



Article Design and Performance Evaluation of a Cherry Tomato Calyx Remover

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Abstract: A prototype for the remover of cherry tomato calyxes was designed and manufactured. The tap remover was designed and manufactured considering the conveyor transport speed, brush length and clearance, and diameter. These were adjusted in three levels to determine the optimal design factor. Performance tests were conducted using Icon 513, a circular-shaped cherry tomato variety, and Minimaru, a jujube-shaped cherry tomato variety. Conveyor transport speeds were set at 210, 280, and 350 mm/s; brush lengths at 70, 80, and 90 mm; brush clearances at 20, 22, and 24 mm; and brush diameters at 0.8, 1.0, and 1.2 mm. The two varieties showed a similar damage rate during calyx removal. However, Minimaru showed a higher calyx removal rate than Icon 513, indicating that it is most suitable for the calyx removal mechanization process.

Keywords: cherry tomato; calyx removal; contribution rate; Taguchi method; robust optimization

1. Introduction

Recently, along with industrialization, the food sector has rapidly developed [1–3]. Cherry tomatoes are vegetables with high production and consumption rates because they can be consumed fresh or processed according to consumer preferences [4–8].

A cherry tomato, *Solanum lycopersicum* var. *cerasiform* [9], is a vegetable with high sugar content, 90% moisture content, and high vitamin A, C, B1, and B2 content [10,11]. Cherry tomatoes are an essential component of diets, and their quality is also important. Unfortunately, fresh fruit is susceptible to mechanical damage, and quality can be significantly reduced due to poor distribution and pre-and post-processing processes [10–12]. Once damaged, fruits and vegetables deteriorate quickly due to physiological effects depending on the distribution period, resulting in considerable deterioration in the quality of fruits and vegetables during distribution [13,14]. Most of the circular shaped cherry tomato varieties are cultivated in Japan and exported at a high cost. However, the cultivation quantity of jujube-shaped cherry tomatoes developed in The Republic of Korea has been increasing recently [15].

Cherry tomatoes are harvested by hand when the degree of coloration is more than 80% and harvested with the calyx attached to the peduncle connecting the plant and fruit. The calyx is firmly attached to the fruit in most scenarios [16]. For the best value, when harvested and distributed, the cherry tomatoes must be delivered with calyxes attached to them to be recognized as high in freshness [17]. However, it takes many man-hours to remove the calyx of cherry tomatoes before eating. According to a study by Choi et al. (2013), diseases occur after five days of storage. The high number of bacteria and mold on the calyx of cherry tomatoes. The shelf life when maintaining the calyx and distributing cherry tomatoes. The storage period of jujube cherry tomatoes with calyx removed was about eight days, whereas cherry tomatoes with their calyx present was



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Copyright: © 2021 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https:// creativecommons.org/licenses/by/ 4.0/). about six days [12]. In the United States and Canada, most tomatoes are packaged without a peduncle and calyx to prevent secondary spoilage infection due to lacerations caused by

sharp calyxes or quality deterioration due to increased respiration [18]. Currently, removing the calyx is performed manually and it causes economic losses from the inefficiency of human labor and deterioration of the cherry tomatoes. To mitigate these problems, performing this work at the factory instead of working outdoors was suggested. It will reduce outdoor labor and improve management and distribution while increasing annual yields [19].

Furthermore, cherry tomato calyx removal relies on manual labor, resulting in high costs and difficulties finding skilled labor [20,21]. Therefore, it is necessary to introduce an automatic process for removing the calyx of cherry tomatoes mechanically. This study designed and manufactured an automatic calyx remover for cherry tomatoesand conducted a performance test on it. The optimal design factors were analyzed by examining the cherry tomato calyx removal and damage rates through tests for each factor required to optimize the machine's performance.

