Pneumatic separation system for collected seedlings using subdivided air streams

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Abstract: To adhere to the needs of automated supply of collected seedlings for mechanized grafting and cutting machines for enhancing their operational efficiency, herein, a separation system that uses subdivided air streams to separate the collected seedlings is developed.   The separation system comprises a feeder for supplying collected seedlings, a seedling separator that uses subdivided air streams, a picking belt for the separated seedlings, a delivery unit for the separated seedlings, a pneumatic unit, and a control unit.   To investigate the complete performance of separation, picking, and delivery of the separation system, several separation experiments were conducted to separate the collected Anthurium seedlings.   The results show that the consistency of the moving direction of seedlings floated by subdivided air streams in the separation container and the moving direction of the picking belt have a significant effect on the picking of the separated seedlings by the picking belt.   Moreover, the seedling supply timing of the feeder has a significant effect on the stability of the collected seedling separation rate during continuous separation.   When this timing is such that the percentage of separated seedlings is 70%, the separation rate of continuous separation operation is 2.24 plant/s (the separation productivity is 8060 plants/h) with 0.12 CV.   The operating conditions are 0.5 MPa separation pressure, 0.5 s nozzle operation time, and 60 mm seedling thickness in the separation container.   Moreover, the staying times of the collected seedlings separated in the separation container are less than 2.5 min.
Keywords: grafting, cuttings, pneumatic separation system, continuous separation, subdivided air stream, separation speed
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1   Introduction

For the automatic production of grafting and cuttings in greenhouse horticulture, the separation of collected seedlings, picking of individual seedlings, and supply of seedlings to grafting and cutting machines are still manually performed in most cases. The collected seedlings are rootless according to the demand of grafting and cutting operations[1,2].   However, the maximum speed of manual seedlings supplied for grafting machines is 1500 plants per hour[3], which is lower than the operational ability of automated machines, such as grafting and cutting machines.   This limitation significantly restricts the working efficiency of grafting and cutting machines.   With regard to auto supplying individual seedlings from the collected seedlings to grafting and cutting machines, there are three steps.   These include separating the collected seedlings

into individual seedlings, identifying the picking position coordinates of individual seedlings on their delivery unit, and picking each individual seedling to operation machines. Identification of position coordinates using machine vision and picking seedlings using a robot arm are common industrial technologies[4-10].   However, it is difficult to separate the collected tender seedlings into individual seedlings.   Therefore, automatic separation of individual seedlings from the collected seedlings is very important for improving the production operation efficiency of grafting and cutting automatic machines.

During the development of an automated cutting machine of Schlumbergera seedlings, the Denbin Company in Denmark uses a set of incremental speed delivery belts to pull the collected Schlumbergera seedlings open.   Subsequently, they identify the position of each individual seedling on the last delivery belt using machine vision and several robot arms pick up the individual seedlings to transplant into a plug tray[11].   This method is suitable for seedlings that are flat in shape, difficult to roll, and have no mutual hooking.   To develop an automated cutting machine for Chrysanthemum seedlings and Schlumbergera seedlings, the ISO Group in the Netherlands has developed a method to separate the collected seedlings by shaking a collected seedling delivery belt for identifying, picking, and transplanting individual seedlings[12]. Compared with Schlumbergera seedlings, the surfaces of Chrysanthemum seedlings are rougher and the leaves are inter-hooked.   Therefore, Chrysanthemum seedlings are more difficult to separate.   The productivity of the cutting machine was

1600 plants/h for Chrysanthemum seedlings and 4000 plants/h for Schlumbergera seedlings[13].

In grading fruit and vegetable processes, mechanical components such as pushing bars, roll brushes, and rotating rollers have been used to separate collected materials[14,15]. Mechanical components are suitable for the separation of agricultural materials with flat shapes, which are difficult to roll during transportation. However, mechanical separating parts have a direct mechanical impact on the separated objects, which leads to damage to agricultural materials[16].

Pneumatic separation has been used in agricultural machinery and food processing equipment for many years because an air stream is an ideal carrier since it is economical and causes less damage to products such as fruits and vegetables[17]. Several researchers have studied the aerodynamic properties for the separation of grains and stems using air flow[18-20]. Moreover, air flow has been applied to separate the kernels and shells of agricultural products such as peanuts, sunflower seeds, and rapeseed[21-23]. Such pneumatic separation of the air flow depends on the difference in the aerodynamic properties of the separating materials. Therefore, it is difficult to apply pneumatic separation to separate the same type of collected material.

In view of the above problems, we have studied a method to separate collected seedlings using subdivided streams. The research results demonstrate that the separator can separate the collected tender seedlings using subdivided air streams without causing damage to them[2]. We proved that the subdivided air streams could separate the collected seedlings and discussed the operating parameters of separating collected seedlings in the separator using subdivided air streams. However, further research is required to determine the coupling performance effect of separation using subdivided air streams and picking seedlings separated from the separator. The separation productivity of the pneumatic separation system should be investigated.

In this study, a separation system was developed, which comprised a seedling separator using subdivided air streams, a feeder for supplying collected seedlings, a picking belt for picking individual separated seedlings, and a delivery unit of individual separated seedlings, a pneumatic unit, and a control unit. Moreover, the continuous separation performance of the separation system of collected seedlings was investigated under all operating conditions, which included supply and separation of collected seedlings and picking, outputting the separated seedlings.

