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Study on Optimal Working Conditions for Picking Head of Self-Propelled Pepper Harvester by Factorial Test

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Abstract

Purpose: Pepper prices have risen continuously because of a decrease in cultivation area; therefore, mechanical harvesting systems for peppers should be developed to reduce cost, time, and labor during harvest. In this study, a screw type picking head for a self-propelled pepper harvester was developed, and the optimal working conditions were evaluated considering helix types, winding directions of helix, and rotational speeds of the helix. **Methods:** The screw type was selected for the picking head after analyzing previous studies, and the device consisted of helices and a feed chain mechanism for conveying pepper branches. A double helix and a triple helix were manufactured, and rotational speeds of 200, 300, and 400 rpm were tested. The device was controlled by a variable speed (VS) motor and an inverter. Both the forward and reverse directions were tested for the winding and rotating directions of the helix. An experiment crop (cultivar: Longgreenmat) was cultivated in a plastic greenhouse. The test results were analyzed using the SAS program with ANOVA to examine the relationship between each factor and the performance of the picking head. **Results:** The results of the double and triple helix tests in the reverse direction showed gross harvest efficiency levels of 60–95%, mechanical damage rates of 8–20%, and net marketable portion rates of 50–80%. The dividing ratio was highest at a rotational speed of 400 rpm. Gross harvest efficiency was influenced by the types of helix and rotational speed. Net marketable portion was influenced by rotational speed but not influenced by the type of helix. Mechanical damage was not influenced by the type of helix or rotational speed. **Conclusions:** Best gross harvest efficiency was obtained at a rotational speed of 400 rpm; however, operating the device at that speed resulted in vibration, which should be reduced.

Keywords: Factorial test, Pepper harvester, Picking head, Screw type, Working conditions

Introduction

Peppers contain a substance called capsaicin, producing mild to intense spice, and they are available in markets in fresh-green or red, dried, or powdered form. The cultivation area for peppers has decreased from 2010 to 2014, and the price of peppers has increased (KOSTAT, 2013). Harvest labor accounts for 32.2% of total labor when hand harvest is used (KOSTAT, 2014a), which requires 10 times higher costs than rice harvesting (KOSTAT, 2014b). For this reason, pepper production has decreased. The mechanization rate for upland farming is 42.7%, and 90% of that is for plowing, land preparation, and pest control. The mechanization rate for sowing, transplanting, and harvesting is only 10% (MIFAFF, 2010). Presently, the mechanization rate for the upland farming has increased by 56% fiducially in 2015 (Choi et al., 2015)

Mechanization for harvesting peppers reduced labor use by 51% and costs by 38% (Hong et al., 2006). The harvest cost for peppers decreased by 51% from 478,320 won to 232,890 won per 1,000 m^2 with the development of harvesting machines (Choi, 2006).

T Company, a domestic company, has been developing

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self-propelled pepper harvesters which include picking heads, screening parts, conveying parts, and collecting parts to reduce labor and costs since 2014.

Many studies have been conducted in Korea to develop pepper harvesting machines, and companies from Israel and the USA have developed pepper harvesters (Paul et al., 2011; Wall et al., 2003).

Paul and Walker (2010) developed four types (Disk, Chain, Creager, and Hernandez) of attachable harvest machines by using the platform of cotton harvesters manufactured by John Deere. In addition, the helix type harvester, which was developed in Israel, was selected for this study. A total of five types of harvesters have been used in the field test. The helix type harvester with a double open-helix showed the best gross harvest efficiency and mechanical damage among the various harvesters.

Lee et al. (1994) designed a screw type harvester for factorial test and examined the four levels of rotational speed (110, 145, 180, and 215 rpm) and three levels of moving speed for the pepper plant (0.1, 0.2, and 0.3 m/s). The best performance was observed at the rotational speed of 180 rpm and moving speed of 0.1 m/s.

Developing pepper harvesters should consider domestic cultivar and cropping systems because these are different from foreign peppers.

Harvesting efficiency is important for the pepper harvester, and the dividing ratio of the picking head is the most important factor that influences the harvesting efficiency.

This study developed a screw type picking head to examine the following design factors: types, winding directions, and rotational speeds of the helix.

