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Performance Analysis for a Card Cleaner Type Separating System of Pepper Harvester

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This study conducted a factorial experiment with an experimental bench to analyze the separation performance of a card cleaner type separating system of pepper harvesters. The factors used for this study were the card arrangement (inline and staggered), slope angle (5° and 15°), and rotational speed (35, 50, and 65 rpm) of the card cleaner. The separation efficiency of peppers was influenced by the slope and rotational speed of the card cleaner in both types of card arrangement. In the inline arrangement, the mixing ratio of foreign materials was influenced by slope angle but not influenced by the rotational speed of the card cleaner. In the staggered arrangement, the mixing ratio of foreign materials was influenced by slope angle and the rotational speed of the card cleaner. The high separation efficiency in the staggered arrangement was obtained under the conditions of a slope of 5° and a rotational speed of 50 rpm. However, the mixing ratio of foreign materials was also high in this condition. The high separation efficiency in the inline arrangement was obtained under the conditions of a slope of 15° and a rotational speed of 50 rpm, and the mixing ratio of foreign materials was relatively low in this condition. Thus, the inline arrangement with a slope angle of 15° was recommended for a separating system of self-propelled pepper harvesters.

Key words: pepper harvester, separating system, card cleaner, field cleaning, factorial experiment

INTRODUCTION

World pepper production in 2012 was estimated to be 31,172,000 metric tons, and pepper production in China took 51% of the world production with 16,024,000 metric tons. Pepper production in the United States took 3.4% of the world production with 1,065,000 metric tons. The United States has increased imports of pepper from Mexico and Peru since NAFTA (North American Free Trade Agreement) was signed in 1994, and pepper production in the US has decreased rapidly due to the intensified price competition. As a result, US market continues to import over 80% of total consumption from overseas (FAOSTAT, 2012).

In Korea, peppers are essential seasoning and they are cultivated to a large extent. The cultivation area for peppers takes 38% of total condiment vegetable cultivation area (KOSTAT, 2014). In the pepper farming, har-

vest labor accounts for 39.2% of total labor when hand harvest is used, therefore, harvest mechanization is required for labor saving in harvesting peppers (Choi, 2006).

Several companies from China, Israel and USA have been developing self-propelled pepper harvesters which include picking heads, separating parts, conveying parts, and collecting parts to reduce labor and costs. The separating parts of the pepper harvester conveys fruits from the picking heads to the collecting parts while discharging foreign materials such as branches and leaves out of the machine. Optimal design of the separating parts is important because it's a big problem for the pepper harvester that peppers are harvested along with branches and leaves. Without adequate separation process of foreign materials, peppers are deteriorated during the storage and transportation, which affects the sale price (Kong *et al.*, 2013). Thus, many studies on the separation process of foreign materials have been conducted. Marshall (1984) evaluated a trash removal system for various pepper cultivars. The performance of the trash removal system was differed depending on the shape and size of the fruits. Cherry pepper showed the separation ratio of more than 90% and damage ratio of less than 4.1%. However, large stems and branches were observed after passing through the separation system, therefore, additional process that picking up the remaining foreign materials beside the conveyor was required. Eaton and Wilson (2005) analyzed the separation ratio of the peppers cultivated in New Mexico, USA using a card cleaner type separation system. They found that the separation ratio of peppers was differed depending on the moisture content of the pepper samples. The separation ratio of peppers immediately after harvest

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was 93.5%, but that of peppers far after the harvest season reduced by 70~75%. Kong *et al.* (2013) developed a separation device using a star wheel and airflow in China. Considering the average lengths of pepper and branch, spacing of the star wheel was designed to be 180~200 mm, and the distance between the axes was designed to be 180~200 mm. And an air blower was designed by measuring terminal velocity of peppers and leaves in the device.