2 Material and methods

2.1 Seedling Properties

To understand the separation performances for the collected seedlings using the separation system, Anthurium seedlings were selected in this study as the research subject, which showed significant inter-hooking with each other among the collected seedlings for seedling production[2]. The geometric and mechanical parameters of the Anthurium seedlings were measured using 100 Anthurium seedlings selected randomly during their cutting period. The plant height, crown radius, projected area of the side view, and terminal velocity were investigated, as shown in Table 1. The plant height, crown radius, and projected area of the side view (A) were measured using Image J (National Institutes of Health, Bethesda, MD, USA) software based on side view images of the seedlings obtained with the seedlings resting stably on a horizontal plane. Moreover, the terminal velocity (V_t) of a

seedling is defined as the air velocity at which the seedling remains in a suspended state in a vertical column duct[2,15]. The terminal velocities of 100 Anthurium seedlings were measured using a vertical air tunnel with an air flow velocity meter.

Table 1   Characteristics of the Anthurium seedlings[a]

|	Plant height /mm	Crown radius /mm	Mass, W/g	Projected area of side view, A/mm²	Terminal Velocity, Vt/m s⁻¹
Max	46.21	41.25	0.35	810.65	1.40
Min	18.17	15.17	0.18	355.33	1.05
Mean	33.90	27.54	0.24	590.20	1.26
CV[b]	0.24	0.29	0.57	0.24	0.09

Note: [a] The age of the Anthurium seedlings was 9 d.
[b] CV is the coefficient of variation, which is the ratio of the standard deviation to the mean value

Owing to the evident difference in sizes of the same batch of Anthurium seedlings, as shown in Table 1, the separation mechanism of Anthurium seedlings of different sizes in the same subdivision air flow field may be different.

2.2 Separation system

2.2.1 Working principles

As shown in Figure 1, the separation system of collected seedlings consisted of a feeder for supplying the collected seedlings, a separator that uses subdivided air streams, a picking belt for picking separated seedlings, a delivery unit for outputting individual separated seedlings, a pneumatic unit, and a control unit.
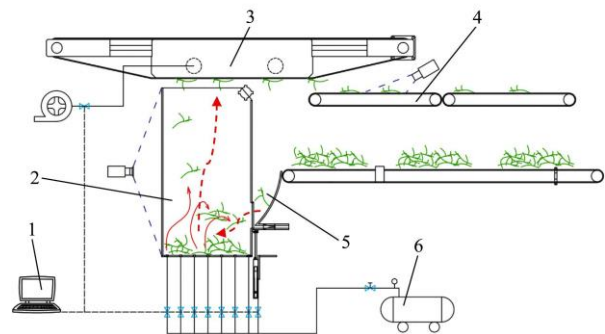
1. Control unit   2. Separator   3. Picking belt   4. Delivery unit of individual separated seedlings   5. Feeder   6. Pneumatic unit

Figure 1   Separation system of collected seedlings

The feeder comprised a supply belt, a pushing nozzle of collected seedlings, a supply box of collected seedlings, and a lifting gate. The complete supply operation is described as follows. After receiving a supply signal from the control unit, the supply belt sends a fixed quantity of collected seedlings into the supply box. After the collected seedlings enter the supply box, the lifting gate opens, the pushing nozzle blows the collected seedlings into the seedling separator, and then the lifting door closes.

The separator using subdivided air streams comprises a separation container, columns of nozzles forming a jet flow array, and a blocking wheel. The function of the separator is to separate the collected seedlings using the subdivided air streams generated by the columns of the nozzles.

The picking belt was a perforated belt with a vacuum chamber, whose function was to pick up separated seedlings using vacuum and send the separated seedlings to the delivery unit.

The delivery unit of outputting individual separated seedlings comprised two delivery belts, where the speed of the first belt was lower than that of the second to significantly enhance the spacing of individual separated seedlings.

The pneumatic unit comprised a negative pressure fan connecting the vacuum chamber of the picking belt, and an air compressor that connected the columns of the nozzles of the separator as well as the lifting cylinder of the lifting gate of the feeder.

The control unit consisted of a programmable logic controller (PLC), a group of solenoid valves controlling the columns of the nozzles, and a sensor device including two machine vision cameras.