Materials and Methods

Picking head

The picking head developed in this study was composed of a conveying part with a feed chain mechanism and driving parts with helices. Each driving part had two 3.4-kW VS motors and an inverter to control the speed of the helix and the feed chain. Power was transmitted using the bevel gears to rotate each helix in different directions. A rail was installed at each end of a helix to adjust the angle of the helix. Figure 1 shows the conceptual diagram of the self-propelled pepper harvester. Figure 2 shows the experiment bench for the picking head used in this study. The type of helix (double helix or triple helix) was

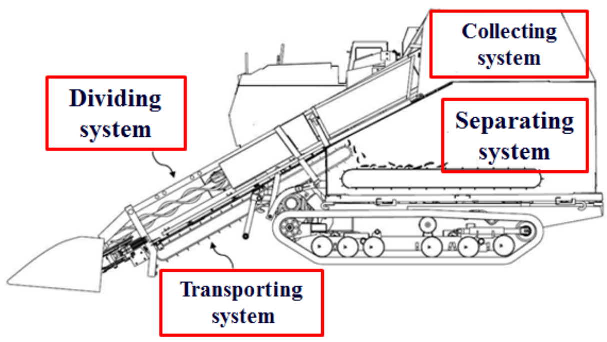
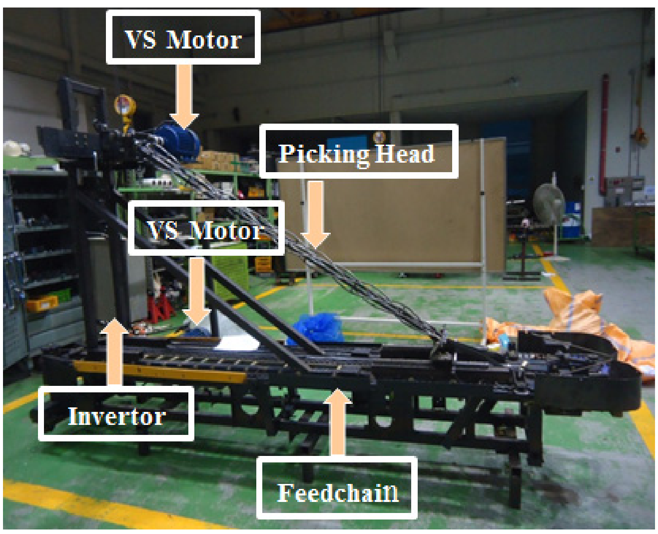


Figure 1. Conceptual diagram of the self-propelled pepper harvester.



<Side View>

<Front View>

Figure 2. Experiment bench for the picking head.

Table 1. Specification and shape of the helix

	Parameter(mm)
Pitch of helix	600
Length of helix	2150
Wire diameter of helix	15
Inner diameter of helix	60
Distance between two helices	35

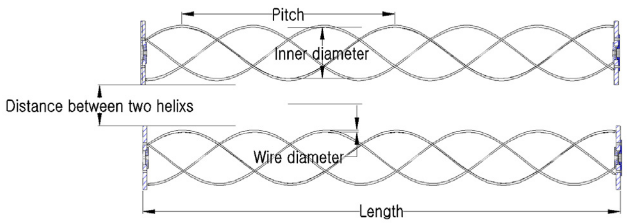


Figure 3. Shape of the helix.

determined based on the number of windings, and Table 1 and Figure 3 show the specification and shape of the helix.

After the rotational speeds of the helix and feed chain were controlled by the inverter of the motor, pepper plants were placed on the feed chain and moved into the two rotating helices to separate the fruits from the plants. The separated plants were removed at the end of the picking head.

Preparation of experimental crop sample

Two hundred pepper plants grown in a plastic greenhouse were collected from a farm in Nampyung, Naju, Jeonnam province on June 15, 2015. The cultivar of the sample was 'Longreenmat,' and it was harvested in the summer. Purchased seedlings were transplanted on February 25, 2015 and harvested three times during May, 2015 with intervals of one week.

