Factorial Experiment for Drum-type Secondary Separating Part of Self-propelled Pepper Harvester

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Abstract

Purpose: This study was conducted to determine the appropriate operating conditions through a factorial experiment for the secondary separating part of the self-propelled pepper harvester. **Methods:** An experimental setup that simulates the secondary separating part of the self-propelled pepper harvester was organized. Test samples were classified into three types according to the number of peppers on a stem, and 12 sets were prepared for each type. Among the operating conditions of the secondary separating part, the rotational speed of drum B (four levels), radial clearance between drums and cylindrical teeth (three levels), and speed ratio between the three drums (two levels) were set as the test factors, and tests were repeated three times for different levels of each factor. The appropriate operating conditions were determined by analyzing the separation ratio and damage ratio of the peppers collected through the secondary separating part. **Results:** The test factors changed the overall separation ratio and overall damage ratio in similar trends. In other words, the conditions that caused high overall separation ratios also exhibited high overall damage ratios. Owing to the high overall damage ratio in the condition with the highest overall separation ratio, the operating conditions should be selected considering both ratios. **Conclusions:** When the condition with more than 60% of overall separation ratio and less than 15% of overall damage ratio was considered as the appropriate operating condition, 70 rpm of the rotational speed of drum B, 5 mm of the radial clearance between drums and cylindrical teeth, and 7:3:5 for the speed ratio of the three drums A, B, and C should be applied for the secondary separating part used in this study. Supplementary studies will be required in the future to find optimal operating conditions through the actual field test under further divided test factors.

Keywords: Drum-type, Factorial experiment, Pepper harvester, Self-propelled, Separating part

Introduction

Peppers are major condiment vegetables widely used in various foods and spices in South Korea. Pepper cultivation area (36,634 ha) accounts for 38% of the total condiment vegetable cultivation area (96,584 ha) (KOSTAT, 2016), which is the largest cultivation area among condiment vegetables.

The total labor time per hectare for outdoor pepper cultivation is 2,436 h in South Korea, and the harvesting work occupied the highest proportion with 39.2% (954 h) (Choi et al., 2010). Therefore, to reduce labor and production costs required for pepper cultivation, labor-saving in harvesting work is most effective, and various studies have been conducted for this purpose. Lee et al. (1993) introduced a pepper separation device with two spiral cylinders in their fundamental study on the development of a pepper harvester. As pepper stems passed between the rotating two spiral cylinders, the peppers, stems, and leaves were separated owing to the friction with the spiral part. A factorial experiment was

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performed using the rotational speed of the spiral cylinders and the conveying speed of the pepper stems as parameters. The condition that led to the highest recovery ratio was found, and in this instance, approximately 10% of the separated peppers were with the stem. Lee et al. (1995) suggested a cost analysis model for pepper harvesting work to determine the economic efficiency of a pepper harvester, based on the surveys on the farmers of major pepper cultivation areas. They reported that increasing the pepper recovery ratio is the most important factor from an economic aspect, and the use of a pepper harvester was profitable only when the cultivation area exceeded a certain level. Lee et al. (1997) conducted a factorial experiment to reduce the size of the spiral-cylinder-type separating part of the pepper harvester introduced in their previous study (Lee et al., 1993). The diameters, inclination angles, and rotational speeds of the spiral cylinders were set as factors, and the recovery ratio of more than 80% could be obtained under certain conditions with a reduced size of the spiral cylinders. Choi et al. (2008) investigated the physical properties of peppers as a precedent study on the development of a mechanical pepper harvesting system. The investigation items included the fruit size, degree of maturity, water content of each part, fruit detachment force, fruit and stalk separation force, and tensile strength of the pepper stem. Park et al. (2015 and 2016) developed a self-propelled pepper harvester, and analyzed the recovery ratios of it through field tests. The developed pepper harvester was a single-row harvester with 46.2 kW of rated power and a spiral-cylinder-type separating part.