The workflow of the seedling separation system is as follows. First, the control unit sent a start signal to the feeder, and a fixed quantity of collected seedlings was supplied into the separator. After the seedlings were placed into the separator, the PLC controlled the group of solenoid valves to form a jet flow array. Moreover, subdivided air streams generated by the columns of nozzles separated the collected seedlings and suspended the separated seedlings up to the upper opening of the separator. The picking belt just moving over the upper opening picked up the suspended individual seedlings with the perforated belt by vacuum and sent the seedlings to the delivery unit of outputting individual separated seedling. On the two delivery belts, the spacing between the individual seedlings was further increased using the speed difference between the two belts. Here, a single supply separation operation was completed. When the quantity of separated seedlings reached a threshold value (evaluated by observing the output of separated seedlings using the camera of the sensor device), the control unit sent a signal to direct the feeder to supply collected seedlings again. Hence, another single supply separation was started. The control flow is shown in Figure 2.
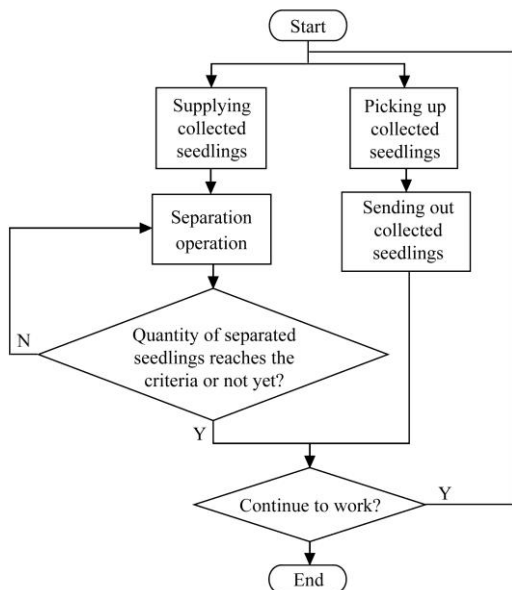

Figure 2   Flowchart for the separation system control

2.2.2   Separator

A jet flow array was placed on the bottom of the separation container, which comprised three rows and eight columns of nozzles, as shown in Figure 3. The eight columns of nozzles were the key to generating subdivided air stream fields in which each column nozzle jet group opened and closed at the same time. The subdivided air streams consisted of columns of jet flows that suspended a mass of collected seedlings, pulling and disengaging different parts of the seedlings, thus allowing the individual seedlings to reach the top of the separation container. This was achieved by controlling the order of the opening and closing of the

nozzles of different jet groups in the jet flow array. Nozzles with an internal diameter of 4 mm, spacing between nozzles of 20 mm, and separation container with a height of 600 mm, length of 160 mm and width of 60 mm were used in this study. These parameters were set according to the previous studies of our research group[2], considering the same Anthurium seedlings as listed in Table 1.
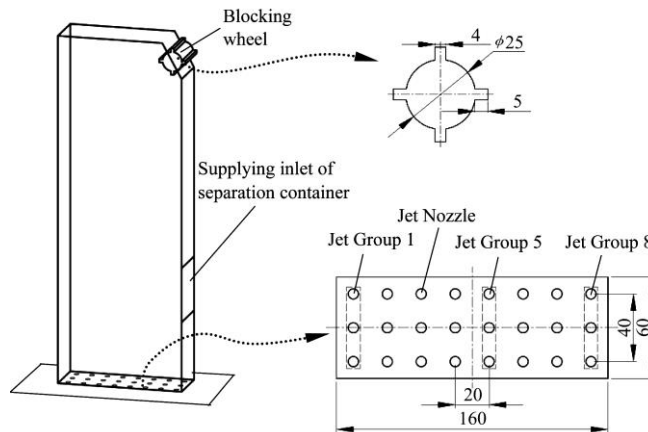

Figure 3   Design of the separator (dimensions in mm)

The blocking wheel was designed to scrape off unseparated seedlings that were hooked from the picking belt back to the separation container. A spacing of 40 mm was set between the upper tangent point of the blocking wheel and the perforated belt of the picking belt, which was similar to the maximums of plant height and crown radius of the Anthurium seedlings listed in Table 1. During separation, the blocking wheel was driven by a motor in the counter-clockwise direction.

2.2.3   Picking belt

The vacuum chamber was connected to the negative pressure fan of the pneumatic unit. When seedlings were separated by subdivided air streams, the perforated belt absorbed the seedlings touching the picking belt using vacuum and sent them to the individual seedling delivery unit.

To ensure that the individual separated seedlings from the separation container could be covered by the picking belt, its width was set to 80 mm, considering the separation container width of 60 mm (Figure 3). To avoid the collapse of the perforated belt due to the vacuum chamber, a belt thickness of 2 mm was selected with PVC as the material. The minimums of plant height and crown width of the Anthurium seedlings (Table 1) were approximately 15-18 mm; in order to achieve absorption of single seedlings by two or more holes for enhanced adsorption effect of the separated seedlings, the spacing between the holes of the perforated belt was set to 15 mm. A belt hole diameter of 6 mm was selected, considering that the air flow driven by the vacuum passed smoothly through the holes, and the seedling leaves were not easily sucked into the holes. The arrangement of the holes in the picking belt is shown in Figure 4.

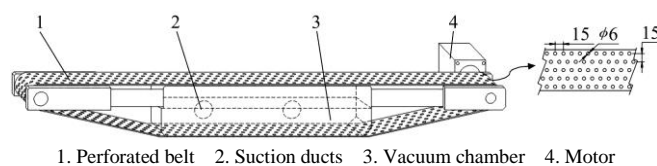1. Perforated belt   2. Suction ducts   3. Vacuum chamber   4. Motor

Figure 4   Structure of the picking belt

The vacuum degree of the vacuum chamber is an important factor in the separation of seedlings. Through a trial separation

test, it was observed that when the vacuum degree reached 0.1 MPa, the individual seedlings could be absorbed and picked up, and when the vacuum degree was greater than 0.2 MPa, some of the individual Anthurium seedlings began to be sucked into the picking belt holes.   Therefore, the operating vacuum degree of the vacuum chamber was set at 0.2 MPa.   According to the observation of the separation operation using subdivided air streams, generally the vertical partial velocities of separated seedlings in the separation container were lower than 0.7 m/s.   Moreover, another trial separation test in which the vertical partial velocity was less than 0.7 m/s showed that when the horizontal velocity of the picking belt exceeded 0.16 m/s, the seedlings began to rebound back to the separation container.   Therefore, the picking belt velocity was set to 0.16 m/s.

