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Technical Note

Development of Autofeeding Device Applicable to a Biodegradable Pot Tray

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Abstract: In this study, a pot autofeeding device for a biodegradable pot tray was developed. The tensile strength and bending strength were measured to identify the physical properties of the biodegradable pot tray. As a result of the measurement, the tensile strength and bending strength of the biodegradable pot tray were 0.06 and 0.17 times smaller than those of the plastic pot tray. Therefore, a new type of pot tray extraction mechanism was designed, considering the physical properties, dimensions, and geometry of the biodegradable pot tray, and it was applied to the pot autofeeding device. The developed pot autofeeding device consists of a pot slot, pot-separating blades, pot holders, air cylinders, and a conveyor device. It can supply 240 pot trays per hour to the seeding process without deformation or damage to the biodegradable pot tray.

Keywords: autofeeding device; biodegradable; pot tray; separating blade; tensile strength

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1. Introduction

As of 2019, 412,457 kilotons of paper and 183,031 kilotons of pulp were produced worldwide [1]. During the production of paper and pulp, various wastes are inevitably generated, including foreign matter, wastewater, and additives [2]. Paper sludge refers to the solid waste generated from the wastewater treatment process [3]. The amount of paper sludge generated accounts for approximately 50% of the total waste generated from the papermaking process [4]. Previously, paper sludge was treated using such methods as ocean dumping, landfill, and incineration. However, ocean dumping has been prohibited since 2014 owing to the London Convention and the Marine Pollution Prevention Act [5,6].

Under the influence of these policies, studies have been conducted to recycle paper sludge as a substitute for cement or to develop ecofriendly treatment measures [7–10]. In the agricultural sector, studies have been conducted to manufacture biodegradable pot trays that can replace the existing plastic pot trays using paper sludge [11,12]. When the hot pepper seedlings grown in the existing plastic pot trays and biodegradable pot trays were compared, there were no differences in plant length, leaf length, and the number of leaves, confirming the applicability of biodegradable pot trays [13,14]. Recently, studies have been conducted to improve the tensile and bursting strengths of biodegradable pot trays by mixing paper sludge with waste newspaper, wet strength agents, and water repellents [15,16]. Biodegradable pot trays can replace plastic pot trays, which are discarded through such methods as incineration after use, and they also have an advantage of being ecofriendly because they decompose in soil naturally [17]. In the case of transplanting using plastic pot trays, seedlings are removed from the pot trays and transplanted to the field. This extraction process may have a negative effect on the growth of crops because it can damage the roots of the seedlings [18]. In contrast, biodegradable pot trays can preserve the roots of seedlings because they are transplanted to the field together with the seedlings without an extraction process, and thus they are favorable for the growth of seedlings [16].

Owing to these benefits, biodegradable pot trays have been used for growing the seedlings of crops, such as tomatoes, cucumbers, lettuce, and hot peppers [19]. In this regard, there is a growing need for studies on the application of biodegradable pot trays to agricultural machines [18]. As a research case for applying biodegradable pot trays to agricultural machinery, a transplanter that can apply chain paper pots was developed [20,21]. Nambu and Tanimura (1992) developed the Ferris-type transplanting mechanism for biodegradable pot trays connected in a single line with applying the planting fingers to the transplanting device of the vegetable transplanter. The planting fingers gripped a cell of the biodegradable pot tray, then it rotated similarly to a Ferris wheel, and released the cells into the ground [20]. As a result of the performance evaluation, the work efficiency of the transplanter with the Ferris-type transplanting mechanism was 100 cells per minute [21]. Kumar and Raheman (2011) developed a transplanter that can transplant a biodegradable pot tray with multiple rows and columns. A supplied biodegradable pot tray was cut into multiple cells by circular blades with left–right movement. Then, each cell was dropped into the ground by the seedling drop tube [22]. Recently, a study has been conducted to shorten the time required for the cutting and extraction of biodegradable pot trays to less than one second for high-speed machine transplanting with circular blades [23].

On the other hand, there has been no prior study on the development of a pot-seeding machine capable of seeding in biodegradable pot trays. Pot-seeding machines significantly affect the increase in the mechanization rate of seeding and transplanting because they have high work efficiency and require less manpower, and pot trays that complete seeding using them are compatible with transplanters [24,25]. Therefore, studies on pot-seeding machines that can perform seeding in biodegradable pot trays are required.

A pot-seeding machine commonly used in agriculture consists of a pot autofeeding device, soil feeder, compressing device, seeding device, and covering soil feeder [26]. Among them, the pot autofeeding device is the important device which separates multi-stacked pot trays one by one and supplies them to the seeding process [27]. The mechanical operation of the pot autofeeding device continuously causes a load on pot trays during the pot tray extraction process. Biodegradable pot trays can be easily deformed and destroyed under load because their tensile strength (approximately 0.69 N/mm^2) is lower than that of polypropylene, which is used as the main material of existing pot trays (34 N/mm^2) [16,17,28]. Biodegradable pot trays are also exposed to continuous contraction and expansion in the manufacturing and storage processes because their materials are vulnerable to deformation by moisture. It is difficult to apply manufactured biodegradable pot trays to machinery because their uniformity and firmness are low [22]. To apply biodegradable pot trays to pot-seeding machines, the machines need to be designed so that biodegradable pot trays cannot be deformed or destroyed by minimizing the load caused by the mechanical operation. To this end, the physical properties of biodegradable pot trays must be considered in the design process of the pot autofeeding device.

This study is a preliminary study for the development of a pot-seeding machine that can be applied to biodegradable pot trays, and a pot autofeeding device for a biodegradable pot tray was developed. The tensile and bending strengths of the biodegradable pot tray were measured and reflected in the design of the pot autofeeding device. It is expected that the development of the pot autofeeding device will contribute to an improvement in the mechanization rate of seeding and the development of pot-seeding machines for biodegradable pot trays.

2. Materials and Methods

2.1. Biodegradable Pot Tray

Figure 1 shows the biodegradable pot tray. The biodegradable pot tray consists of paper sludge, a strength resin that increases the strength of paper, and a size agent for water resistance reinforcement. Their proportions are shown in Table 1 [16]. The total weight of the biodegradable pot tray is 227.17 g. As shown in Figure 2, the biodegradable pot tray has a characteristic of being bent by its own weight. The pot tray has a length of 440 mm, a

width of 300 mm, and a height of 45 mm. Twelve cells are arranged in the lateral direction and eight cells in the longitudinal direction. Thus, the pot tray has a total of 96 cells. The shape of each cell is a truncated pyramid with square bases, and the lengths of upper base and lower base were 28.5 mm and 20.5 mm, respectively. At the bottom of the pot tray, there are empty spaces between the cells. The empty spaces are arranged at an interval of 36.5 mm.

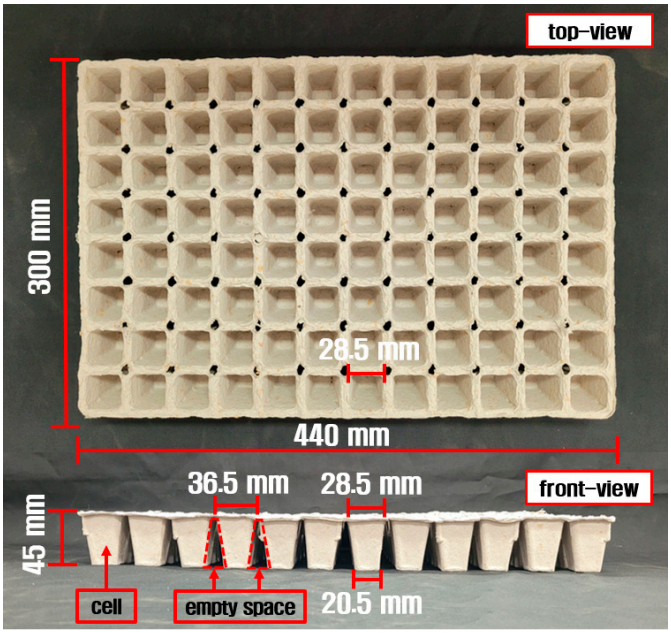


Figure 1. Dimensions of the biodegradable pot tray.

Table 1. Component ratio of the biodegradable pot tray ingredients.