By using the developed pepper harvesters (Park et al., 2015; Park et al., 2016), the separation and collection of peppers can be performed as an integrated task, but as mentioned in the study of Lee et al. (1993), stemmed peppers might be released from the separating part. Therefore, to improve the recovery ratio of peppers, a secondary separating part is required to separate the stems from the stemmed peppers. In this study, a factorial experiment was conducted for the rotating-drum-type secondary separating part developed for that purpose. The influence of various factors was analyzed, and an appropriate operating condition was determined.

Materials and Methods

Self-propelled pepper harvester

The self-propelled pepper harvester applied in this study is shown in Figure 1. Its main components are the primary separating part, secondary separating part, conveying part, collecting part, and driving part. The functions of each part are described in the following section.

① Primary separating part: It is the first part to make contact with the pepper plants, and it separates peppers from the stems. It consists of two adjacent spiral cylinders as shown in Figure 2 (Park et al., 2015; Park et al., 2016). When pepper plants pass through the primary separating part, they are separated into peppers, leaves, and stems, which are then passed into conveying part 1.

② Conveying part 1: It conveys the peppers, leaves, and stems separated in the primary separating part to the secondary separating part.
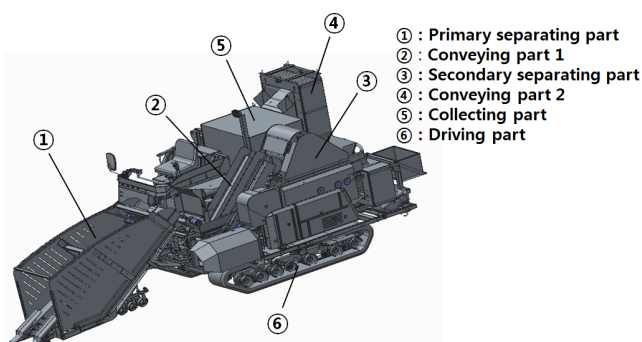
③ Secondary separating part: It separates the peppers

① : Primary separating part
② : Conveying part 1
③ : Secondary separating part
④ : Conveying part 2
⑤ : Collecting part
⑥ : Driving part

Figure 1. Schematic view of the developed self-propelled pepper harvester.
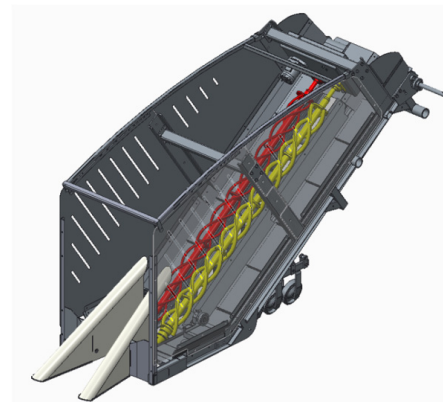

Figure 2. Schematic view of the primary separating part.

and stems that were not separated in the primary separating part.

④ Conveying part 2: It conveys the peppers separated through the secondary separating part to the collecting part. A blower is placed between the secondary separating part and conveying part 2 so that wind can remove the leaves.

⑤ Collecting part: It is the place where peppers are finally collected. All foreign materials other than peppers are removed before they reach the collecting part, and only peppers are collected in the collecting part.

⑥ Driving part: It allows the self-propelled pepper harvester to move back and forth through the track system.

Peppers in pepper plants are separated and collected by passing through the primary separating part, conveying part 1, secondary separating part, conveying part 2, and collecting part of the self-propelled pepper harvester in sequence.

Details of secondary separating part

Figure 3 shows the secondary separating part of the self-propelled pepper harvester. It consists of three rotating drums with several cylindrical teeth in the radial direction. While stemmed peppers pass through the rotating drums, the stems and peppers are separated owing to friction with the cylindrical teeth.

