

An Analysis of Design Factors for Developing *Opuntia Humifusa* Spines Removal Device

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Received: June 10th, 2013; Revised: August 6th, 2013; Accepted: August 24th, 2013

Abstract

Purpose: *Opuntia Humifusa* has been used in the food and beauty industry after removing spines and glochids clearly. This study compared the methods used in removing spines and analyzed the design factors for developing a spine removal device. **Method:** This study compared the spine removal ratios in accordance with the length of brush, water spray pressure, the number of water spray, and the size of *Opuntia Humifusa* in a rotating brush device and a water spray device. In addition, this study compared the reversal ratios according to the inclination angle of a conveyor, the drop height of *Opuntia Humifusa*, and the speed of the conveyor to analyze the reversal factors. **Results:** The spines were not removed clearly in the rotating brush method, and the glochids were nailed deeply. The spine removal ratio was 96.9% with the water spray pressure of 20 kgf/cm² and the conveyor speed of 10 cm/s in the water spray method. The number of water spray was correlated with the spine removal ratio, and the average spine removal ratio was 95.6% with three cycles of water spray. The reversal ratio was 97% with the inclination angle of the conveyor 20°, the drop height of 380 mm, and the conveyor speed of 10 cm/s. **Conclusions:** In order to develop a *Opuntia humifusa* spine removing device, this study compared the rotating brush and water spray methods. As a result, each spine removal performance of the rotating brush and water spray methods was 96.9% and 95.6%, respectively. Although the performance of the rotating brush method was slightly higher than that of the water spray method, the water spray method was suitable for removing spines from stem because the epidermis of stem was damaged and the glochids were nail deeply in the rotating brush method. Further studies on appropriate arrangement of spray nozzles, maintaining the optimal water spray pressure, the speed and angle control of the feeding conveyor, and devices for inducing the stem to the center will be needed in combining the water spray device and the reversal device.

Keywords: Brush, *Opuntia humifusa*, Reversal device, Spine remover, Water spray

Introduction

Opuntia Humifusa is a Korea native cactus which is rich in fiber, calcium, and vitamin C, and its antioxidant effect is higher than *Opuntia ficus-indica* var *saboten* (Kwon and Song, 2005; Lee et al, 2004; Park et al, 2005). Its fruits and stems are used in cosmetics, tea, soap, noodle, and rice wine due to the effective ingredient.

Opuntia Humifusa grows up to 30 cm and has glochids while *Opuntia ficus-indica* var *saboten* grows up to 1-2 m

and has long and thick spines. The stem of one *Opuntia Humifusa* has 40-60 spine follicles, and 2 mm long 200 glochids are embedded on the epidermis of one spine follicle (Kim, 2011, Moon, 2003). The spines should be removed to be used in the food and beauty industry; otherwise, it would degrade the taste or hurt the skin (Oh and Lee, 2011). The food processing of *Opuntia Humifusa* starts with cleaning and freeze-drying, crushing, extracting, mixing, and packaging follow next (Kim and Kim, 2011; Lim, 2012). Therefore, removing spines at the cleaning stage is an essential part in the food processing of *Opuntia Humifusa*.

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There are several methods to remove spines from Opuntia Humifusa or Opuntia ficus-indica var saboten. Some conventional methods used the friction of rubber (Charles and Felker, 1987) and the plastic brush attached to two rollers (Lydakakis et al, 2005; Moon, 2001). Both the methods were applied to removing the spines of Opuntia Humifusa, but the glochids were not removed clearly. According to Kim and Kim (2012), the spines were removed by the friction of the Opuntia Humifusa and the brushes when Opuntia Humifusa and water were placed and agitated in a drum with the brushes. However, this method damaged Opuntia Humifusa and did not remove the glochids. Oh and Lee (2011) sliced the epidermis of Opuntia Humifusa 1.0-1.5 mm using a compression-rotation slice device, but this method degraded the processing yield.

Thus, the spine removing without damage and loss to Opuntia Humifusa is an essential part in the processing of Opuntia Humifusa. This study compared several spine removal methods in order to design an effective device. In addition, this study analyzed the design factors for developing a spine removal device.

Materials and Methods

This study compared the spine removal ratios in accordance with the length of brush, water spray pressure, the number of water spray, and the size of Opuntia Humifusa using a rotating brush device and a water spray device. In addition, this study compared the reversal ratios according to the inclination angle of a conveyor, the drop height of Opuntia

Humifusa, and the speed of the conveyor to analyze the reversal factors.