Items	Ingredients of Biodegradable Pot Tray		
	Paper Sludge	**Strength Agent**	**Sizing Agent**
Component ratio	90.90%	4.55%	4.55%

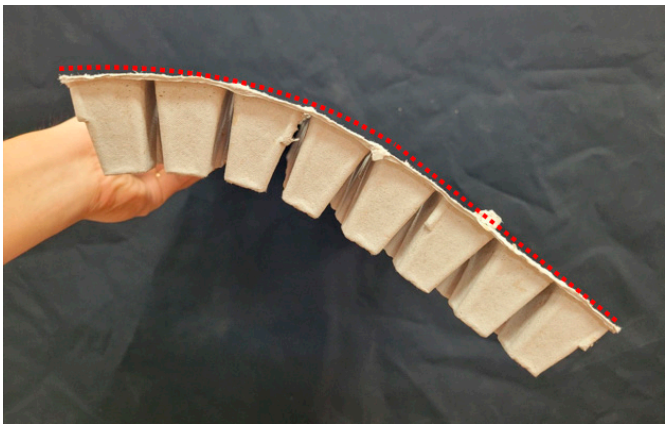


Figure 2. Deflection shape of biodegradable pot tray caused by its self-weight.

2.2. Characteristics of Current Pot Autofeeding Device

A pot-seeding machine commonly used in agriculture consists of a pot autofeeding device, soil feeder, compressing device, seeding device, and covering soil feeder (Figure 3). When multi-stacked pot trays are inserted into the autofeeding device, the pot trays are

separated one by one by the pot tray extraction mechanism of the pot autofeeding device and transported to the soil feeder. The soil feeder fills each cell of the pot tray with soil. The compressing device then presses the soil filled in each cell into a conical shape to create a space for seeding. Subsequently, seeding is performed on the pressed soil by the seeding device. Finally, each cell of the pot tray is filled with covering soil by the covering soil feeder. The pot autofeeding device applied to a pot-seeding machine is an important device that significantly affects the improvement in the work efficiency of the pot-seeding machine because it automatically separates the inserted pot trays one by one and supplies them to the seeding process without requiring manpower. The commercial pot autofeeding devices have different pot tray extraction mechanisms. For representative pot tray extraction mechanisms, the hook-type, roller-type, and flat-type separators were applied. Each extraction mechanism operates as follows.

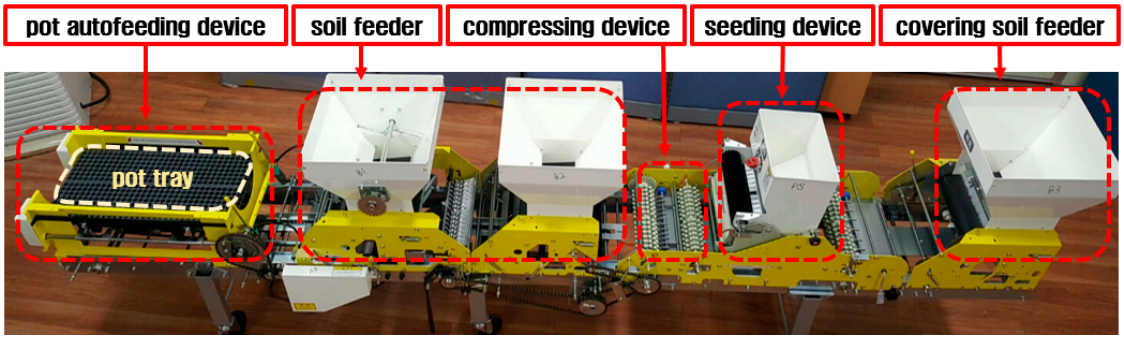


Figure 3. Picture of the mechanical pot tray seeding machine commonly used in agriculture.

A pot autofeeding device that extracts pot trays using the hook-type separator is shown in Figure 4. For this pot tray extraction mechanism, when stacked pot trays are placed in the pot autofeeding device, they are supported by pot holders. The hook-type separator is mounted on a cylindrical rod with rotational motion. Therefore, whenever the rod rotates, the hook-type separator also rotates. When the rotating hook-type separator contacts the top edge of the pot tray, it pulls down the pot tray in the direction of gravity to drop it. The separated pot tray is sent to the seeding process through the transport system.

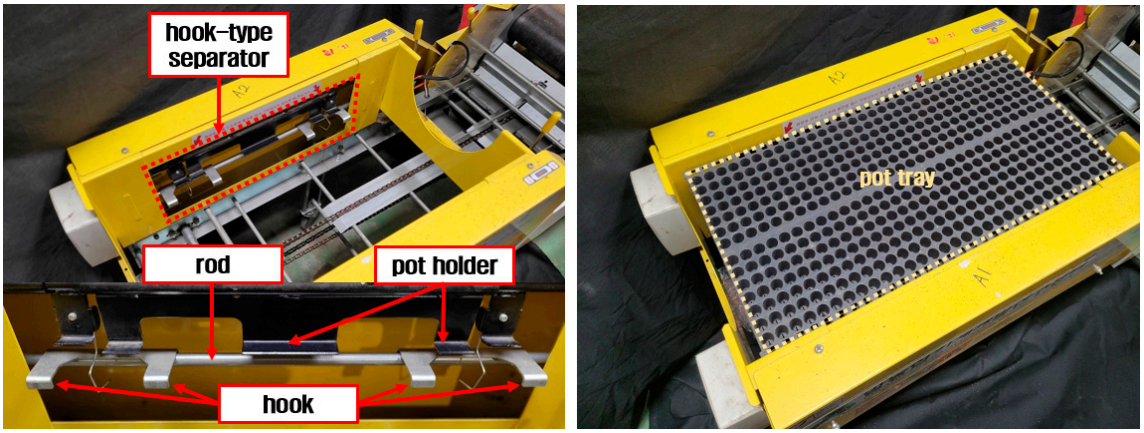


Figure 4. View of the pot autofeeding device with a hook-type separator applied.

Figure 5 shows the operation of the pot tray extraction mechanism using the flat-type separator. When stacked pot trays are placed in the pot autofeeding device, they are supported by pot holders. The flat-type separator can be moved in the vertical and horizontal directions because it is equipped with two air cylinders. The flat-type separator moves in the horizontal direction to contact the hollow between the pot trays and then

moves in the vertical downward direction to separate the pot tray at the bottom. The separated pot tray is sent to the seeding process through the transport system.

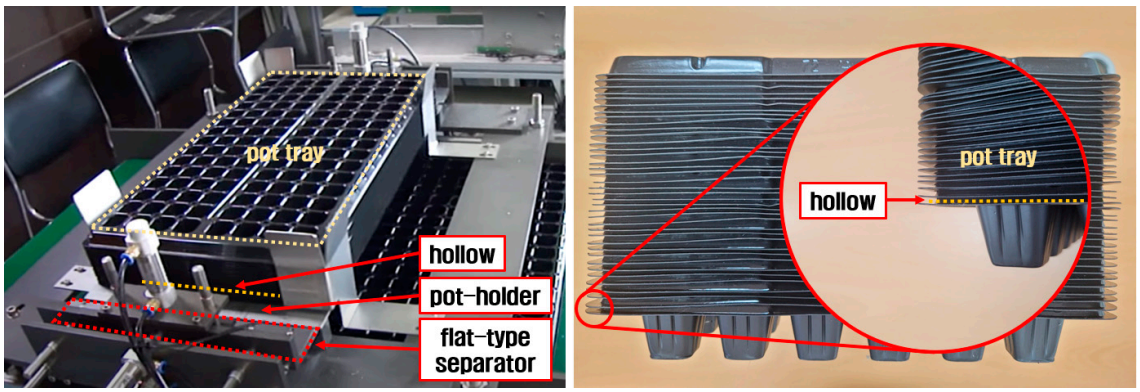


Figure 5. View of the pot autofeeding device with a flat-type separator applied.

Figure 6 shows the pot autofeeding device that extracts pot trays through the roller-type separator. For this pot tray extraction mechanism, when obliquely stacked pot trays are inserted into the pot autofeeding device, the top edge of the pot tray located at the bottom comes into contact with the roller-type separator. The roller-type separator then rotates to separate the pot tray and sends it to the seeding process.