Figure 4 shows the detailed dimensions of the rotating drums and cylindrical teeth. Rotating drum A is located at the top among the three rotating drums when viewed from the front of the self-propelled pepper harvester, and drums B and C are located at the bottom left and right,
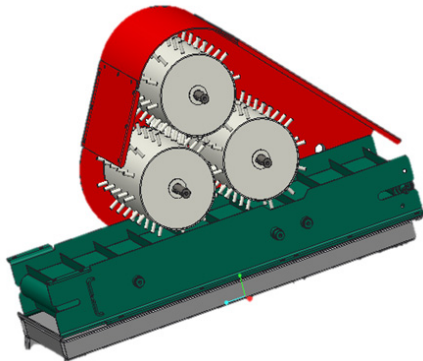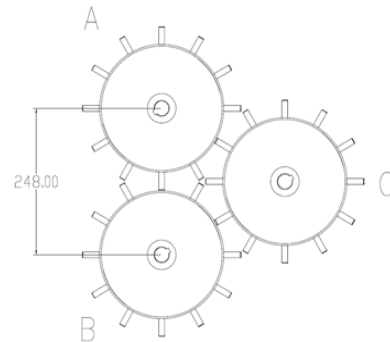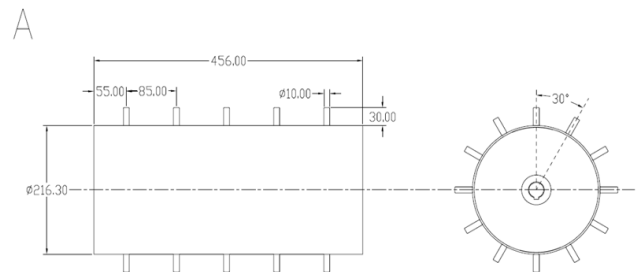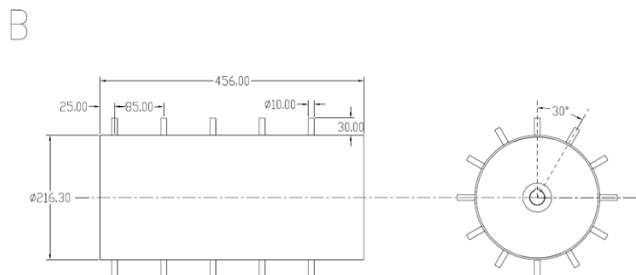
respectively. The center distances between adjacent rotating drums are 248 mm, the angle between each cylindrical tooth with respect to the center of the rotating drum is 30°, and the number of cylindrical teeth per rotating drum is 60.
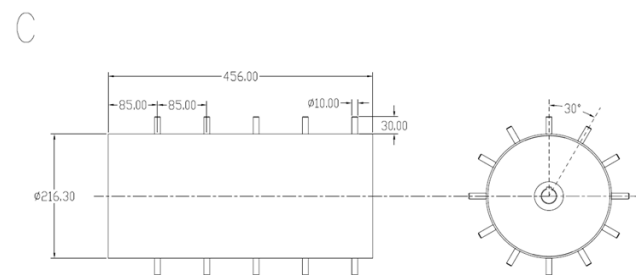

(a) center distance

(b) dimensions of drum A

(c) dimensions of drum B

(d) dimensions of drum C

Figure 4. Shape and dimensions of rotating drum and cylindrical teeth.

Figure 3. Schematic view of the secondary separating part.

Experimental setup

An experimental setup simulating the secondary separating part was prepared. The concept and actual shape of the experimental setup are shown in Figures 5 and 6, respectively. A motor was used as a power source, and chains and sprockets were used as power transmission devices. The rotational speed of the motor was controlled by an inverter. The power of the motor was transmitted to the other rotating drums and conveyor through the rotating drum B, which is directly connected with the motor. The rotational directions of the rotating drums were the same as in the actual self-propelled pepper harvester: The rotating drums A and B rotated in a counterclockwise direction, while the rotating drum C rotated in a clockwise direction (Fig. 7). Stemmed peppers were moved into the rotating drums through a c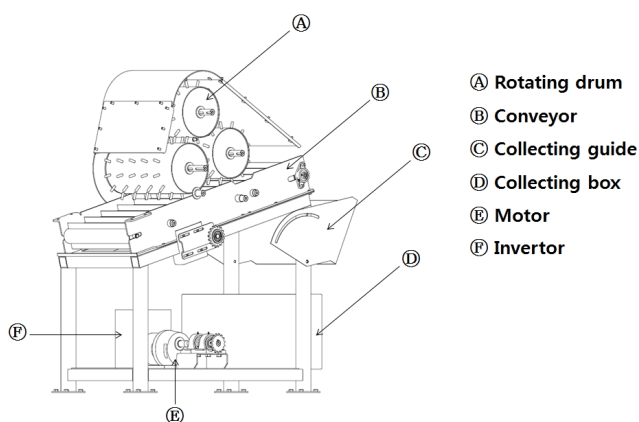onveyor, and the conveying speed was adjusted by a chain-sprocket device. The peppers separated from the stemmed peppers by the rotating drums were collected in the collecting box via the collecting guide.