Herbon *et al.* (2006) developed a sorting system using weight difference between pepper and foreign material in the fast-moving belt with velocity difference. The results showed 83.45% of the separation ratio, but further studies on field test are still needed. Wolf and Alper (1984) developed a machine harvesting system for paprika. The separation device discharged small plant particles such as seeds, leaves, and twigs while transporting fruits. The device consisted of three star wheels rotating in a single direction and a square rubber plate, and it showed 42% of the separation ratio. They predicted that eight star wheels would improve the performance of the device. Hong *et al.* (2006) conducted a study with peppers mixed with foreign materials such as leaves and stems in a separating device having a fan, a belt conveyor for discharging peppers, and a foreign material discharge cylinder. Leaves were discharged at wind speeds of 12 to 15 m/s, and the separation ratio was 95%. Choi (2006) analyzed the performance of a mechanical harvesting system using pepper cultivar of Wangdaebak, Saengryek No. 211, and Saengryek No. 213. The experimental device consisted of an air blower, an oscillating sieve separator, and a conveyor was manufactured by improving a separation device of a head-feed combine. After examining the terminal air speed, oscillating frequency, and oscillating amplitude of the devices, optimum operation that produced the divided fruit ratio of 68.2% was observed at a terminal air speed of 6.2 m/s, an oscillating frequency of 6.9 Hz, an oscillating amplitude of 40 mm, and the diameter and spacing of cleaning fingers of 6 mm and 29 mm, respectively.

Card cleaner type separation system for pepper harvesters have been widely used because of several advantages such as simple structure, easy manufacturing, and good separation performance. There is, however, not much experimental researches for them, especially for important factors affecting separation performance.

In this study, the factorial experiment was conducted to analyze the separation performance of a card cleaner type separating system of pepper harvesters. The factors used for this study were the card arrangement, slope angle, and rotational speed of the card cleaner. These parameters are important in the card cleaner type separating system, but experimental studies for their effects have not been performed. Optimum working conditions were determined through the experiment, and suggestions to improve the separation performance were presented by analyzing the separation performance for each factor.

MATERIALS AND METHODS

Experimental Device

Fig. 1 shows the shape of the experimental bench used in this study, and Fig. 2 depicts the specification of the device. Driving part had a 0.4-kW variable speed (VS) motor and an inverter to control the conveying speed of the card cleaner, and the bars in the fifteen axes were driven by a chain and sprocket. Spacers were inserted between the cards to separate the foreign materials such as twigs and leaves from the fruits on the

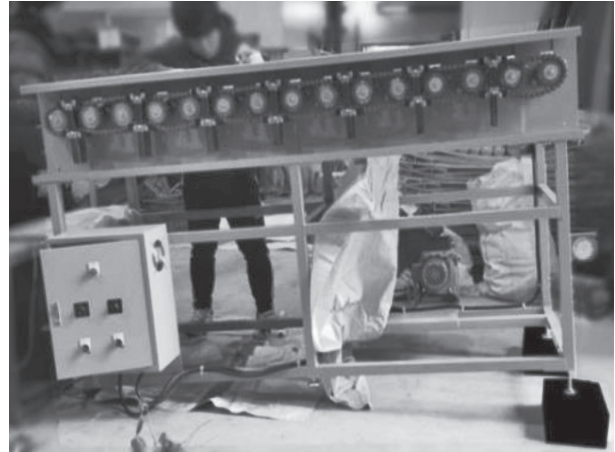


Fig. 1. Experimental bench for the separating part.

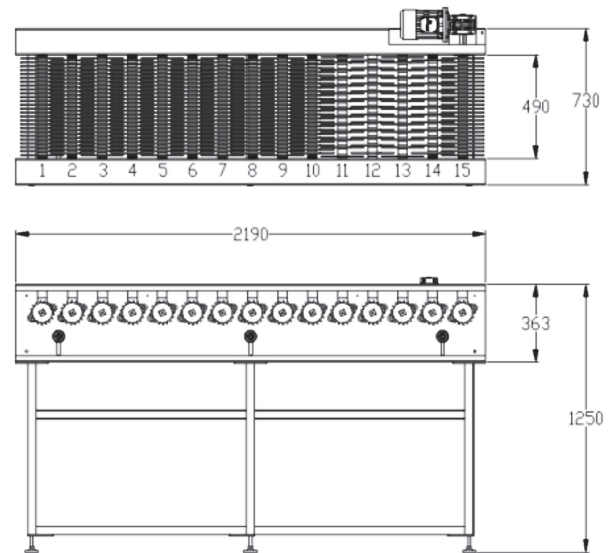


Fig. 2. Specification of the experimental device for the separating part.