2. Materials and Methods

2.1. The Conveyor System for Cherry Tomatoes Removal

The conveyor-type cherry tomato calyx remover was manufactured in a hopper-type to put cherry tomatoes packaged in a bulk box or pack (Figure 1). The inlet hopper was designed and manufactured to be manually allow intakes that are in proportion to the conveyor's speed with an inclination within 5° in the moving direction. A conveyor moves the added cherry tomatoes to the removal unit equipped with a brush. The rotation speed of the conveyor motor was 40 rpm by default (this speed can be adjusted). Additionally, conveyors are partitioned at 150 mm intervals. Therefore, according to the shape of the cherry tomatoes during movement, the short radius was rotated along the axis. The cherry tomatoes were then supplied and moved by the conveyor rotator while passing through the point where the brush was installed, and the calyx comes into contact with the brush and falls off. The length of the brush facility section was 500 mm, and the calyx was removed from the first rotation section of cherry tomatoes, i.e., the first half of the brush. Cherry tomatoes with calyx were removed, and the calyx was moved to the end of the conveyor. Cherry tomatoes were discharged into a collection container, and the calyx was discharged into a separate container at the bottom (Figure 1). The frame size of the conveyor-type cherry tomato calyx remover was $W = 370 \times L = 980 \times H = 940$ (Table 1) [22–24].



Figure 1. Prototype of the cherry tomato calyx remover (a) and three-dimensional design (b).

Description	Unit	Specifications
Dimensions	(mm)	W370 \times L980 \times H940
Input port specification	(mm)	W364 \times L450 \times H70
Transport velocity	(mm/s)	210~350
Throughput	(kg/h)	100
Possible size	(mm)	20~30
Brush material	-	Polyethylene
Conveyor type	-	Belt conveyor

Table 1. Specifications of the conveyor-type calyx remover.

2.2. Test Sample

A demonstration test was conducted to evaluate the performance of the calyx remover. Different varieties of cherry tomatoes, including circular-shaped and jujube-shaped cherry tomatoes, were studied. The circular-shaped cherry tomatoes are characterized by a strong calyx attached to maintain freshness, and Nongwoo Bio's Icon 513 was used. Alternatively, jujube cherry tomatoes are oval-shaped, and the calyx are weakly attached. Consequently, it is easier to remove the calyx using a machine andNongwoo Bio's Minimaru was used. The information website for cherry tomatoes (Korea Agricultural Marketing Information Service) provides circular-shaped and jujube-shaped cherry tomatoes information using size and weight. The cherry tomatoes are classified into upper, middle, and lower grades [25]. The cherry tomatoes used were shipped from a farm on the same day, and those selected in the middle-grade standard were used (Figure 2).



Figure 2. Cherry tomatoes used in performance tests: (**a**) circular-shaped cherry tomato (Icon513) (**b**) jujube-shaped cherry tomato (Minimaru).

2.3. Experimental Design

2.3.1. Design Factors for Performance Analysis

Taguchi's design of experiments (DOEs) was implemented to optimize the design factors by performing a few experiments with many design variables. The Taguchi method, conducts robust analyses to maintain consistent performance in various environments by reflecting the uncontrollable noise factor in the experiment as a controllable factor [26]. To analyze the cherry tomato calyx remover, which was designed using a conveyor belt (Table 2), four factors, controllable input speed, brush length, brush clearance, and brush diameter was controlled at three levels in removing the cherry tomato calyx (Table 2). For each trial, 10 kg of cherry tomatoes were used. Additionally, optimal design factors were analyzed when removing circular-shaped and jujube-shaped cherry tomato calyxes by applying uncontrollable factors according to the size of cherry tomatoes.

Factors	Level 1	Level 2	Level 3
Transport velocity (mm/s)	210	280	350
Brush length (mm)	70	80	90
Brush clearance (mm)	20	22	24
Brush diameter (mm)	0.8	1.0	1.2

Table 2. Controllable factors and their levels for conveyor-type calyx remover.