2.3   Single feed separation experiment

A single supply separation experiment was conducted to investigate the comprehensive operation effect of separation and picking.   The separation speed (SS), which is the number of seedlings separated per unit time from the separation system, and the coefficient of variation (CV) of the SS were investigated to understand the separation ability and its stability in a single supply separation cycle.

The collected Anthurium seedlings for this study were in their transplanting period, in which the projected area of the side view (A) of these seedlings ranged from approximately 355-812 mm^2. There must have been differences in the separation performance for such a large variation in A.   Therefore, A was determined as an influencing factor for SS and CV, and its three level values were set as 355-508 mm^2, 508-660 mm^2, and 660-812 mm^2, which were defined as small, medium, and large seedlings, respectively.

To obtain a reasonable separation effect of subdivided air streams in the separator, the operation time and the pressure of each jet group, and the thickness of the collected seedlings in the separation container were set to be consistent with those in the previous separation study using the subdivided air streams, that is, 0.5 s, 0.5 MPa, and 60 mm, respectively[2].

To investigate the separation, picking, and output performance of the collected Anthurium seedlings using subdivided air streams, a set of perception devices were constructed, which included a Sony FDR-AX700 camera facing the separation container for observing the separation performance, and a Cognex-micro1100c camera (Cognex, Natick, USA) facing the individual seedling delivery unit for observing the practical output of the separated seedlings.   The single supply separation experiments were repeated five times under different seedling sizes.

2.4   Continuous feed separation experiment

The production efficiency and separation operation stability of the collected seedling separation system were investigated during continuous operation in a continuous supply separation experiment. The SS, CV, and separation productivity (SP) were investigated. The Anthurium seedlings, immediately after tissue culture, were used as the experimental subject, and the large, medium, and small seedlings each accounted for approximately one-third of the total seedlings.   The continuous supply separation experiment used the same separation system and operating parameters as the single supply separation experiment.   However, the feeder operated more than once (Figure 5), and the separation flow is shown in Figure 2. Moreover, to obtain a stable separation rate, it was important to determine the appropriate timing for supplying the seedlings.   In the separation container, more seedlings were damaged when more

seedlings remained, and when less seedlings remained, the SS was more unstable.   To maintain a stable separation rate for continuous separation operation, it was necessary to determine a reasonable seedling supply timing to maintain sufficient seedling quantity in the separation container.   However, it was not easy to evaluate the number of seedlings in the separation container at any moment during a separating operation using the camera facing it, because the seedlings were moving unsteadily.   Therefore, the other camera facing the outlet of the picking belt was used to count the number of seedlings (Ns), which were separated by the separation system.   The total seedling number (Nt) was counted with 30 different batches of Anthurium seedlings of 60 mm seedling thickness in the separation container, which were measured and calculated as 115±7.6.   In this study, the percentage of separated seedlings (PSS) was applied to indirectly explain the number of seedlings in the separation container.   The PSS was calculated as Ns divided by Nt.   Moreover, the level values were selected as 60%, 70%, 80%, and 90%.
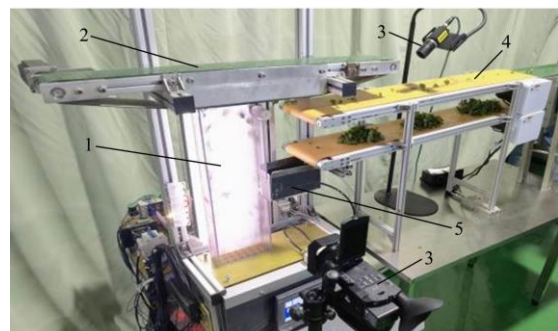
1.Separator   2.Picking belt   3.Cameras   4.Delivery unit of individual separated seedlings   5.Feeder

Figure 5   Experiment system of the separation system of collected seedlings using subdivided air streams

In this experiment, the same set of perception devices as in the single supply separation experiment was used to observe the separation performance.   To investigate the staying times of the collected Anthurium seedlings inside the separation container according to the order of batch supply of the feeder, the seedlings of each supply batch were painted a particular colour using mark pens of different colours in the separation experiment (Figure 6). The continuous supply separation experiments were repeated five times under different PSS.