Materials

The frozen stems of Opuntia Humifusa produced at Bian-myun, Uiseong-gun, Gyeongbuk province were used for this study. This study selected and used Opuntia humifusa similar in size because it varies in size from 50 to 100 mm. Different-sized Opuntia humifusa were used because the Opuntia humifusa used for the brush method and the water spray method were produced in different periods. The width of the stem was regarded as the size of Opuntia Humifusa shown in Figure 1(A). Three different sizes of stem, 60 ± 1.6 mm, 80 ± 0.9 mm, and 85 ± 1.2 mm, were used with the brush method, and 72 ± 0.8 mm, 83 ± 1.3 mm, 94 ± 1.7 mm were used with the water spray method. Figure 1(B) shows the glochids which were embedded on the epidermis.

Experiments

Spine removal device by rotating brush

The rotating brush method removed the spines by rotating a brush on the fixed stem. The device was composed of the rotating brush and a holder which fixed the stem.

The rotating brush was made of polyethylene; two different bristle lengths 20 mm and 70mm were used for this study. The holder should endure the contact force of the brush, and it should be flat to ensure maximum contact area with the curved shape stem. Thus, the holder was made with 2 mm thick stainless wire by collocating at 20 mm intervals, and the size of it was 170×320 mm.

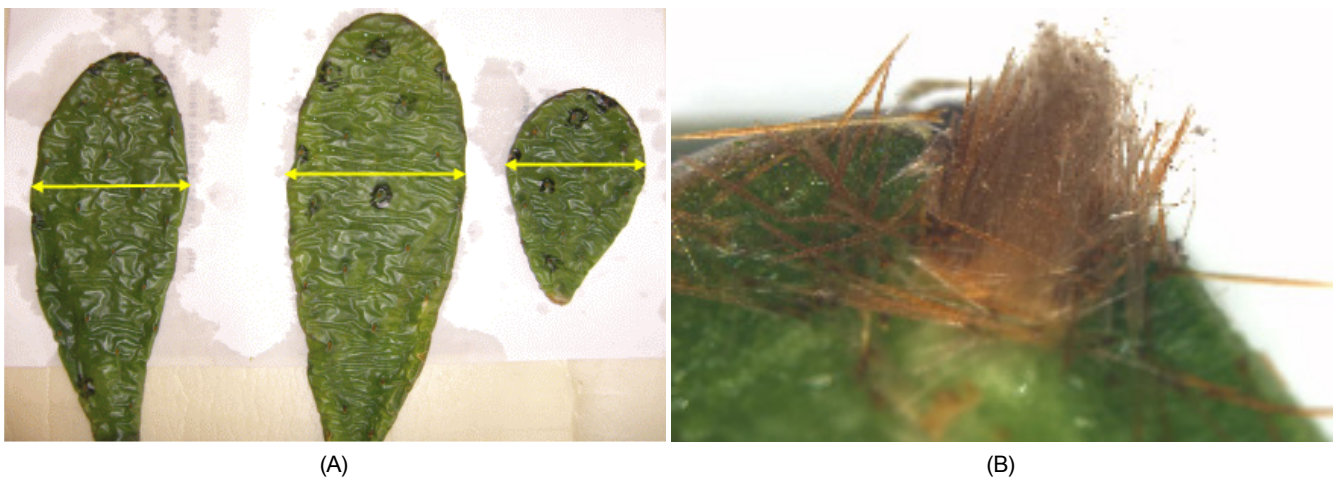


Figure 1. Three sizes of the stem (A) and glochids in one spine follicle (B).