Experimental samples

The variety of the peppers used in the experiment was "Cheonsang." Samples that were planted on July 15, 2016 and harvested on February 20, 2017 were used. The average dimensions of the randomly selected sample of 30 peppers were the following: maximum diameter of 14.7 mm, length of 124.8 mm, and weight of 14.8 g (Fig. 8).

In actual pepper harvesters, various types of stemmed peppers flow into the secondary separating part. In this study, stemmed peppers were classified into three types according to the number of peppers on a stem: a stem with a pepper (type 1), stem with two peppers (type 2), and stem with three peppers (type 3) (Fig. 9).
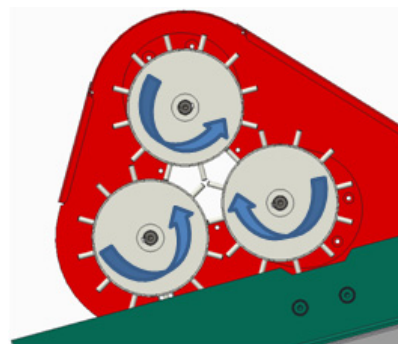

Ⓐ Rotating drum
Ⓑ Conveyor
Ⓒ Collecting guide
Ⓓ Collecting box
Ⓔ Motor
Ⓕ Invertor

Figure 5. Schematic view of test equipment.

Figure 7. Rotating direction of the drums.

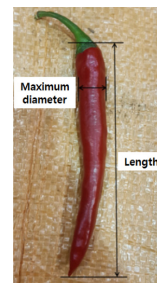
Figure 6. Image of test equipment.

Figure 8. Pepper plants used in this study.

Figure 9. Types of experimental sample peppers.

Figure 10. Marking to identify the type of pepper.

Twelve randomly selected sets of test samples were prepared for each pepper type. As one set contains one, two, and three peppers for each type, the number of sample peppers was 12 for type 1, 24 for type 2, and 36 for type 3. In the experiment, test samples of type 1, type 2, and type 3 were put into the conveyor together, considering the actual working conditions. To distinguish which type of peppers were collected in the collecting box, different markings were applied to each pepper type (Fig. 10).

Experimental conditions

The translational speed of the conveyor in the experiment was fixed at 0.2 m/s considering the actual operating speed of the self-propelled pepper harvester. The rotational speed of drum B, radial clearance between drums and cylindrical teeth (Fig. 11), and speed ratio among the three drums were selected as test factors. Below are the detailed experimental values for each factor.

A. Rotational speed of drum B: 40, 70, 100, and 130 rpm (four levels)

Figure 11. Radial clearance between rotating drum and cylindrical teeth.

B. Radial clearance between drums and cylindrical teeth: 2, 5, and 10 mm (three levels)

C. Speed ratio of the three drums (drums A, B, and C): 7:3:5 and 5:3:7 (two levels)

Tests were repeated three times for each test condition. The separation ratio and damage ratio of the peppers collected in the collecting box were analyzed using their average values of three repetitions. The separation ratio refers to the ratio of the number of separated peppers to the number of input peppers as shown in equation (1), and the damage ratio indicates the ratio of the number of damaged peppers to the number of input peppers as shown in equation (2). Only the separation of peppers from stems were considered, regardless of damage to peppers, for the calculation of the separation ratio, while only the damage to peppers was considered, regardless of the separation of peppers from stems, for the calculation of the damage ratio.