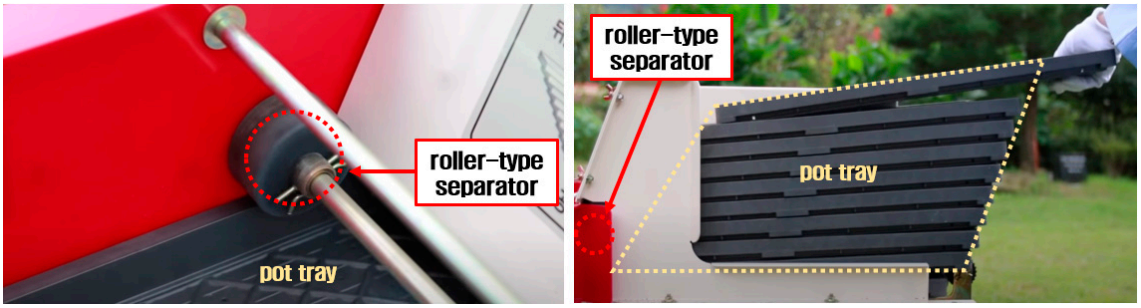


Figure 6. View of the pot autofeeding device with a roller-type separator applied.

2.3. Requirements for Pot Autofeeding Device

The following requirements must be considered for the design of a pot autofeeding device applicable to biodegradable pot trays.

1. To minimize the manpower required in the pot tray separation process and improve work efficiency, the pot autofeeding device must be designed so that multi-stacked biodegradable pot trays can be automatically separated one by one and sent to the seeding process.
2. The components of the pot autofeeding device must be designed considering the strength, dimensions, and geometry of biodegradable pot trays.
3. The components of the pot autofeeding device must be designed to prevent the bending of the biodegradable pot tray during the pot tray extraction process for the smooth operation of the pot autofeeding device.
4. The pot autofeeding device must be designed so that biodegradable pot trays cannot be deformed or destroyed by minimizing the load applied to the pot trays by the pot tray extraction mechanism.

As shown in Figures 4–6, plastic pot tray extraction methods that applied the hook-type, flat-type, and roller-type separators extract a pot tray by applying a load while the separator is in contact with the edge of the pot tray through mechanical behavior. Plastic pot trays are separated without deformation or destruction even if stress is concentrated on

a small area, such as an edge. This is because the physical properties of the plastic material are considered, and an appropriate load is transferred to the edge of the pot tray within a range that does not exceed the tensile strength of the material.

However, biodegradable pot trays are unfavorable for application to machines because their firmness is lower than that of plastic materials, and thus, they are easily deformed and destroyed under a relatively small load [17,22,28].

Therefore, the applicability of the existing plastic pot tray extraction mechanisms must be examined to select a mechanism for the pot autofeeding device applicable to biodegradable pot trays. If the existing mechanisms are not applicable, a new-type pot tray extraction mechanism that can prevent deformation or destruction to biodegradable pot trays needs to be studied. For such a decision, the physical properties of biodegradable and plastic pot trays must be analyzed and compared first.

Accordingly, it is necessary to select a pot extraction mechanism that suitable with the biodegradable pot tray in order to develop a pot autofeeding device. In addition, the performance evaluation should be performed to confirm deformation or damage of the biodegradable pot tray using the developed pot autofeeding device.

2.4. Experimental Design

2.4.1. Tensile and Bending Strength

The tensile and bending strengths of biodegradable and plastic pot trays were measured. The tensile and bending strengths are important indicators of the physical properties of pot trays [16]. They were measured using a universal testing machine (AGS-50kNX, Scientific, Japan) (Figure 7 and Table 2). The measurements were obtained using three specimens for each experiment. The specimens were extracted from the outer walls of the pot trays (Figure 8). For tensile strength measurement, both ends of the specimen were fixed with two jigs and the load at the time of fracture was measured by pulling the specimen. As for the test conditions, the gauge length and tensile speed were 30 mm and 5 mm/min, respectively. The tensile strength was derived by dividing the measured load by the cross-sectional area of the specimen before measurement. The tensile strength of a pot tray can be determined through Equation (1) [29].

$$\sigma_t = \frac{W_{max}}{A_0} \tag{1}$$

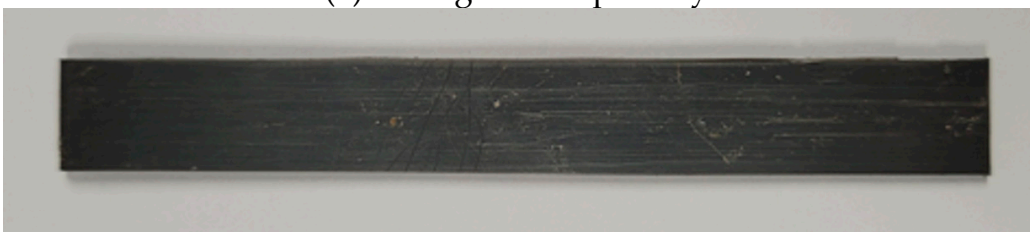
where σ_t: tensile strength, N/mm^2; W_{max}: maximum tensile load, N and A_0: area of cross section, mm^2.

Figure 7. View of the universal testing machine used.

Table 2. Specifications of the universal testing machine.

Items	Specifications
Model/Company/Nation	AGS-50kNX/Scientific/Japan
Max. Load Capacity (kN)	50
Crosshead Speed Accuracy	0.1
Speed Range (mm/min)	0.001 to 1600
Max. Return Speed (mm/min)	2200

(**a**) biodegradable pot tray



(**b**) plastic pot tray

Figure 8. View of the specimen for measuring the tensile and bending stresses.

The bending strength was measured using the three-point bending method. While the specimen remained parallel to the ground, its bottom was supported with two jigs. The top of the specimen was pressed using a crosshead, and the generated load was measured. The distance between the jigs was 30 mm, and the crosshead speed was set to 2.8 mm/min. The bending strength of a pot tray can be determined through Equation (2) [30].

$$\sigma_b = \frac{3PL}{2BD^2} \quad (2)$$

where σ_b: bending strength, N/mm^2; P: maximum bending load, N; L: length between jigs, mm; B: width of the specimen, mm and D: depth of the specimen, mm.

2.4.2. Performance Evaluation

A pot extraction mechanism was selected for use with biodegradable pot trays, and a performance evaluation was performed using the pot autofeeding device developed by reflecting the selected pot extraction mechanism. The method of performance evaluation is as follows. The developed autofeeding device was operated with inserting the stacked biodegradable pot trays continuously. During the pot extraction process, it was confirmed that the components of the pot extraction mechanism were working normally. In addition, after the pot extraction process, the biodegradable pot trays supplied to the seeding process were collected, and then damage and deformation of the biodegradable pot trays were observed. The performance evaluation time was set to 1 h. The work efficiency of the pot autofeeding device was derived by counting the number of extracted biodegradable pot trays.

3. Results and Discussion

3.1. Result of Experiment

The results of the tensile strength and bending strength tests conducted on the biodegradable and plastic pot trays are as follows. The tensile strength was determined to be 12.66 ± 0.87 N/mm^2 for the plastic pot tray and 0.70 ± 0.03 N/mm^2 for the biodegradable pot tray (Table 3). The tensile strength of the biodegradable pot tray was 0.06 times that of the plastic pot tray. The bending strength was measured to be 22.26 ± 0.28 N/mm^2 for the plastic pot tray and 3.89 ± 0.54 N/mm^2 for the biodegradable pot tray (Table 4). The bending strength of the biodegradable pot tray was 0.17 times that of the plastic pot tray. It is judged that this difference occurred due to the characteristics of the main ingredient constituting the biodegradable pot tray and the plastic pot tray.

Table 3. Tensile strength of the biodegradable pot tray.

Items	Tensile Strength (N/mm^2)	
	Plastic Pot Tray	Biodegradable Pot Tray
1st Specimen	12.91	0.69
2nd Specimen	13.57	0.74
3rd Specimen	11.49	0.66
Average	12.66	0.70
Standard deviation	0.87	0.03

Table 4. Bending strength of the biodegradable pot tray.

Items	Bending Strength (N/mm^2)	
	Plastic Pot Tray	Biodegradable Pot Tray
1st Specimen	22.62	3.61
2nd Specimen	22.20	4.65
3rd Specimen	21.95	3.41
Average	22.26	3.89
Standard deviation	0.28	0.54

The results of the tensile and bending strength measurements show that the strength of the biodegradable pot tray is significantly lower than that of the plastic pot tray. Accordingly, it is judged that the hook-type, roller-type, and flat-type separators, which were developed for plastic pot trays, are not suitable for extracting biodegradable pot trays. Therefore, a pot autofeeding device with a new-type mechanism that can minimize deformation or damage to pot trays was developed considering the physical properties of the biodegradable pot tray.