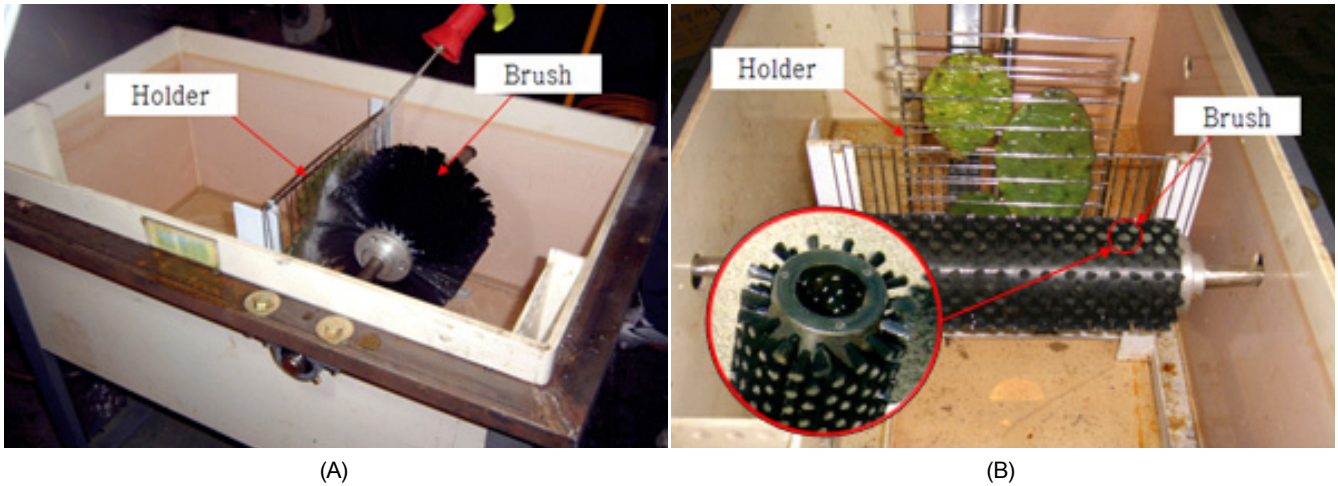


Figure 2. Rotating brush device with 70 mm bristle lengths (A) and 20 mm (B).

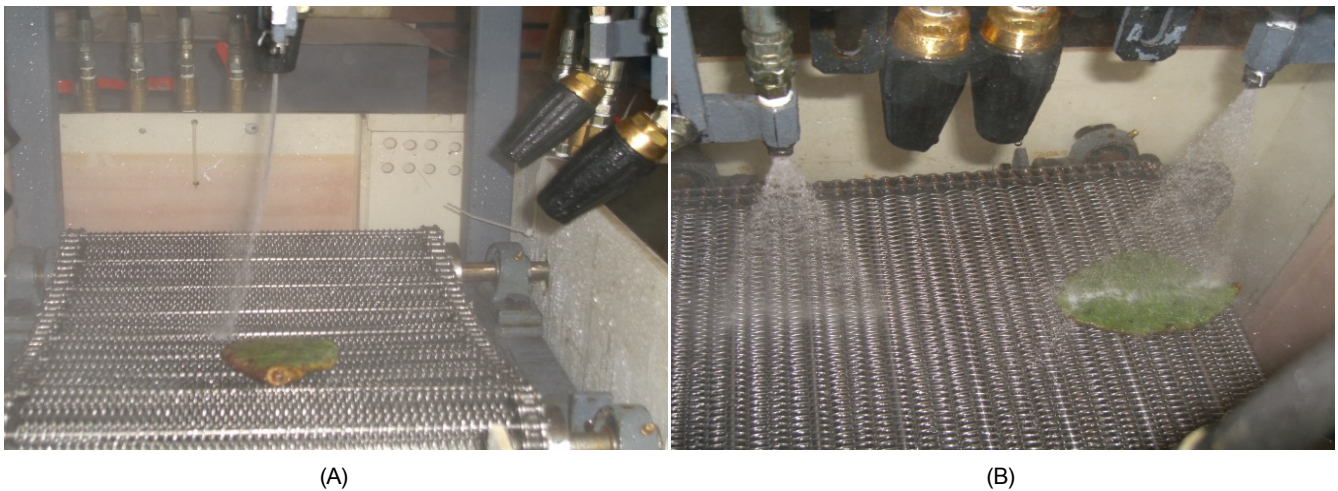


Figure 3. Rotating nozzle (A) and fan shaped nozzles (B).

Water spray device

The spines were removed by the water pressure on the stem fixed with various shaped nozzles in the water spray device. In the prior experiment, spines were not removed when using spray type nozzles and removed when using linear type nozzles. However, a linear type nozzle was not effective because the area to remove spines was too small when using it. Linear and rotating nozzle were effective because the area to remove spines became larger when using it.

A ray of water was sprayed at an angle of 20° in circular motions from the rotating nozzle (Nozzle 7265, Cat Pumps Inc., USA), and the throw distance was set by 200 mm considering the width of the stem. The device for removing spines on the side was needed because the spines were spread on the side along with the front and the back of the

stem. Each two rotating nozzles were arranged on the upper, the left, and the right side of the device, and the spray angle on the side was 45° . Power sprayer (WPS-100A, Wondae Precision, Korea) and regulator controlled the pressure of the nozzles.

The stem of Opuntia Humifusa was slipped to the side due to the sprayed water pressure. For this reason, the fan shaped nozzles (VP, DST, Korea) were used for fixing, and they fixed the stem well. The fan shaped nozzles were shown in Figure 3(B), and they were arranged at the same intervals as the rotating nozzles.