The condition that had the higher separation ratio and lower damage ratio was considered to be the optimal operating condition.

$$SR = \frac{N_S}{N_t} \times 100 \qquad (1)$$

where, SR = Separation ratio of sample peppers (%)

N_t = Number of input peppers

N_s = Number of collected peppers that are separated from stems

$$DR = \frac{N_d}{N_t} \times 100 \qquad (2)$$

Where, DR = Damage ratio of sample peppers (%)
N_d = Number of damaged peppers in the collecting box

Results and Discussion

Influence of the drum speed ratio

Under the condition that the rotational speed of drum B was 70 rpm and the radial clearance between drums and cylindrical teeth was 5 mm, the separation ratio and the damage ratio according to the drum speed ratio were investigated.

Figure 12 shows the separation ratio for each sample type. When the rotational speed ratio of drums A, B, and C was 7:3:5, the separation ratio of type 1 was the lowest at 19.44% and that of type 3 was the highest at 78.7%. When the rotational speed ratio was 5:3:7, the separation ratio of type 1 was also the lowest at 8.33%, but those of type 2 and type 3 were identical at 61.11%. For all the sample types, the separation ratios were higher by 2.78–17.59% when the rotational speed ratio was 7:3:5. Therefore, the speed ratio of 7:3:5 is more appropriate from the aspect of the separation ratio.

Figure 13 shows the damage ratio for each sample type. When the rotational speed ratio of drums A, B, and C was 7:3:5, the damage ratios of type 1 and type 3 were the same at 13.89% and that of type 2 was the lowest at 11.11%. The differences in the damage ratios were less than 3%. When the rotational speed ratio was 5:3:7, the damage ratio of type 2 was the highest at 15.28%, and those of type 1 and type 3 were 5.56% and 8.33%, respectively. The differences in the damage ratios were

relatively higher. The damage ratios were higher by 8.33% and 5.56% for type 1 and 3 samples, respectively, while that of the type 2 sample was lower by 4.17%, when the rotational speed ratio was 7:3:5.

The separation ratio and damage ratio differed depending on the sample pepper type. Type 1 and 3 samples appeared to be more sensitive than type 2 sample to the rotational speed ratio, because they showed larger differences in the separation ratio and damage ratio depending on the rotational speed ratio.

Figure 14 shows the overall separation ratio and overall damage ratio considering all the sample peppers of the three types. When the rotational speed ratio of drums A, B, and C was 7:3:5, the overall separation ratio and overall damage ratio were 63.99% and 12.96%, which were higher than 52.31% and 10.19% at the rotational speed ratio of 5:3:7. While the overall separation ratio was higher by more than 10%, the overall damage ratio showed a difference of about 2.8%.
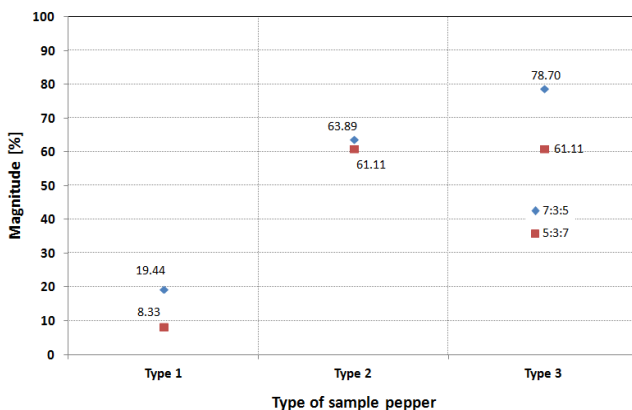

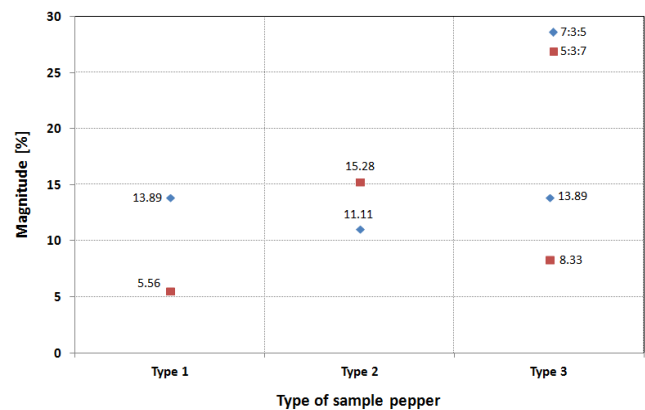**Figure 13.** Damage ratio of each type of pepper sample according to drum speed ratio.