Table 1. Specifications of the card

| Parameters | Value |
|------------------------------|-------|
| Length of card (mm) | 150 |
| Width of card (mm) | 150 |
| Thickness of card (mm) | 4.8 |
| Distance between cards (mm) | 13.2 |
| Distance between shafts (mm) | 140 |

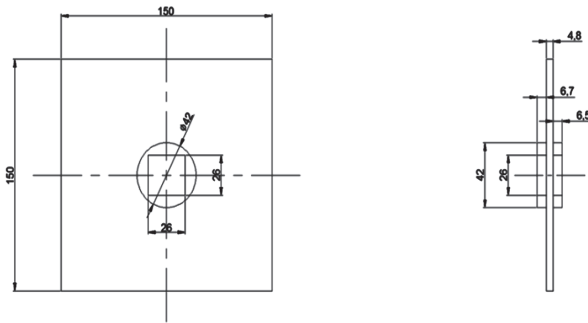


Fig. 3. Shape of the card used in this study.

11~14th axes, the final stage of the separation part. The slope angle of the card cleaner was adjusted by the pedestal placed under the card cleaner.

25~26 plastic cards were installed on each axis of the card cleaner. Fig. 3 and Table 1 show the shape and specification of the card cleaner.

Physical Properties of Sample Peppers

The cultivar of the test sample was 'Nokhwang', and it was grown in a plastic greenhouse at Gwangju, Republic of Korea. The sample was transplanted on July 15, 2015 and harvested on March 7, 2016.

Physical properties of the pepper plants and fruits were measured. The properties of 10 randomly selected pepper plants and 30 fruits from the 10 pepper plants were investigated. Fig. 4 shows the measuring positions in the pepper plants and fruits, and Table 2 presents the

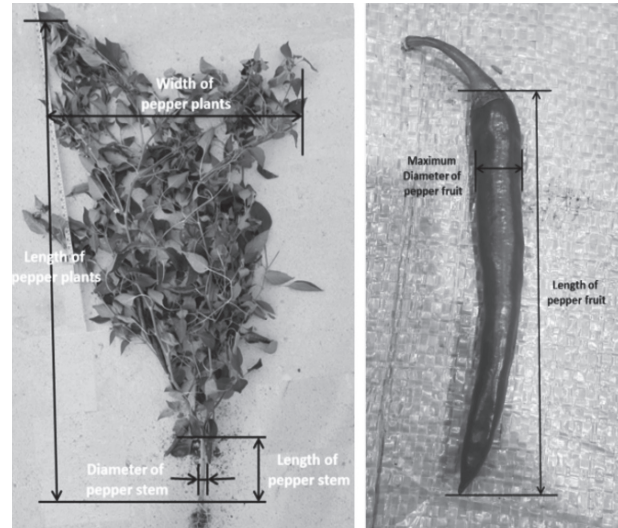


Fig. 4. Measuring positions for the physical properties of the sample peppers.

physical properties of them. The moisture content of branch, leaf, and fruit were measured by oven-dry method (70°C for 24 hours). The fruit was cut less than 3 mm without stem for the moisture content measurement. Table 3 presents the moisture contents of the peppers used in the study.