2.3.2. Taguchi Orthoganal Arrays

An $L_9(3^4)$ -orthogonal type array consisting of four control factors and three levels was designed (Table 3) to analyze the effect of change in control factor variables on the cherry tomato stem removal and damage rates [27]. The noise factor was set to two levels due to the weight of cherry tomatoes, which is difficult to control even when graded by size due to the variation in the characteristics of agricultural products.

Table 3. Taguchi orthogonal array $(L_9(3^4))$ to analyze the effect of change in control factors.

	Combinations of Factors				
Test No.	Transport Velocity (mm/s)	Brush Length (mm)	Brush Clearance (mm)	Brush Diameter (mm)	
1	210	70	20	0.8	
2	210	80	22	1	
3	210	90	24	1.2	
4	280	70	22	1.2	
5	280	80	24	0.8	
6	280	90	20	1	
7	350	70	24	1	
8	350	80	20	1.2	
9	350	90	22	0.8	

2.4. Removal and Damage Rates of Cherry Tomatoes

The cherry tomato calyx removal rate by design factor (1) is the ratio of the number of cherry tomatoes from which the calyx has been removed to the number of added cherry tomatoes, and the damage rate (2) is the ratio of the number of damaged cherry tomatoes to the number of cherry tomatoes injected. All experiments were conducted in triplicate, and the average value was used.

Eliminate ratio (%) =
$$\frac{Number \ of \ Eliminate \ samples}{Number \ of \ Input \ samples} \times 100$$
 (1)

Damage ratio (%) =
$$\frac{Number \ of \ Damage \ samples}{Number \ of \ Input \ samples} \times 100$$
 (2)

The damaged cherry tomatoes were photographed with a smartphone camera (Galaxy A31, Samsung, Seoul, Korea). After removing the background and shade, as shown in Figure 3. In the processed photographs, pixel values of the total area of cherry tomatoes were measured using image programs (Image J, NIH, Bethesda, MD, USA). After converting to 8 bit-color, the pixels of the cherry tomato epidermis were measured. The degree of damage was calculated as shown in Equation (3) by dividing the pixel value covered by cherry tomatoes from the pixel value covered by damage among all pixels.

Damage rate (%) =
$$\frac{P(Damage area)}{P(Cherry tomato area)} \times 100$$
 (3)



Figure 3. Analysis of damage to cherry tomatoes: (**a**) The original picture, (**b**) background and shadow removed from picture, (**c**) full pixel of cherry tomato, and (**d**) damage part highlighted.

After the calyx removal process, the criterion for sorting damage to cherry tomatoes was determined based on if the damage pixel value ratio was 0.1% or more.

2.5. Loss Function and S/N (Signal to Noise) Ratio

Among the quality targets of the Taguchi technique, the calyx elimination rate was analyzed by applying the characteristics of the larger, the better, and the damage rate by applying the smaller the better. Additionally, when a signal is an input to the system, it is calculated relative to how much noise interferes with it that affects the output; the S/N ratio of the characteristics of the larger the better (4) and the smaller the better (5) is calculated. Finally, the degree of influence of each control factor that did not consider the interaction on the cherry tomato calyx removal ability were analyzed.

The larger, the better SN ratio =
$$-10\log_{10}\frac{1}{n}\sum_{i=1}^{n}\frac{1}{yi^2}$$
 (4)

The smaller, the better SN ratio =
$$-10log_{10}\frac{1}{n}\sum_{i=1}^{n}yi^2$$
 (5)

where *n* is the number of trial test and y_i is the *i*th number of quality characteristics.

2.6. Analysis of the Influence of Control Factors on Cherry Tomato Calyx Removal

The removal and damage rates according to the control factor conditions were analyzed using the Minitab program (Minitab v.20, Minitab Inc., State College, PA, USA). This was done to calculate the effect of each control factor on the performance of the cherry tomato calyx remover when interaction was not considered. Additionally, the sum of squares (SS) of each design factor was calculated by analysis of variance. This was done to verify the design factors' contribution rate and calculated using Equation (6).