The properties of 30 fruits from randomly selected 10-week old pepper plants were investigated. Table 2 and Figure 4 show the properties of the plants, and Table 3 and Figure 5 present the properties of the fruits. Figure

Table 2. Properties of the pepper plants

Parameter	Unit	Average	Standard deviation
Length of pepper plant	mm	1096	6.13
Width of pepper plant	mm	824	15.08
Diameter of pepper stem	mm	16	2.84
Length of pepper stem	mm	280	1.18
Number of pepper fruit	Ea	35	9.24

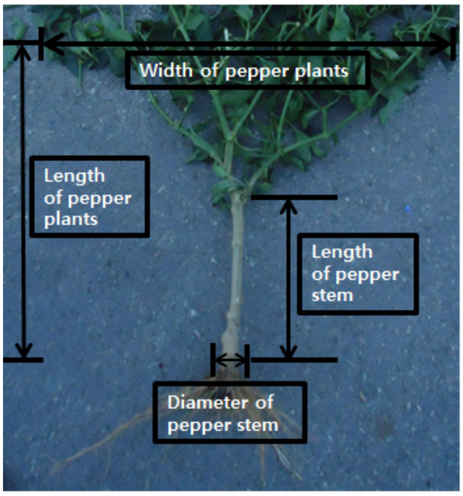


Figure 4. Measurement standard of the pepper plants.

Table 3. Properties of the fruits

Parameter	Unit	Average (mm)	Standard deviation
Length	mm	197.67	14.13
Maximum Diameter	mm	16.41	3.19
Weight	g	26.73	6.46

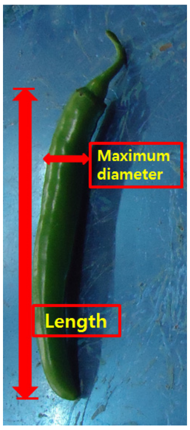


Figure 5. Diameter and length of the fruit.

Figure 6. Pepper plants in greenhouse.

6 shows the plants grown in the greenhouse.

Test Factors and Method

Factors to be examined for this study were the types of the helix (double helix and triple helix) and rotational speeds of the helix (200, 300, and 400 rpm). Figure 7 depicts the winding directions of the helix (forward direction and reverse direction).

The winding direction of the helix is the same as the rotational direction in the forward direction, and the winding direction of the helix is opposite to the rotational direction in the reverse direction.

Double helices and triple helices were mainly examined in the reverse direction in this study, but an experiment with the forward direction was added.

The values for three fixed factors were determined: angle of the helix (30˚), moving speed of the feed chain (0.3 m/s), and distance between two helices (35 mm). Factors for the main experiment were rotational speed (200, 300, and 400 rpm) and the two types of helix with a reverse winding direction of the helix. Table 4 presents the factors of the picking head for the main experiment. Factors for the additional experiment were the two types of helix with a forward direction and the influence of leaf-removal with a reverse direction. Table 5 shows the factors for the additional experiment. The pepper plants were supported by hand so as not to be tangled at the helix. Four plants were processed in each experiment, and three experiments were repeated.

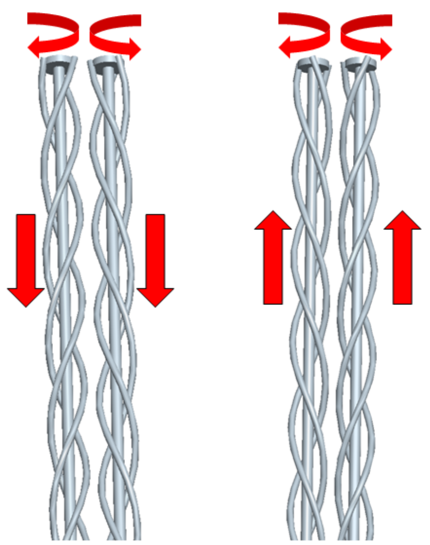


Figure 7. Winding directions of the helix.

Table 4. Factors of the picking head for the main experiment

Parameter	Unit	Value
Rotational speed of the helix	rpm	200, 300, 400
Types of the helix	-	Double, Triple
Winding directions of the helix	-	Reverse
Angle of the helix	Degree (˚)	30
Moving speed of the feed chain (m/s)	m/s	0.3

Paul and Walker (2010) analyzed the field tests by using six factors. This study used three factors of the same factors: gross harvest efficiency, mechanical damage, and net marketable portion.