Condition of Sample Peppers

The amounts of sample peppers were determined based on the separation work with five pepper plants. Only the peppers passing through the picking head were

Table 2. Physical properties of the sample peppers

| Parameters | | Average value | Standard deviation |
|------------|------------------------------|---------------|--------------------|
| Plant | Length of pepper plant (mm) | 1618 | 97.24 |
| | Width of pepper plant (mm) | 830 | 60.17 |
| | Length of pepper stem (mm) | 209.5 | 32.05 |
| | Diameter of pepper stem (mm) | 15.8 | 3.16 |
| Fruit | Length (mm) | 124.77 | 13.68 |
| | Max. diameter (mm) | 14.67 | 1.89 |
| | Weight (kg) | 13.34 | 3.22 |
| | Amount (ea/plant) | 85.6 | 8.18 |

Table 3. Moisture contents of the sample peppers

| Part | Weight before oven drying (g) | Weight after oven drying (g) | Moisture contents (%) |
|--------|-------------------------------|------------------------------|-----------------------|
| Fruit | 134.51 | 14.84 | 88.97 |
| Branch | 50.00 | 10.52 | 78.96 |
| Leaf | 50.00 | 10.85 | 78.30 |

Table 4. Weight and length of sample peppers

| Pepper weight (g) | Branch weight (g) | Branch length (mm) |
|-------------------|-------------------|--------------------|
| 2100 | 400 | 200 |



(a) Pepper



(b) Branch



(c) Mixture of pepper and branch

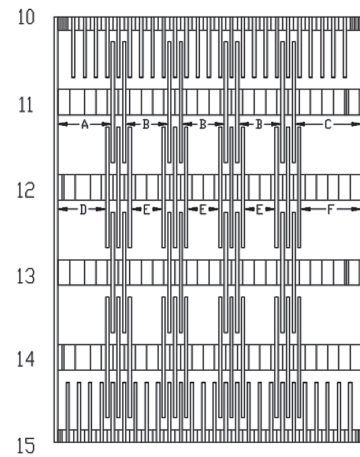
Fig. 5. Samples for the experiment.

used in this study, and 200 mm-length branches were used considering the length range observed in the field measurement (150~250 mm). Leaf-removed plants were prepared to make similar conditions that Ethephon and salt treatment before machine harvesting (Fig. 5 and Table 4).

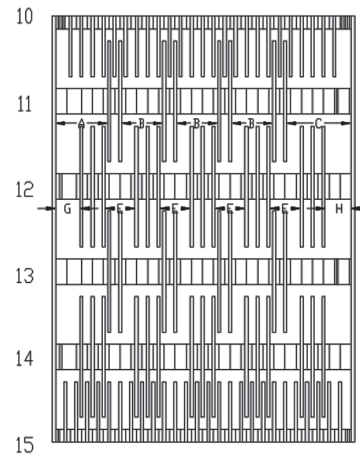
Parameters

The separation performance was examined with two types of card arrangement, inline arrangement that used in the USA and staggered arrangement that tried first in this study. Fig. 6 shows each type of card arrangement, and Table 5 presents the distance between the cards in each arrangement.

The experiments were conducted by changing the



(a) Inline arrangement



(b) Staggered arrangement

Fig. 6. Distance between the cards in each arrangement.

rotational speed of driving axis and slope angle to investigate the factors that influence the separation performance for each card arrangement. Table 6 presents kind of factors and their magnitude that examined in this study.

Working time of 11.25 sec was used following the results of picking head tests under the conditions of working distance of 2.25 m (five pepper plants) and working speed of 0.2 m/s. The tests were repeated three times, and the separation efficiency of peppers and mixing ratio of foreign materials were analyzed with the sample at the collecting box after each test was finished. Fig. 7 presents the position of the collecting box in the experimental bench.

Table 5. Distance between the cards in each arrangement

| A (mm) | B (mm) | C (mm) | D (mm) | E (mm) | F (mm) | G (mm) | H (mm) |
|--------|--------|--------|--------|--------|--------|--------|--------|
| 88.4 | 67.2 | 108.2 | 79.4 | 49.2 | 99.4 | 43.4 | 45.2 |

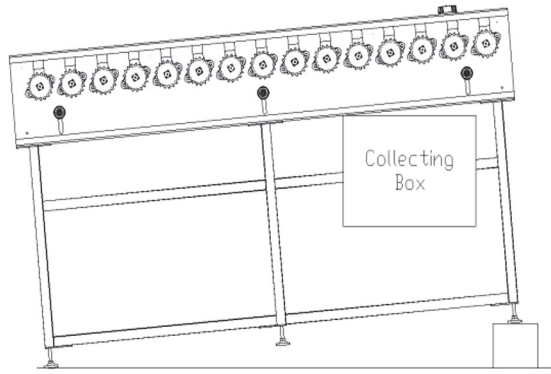


Fig. 7. Position of the collecting box.