The contribution rate (%) =
$$\frac{Adj SS (Factor)}{Adj SS (Total)} \times 100$$
 (6)

3. Results and Discussion

3.1. Cherry Tomato Calyx Remover Design Condition Analysis

The Taguchi method evaluates the influence of control factors and their levels on the experimental results using S/N ratio and determines the best conditions. Table 4 shows the S/N ratio of the analysis result using Taguchi orthogonal array. In the case of circular-shaped cherry tomatoes, at a feed rate of 350 mm/s, a brush length of 70 mm, a brush clearance of 24 mm, and a brush diameter of 1.0 mm, the calyx remover S/N ratio was the highest at 30.26%, but the damaged S/N ratio was the lowest at -38.40%. At a feed speed of 350 mm/s, brush length of 80 mm, brush clearance of 22 mm, and brush diameter of 0.8 mm, the calyx removal S/N ratio was 13.86%, but the damage S/N ratio was the highest at 0%. The cherry tomato variety has been improved, making it hard for the calyx to be removed, resulting to a low S/N ratio for calyx remover. For jujube-shaped cherry tomatoes, at a feed rate of 280 mm/s, brush length of 90 mm, brush clearance of 20 mm, and brush diameter of 1.0 mm, the calyx remover S/N ratio was the highest at 40.00%, but the damage S/N ratio was -38.37%. Furthermore, at a feed rate of 210 mm/s, brush length of 90 mm, brush clearance of 24 mm, and brush diameter of 1.2 mm, the damage S/N ratio was -8.36%, and the calyx removal S/N ratio was 23.69% (Table 4). Therefore, the mechanical removal of the calyx was better in the jujube-type cherry tomato varieties than the original ones.

Table 4. Mean ratio (eliminate and damage) and S/N ratios (eliminate and damage) to remove calyx using the Taguchi method.

	(Circular-Shaped Cherry Tomato			Jujube-Shaped Cherry Tomato				
Test No	Elimi	Eliminate		Damage		Eliminate		Damage	
	AVE/SD (%)	SN Ratio (%)	AVE/SD (%)	SN Ratio (%)	AVE/SD (%)	SN Ratio (%)	AVE/SD (%)	SN Ratio (%)	
R1	15.52 ± 8.65	22.61	15.52 ± 2.97	-24.19	61.66 ± 2.35	35.71	38.33 ± 15.45	-31.67	
R2	30.28 ± 16.92	28.96	29.8 ± 3.94	-29.72	62.19 ± 3.51	35.67	53 ± 12.66	-34.56	
R3	2.77 ± 2.07	8.34	2.85 ± 2.10	-9.23	15.62 ± 4.57	23.69	1.85 ± 2.61	-8.36	
R4	27.94 ± 3.86	27.04	49.61 ± 7.89	-33.94	86.87 ± 7.74	38.71	96.16 ± 0.57	-39.66	
R5	9.72 ± 8.56	17.26	2.77 ± 3.92	-11.88	19.33 ± 15.48	22.14	9.89 ± 13.98	-19.91	
R6	31.25 ± 6.75	29.83	75.69 ± 4.28	-37.62	100 ± 0	40.00	82.89 ± 9.84	-38.37	
R7	32.62 ± 8.87	30.26	81.07 ± 5.47	-38.40	53.33 ± 4.71	33.71	75 ± 25.49	-37.60	
R8	4.94 ± 4.55	13.86	0 ± 0	*	89.26 ± 4.95	39.01	20.76 ± 2.97	-26.34	
R9	7.3 ± 5.22	10.38	56.11 ± 13.63	-35.52	69.21 ± 0.70	36.62	75.91 ± 8.33	-37.69	

*: no analyzed values.