3.2. Development of Pot Autofeeding Device

A pot autofeeding device with a new-type mechanism that can prevent deformation or destruction to the biodegradable pot tray in the pot tray extraction process was designed and fabricated considering the physical properties, dimensions, and geometry of the biodegradable pot tray.

3.2.1. Design of Main Components

The characteristics of each main component which constituting the pot autofeeding device are as follows.

1. Pot slot: the pot slot is the position where the biodegradable pot tray is inserted in the pot autofeeding device, and its geometry is shown in Figure 9. The length and width of the pot slot were designed to be 440 mm and 300 mm, respectively, considering the size of the biodegradable pot tray. The height of the pot slot is 240 mm, facilitating the input of 13 pot trays at a time.

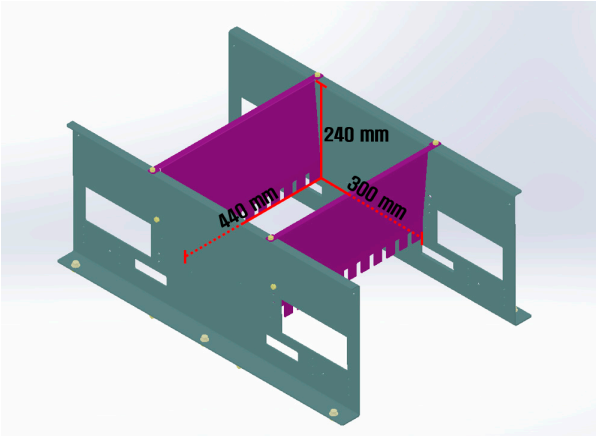


Figure 9. Shape of the pot slot.

2. Pot-separating blades: Figure 10 shows the geometry of the pot-separating blades. The blades are inserted into the spaces between the cells of the biodegradable pot tray to support or separate the pot tray. The biodegradable pot tray has a low bending strength, and thus, deflection occurs owing to its own weight. To prevent this, the number of pot-separating blades was maximized so that the entire pot tray could be supported. Therefore, 11 pot-separating blades were arranged at intervals of 36.5 mm to form an assembly. This interval is the same as the interval of the spaces located between the cells of the biodegradable pot tray. Each assembly is distinguished as either upper or lower pot-separating blades depending on its position. As the upper/lower pot-separating blades are located at both sides of the pot autofeeding device, 44 pot-separating blades were used in the pot autofeeding device. The thickness of the pot-separating blades was set to 4.5 mm, which was smaller than the width of the spaces located between the cells of the biodegradable pot tray (8 mm). Among the components of the pot autofeeding device, the pot-separating blades generate relatively large loads on the biodegradable pot tray during their operation. Such loads can be dispersed and geometry deformation can be minimized by designing the area in which the pot-separating blades are in contact with the biodegradable pot tray to be larger. The area can be increased by maximizing the length of the pot-separating blades. Considering that the width of the biodegradable pot tray is 300 mm, the length of the pot-separating blades was set to 150 mm. Therefore, the total length of contact between a pair of pot-separating blades and the biodegradable pot tray is 300 mm.

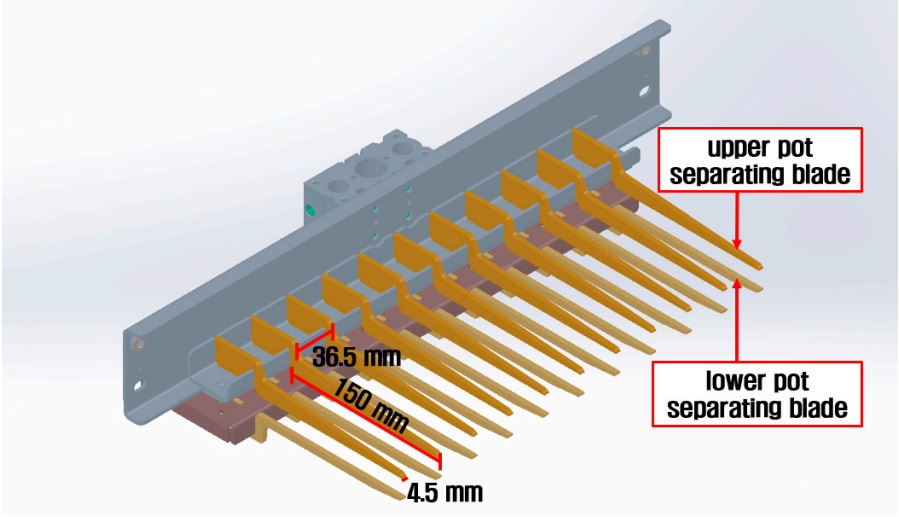


Figure 10. Shape of the pot-separating blade.

3. Pot holders: the pot holders support the inserted biodegradable pot tray, and their geometry is shown in Figure 11. The pot holders are located on both sides of the pot autofeeding device. Their width and height were set to 80 and 30 mm, respectively. Their length was set to 440 mm, which is the same as the length of the biodegradable pot tray.

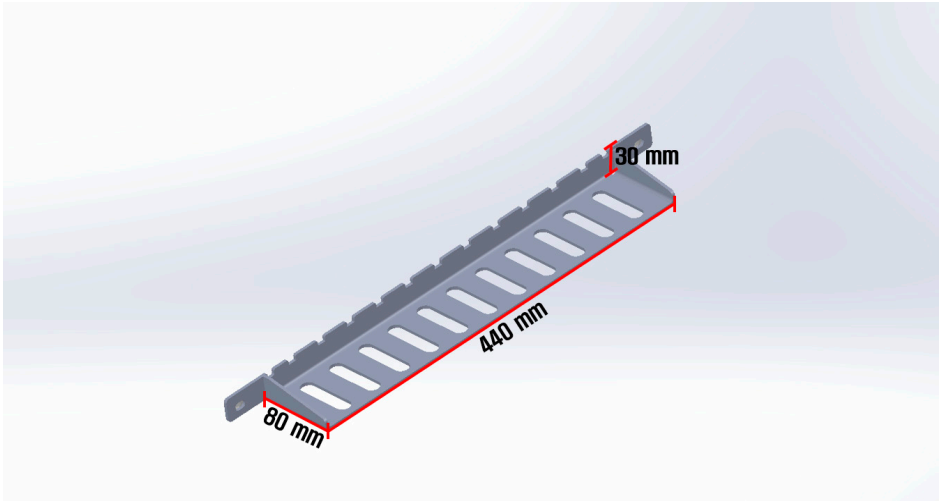
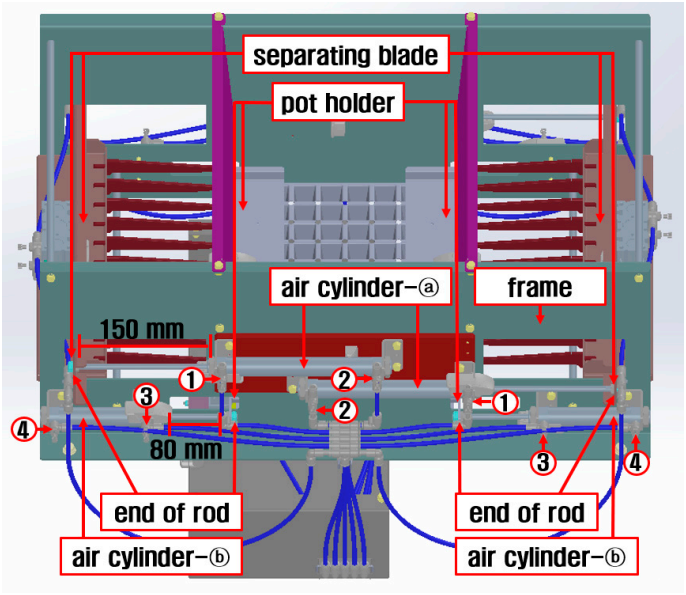
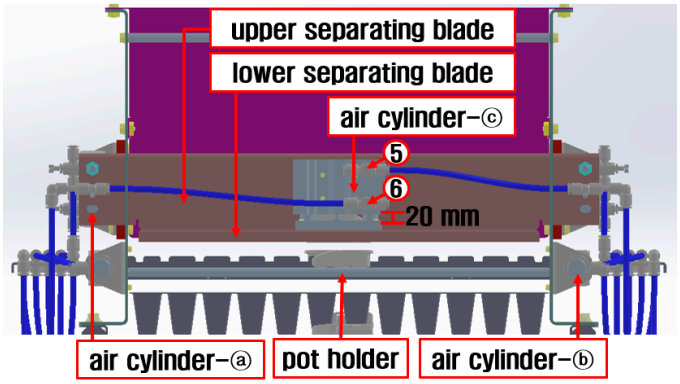


Figure 11. Shape of the pot holder.