Table 6. Experimental factors in this study

| Factors | Values |
|------------------------|-------------------|
| Rotational speed (rpm) | 35, 50, 65 |
| Slope angle (degree) | 5, 15 |
| Card arrangement | Inline, Staggered |

Analysis Method

The separation efficiency of peppers and mixing ratio of foreign materials were examined by measuring the weights of the fruits and foreign materials collected at the collecting box. The separation efficiency of peppers means the ratio of fruits collected at the collecting box to the total amount of peppers supplied to the separation part as represented in equation (1).

$$D_{sep} = \frac{P_{cp}}{P_{tp}} \times 100 \quad (1)$$

where, D_{sep} is the separation efficiency of peppers (%), P_{tp} is the total amount of fruits supplied to the separation part (g), P_{cp} is the amount of peppers supplied to the separation part (g).

The mixing ratio of foreign materials means the ratio of foreign materials collected at the collecting box to the total amount of foreign materials supplied to the separation part as represented in equation (2).

$$D_{mrf} = \frac{P_{cf}}{P_{tf}} \times 100 \quad (2)$$

where, D_{mrf} is the mixing ratio of the foreign materials (%), P_{tf} is the total amount of foreign materials supplied to the separation part (g), P_{cf} is the amount of foreign materials collected at the collecting box (g).

RESULTS AND DISCUSSION

Table 7 provides the results of the experiments conducted by changing slope angle of the card cleaner and rotational speed of driving axis with two types of card arrangement.

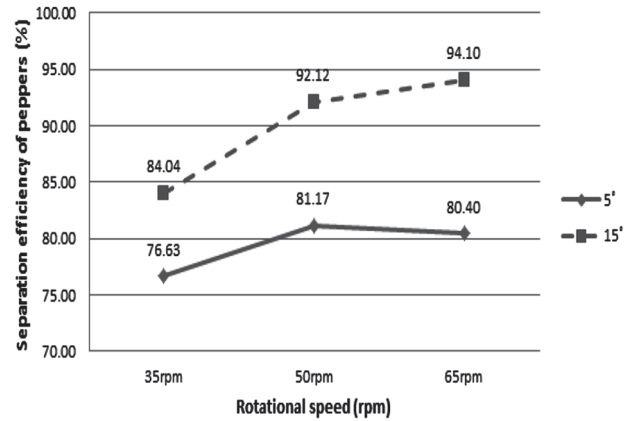


Fig. 8. Results of the separation efficiency of peppers in the inline arrangement.

Separation Efficiency of Peppers in the Inline Arrangement

Fig. 8 shows the tendency of separation efficiency according to the slope angle and rotational speed of the card cleaner in the inline arrangement. In terms of rotational speed of the card cleaner, there was no significant difference between 50 rpm and 65 rpm in the separation efficiency, but there was significant difference between 35 rpm and 50 or 65 rpm. In terms of slope angle of the card cleaner, 15° showed higher separation efficiency than 5° by 7.4~13.7% in the different rotational speed condition.

According to the results shown in Table 8 (SAS, 1990), the slope angle and rotational speed of the card cleaner influenced the separation efficiency of peppers at a 95% confidence level. In addition, interactions between slope angle and rotational speed also influenced the separation efficiency of peppers.