Figure 12. Separation ratio of each type of pepper sample according to drum speed ratio.
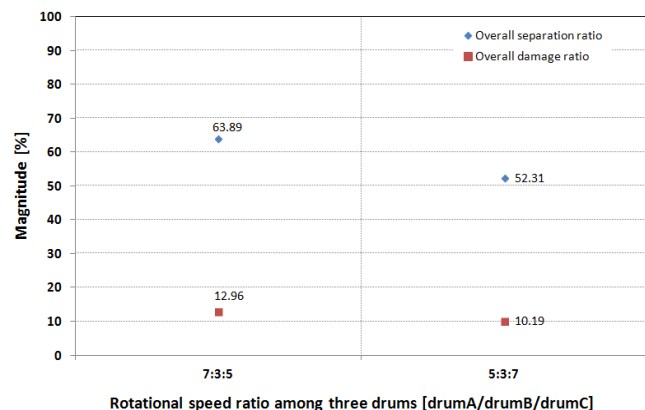

Figure 14. Overall separation ratio and damage ratio according to drum speed ratio.

Therefore, it can be concluded that the rotational speed ratio of 7:3:5 was a more effective working condition than that of 5:3:7.

Influence of the rotational speed of drum B

Under the condition that the radial clearance between drums and cylindrical teeth was 5 mm and the speed ratio of drums A, B, and C was 7:3:5, the separation ratio and the damage ratio according to the rotational speed of drum B were investigated.

Figure 15 shows the separation ratio for each sample type. The separation ratio tended to increase as the sample type changed from type 1 to type 2 and type 3. The maximum separation ratio was obtained in the type 3 sample when the rotational speed of drum B was 130 rpm, while the minimum separation ratio was found in the type 1 sample when the rotational speed of drum B was 40 rpm. The maximum and minimum ratios were 91.67% and 8.33%, respectively. A separation ratio of more than 60% was obtained in the type 3 sample with all the rotational speeds, and in the type 2 sample with 70 rpm and 130 rpm. The condition with a separation ratio of more than 60% was not found in the type 1 sample.

Figure 16 shows the damage ratio for each sample type. The damage ratios ranged between 2.78% and 22.22%. The maximum damage ratio occurred in the type 2 sample when the rotational speed of drum B was 130 rpm, while the minimum damage ratio appeared in the type 1 sample when the rotational speed of drum B was 40 rpm. According to the rotational speed, the damage ratio was highest when the rotational speed of drum B was 130 rpm. As for the sample types, there were no constant tendencies according to the sample type, and

the tendencies were different according to the rotational speed. The separation ratio and damage ratio were both highest for a rotational speed of 130 rpm, and the damage ratio of less than 15% was obtained for rotational speeds less than 130 rpm, for all sample types

Figure 17 shows the overall separation ratio and overall damage ratio considering all the sample peppers of the three types. It can be seen that the overall separation ratio and overall damage ratio showed similar tendencies according to the rotational speed. In other words, the overall damage ratio was high when the overall separation ratio was high, and the overall damage ratio was low when the overall separation ratio was low. The condition with more than 60% of the overall separation ratio and less than 15% of overall damage ratio was found only for a rotational speed of 70 rpm.

