, which has poor adaptability to seedlings with different ages. The cutting device designed in this study is suitable for the one-cotyledon splicing grafting method for melon seedlings. Its unique feature is that it can be precisely adjusted according to the preset cutting angle, which provides more convenience for grafting experiments. In the aspect of cutting accuracy, the precision rotary adjustment mechanism is used for achieving fine adjustment of cutting angle, and high cutting accuracy is obtained. The cutting accuracy error mainly comes from the coincidence effect of the seedling stem and cursor, which requires the operators to coordinate and fix the seedlings with their eyes and hands. The development and application of the cutting device can provide a reference for the improvement and optimization of the cutting mechanism for the grafting machine.

5. Conclusions

Grafting robots can reduce grafting work intensity, improve grafting productivity, and replace grafters in the future. At present, the grafting success efficiency of a grafting robot does not have the advantage of hand-grafting, seedling companies in China cannot use the robots. Lacking grafting seedling production technology for the grafting robot is one main insufficiency. Hole-insertion grafting is the most popular method used for Watermelon grafting in China. However, one cotyledon grafting is the only method that has been automated with a grafting robot. The grafting parameters, such as cutting angle and the aging of scion and rootstock, are not clear.

In order to provide a reference standard for the setting of cutting parameters in mechanized grafting, we performed experiments to study the influence of the cutting angle of the rootstock and scion on the grafting survival rate and the later growth of grafted watermelon seedlings.

The results showed that different cutting angles had no significant impact on the grafting survival rate. However, the cutting angle had a certain influence on the formation of the phloem reconnection, the adhesion force and the dry weight. A larger cutting angle for the rootstock and scion led to a delay in the reconnection of the phloem and a decrease in adhesion force. Considering seedlings growth and adhesion, we suggest a cutting angle of about 14° for the scion and a cutting angle of about 17° for the rootstock. In this situation, the incision lengths of rootstocks and scions were 6.46 mm and 5.48 mm, respectively. However, the grafting union is the joining of the two parts, the cutting area of scion and rootstock. This research only studies the effects of the single factor, the interaction effects of the rootstock and scion cutting angle was not studied. It was unknown whether the rootstock and scion cut by machine using the recommend cutting angle has high utilization rate and success rate.

At present, technical standards of seedling cultivation suitable for machine grafting are very scarce. More research is needed to further study such as different healing environment, and different species of cucurbit. In addition, it is necessary to determine the age and plant-type structures of grafted seedlings for different varieties. This work is difficult and meaningful. With the implementation of standards related to grafting processes, more seedling cultivation enterprises can cultivate standard seedlings suitable for machine grafting, which would be conducive to promoting the rapid application of grafting machines and would reflect the value of standardization and efficiency.

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