Mixing Ratio of Foreign Materials in the Inline Arrangement

Fig. 9 presents the results of the mixing ratio of foreign materials according to the slope angle and rotational speed of the card cleaner in the inline arrangement. In terms of rotational speed of the card cleaner, the mix-

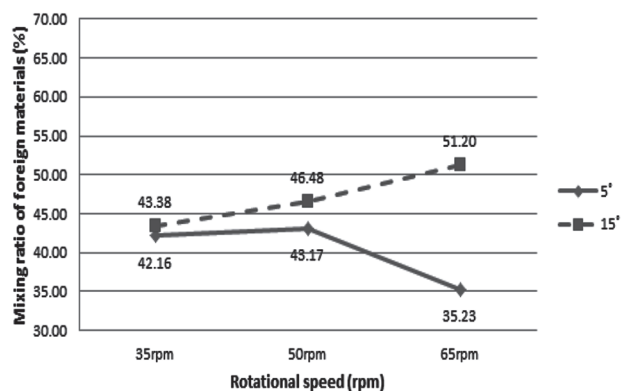


Fig. 9. Results of the mixing ratio of foreign materials in the inline arrangement.

Table 7. Experimental results

| Card arrangement | Slope angle (degree) | Rotational speed (rpm) | Separation efficiency of pepper (%) | Average separation efficiency (%) | Mixing ratio of foreign materials (%) | Average mixing ratio (%) |
|-----------------------|----------------------|------------------------|-------------------------------------|-----------------------------------|---------------------------------------|--------------------------|
| Inline arrangement | 5 | 35 | 76.80 | 76.63 | 42.18 | 42.16 |
| | | | 75.60 | | 39.20 | |
| | | | 77.50 | | 45.10 | |
| | | 50 | 80.00 | 81.17 | 40.50 | 43.17 |
| | | | 81.70 | | 45.40 | |
| | | | 81.80 | | 43.60 | |
| | | 65 | 78.90 | 80.40 | 36.43 | 35.23 |
| | | | 81.30 | | 34.00 | |
| | | | 81.00 | | 35.25 | |
| | 15 | 35 | 85.30 | 84.04 | 43.03 | 43.38 |
| | | | 84.48 | | 43.60 | |
| | | | 81.84 | | 43.50 | |
| | | 50 | 94.41 | 92.12 | 46.58 | 46.48 |
| | | | 89.49 | | 43.35 | |
| | | | 92.45 | | 49.53 | |
| | | 65 | 93.90 | 94.10 | 54.10 | 51.20 |
| | | | 94.30 | | 51.75 | |
| | | | 94.09 | | 47.75 | |
| Staggered arrangement | 5 | 35 | 79.56 | 79.58 | 43.48 | 44.24 |
| | | | 80.16 | | 43.08 | |
| | | | 79.01 | | 46.18 | |
| | | 50 | 89.71 | 90.61 | 57.13 | 53.88 |
| | | | 90.48 | | 51.53 | |
| | | | 91.66 | | 52.98 | |
| | | 65 | 89.71 | 89.32 | 43.93 | 45.19 |
| | | | 88.53 | | 43.58 | |
| | | | 89.72 | | 48.08 | |
| | 15 | 35 | 86.94 | 87.76 | 43.18 | 52.58 |
| | | | 85.72 | | 50.58 | |
| | | | 90.61 | | 63.98 | |
| | | 50 | 95.26 | 95.23 | 61.05 | 59.69 |
| | | | 94.73 | | 63.13 | |
| | | | 95.70 | | 54.90 | |
| | | 65 | 98.63 | 97.15 | 55.85 | 59.25 |
| | | | 96.64 | | 61.00 | |
| | | | 96.19 | | 60.90 | |

Table 8. Statistical results of the separation efficiency of peppers in the inline arrangement

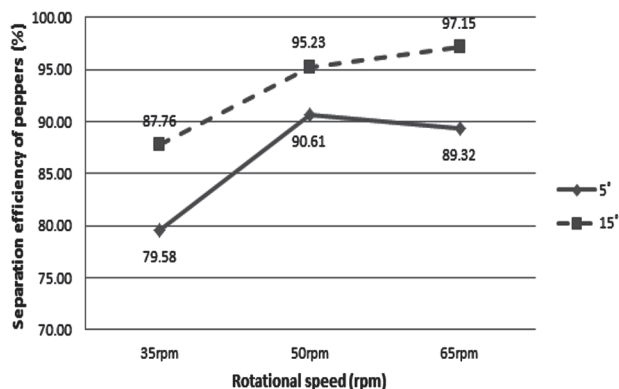
| Source | DF | Anova SS | Mean Square | F Value | Pr >F |
|------------------|----|----------|-------------|---------|--------|
| Slope angle | 1 | 513.7 | 513.7 | 221.8 | <.0001 |
| Rotational speed | 2 | 175.8 | 87.9 | 37.9 | <.0001 |
| Angle*Speed | 2 | 29.8 | 14.9 | 6.4 | 0.0126 |
| Error | 12 | 27.8 | 2.3 | | |
| Total | 17 | 747.1 | | | |