Figure 6   Seedlings painted with different colours, where each colour represents a supply batch

3   Results and discussion

3.1   Single feed separation

In Figure 7, the curves show a sharp fluctuation of SS in a single supply separation cycle for three sizes of seedlings in which the separating operations were unstable.   In addition, with a decrease in seedling number in the separation container, the SS

values of different seedling sizes decrease. Moreover, SS is inversely proportional to the size of the seedlings most of the time. For larger projected area of the side, the windward area is larger[2,15]. Under the action of conventional vertical airflow, a larger windward area reduces the seedling terminal velocity to a small value and considerably increases the seedling moving resistance, leading to low moving velocity of the seedling[22]. On the contrary, the moving velocities of small seedlings are higher. The effects of subdivided air stream fields on seedlings of different sizes are complex. Large seedlings may bear a combined effect of multiple subdivided air streams, and the action force on seedlings always changes with the variation in subdivided air stream fields. In the case of small seedlings, the seedlings are affected by a single subdivided air stream, and the action force for different subdivided air streams is unstable for small seedlings. By observing the separation operation of different-sized seedlings in the separation container, the moving velocities of small seedlings are the highest in the separation container, which lead to higher separating frequencies.

Figure 8 shows the seedling numbers touching the picking belt for each jet group and the seedling numbers actually picked by the picking belt in a single supply separation cycle, for three sizes of seedlings. The picking success ratio, which is in a jet group, the proportion of the number of picking belt adsorbed seedlings to the total number of seedlings sent to picking belt by jet group.The picking success ratio of large, medium, and small seedlings are 6.9%-12.0%, 5.4%-13.5%, and 5.2%-29.6%, respectively, and hence, most of the seedlings touching the picking belt bounce back to the separation container. The variation ranges of the picking success ratio of the three sizes of seedlings are large, suggesting that the separating performance of each jet group is different. The three sizes of seedlings reflect the fact that jet group 1 has the largest pushing quantity and highest pickup success ratio.
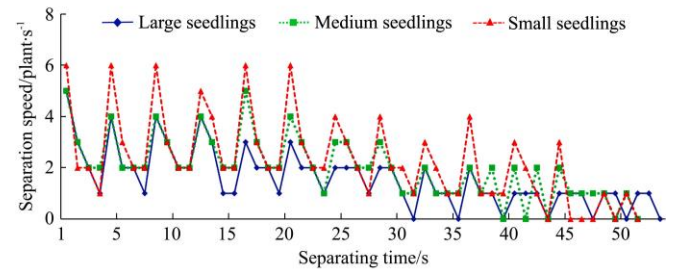

Figure 7   Separation speed of seedlings of three sizes in single supply separation experiment

a. Large seedlings   b. Medium seedlings   c. Small seedlings
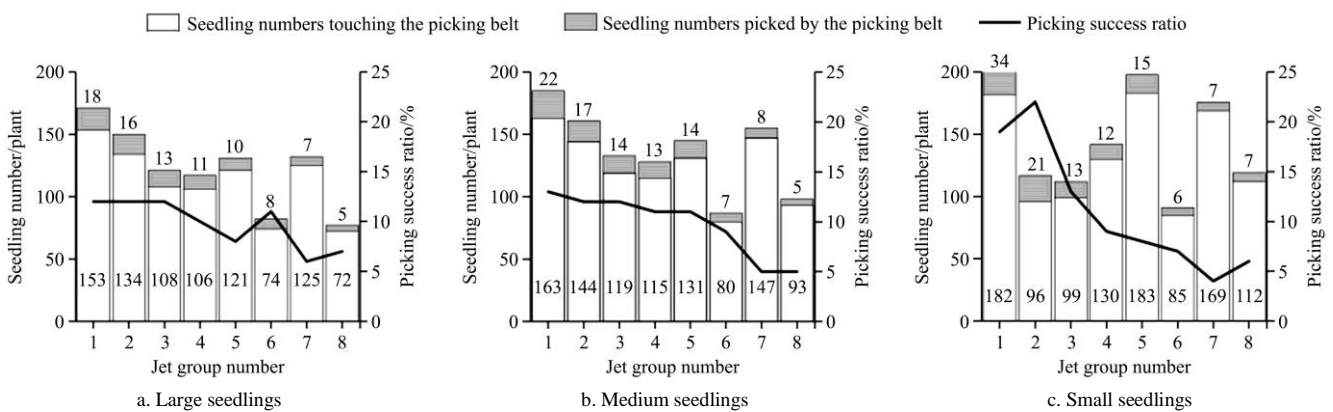
Figure 8   Ratios of seedling numbers touching the picking belt and seedling numbers picked by the picking belt in a single supply separation cycle