4. Air cylinders: the air cylinders drive the pot-separating blades and pot holders, and their geometry is shown in Figure 12. Three types of air cylinders were used in the pot autofeeding device. Table 5 shows their specifications. The length of the pot-separating blades was set to 150 mm in Figure 10. During the pot tray extraction process, the blades need to insert 150 mm into the empty spaces of the biodegradable pot tray. Therefore, an air cylinder-ⓐ which has a stroke of 150 mm, was used for operating the pot-separating blades. The body of air cylinder-ⓐ is attached to the center of the frame outer wall, and the end of the piston rod is fixed to the pot-separating blades. When compressed air is supplied through position ①, the piston rod moves into the air cylinder body and pulls the pot-separating blades to the inside of the pot slot. Conversely, when compressed air is supplied through position ②, the piston rod protrudes and the pot-separating blades return to the outside of the pot slot. The width of the pot holders was set to 80 mm in Figure 11. The pot holders need to move 80 mm to support the biodegradable pot tray. Therefore, an air cylinder-ⓑ which has a stroke of 80 mm, was selected for operating the pot holders. The operation mechanism of air cylinder-ⓑ is the same as that of air cylinder-ⓐ. The body of air cylinder-ⓑ is attached on the frame outer wall, and the end of the piston rod of the air cylinder-ⓑ is fixed to the pot holders. Therefore, when compressed air is supplied to position ③, the pot holders move to the outside of the pot slot. When compressed air is supplied to position ④, they return to the inside of the pot slot. An air cylinder-ⓒ was designed to operate the lower pot-separating blade in Figure 10. The body of air cylinder-ⓒ and the end of the piston rod are fixed to the upper and lower pot-separating blades, respectively. At the beginning of the operation of the pot autofeeding device, compressed air is supplied to position ⑥, and the upper/lower pot-separating blades are in contact with each other. However, when compressed air is supplied to position ⑤, the lower pot-separating blade moves downward and is separated from the upper pot-separating blade. Air cylinder-ⓒ has a stroke of 20 mm. Therefore, the lower pot-separating blade moves 20 mm downward from the upper pot-separating blade. The proper pressure of all air cylinders was set to 0.6 bars.



(**a**) side view



(**b**) front view

Figure 12. Shape of 3D model that the air cylinders applied to the pot autofeeding device.

Table 5. Specifications of the air cylinders used.

Items		Specifications		
Model/Company/Nation		ACS4-N LB20-S150 /KCC company/ South Korea	ACS4-N LB20-S80 /KCC company/ South Korea	ANGM 25-S20 /KCC company/ South Korea
Fluid type used		Air	Air	Air
Pressure (MPa)	Max.	1.0	1.0	1.0
	Min.	0.05	0.05	0.12
Piston speed (mm/s)	Max.	1000	1000	500
	Min.	750	750	50
Stroke (mm)		150	80	20
Inner diameter of rod (mm)		20	20	20

5. Conveyor device: The conveyor device transports the extracted biodegradable pot tray to the seeding process, and its geometry is shown in Figure 13. It has a length of 1800 mm and a height of 700 mm. Its width was set to 440 mm, which is the same as the length of the biodegradable pot tray. The conveyor device transports the biodegradable pot tray to the seeding process at a speed of 18.16 mm/s.

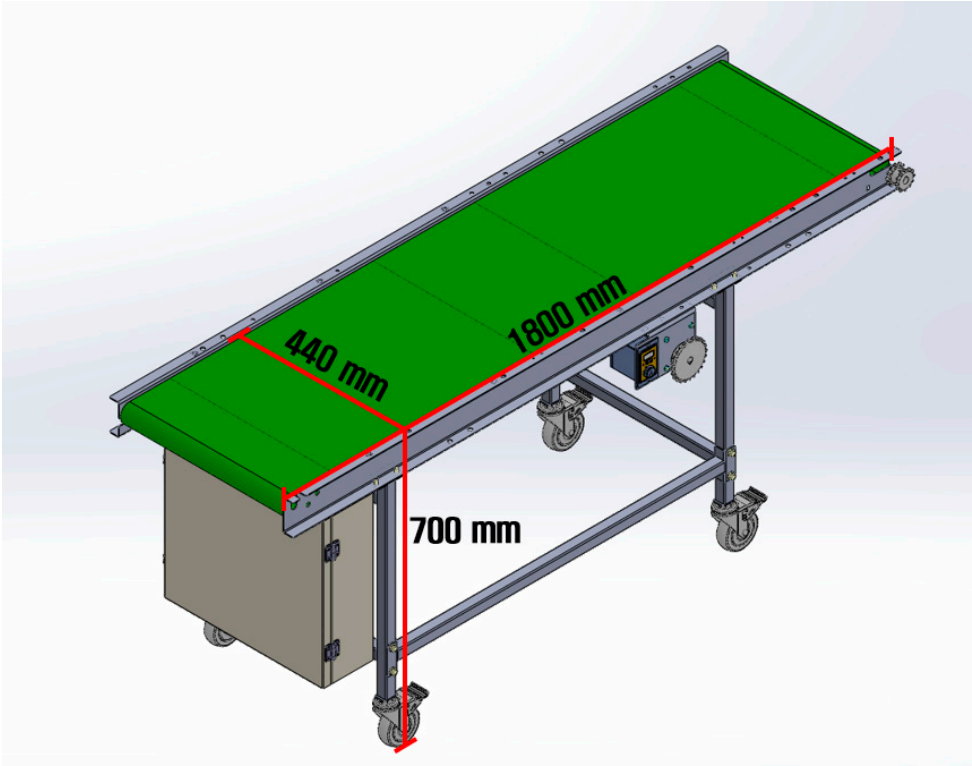
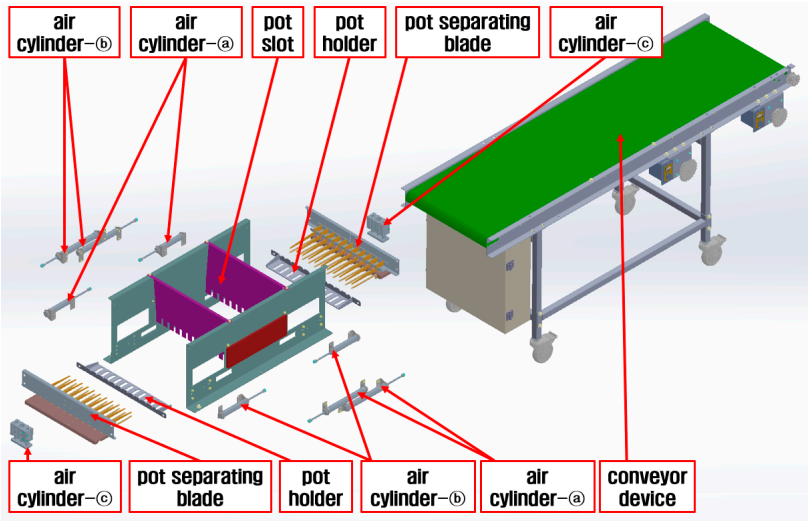


Figure 13. Shape of the conveyor device.

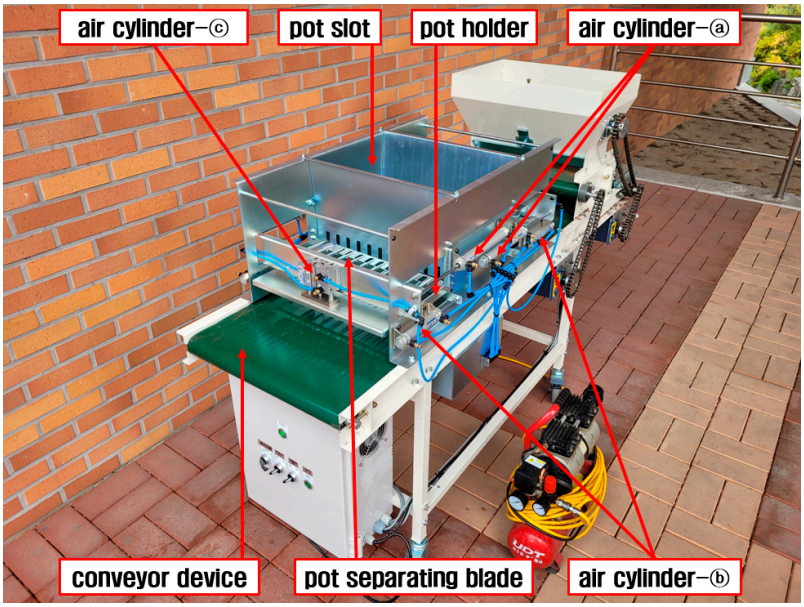
3.2.2. Operating Procedure of Developed Pot Autofeeding Device

Figure 14 shows the overall geometry of the pot autofeeding device that was designed considering the dimensions, geometry, and physical properties of the biodegradable pot tray. The main components of the pot autofeeding device are a pot slot, pot-separating blades, pot holders, air cylinders, and a conveyor device.