Table 9. Statistical results of the mixing ratio of foreign materials in the inline arrangement

| Source | DF | Anova SS | Mean Square | F Value | Pr >F |
|------------------|----|----------|-------------|---------|--------|
| Slope angle | 1 | 210.3 | 210.3 | 34.8 | <.0001 |
| Rotational speed | 2 | 14.1 | 7.0 | 1.2 | 0.3451 |
| Angle*Speed | 2 | 191.1 | 95.6 | 15.8 | 0.0004 |
| Error | 12 | 72.6 | 6.0 | | |
| Total | 17 | 488.1 | | | |

ing ratio of the foreign materials was lowest at a rotational speed of 65 rpm when the slope angle was 5° and, and it increased with increasing rotational speed when the slope angle was 15°. The low mixing ratio of foreign materials at 5° and 65 rpm was caused by the rapid rotation of the card cleaner, which discharged longer foreign materials than fruits not collecting them at the collecting box. In terms of slope angle of the card cleaner, a slope of 5° showed lower mixing ratio of foreign materials by 1.2~16% than a slope of 15° in the different rotational speed condition.

According to the results shown in Table 9 (SAS, 1990), the slope angle of the card cleaner influenced the mixing ratio of foreign materials at a 95% confidence level. However, the rotational speed of the card cleaner did not influence the mixing ratio of foreign materials because no significant difference was observed between rotational speed and mixing ratio of foreign materials. In addition, interactions between slope angle and rotational speed influenced the mixing ratio of foreign materials.

**Fig. 10.** Results of the separation efficiency of peppers in the staggered arrangement.

Results Summary for the Inline Arrangement

In the inline arrangement, the separation efficiency of peppers was influenced by both slope angle and rotational speed of the card cleaner, but mixing ratio of foreign materials was influenced by only the slope angle of the card cleaner. The separation efficiency of peppers was highest at 15° and 65 rpm, and the mixing ratio of foreign materials was higher at 15° than 5°. When the slope angle was increased, fruits and foreign materials stayed longer on the card cleaner which resulted in increasing the amount of fruits and foreign materials collected at the collecting box. In addition, there was no significant difference in the separation performance at the rate of over 50 rpm.

Separation Efficiency of Peppers in the Staggered Arrangement

Fig. 10 shows the results of the separation efficiency of peppers according to the slope angle and rotational speed of the card cleaner in the staggered arrangement.

In terms of rotational speed of the card cleaner, there was no significant difference between 50 rpm and 65 rpm in the separation efficiency, but there was significant difference between 35 rpm and 50 or 65 rpm. In terms of slope angle of the card cleaner, 15° showed higher separation efficiency than 5° by 4.6~8.2% in the different rotational speed condition.

According to the results shown in Table 10 (SAS, 1990), the slope angle and rotational speed of the card cleaner influenced the separation efficiency of peppers at a 95% confidence level. In addition, interactions between slope angle and rotational speed did not influence the separation efficiency of peppers.