By analyzing the videos captured using the Sony FDR-AX700 camera facing the separation container, the seedlings successfully picked up by the picking belt were selected. The touching picking belt velocity (V_{tp}) of each seedling successfully picked up by the picking belt was extracted, as shown in Figure 9. Each point represents a V_{tp} value, in which the distance from each point to the origin point A is the value of V_{tp}, and the connection line between the two points is the direction of V_{tp}. The red, green, blue, and black dots represent individual seedlings pushed by the jet groups 1 and 2, 3 and 4, 5 and 6, and 7 and 8, respectively. Moreover, the pie charts in Figure 9 explain the ratios of individual seedlings pushed by each double-jet group for the three sizes of seedlings. Point B represents the picking belt velocity (V_b), which was set as 0.16 m/s in the X-axis direction. As shown in Figure 9, when V_{tp} is closer to V_b, more seedlings are picked up by the picking belt. The highest density of seedlings is picked by the picking belt under 0.16 m/s horizontal partial velocity, which is the picking belt velocity for each seedling size. When the seedling horizontal velocity is the picking belt velocity, the picking belt can bear higher seedling vertical velocity for picking up individual seedlings. The highest vertical velocities are 0.56 m/s, 0.64 m/s, and 0.69 m/s for large, medium, and small seedlings, respectively. When a seedling touches the picking belt, there is a collision between the seedling and picking belt generated by the direction difference between V_{tp} and V_b. Here, for larger direction difference between V_{tp} and V_b, the collision is stronger. Moreover, the value of difference of V_{tp} in the horizontal direction and V_b have a similar effect on the changing trend of the collision. The three pie charts of seedlings of different sizes in Figure 9 show that the picking belt picks up the most seedlings separated from the jet groups 1-2 and the least seedlings separated from the jet groups 7-8. The jet groups 3-4 and 5-6 are in the middle in decreasing order. Although the turbulence of the subdivided air flow field has strong randomness, considering the moving direction of the picking belt, the action direction of the subdivided air streams still has a significant effect on the separated seedlings being picked up. Under the same seedling thickness of the separation container, the largest seedling numbers are of small seedlings. Therefore, in the single supply separation cycle, the separated seedlings are maximum. Moreover, as shown in Figure 9, the V_t range of small seedlings is the largest.

a. Large seedlings

b. Medium seedlings

c. Small seedlings
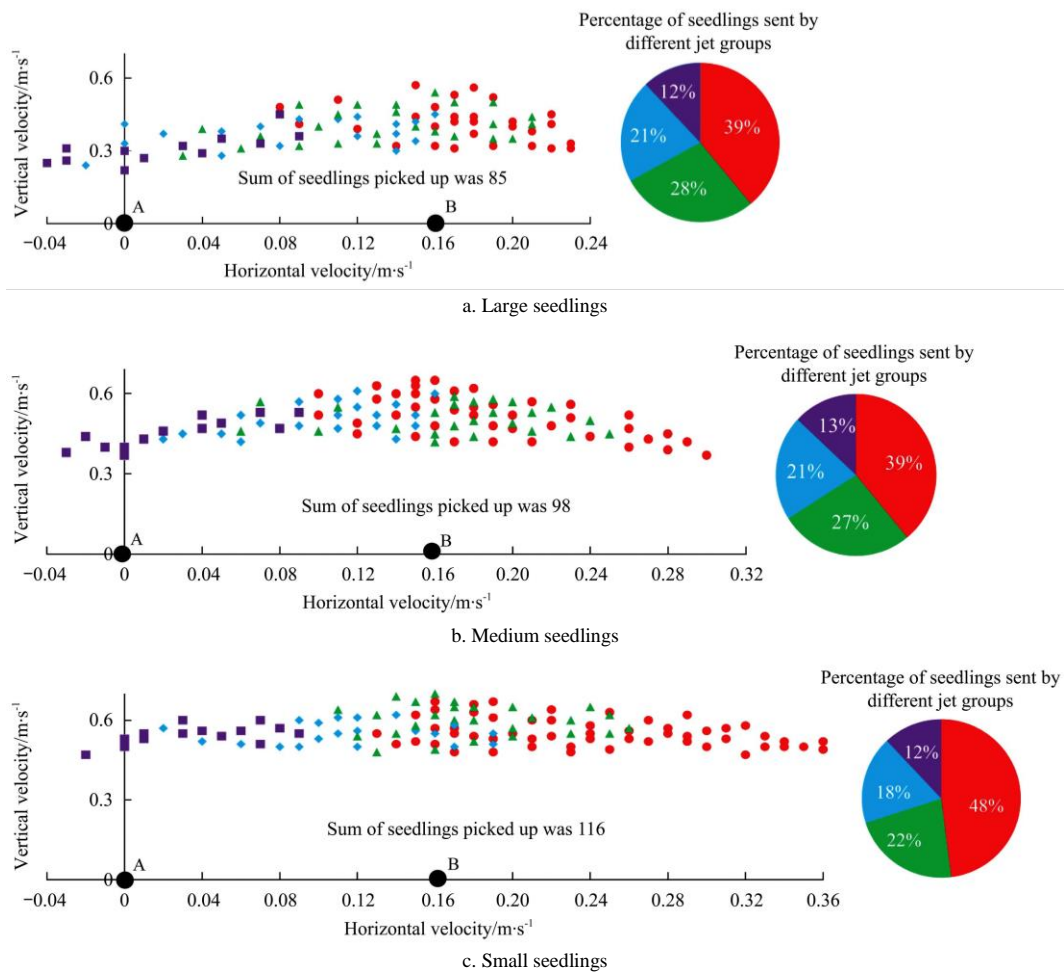
Note: Red, green, blue, and violet represent the seedlings pushed by the jet group 1 and 2, 3 and 4, 5 and 6, and 7 and 8, respectively.