(**a**) 3D model

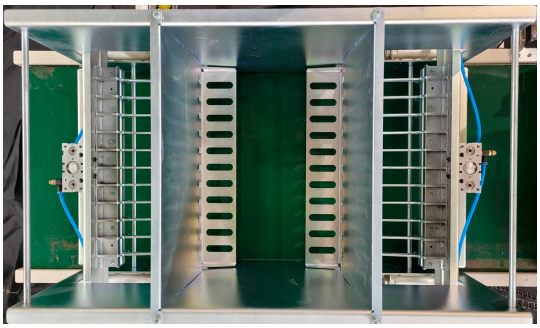
Figure 14. *Cont.*



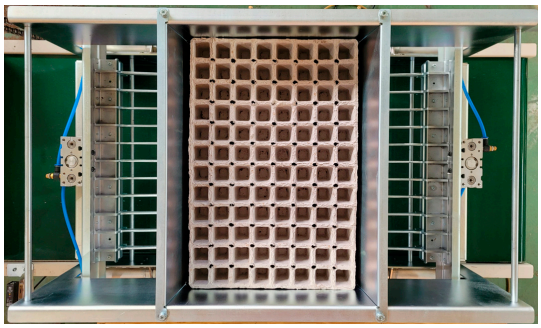
(**b**) picture

Figure 14. Shape of the pot autofeeding device.

Figure 15 shows the operating procedure of the developed pot autofeeding device for the biodegradable pot tray. The operator places the biodegradable pot trays stacked in 13 layers into the pot slot. The lower part of the first biodegradable pot tray located at the bottom is supported by the pot holders located inside the pot slot (Figure 15a,b). Subsequently, air cylinder-ⓐ operates to insert the upper/lower pot-separating blades into the empty spaces between each cell of the second biodegradable pot tray (Figure 15c–e). In this instance, the upper pot-separating blade supports the lower part of the second biodegradable pot tray. Air cylinder-ⓑ operates to move the pot holders to the outside of the pot slot (Figure 15f). The first biodegradable pot tray does not drop vertically owing to the friction with the second biodegradable pot tray. Subsequently, air cylinder-ⓒ operates to move the lower pot-separating blade with the down-up motion (Figure 15g). The first biodegradable pot tray is separated from the second biodegradable pot tray as the lower pot-separating blade comes into contact with the upper part of the first biodegradable pot tray. The first biodegradable pot tray then drops onto the conveyor device to be transported to the seeding process (Figure 15h). Subsequently, the pot holders again move to the inside of the pot slot (Figure 15i), and the upper/lower pot-separating blades again move toward the outside of the pot slot (Figure 15j). Through this pot tray extraction mechanism, the biodegradable pot trays are sequentially extracted and transported to the seeding process one by one.



(**a**)



(**b**)

Figure 15. *Cont.*

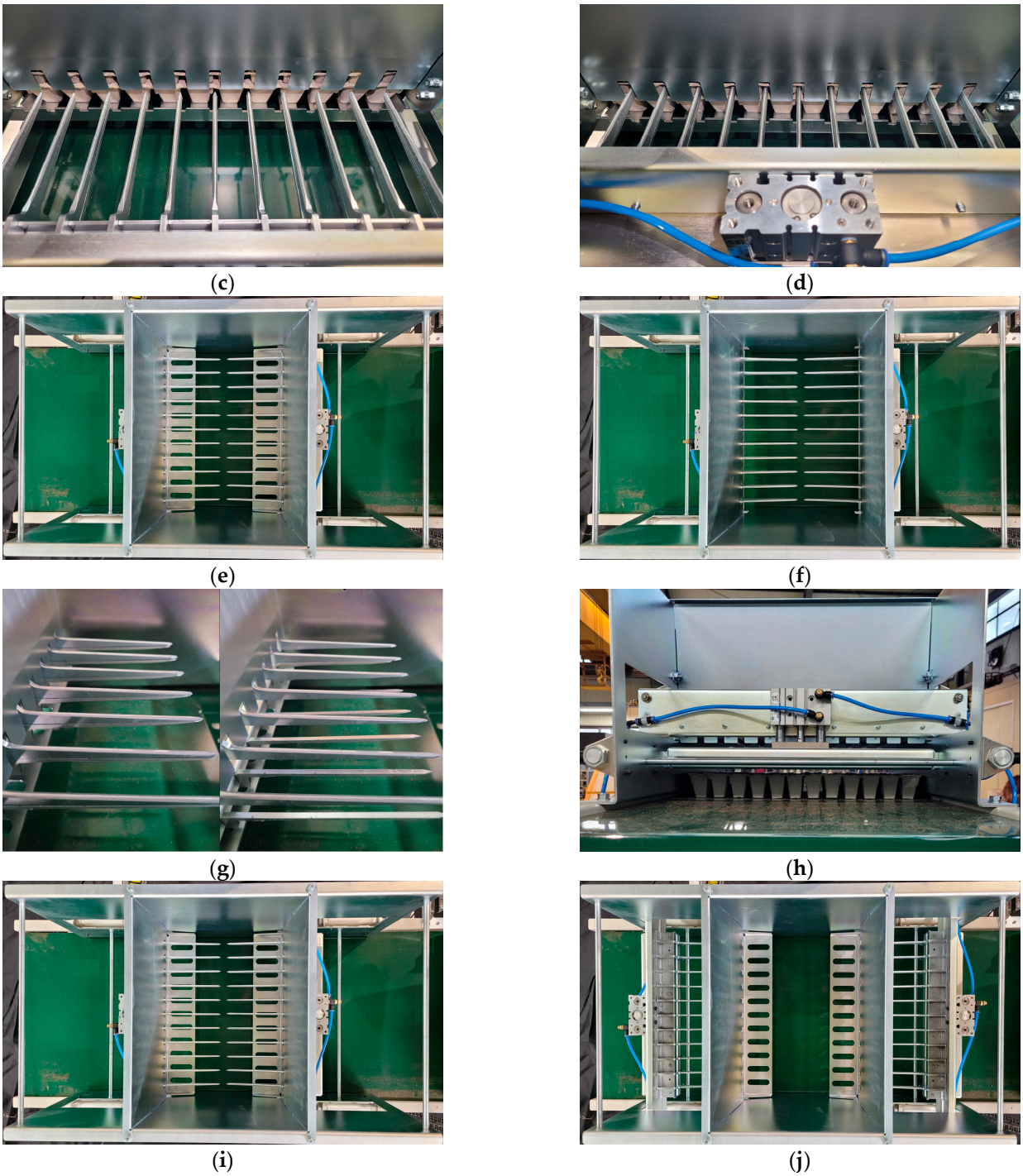
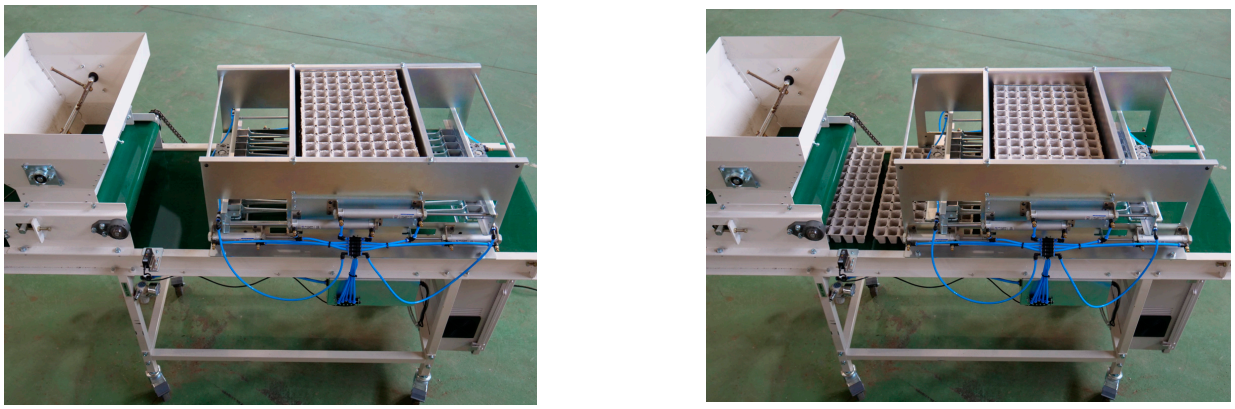