The three factors were calculated with equations (1), (2), and (3). Gross harvest efficiency refers to the harvest efficiency of pepper fruits, and mechanical damage means the percentage of damaged fruits out of the total harvested fruits. Net marketable portion refers to the percentage of marketable fruits, which is the ratio of successfully harvested fruits to the total fruits harvested. Rotational speed of the helix was measured with a laser type rpm meter. Table 6 presents the specifications of a laser type rpm meter. Slats were installed at both ends of the harvesting device to prevent the losses of fruits, stems, and leaves during the process.

$$D_{ghe}(\%) = \frac{P_{dp}}{P_{tp}} \times 100(\%) \tag{1}$$

$$M_{dp}(\%) = \frac{P_{dop}}{P_{dp}} \times 100(\%) \tag{2}$$

Table 5. Factors of the picking head for the additional experiment

Condition	Winding direction of the helix	Types of helix	Rotational speed of the helix (rpm)
Normal Condition	Forward direction	Double, Triple helix	400
Leaf-removal	Reverse direction	Double helix	400

Table 6. Specification of rotational speed measuring equipment

Item	Specification
Model number	PLT200
Company / Nation	NONARCH / USA
Measuring range	5~200,000 rpm
Resolution	1 rpm
Accuracy	0.01%

$$N_{mp}(\%) = \frac{P_{dp} - P_{dop}}{P_{tp}} \times 100(\%) \tag{3}$$

Where, D_{ghe} : Gross harvest efficiency (%)
M_{dp} : Mechanical damage (%)
N_{mp} : Net marketable portion (%)
P_{tp} : Total number of fruits (Ea)
P_{dp} : Total number of divided fruits (Ea)
P_{dop} : Number of damaged fruits (Ea)

Test analysis

Gross harvest efficiency, mechanical damage, and net marketable portion were examined by the factorial test of the picking head.

Peppers with stems were included in the divided peppers because the stem could be separated during the screening process or during post-harvest processing; thus, this study focused on gross harvest efficiency.

The most important factors were rotational speed and types (double or triple helix) of the helix; therefore, two-way analysis of variance (ANOVA) was used to analyze the relationship between the factors and the performance of the picking head. One-way ANOVA was used to compare two factors in the dividing ratio.

Distribution analysis was conducted using SAS software based on the results of the experiment (SAS, 1990).

Figure 8. Process of the experiment.

Figure 9. Sample used in the experiment.

Table 7. Experiment results in the reverse direction

Types of Helix	RPM	Gross harvest efficiency (%)	Average Ratio (%)	Mechanical damage (%)	Average Ratio (%)	Net marketable portion (%)	Average Ratio (%)
Double helix	200	70.34	68.21	9.64	10.98	63.56	60.80
		74.29		10.26		66.67	
		60.00		13.04		52.17	
	300	87.62	78.72	16.30	15.30	73.33	66.62
		74.63		17.00		61.94	
		73.91		12.61		64.60	
	400	92.62	91.62	13.93	16.06	78.69	76.57
		86.41		16.85		71.84	
		95.83		17.39		79.17	
Triple helix	200	64.41	66.05	21.05	14.54	50.85	56.40
		70.67		12.93		61.54	
		62.88		9.64		56.82	
	300	75.46	72.75	15.45	11.89	63.80	64.07
		68.94		10.99		61.36	
		73.86		9.23		67.05	
	400	79.83	81.52	13.68	12.02	68.91	71.72
		83.93		13.48		72.64	
		80.80		8.91		73.60	

Results and Discussion

Comparison of dividing ratio and damage ratio

Figure 8 depicts the process of the experiment, and Figure 9 shows the sample used in the experiment.

Table 7 presents the results of the double helix and triple helix in the reverse direction. The results showed a gross harvest efficiency of 60–95%, mechanical damage of 8–20%, and a net marketable portion of 50–80%. The dividing ratio was highest at a rotational speed of 400 rpm. In addition, gross harvest efficiency and net marketable portion obtained using the double helix were higher compared to those obtained using the triple helix.

Figure 10 shows processed peppers: divided peppers, stem-attached peppers, and damaged peppers. Damaged peppers were the ones that had damage on the pepper or were missing their stalk.