Figure 9   Velocity distribution of seedlings picked up by the picking belt in a single supply separation cycle

3.2   Continuous feed separation

Figure 10 shows the experimental result of continuous separation in the separation system, where continuous separation operations of eight supply cycles are shown under different PSS values.   In Figure 10, the four bar and curve plots show the SS change in continuous supply separating operation under different seedling supply timings, with PSS values of 60%, 70%, 80%, and 90%, respectively.   The horizontal axis of each plot is the separating time, and each vertical bar represents a separation cycle of the eight jet groups for each cycle time of 4 s.   Moreover, the height of each bar represents the number of individual seedlings separated.   The black curve is the variation of SS in continuous supply separation, where the black dotted lines represents the SS mean in each bar and curve plot.   According to the results in Figure 10, the SS of the collected seedlings shows dynamic fluctuations throughout time.   Moreover, as the PSS increases from 60% to 70%, 80%, and 90%, the SS mean increases as   2.20 plant/s, 2.24 plant/s, 1.93 plant/s, and 1.82 plant/s, with CV values of 0.12, 0.12, 0.22, and 0.36, respectively.   On one hand, the results show that the stability of SS evidently improves when PSS decreases from 80% to 70%, while the SS also increases.   On the other hand, decreasing PSS leads to a longer staying time in the separation container for some of the collected seedlings, which may be damaged or have lost water content.   Figure 11 shows the staying time means of seedlings in the separation container for the PSS values of 60%, 70%, 80%, and 90%.   The staying time means of seedlings in

the separation container were (3.68±1.43) min, (2.31±0.65) min, (4.07±0.47) min, and (3.13±0.33) min, respectively, which show a fluctuation under different PSS values.   However, value discreteness of the staying times increased with a decrease in the PSS value.   It reflects the fact that the staying times of seedlings in the separation container are unstable near the PSS values of 60%.   Figure 12 shows the percentages of sorted seedlings in the continuous separation operations under different PSS values, which are individual seedlings separated, seedlings hooked by the picking belt, hook seedlings separated and seedlings moved out of the separation system.   Observing the staying time means in Figure 11, for the PSS values of 60%, 70%, 80%, and 90%, the separating operation time of each supply cycle decreases.   As shown in Figure 11, with a decrease in the PSS value, the percentages of the seedlings sorted show different changes, which are the individual seedlings separated, seedlings hooked by the picking belt, hook seedlings separated and seedlings moved out of the separation system.   When the PSS values were 60% and 70%, the percentage of the individual seedlings separated reached 88.2% and 90.5%.

In summary, by comprehensively considering the stability of SS, staying times of seedlings in the separation container, and percentages of the individual seedlings separated, the optimal PSS is determined as approximately 70%, where the mean value of SS is 2.24 plant/s or separation productivity is 8060 plants/h with a CV of 0.12.

In the previous study, the separation productivity of the

collected Anthurium seedlings inside a separator was 17 100 plants/h[2].   However, the separation productivity of the separation system is only 8060 plants/h in this study, which is 47.1% of that in the previous study.   Although the separator could push a large number of individual seedlings to the picking belt, the quantity of

seedlings separated is approximately half the quantity of seedlings pushed.   However, the productivity of grafting and cutting machines   is   800-4000   plants/h[3,11,23],   and   the   separation productivity of the separation system in this study can still meet the productivity demands of grafting and cutting machines.

a. PSS = 60%

b. PSS = 70%

c. PSS = 80%

d. PSS = 90%
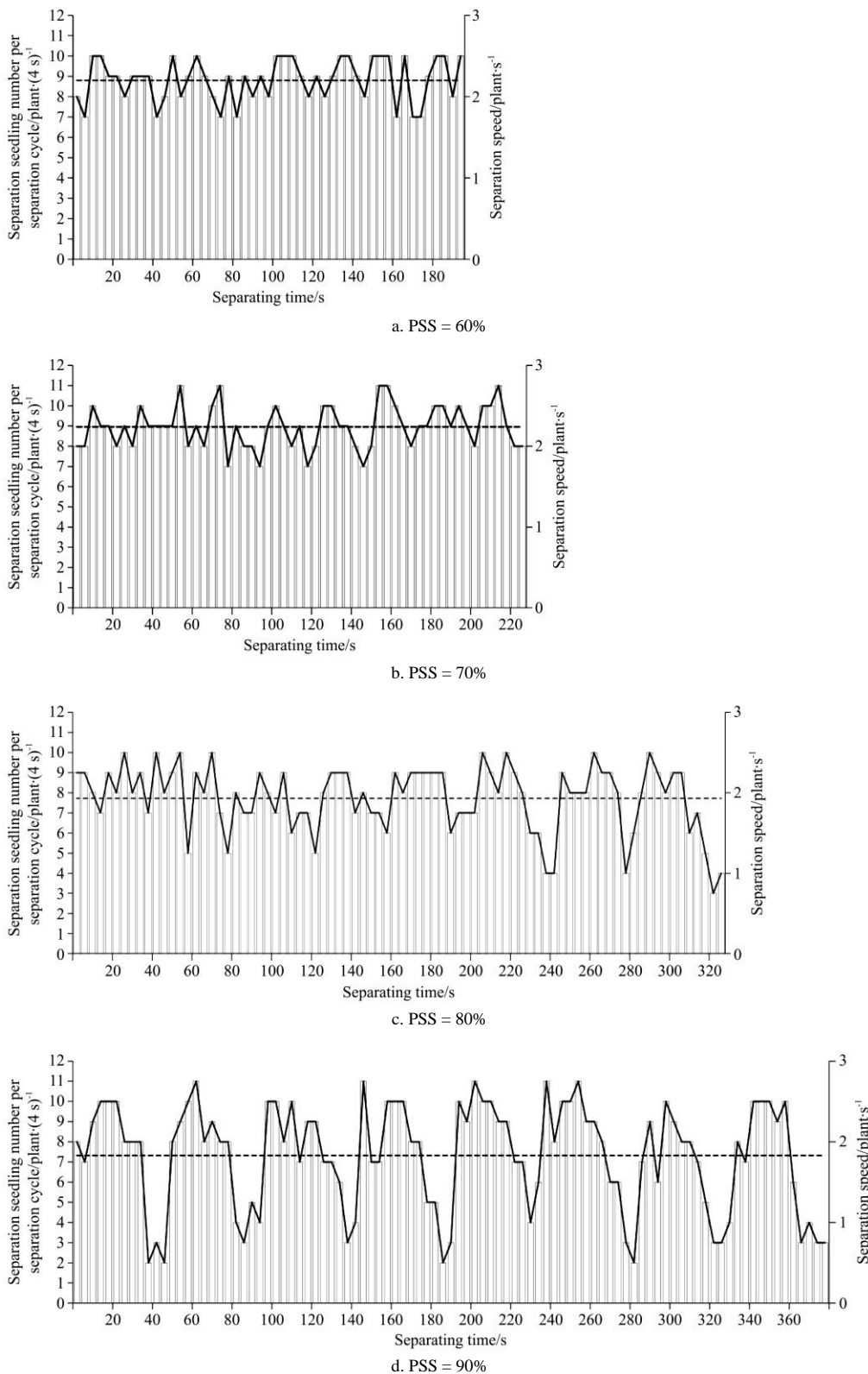
Note: PSS - percentage of the seedlings separated, %.