Mixing Ratio of Foreign Materials in the Staggered Arrangement

Fig. 11 presents the results of the mixing ratio of foreign materials according to the slope angle and rota-

Table 10. Statistical results of the separation efficiency of peppers in the staggered arrangement

| Source | DF | Anova SS | Mean Square | F Value | Pr >F |
|------------------|----|----------|-------------|---------|--------|
| Slope angle | 1 | 212.7 | 212.7 | 125.6 | <.0001 |
| Rotational speed | 2 | 354.7 | 177.4 | 104.7 | <.0001 |
| Angle*Speed | 2 | 11.6 | 5.8 | 3.4 | 0.0665 |
| Error | 12 | 20.3 | 1.7 | | |
| Total | 17 | 599.4 | | | |

tional speed of the card cleaner in the staggered arrangement. In terms of rotational speed of the card cleaner, the mixing ratio of the foreign materials was lowest at the rotational speed of 35 rpm when the slope angles were 5°. In terms of slope angle of the card cleaner, a slope of 5° showed lower mixing ratio of foreign materials by 5.8–14.1% than a slope of 15° in the different rotational speed condition.

According to the results shown in Table 11 (SAS, 1990), the slope angle and rotational speed of the card cleaner influenced the mixing ratio of foreign materials at a 95% confidence level. In addition, interactions between slope angle and rotational speed did not influence the mixing ratio of foreign materials.

Results Summary for the Staggered Arrangement

In the staggered arrangement, the separation efficiency of peppers and mixing ratio of foreign materials were influenced by both slope angle and rotational speed of the card cleaner. The separation efficiency of peppers was highest at 15° and 65 rpm, and the mixing ratio of foreign materials was lower at 5° than 15°.

When the slope angle was increased, fruits and foreign materials stayed longer on the card cleaner which resulted in increasing the amount of fruits and foreign materials collected at the collecting box. In addition, there was no significant difference in the separation performance at the rate of over 50 rpm.

CONCLUSIONS

This study conducted experiment for a card cleaner type separation device to analyze the separation perfor-

mance according to the influence factors such as card arrangement, slope angle, and rotational speed of the card cleaner.

When the slope angle was increased, the separation efficiency and mixing ratio of foreign materials also increased in the two types of card arrangement, i.e. inline arrangement and staggered arrangement. The separation performance is optimized when separation efficiency is increased and mixing ratio of foreign materials is minimized. In the slope angle of 5°, the highest separation efficiency was obtained in the staggered arrangement at rotational speed of 50 rpm (separation efficiency of 90.61%). However, in this condition, the mixing ratio of foreign materials was high as 53.88%, which requires additional separation processes. In the slope angle of 15°, the high separation efficiency was obtained inline arrangement at rotational speed of 50 rpm (separation efficiency of 92.12%). The mixing ratio of foreign materials was relatively low (46.48%) in this condition. Thus, the results of this study suggested that self-propelled pepper harvesters should be designed to have the inline arrangement card cleaner with a slope angle of 15°.

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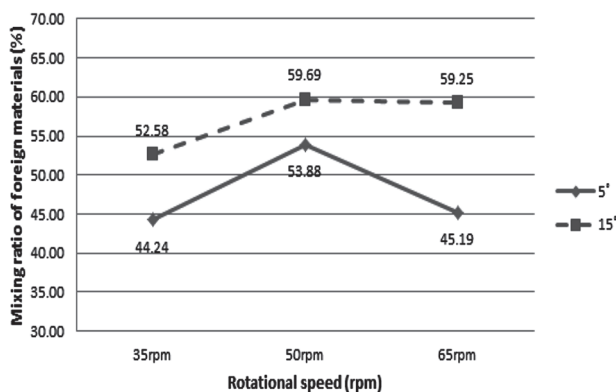


Fig. 11. Results of the mixing ratio of foreign materials in the staggered arrangement.

Table 11. Statistical results of the mixing ratio of foreign materials in the staggered arrangement

| Source | DF | Anova SS | Mean Square | F Value | Pr >F |
|------------------|----|----------|-------------|---------|--------|
| Slope angle | 1 | 397.6 | 397.6 | 15.3 | 0.0021 |
| Rotational speed | 2 | 210.9 | 105.5 | 4.1 | 0.0449 |
| Angle*Speed | 2 | 53.5 | 26.7 | 1.0 | 0.3864 |
| Error | 12 | 311.4 | 25.9 | | |
| Total | 17 | 973.4 | | | |

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