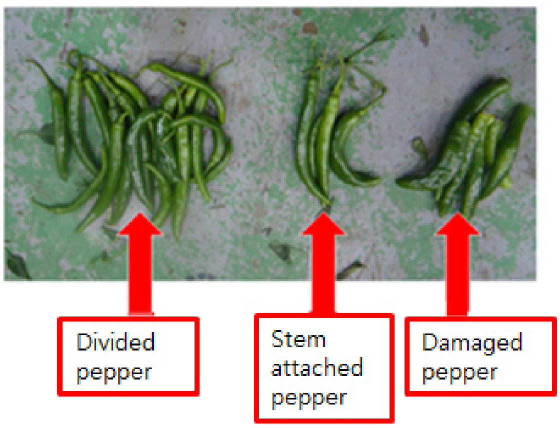


Figure 10. Processed peppers.

Tables 8 and 9 present the results of additional tests. Table 8 shows the results of the forward direction at 400 rpm, and Table 9 provides the results of leaf-removed pepper plants for the conditions of reverse direction, double helix, and 400 rpm.

Gross harvest efficiency, with a 95% confidence level, from the experiment was analyzed using two-way ANOVA, and mechanical damage and net marketable portion were also analyzed.

Table 10 shows the statistical results of gross harvest efficiency based on the rotational speed and types of helix for the reverse direction. P-value based on the type of helix was calculated as 0.0275. That was lower than the significance level of 0.05, which showed significant difference between the types of helix and gross harvest efficiency. In addition, P-value based on rotational speed was calculated as below 0.0001. That was lower than the significance level of 0.05, which showed significant difference between the rotational speed and gross harvest efficiency. Therefore, it can be said that a double helix is better than a triple helix for dividing ratio, and the dividing ratio increases with increasing rpm.

Table 11 shows the statistical results of mechanical damage based on the rotational speed and types of helix in the reverse direction. No significant difference was observed in the results of the rotational speed and types of the helix. Therefore, it can be said that the type of helix and rotational speed did not influence the mechanical

Table 8. Results of the forward direction at 400 rpm

Type of helix	Gross harvest efficiency (%)	Average Ratio (%)	Mechanical damage (%)	Average Ratio (%)	Net marketable portion (%)	Average Ratio (%)
Double helix	82.21	76.67	21.64	15.94	64.42	64.34
	78.57		11.36		69.64	
	69.23		14.81		58.97	
Triple helix	69.93	76.83	43.00	30.71	39.86	53.66
	81.10		23.31		62.20	
	79.46		25.84		58.93	

Table 9. Results of leaf-removed pepper plants in the conditions of reverse direction, double helix, and 400 rpm

Condition	Gross harvest efficiency (%)	Average Ratio (%)	Mechanical damage (%)	Average Ratio (%)	Net marketable portion (%)	Average Ratio (%)
Leaf-removed plants	87.23	81.39	14.63	12.55	74.47	71.10
	75.68		10.71		67.57	
	81.25		12.31		71.25	

Table 10. Statistical results of gross harvest efficiency based on the rotational speed and types of the helix in the reverse direction

Source	DF	ANOVA SS	Mean Square	F Value	Pr > F
Types of helix (Double, Triple)	1	167.3230	167.3230	6.05	0.0275
Rotational speed	2	1142.2408	571.1204	20.66	<.0001
Error	14	386.9417	27.6387		
Total	17	1696.5056	766.0821		

Table 11. Statistical results of mechanical damage based on the rotational speed and types of the helix in the reverse direction

Source	DF	ANOVA SS	Mean Square	F Value	Pr > F
Types of helix (Double, Triple)	1	7.5530	7.5530	0.58	0.4586
Rotational speed	2	5.0699	2.5349	0.19	0.8251
Error	14	182.0494	13.0035		
Total	17	194.6723	23.0914		

Table 12. Statistical results of net marketable portion based on the rotational speed and types of the helix in the reverse direction

Source	DF	ANOVA SS	Mean Square	F Value	Pr > F
Types of helix (Double, Triple)	1	69.6200	69.6200	3.13	0.0987
Rotational speed	2	728.6773	364.3386	16.37	0.0002
Error	14	311.5973	22.2569		
Total	17	1109.8946	456.2155		

Table 13. Gross harvest efficiency with double helix and 400 rpm

Source	DF	ANOVA SS	Mean Square	F Value	Pr > F
Winding direction of the helix	1	41.3962	41.3962	0.19	0.6825
Error	4	854.0786	213.5196		
Total	5	895.4748	254.9158		

damage. Table 12 shows the statistical results of net marketable portion based on the rotational speed and types of helix in the reverse direction. P-value based on the type of helix was calculated as 0.0987. That was higher than the significance level of 0.05, which showed no significant difference between the types of helix and net marketable portion. However, P-value based on rotational speed was calculated as 0.0002. That was lower than the significance level of 0.05, which showed significant difference between the rotational speed and net marketable portion. Therefore, it can be said that net marketable portion was influenced by the rotational speed and increased with increasing rpm.