Figure 15. Operating procedure of the pot autofeeding device for the biodegradable pot tray: (**a**) an initial condition; (**b**) supplying the biodegradable pot tray into the pot slot; (**c**) the shape of the pot separating blades before inserting; (**d**) inserting of pot separating blades into the spaces of biodegradable pot tray; (**e**) the shape of pot separating blades after inserting; (**f**) the pot holders move to the outside of the plot slot; (**g**) the lower pot-separating blade moves downward for separating the bottom biodegradable pot tray; (**h**) separated biodegradable pot tray drops onto the conveyor belt to be transported to the seeding process; (**i**) the pot holders return to the inside of the pot slot; (**j**) the pot-separating blades return toward the outside of the pot slot.

3.3. Result of Performance Evaluation

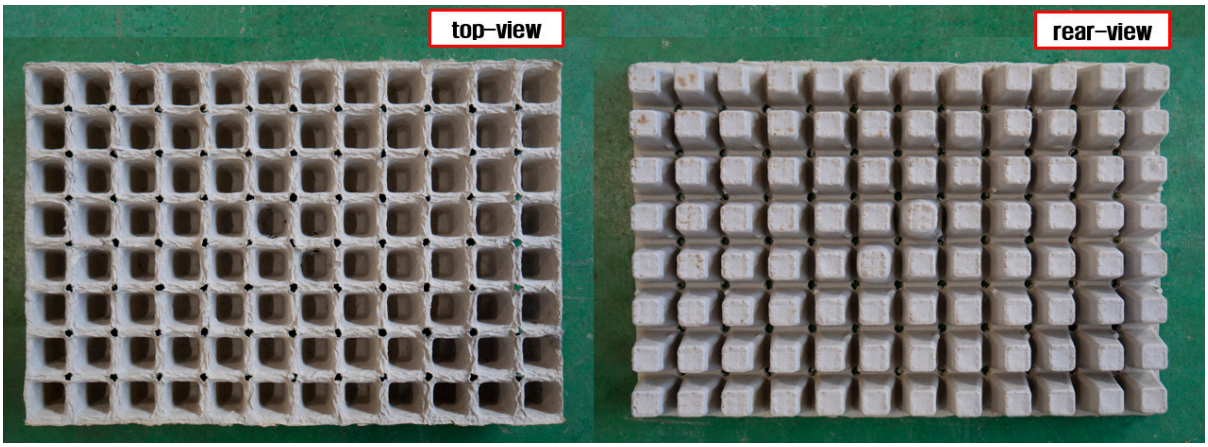
Figure 16 shows that conducting the performance evaluation of the pot autofeeding device. As a result of observing whether the pot autofeeding device operates normally under the condition that the biodegradable pot tray was inserted into the pot slot continuously, it was confirmed that the pot autofeeding device can automatically separate the stacked biodegradable pot trays one by one and send them to the seeding process without malfunction occurred. In addition, the result of counting the number of the biodegradable pot trays supplied for 1 h through the pot autofeeding device, it was observed that 240 biodegradable pot trays were supplied to the seeding process per hour.



(**a**) initial condition (**b**) operating condition

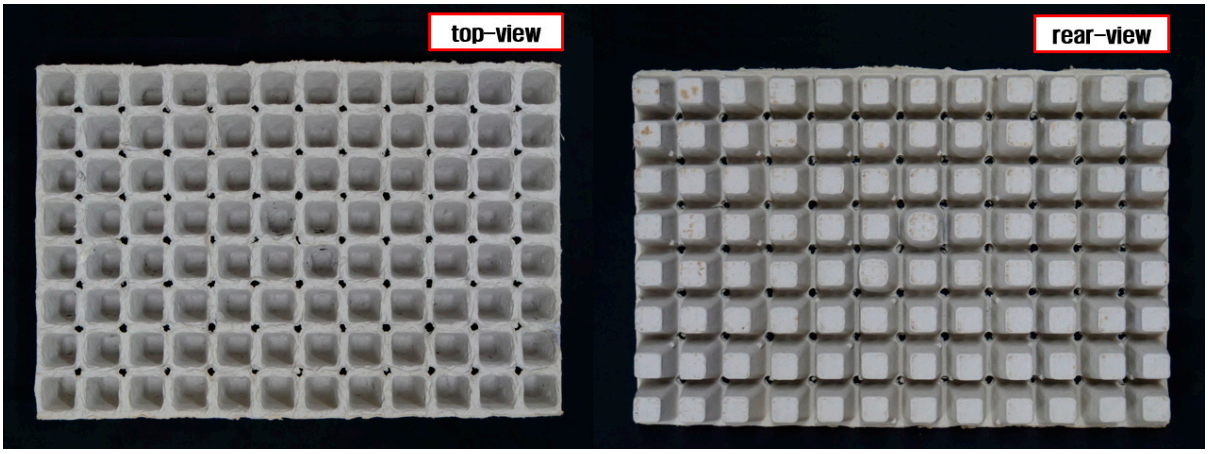
Figure 16. The picture of conduction the performance evaluation.

As a result of a complete enumeration survey regarding to the 240 biodegradable pot trays supplied to the seeding process, it was confirmed that no deformation or damage occurred in all biodegradable pot trays (Figure 17). This indicates that the new-type pot extraction mechanism is suitable for supplying the separating biodegradable pot trays. In particular, it was judged that the developed pot autofeeding device prevents the bending of the biodegradable pot tray due to its own weight in the pot extraction process by applying the pot separating blades, and it also prevents the deformation or destruction of the biodegradable pot tray by dispersing the load generated by the mechanical behavior of the components.



(**a**) before the pot extraction process

Figure 17. *Cont.*



(**b**) after the pot extraction process

Figure 17. Picture of the biodegradable pot tray used for confirming the deformation and damage.

4. Conclusions

In this study, a pot autofeeding device for a biodegradable pot tray was developed considering the physical properties, dimensions, and geometry of the pot tray.

The pot tray extraction mechanisms commercialized for plastic pot trays were investigated, and their applicability to biodegradable pot trays was examined. To this end, specimens were secured from actual biodegradable and plastic pot trays, and their tensile and bending strengths were measured using a universal testing machine. The tensile and bending strengths of the biodegradable pot tray were derived as 0.70 ± 0.03 and 3.89 ± 0.54 N/mm^2, respectively, whereas those of the plastic pot tray were 12.66 ± 0.87 and 22.26 ± 0.28 N/mm^2, respectively. As a result of the measurement, the tensile strength and bending strength of the biodegradable pot tray were 0.06 and 0.17 times smaller than those of the plastic pot tray. It is judged that this difference occurred due to the material property of the biodegradable pot tray and the plastic port tray.

As the strength of the biodegradable pot tray was lower than that of the plastic pot tray, a new-type pot tray extraction mechanism was developed considering the physical properties, dimensions, and geometry of the biodegradable pot tray.

The developed pot autofeeding device consists of a pot slot, pot-separating blades, pot holders, air cylinders, and a conveyor device. The pot holders support the stacked biodegradable pot trays inserted into the pot slot. The pot separating blades insert into the stacked biodegradable pot trays and extract them one by one. Then, the separated biodegradable pot tray is transferred to the seeding process by a conveyor device. A performance evaluation was conducted to confirm that the components of the pot autofeeding device operate normally during the operation procedure. In addition, the biodegradable pot tray supplied to the seeding process was collected, and then damage and deformation occurring in the biodegradable pot tray were observed. As a result of observing whether the pot autofeeding device works normally, it was checked that the stacked biodegradable pot trays were extracted one by one automatically without malfunction occurred. The work efficiency of the pot autofeeding device was 240 pot trays per hour. As a result of a complete enumeration survey regarding to the 240 biodegradable pot trays supplied to the seeding process, it was confirmed that no deformation or damage occurred in all biodegradable pot trays. This indicates that the new-type pot extraction mechanism is suitable for supplying the separating biodegradable pot trays. Especially, it judged that the developed pot autofeeding device prevents the bending of the biodegradable pot tray due to its own weight in the pot extraction process by applying the pot separating blades, and it also prevents the deformation or destruction of the biodegradable pot tray by dispersing the load generated by the mechanical behavior of the components.