Influence of the radial clearance

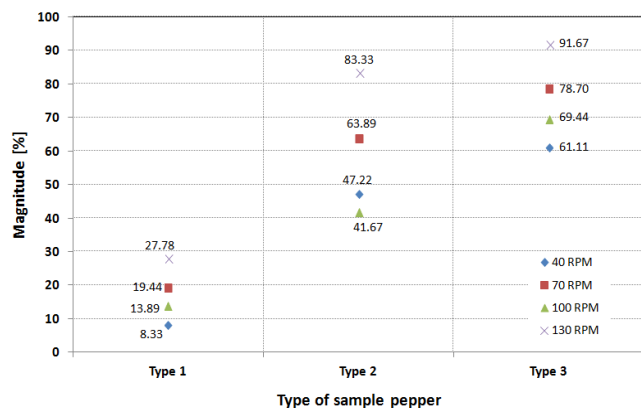Under the condition that the rotational speed of drum B was 70 rpm and the speed ratio of drums A, B, and C was

Figure 16. Damage ratio of each type of pepper sample according to rotational speed of drum B.
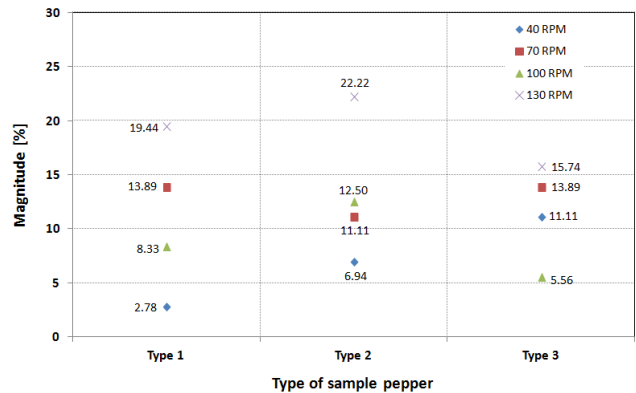

Figure 15. Separation ratio of each type of pepper sample according to rotational speed of drum B.
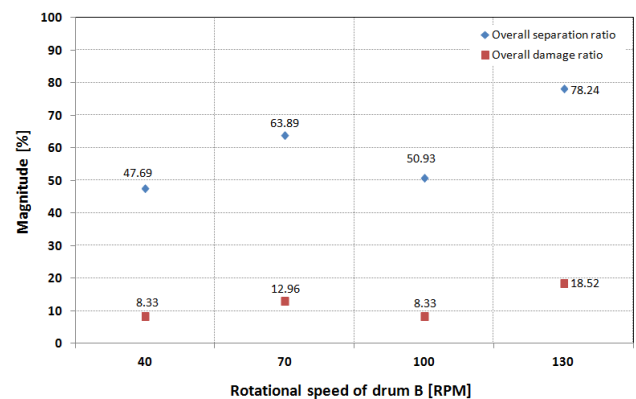

Figure 17. Overall separation ratio and damage ratio according to rotational speed of drum B.
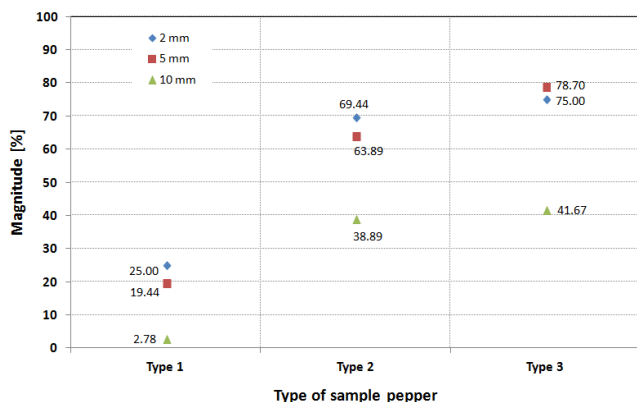
Figure 18. Separation ratio of each type of pepper sample according to radial clearance.
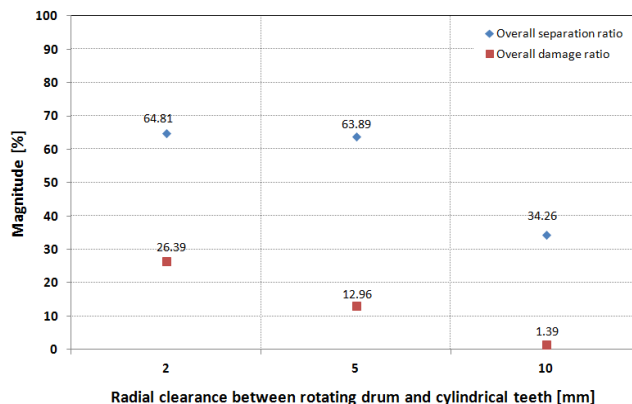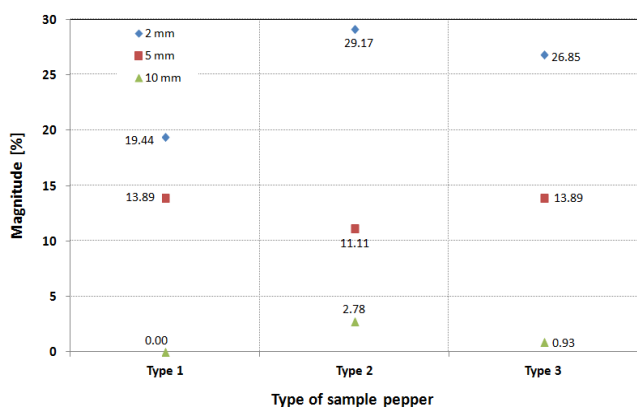