The dividing ratio at 400 rpm was high in the reverse direction; therefore, an additional test in the forward direction was conducted. As in Table 13, the results for the conditions of double helix, forward direction, and reverse direction were compared using one-way ANOVA. The results in the reverse direction showed a higher value than for the forward direction. However, P-value (0.6825) was greater than the significance level of 0.05, and it was considered to show no significant difference between the winding directions of the helix.

Table 14 shows the comparison of a triple helix in the forward direction and reverse direction; gross harvest efficiency was high in the reverse direction, as with the double helix. However, P-value (0. 2727) was larger than the significance level of 0.05, which showed no significant difference between the winding directions of the helix.

Before operating the pepper harvesters in other countries, Ethephon was applied to the plants to dampen the leaves. To make similar conditions, an additional experiment was conducted with leaf-removed plants. The experimental conditions were the double helix, 400 rpm, and reverse direction. Tables 15 and 16 show the statistical results of gross harvest efficiency and mechanical damage based on

Table 14. Gross harvest efficiency with triple helix and 400 rpm

Source	DF	ANOVA SS	Mean Square	F Value	Pr > F
Winding direction of the helix	1	33.1350	33.1350	1.16	0.2727
Error	4	82.0876	20.5219		
Total	5	115.2226	53.6569		

Table 15. Statistical results of gross harvest efficiency based on removal of leaves

Source	DF	ANOVA SS	Mean Square	F Value	Pr > F
With/without leaves	1	75.9045	37.9522	0.59	0.6091
Error	4	193.7746	64.5915		
Total	5	269.6791	102.5437		

Table 16. Statistical results of mechanical damage based on removal of leaves

Source	DF	ANOVA SS	Mean Square	F Value	Pr > F
With/without leaves	1	13.8457	6.9228	1.08	0.4443
Error	4	19.2988	6.4329		
Total	5	33.1445	13.3557		

removal of leaves. For all conditions (with leaves and without leaves), significant difference was not observed in the results. Therefore, it can be said that gross harvest efficiency and mechanical damage were not influenced by the presence or absence of leaves.

Conclusions

This study analyzed the performance of the picking head of self-propelled pepper harvesters. A screw type picking head was developed to examine the performance by considering the winding directions, types, and rotational speeds of the helix. Gross harvest efficiency, mechanical damage, and net marketable portion were measured in the conditions of reverse direction, double helix, and triple helix at each rotational speed. Additional tests in the forward direction and with leaf-removed plants were conducted. One-way ANOVA and two-way ANOVA were used to analyze gross harvest efficiency based on the rotational speeds and types of helix. Mechanical damage and net marketable portion were also analyzed. The results of this study are as follows:

(1) The results of the double helix and triple helix experiments in the reverse direction showed a gross harvest efficiency of 60–95%, mechanical damage of 8–20%, and a net marketable portion of 50–80%. The dividing ratio was the highest at a rotational speed of 400 rpm. Gross harvest efficiency was influenced by the types of helix and rotational speed. Net marketable portion was influenced by the rotational speed but not influenced by the type of helix. Mechanical damage was not influenced by the type of helix or rotational speed.

(2) The results of gross harvest efficiency, mechanical damage, and net marketable portion in the forward direction showed that no factors influenced the dividing ratio.

(3) The presence of leaves on the plants in the reverse direction did not influence the dividing ratio or damage ratio.

(4) The best dividing ratio was observed at a rotational speed of 400 rpm. However, vibration was generated at this speed, which could be dangerous in operating the device; therefore, methods to reduce the vibration at 400 rpm should be examined.

(5) Further studies about field tests with once-over harvested peppers are needed to improve the device.

Conflict of Interest

The authors have no conflicting financial or other interests.

Acknowledgement

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