It is expected that the development of the pot autofeeding device for the biodegradable pot tray will reduce the manpower and labor load of seeding and improve the applicability of biodegradable pot trays.

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References

1. Korea Paper Association: Paper production by region. Available online: http://www.paper.or.kr/sub_5/5_1_3.php (accessed on 10 October 2022).
2. Skinner, H.J. Waste problems in the pulp and paper industry. *Ind. Eng. Chem.* **1939**, *31*, 1331–1335. [CrossRef]
3. Boni, M.R.; D'Aprile, L.; De Casa, G. Environmental quality of primary paper sludge. *J. Hazard. Mater.* **2004**, *108*, 125–128. [CrossRef]
4. Lee, Y.H.; Jo, H.M.; Kim, S.H.; Lee, J.Y. Fundamental study of the production of paper ash made from paper sludge I: Evaluation of the characteristics of paper ash made from paper sludge in a specialty paper mill. *J. Korea TAPPI* **2020**, *52*, 113–119. [CrossRef]
5. Ko, J.C.; Kim, S.H.; Park, Y.K.; Jeon, J.Y.; Kim, J.H.; Park, J.S. Pyrolysis characteristics of sludge discharged from paper mill process. *J. Korra* **2009**, *17*, 80–87.
6. Song, D.B.; Lim, K.H.; Jung, D.H.; Yoon, J.H. Analysis of drying performance and cost of large-capacity sewage sludge dryer. *J. Biosyst. Eng.* **2021**, *46*, 105–111. [CrossRef]
7. Takizawa, S.; Baba, Y.; Tada, C.; Fukuda, Y.; Nakai, Y. Pretreatment with rumen fluid improves methane production in the anaerobic digestion of paper sludge. *Waste Manag.* **2018**, *78*, 379–384. [CrossRef]
8. Bui, N.K.; Satomi, T.; Takahashi, H. Influence of industrial by-products and waste paper sludge ash on properties of recycled aggregate concrete. *J. Clean. Prod.* **2019**, *214*, 403–418. [CrossRef]
9. Chen, M.; Zheng, Y.; Zhou, X.; Li, L.; Wang, S.; Zhao, P.; Lu, L.; Cheng, X. Recycling of paper sludge powder for achieving sustainable and energy-saving building materials. *Constr. Build. Mater.* **2019**, *229*, 116874. [CrossRef]
10. Kang, I.K.; Oh, H.Y.; Han, D.Y.; Lim, Y.T.; Jang, M.M.; So, S.Y. An analysis of characteristics of asphalt concrete using paper sludge. *Conf. AIK* **2020**, *40*, 461.
11. Schrader, J.A.; Srinivasan, G.; Grewell, D.; McCabe, K.G.; Graves, W.R. Fertilizer effects of soy-plastic containers during crop production and transplant establishment. *Hortscience* **2013**, *48*, 724–731. [CrossRef]
12. Nandede, B.M.; Raheman, H.; Kumar, G.V.P. Standardization of potting mix and pot volume for the production of vegetable seedlings in paper pot. *J. Plant Nutr.* **2014**, *37*, 1214–1226. [CrossRef]
13. Seo, T.C.; An, S.W.; Jang, H.W.; Nam, C.W.; Chun, H.; Kim, Y.C.; Kang, T.K.; Lee, S.H. An approach to determine the good seedling quality of grafted tomatoes (*Solanum lycopersicum*) grown in cylindrical paper pot through the relation analysis between DQI and short-term relative growth rate. *J. Bio-Env. Control* **2018**, *27*, 302–311. [CrossRef]
14. Lee, J.H.; Lee, D.H.; Choi, G.M.; Kim, E.G.; Kim, T.H.; Kim, H.T. Analysis of plant guarding characteristics of biodegradable pot for transplant. *Proc. Conf. Korean Soc. Agric.* **2019**, *24*, 494–495.
15. Lee, J.Y.; Kim, C.H.; Lee, G.S.; Jo, H.S.; Nam, H.G.; Park, H.H.; Moon, S.O. Physico-chemical characteristics of biodegradable seedling pots made of paper mill sludges. *J. Korea TAPPI* **2014**, *46*, 9–18. [CrossRef]
16. Park, J.H.; Lee, G.H.; Lee, H.M.; Madhavi, B.G.K.; Arulmozhi, E.; Bhujel, A.; Moon, B.E.; Kim, H.T. Physical properties and plant growth according to the content of additives in the biodegradable pot for mechanical transplanter. *JALS* **2022**, *56*, 129–134. [CrossRef]
17. Park, H.S.; Son, K.Y.; Kang, J.R.; Seo, W.J.; Lee, S.J.; Lee, W.K. Study on properties of eco-friendly pot with biodegradable PLA/PBAT blend film. *J. Environ. Sci. Int.* **2015**, *24*, 1037–1043. [CrossRef]
18. Jang, Y.N.; An, S.W.; Chun, H.; Lee, H.J.; Wi, S.H. The growth of cucumber seedlings grown in paper pot trays affected by nutrient management during seedling period, seedling age, and night temperature after transplanting. *J. Bio-Env. Control* **2019**, *28*, 396–403. [CrossRef]
19. Seo, T.C.; An, S.W.; Kim, S.M.; Nam, C.W.; Chun, H.; Kim, Y.C.; Kang, T.K.; Kim, S.W.; Jang, K.S. Effect of the seedlings difference in cylindrical paper pot trays on initial root growth and yield of pepper. *J. Bio-Env. Control* **2017**, *26*, 368–377. [CrossRef]

20. Nambu, T.; Tanimura, M. Development of automatic transplanter using chain pot for vegetable crops. *Int. Symp. Transpl. Prod. Syst.* **1992**, *319*, 541–546.
21. Suggs, C.W.; Thomas, T.N.; Eddington, D.L.; Peel, H.B.; Seaboch, T.R.; Gore, J.W. Self feeding transplanter for tobacco and vegetable crops. *Appl. Eng. Agric.* **1987**, *3*, 148–152. [CrossRef]
22. Kumar, G.V.P.; Raheman, H. Development of a walk-behind type hand tractor powered vegetable transplanter for paper pot seedlings. *Biosyst. Eng.* **2011**, *110*, 189–197. [CrossRef]
23. Lee, M.H.; Moon, B.E.; Jo, J.M.; Choi, T.H.; Kim, H.T. Development of Automatic type transplanter for biodegradable seedling pot. *Proc. Conf. Korean Soc. Agric.* **2017**, *22*, 136.
24. Jun, H.J.; Yu, S.H.; Choi, I.S.; Kim, J.G.; Lee, S.H.; Kang, T.G.; Kim, Y.K.; Choi, Y. Study on compatibility between plug tray sowing, seedlings and transplanters for planting mechanization of sesame. *Proc. Conf. Korean Soc. Agric.* **2018**, *23*, 155.
25. Choudhary, V.; Machavaram, R. Need of automation in paddy nurseries for raising paddy seedlings in India: A Review. *J. Biosyst. Eng.* **2022**, *47*, 209–222. [CrossRef]
26. Hwang, S.J.; Lee, J.Y.; Nam, J.S. Irrigation System for a Roller-Type Onion Pot Seeding Machine. *Appl. Sci.* **2019**, *9*, 430. [CrossRef]
27. Hwang, S.J.; Nam, J.S. Development of automatic accumulating equipment for roller-type onion pot-seeding machine. *Appl. Sci.* **2019**, *9*, 2139. [CrossRef]
28. Juvinall, R.C.; Marshek, K.M. *Machine Component Design*, 5th ed.; WILEY (John Wiley & Sons): Hoboken, NJ, USA, 2015; pp. 338–340.
29. Malik, G.K.; Khuntia, A.; Mitra, J. Comparative effect of different plasticizers on barrier, mechanical, optical, and sorption properties of hydroxypropyl methylcellulose (HPMC)–based edible film. *J. Biosyst. Eng.* **2022**, *47*, 93–105. [CrossRef]
30. Sim, J.H.; Lee, J.B.; Hwang, S.S. Effect of glazing on the flexural strength of lithium disilicate glass ceramics. *Korean J. Dent. Mater.* **2019**, *46*, 185–194. [CrossRef]