3.2. Analysis of the Effect of Control Factors on the Removal of Cherry Tomato Calyx

The effect of each control factor, not considering the interaction on the cherry tomato calyx removal and damage rate, was ranked based on the delta statistic by comparing the state size of the effect according to the response table of the S/N ratio for the control factor. The delta statistic is the difference between the largest and the smallest mean values of each factor. For example, in circular-shaped cherry tomatoes, the S/N ratio of the calyx removal rate was the most influential factor with brush diameter, followed by brush length, conveyor transport speed, and brush clearance (Table 5). Additionally, when the circular-shaped cherry tomato calyx was removed, the conveyor transport speed of 280 mm/s, brush length of 70 mm, brush clearance of 22 mm, and brush diameter of 1.0 mm were the controllable design conditions.

Level	Transport Velocity	Brush Length	Brush Clearance	Brush Diameter
1	19.98	26.64	22.11	16.75
2	24.72	20.03	22.13	29.69
3	18.17	16.19	18.62	16.42
Delta	6.54	10.45	3.51	13.27
SS	68.55	167.70	24.42	343.50
Contribution rate	11.34	27.75	4.04	56.85
Rank	3	2	4	1

Table 5. Response table for elimination S/N ratios of circular-shaped cherry tomato.

The contribution rate calculated from the sum of squares (SS) of each design factor corresponded with the influence priority ranked using the delta statistic. For example, the contribution rate of brush diameter and priority was highest at 56.85%; the contribution rate of brush length was 27.75%, the contribution rate of the transport velocity was 11.34%, and the contribution rate of brush clearance was 4.04% (Table 5). Thus, the contribution rate of each design factor can be prioritized when design factors affecting the cherry tomato removal rate and damage rate overlaps.

When removing the calyx of cherry tomatoes, the damage rate increases in proportion to the removal rate; therefore, it is necessary to find an appropriate optimal performance interval by comparing the removal and damage rates. When removing the circular-shaped cherry tomato calyx, the S/N ratio of the damage rate was the most influential factor of the conveyor transport speed, and the brush diameter, clearance, and brush length in that order. Additionally, it is optimal to reduce the damage rate when the conveyor feed speed is 210 mm/s, brush length is 80 mm, and brush clearance is 24 mm. The brush diameter is 1.2 mm as controllable design conditions when removing the circular-shaped cherry tomato calyx. However, through the delta ranking of the removal and damage S/N ratio, the removal S/N ratio damages the brush diameter and length as each priority design factor. Therefore, the optimal design conditions for the cherry tomato calyx remover designed by comparing the removal and damage S/N ratio delta rank are conveyor feed speed of 210 mm/s, brush length of 70 mm, brush clearance of 24 mm, and brush diameter of 1.0 mm. The contribution rate of each design factor affecting the damage rate of circular-shaped cherry tomatoes was 29.21% for conveyor transport speed, 28.04% for brush clearance, 27.81% for brush diameter, and 14.92% for brush length. The difference in the contribution rate between the first, second, and third influence ranks showed a slight difference of 1.17–1.4% (Table 6).

Level	Transport Velocity	Brush Length	Brush Clearance	Brush Diameter
1	-21.05	-32.18	-30.91	-23.87
2	-27.82	-20.80	-33.07	-35.25
3	-36.97	-27.46	-19.84	-21.59
Delta	15.91	11.38	13.22	13.66
SS	304.20	155.40	292.00	289.60
Contribution rate	29.21	14.92	28.04	27.81
Rank	1	4	3	2

Table 6. Response table for damage S/N ratios of circular-shaped cherry tomato.

The calyx removal S/N ratio was the most influential factor with brush clearance in jujube-shaped cherry tomatoes, followed by the brush diameter, transport velocity, and brush length. Additionally, the transport velocity is 350 mm/s, brush length is 70 mm, brush clearance is 20 mm, and brush diameter is 1.0 mm when the jujube-shaped cherry tomato calyx was removed. The contribution rate of each design factor affecting the removal rate of jujube-shaped cherry tomatoes was the highest at 72.63% for brush clearance, 10.81% for brush diameter, 10.02% for transport velocity, and 6.52% for brush length. The contribution rates of the second, third, and fourth ranks of influence showed a

showing a significant difference (Table 7).