Figure 19. Damage ratio of each type of pepper sample according to radial clearance.

7:3:5, the separation ratio and damage ratio according to the radial clearance between drums and cylindrical teeth were investigated.

Figure 18 shows the separation ratio for each sample type. The separation ratio tended to rise as the radial clearance decreased and as the sample type changed from type 1 to type 2 and type 3. The maximum separation ratio was found in the type 3 sample with a 5 mm radial clearance, and the minimum separation ratio was observed in the type 1 sample with a 10 mm radial clearance. The maximum and minimum ratios were 78.7% and 2.78%, respectively. A separation ratio of more than 60% was obtained in the type 2 and 3 samples with the radial clearance of less than 10 mm. The condition with a separation ratio of more than 60% was not found in the type 1 sample.

Figure 19 shows the damage ratio for each sample type. The damage ratios were in the range between 0% and 29.17%. The maximum damage ratio occurred in the type

Figure 20. Overall separation ratio and damage ratio according to radial clearance.

2 sample with a 2 mm radial clearance, and the minimum damage ratio appeared in the type 1 sample with a 10 mm radial clearance. The damage ratio was higher with a smaller radial clearance. There were no constant tendencies according to the sample type, and the tendencies were different according to the radial clearance. The damage ratio of less than 15% was obtained in the radial clearance of more than 2 mm for all types of pepper samples.

Figure 20 shows the overall separation ratio and overall damage ratio considering all the sample peppers of the three types. The overall damage ratio increased as the radial clearance decreased. The overall separation ratio was similar for 2 mm and 5 mm radial clearances, and it was lowest for a 10 mm radial clearance. The condition with more than 60% of overall separation ratio and less than 15% of overall damage ratio was found only with a 5 mm radial clearance.

Operating condition selection from the experimental results

When the condition with more than 60% of the overall separation ratio and less than 15% of the overall damage ratio is set as the appropriate operating condition of the secondary separating part of self-propelled pepper harvester, the value of each experimental factor should be determined as follows, based on the experimental results:

A. Rotational speed of drum B: 70 rpm
B. Radial clearance between drums and cylindrical teeth: 5 mm
C. Rotational speed ratio of the three drums (drums A, B, and C): 7:3:5

Conclusions

In this study, a factorial experiment was performed for the rotating-drum-type secondary separating part of the self-propelled pepper harvester. An experimental setup simulating the shape and operation of the actual separating part was prepared, and tests were conducted using three types of test samples classified according to the number of peppers on a stem.

Among the operating conditions of the secondary separating part, the rotational speed of drum B, radial clearance between drums and cylindrical teeth, and rotational speed ratio of the three drums were set as test factors. The separation ratio and damage ratio of the peppers collected in the collecting box were analyzed for the different test conditions. The separation ratio and damage ratio were derived using the average values of the three repeated tests, and appropriate operating conditions were determined for the criterion of more than 60% of overall separation ratio and less than 15% of overall damage ratio.

Conflict of Interest

The authors have no conflicting financial or other interests

Acknowledgement

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