◆ Black curve is the variation of SS in continuous supply separation such that the black dot line is the SS mean.

Figure 10   Separation speed of the separation system in continuous separation operation under different PSS values
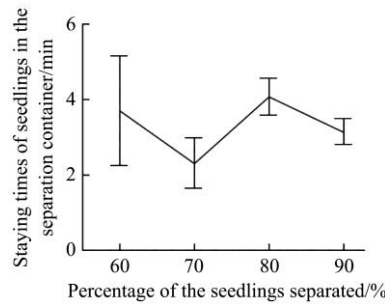
Figure 11　Staying times of seedlings in the separation container in continuous separation operation under different PSS values
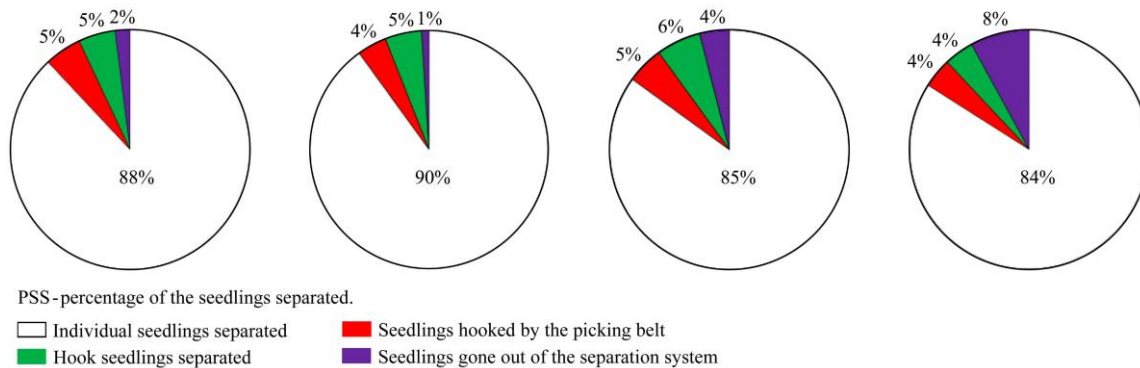

Figure 12　Percentages of sorted seedlings in the continuous separation operations under different PSS values

4　Conclusions

Through a series of units enabling the supply of collected seedlings, separation of subdivided air stream fields, vacuum adsorption picking by a picking belt, and incremental speed separation of convey belts, a separation system composed of the above units was able to achieve continuous separation operation for the collected seedlings. The consistency of the picking belt moving direction and the moving direction of seedlings floated by subdivided air streams in the separation container have a significant effect on the picking of separated seedlings by the picking belt. Different jet groups have different effects on the action of picking seedlings floating in the separation container. The seedling supply timing of the feeder has a significant effect on the stability of the collected seedling separation rate during continuous separation. The feeder supplies seedlings into the separation container with the percentages of separated seedlings of 60%, 70%, 80%, and 90%; the coefficients of variation of the separating rate of the separation system are 0.12, 0.12, 0.22, and 0.36, respectively. When the feeder supplies seedlings with the percentage of separated seedlings of 70%, the separation rate of a continuous separation operation is 2.24 plant/s with 0.12 CV and separation productivity is 8060 plants/h for the collected Anthurium seedlings. This is achieved under the conditions of 0.5 MPa separation pressure, 0.5 s nozzle operation time, and 60 mm seedling thickness, Here, the staying times of the collected seedlings in the separation container are less than 2.5 min.

Acknowledgements

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