 Table 7. Response table for eliminate S/N ratios of jujube-shaped cherry tomato.

 Level
 Transport Velocity
 Brush Length
 Brush Clearance
 Brush Diameter

slight difference, and the brush clearance contribution rates were 72.63% and 61.82–66.11%,

Level	Transport Velocity	Brush Length	Brush Clearance	Brush Diameter
1	31.69	36.05	38.24	31.50
2	33.62	32.28	37.01	36.46
3	36.45	33.44	26.52	33.81
Delta	4.76	3.77	11.73	4.97
SS	34.37	22.38	249.02	37.08
Contribution rate	10.02	6.52	72.63	10.81
Rank	3	4	1	2

Like circular-shaped cherry tomatoes, the damaged S/N ratio increases in proportion to the removed S/N ratio when the calyx of the jujube-shaped cherry tomatoes was removed. Therefore, it is necessary to find an appropriate optimal performance interval by comparing the removal rate and damage S/N ratio. It was analyzed that the damage S/N ratio of jujube cherry tomatoes is the factor that has the most significant influence on brush clearance, and it affects the brush diameter, brush length, and conveyor transport speed. Additionally, like the optimal condition for reducing the damage S/N ratio of circular-shaped cherry tomatoes, it is the optimal condition to minimize the damage S/N ratio when the conveyor transport speed was 210 mm/s, brush length was 80 mm, brush clearance was 24 mm, and brush diameter was 1.2 mm (Table 8).

Table 8. Response table for damage S/N ratios of jujube-shaped cherry tomato.

Level	Transport Velocity	Brush Length	Brush Clearance	Brush Diameter
1	-24.87	-36.32	-32.13	-29.76
2	-32.65	-26.94	-37.31	-36.85
3	-33.88	-28.14	-21.96	-24.79
Delta	9.01	9.38	15.35	12.05
SS	143.40	156.20	365.90	220.20
Contribution rate	16.19	17.63	41.32	24.86
Rank	4	3	1	2

For the removed and damaged S/N ratios of jujube-shaped cherry tomatoes, the first and second places in the delta were identical to the original ones. Therefore, priority was given to the design conditions of the removal S/N ratio, which showed a significant difference in delta values. Furthermore, the conveyor transport speed was 350 mm/s, brush length was 80 mm, brush clearance was 20 mm, and brush diameter was 1.2 mm. The contribution rate of each design factor affecting the jujube-shaped cherry tomato damage rate was the highest at 41.32%, followed by the brush diameter at 24.86%. The contribution rates of brush length and transport velocities were 17.63% and 16.19%, respectively, in the third and fourth places, showing a slight difference of 1.44% (Table 8). In the jujube-shaped cherry tomato experiment, the same factors, such as brush clearance and diameter, had the same influence on removal and damage, so the ranking could be determined by reflecting the contribution rate.

4. Conclusions

This study designed and manufactured a device to remove cherry tomato calyxes using a brush during transport using a conveyor system. Four factors were considered (transport velocity, brush length, brush clearance, and brush diameter) in three levels. The two varieties studied (a circular-shaped cherry tomato variety and Minimaru, a jujubeshaped cherry tomato variety) showed a similar trend in the damage rate when the calyx was removed. However, the Minimaru showed a higher calyx removal rate than the Icon 513 cherry tomato, indicating that it was the most suitable for calyx removal mechanization. The cherry tomato calyx remover manufactured based on the design factors determined in this study can reduce post-harvest losses. Future studies with the optimal design conditions determined in this study will be conducted. Additionally, more varieties and grades will be considered.

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