A reversal device was needed to remove the spines on the back side after removing them on the front. After the stem was transferred to the conveyor, it was flipped over at the same time with dropping as in Figure 4. The reversal factors were discovered while controlling the angle and

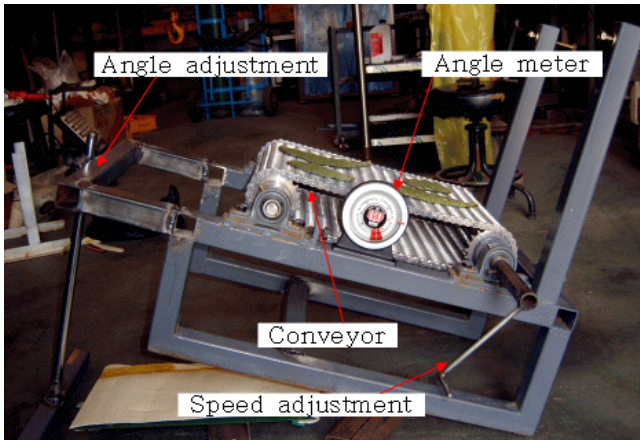


Figure 4. The reversal device.

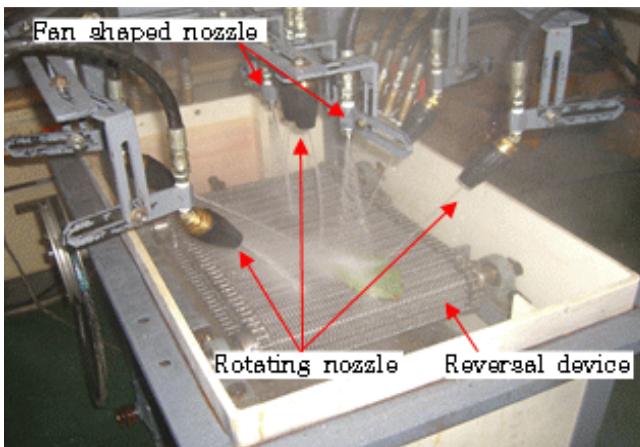


Figure 5. The water spray device with the reversal device.

the speed of the conveyor.

Figure 5 shows the water spray device with the reversal device used for this study.

Method

Performance test of the spine removal device

The experiments were conducted to see the performance of the rotating brush method and the water spray method. The performance was represented as a ratio shown in equation (1) by counting the number of the spines before and after the experiment. The removal of the spines was observed by the naked eyes.

$$T = \frac{B - A}{B} \times 100 \quad (1)$$

where, T : Spine removal ratio (%)

A : the number of the spines after the experiment (ea)

B : the number of the spines before the experiment (ea)

Performance test of the rotating brush

The experiments were conducted with two different length bristles, 20 mm and 70 mm, and compared the spine removal performance depending on the bristle lengths. The brushes were directly connected to the rotating motor at 1,710 rpm. The front and the back of the stem were contacted with the brush six times respectively.

Performance test of the water spray device

Optimal water pressure and the conveyor speed were calculated while varying pressure and speed. With these values, the performance of spine removal of each size of stem and the number of water spray were analyzed.

The experiment was conducted with the water pressure of 15, 20, 25 kgf/cm² and the conveyor speed of 5, 10, 15 cm/s. The stem was placed on the rotating stainless steel chain belt, and the water was sprayed three times on each side of it.

Performance test of the reversal device

The test was conducted 100 times with the inclination angle of the conveyor 15, 20, 25°, the drop height of 330, 380, 430 mm, and the conveyor speed of 5, 10, 15 cm/s, respectively. The performance was represented as a ratio shown in equation (2) by calculating the number of reversal while dropping and test times.

$$R = \frac{Nr}{No} \times 100 \quad (2)$$

where, R : Reversal ratio (%)

Nr : Number of reversed stem (ea)

No : Number of stem (ea)

Results and Discussion

Performance result of the spine removal device

The spine removal ratio by the rotating brush device is shown in Table 1. The 20 mm bristle showed 12.4% removal ratio on the front and back, 2.0% on the side. The 70 mm bristle showed 96.9% on the front and back, but 18.3% on the side. From the results, the spine removal ratio by the bristle lengths showed that the larger brush was much better than the smaller one and another device for

Table 1. Spine removal ratio by the rotating brush device (Unit : ea, %)

| Brush type (mm) | Thorn bundles | | Opuntia humifusa size (mm) | | | Average |
|-----------------|----------------|--------------|----------------------------|------|------|---------|
| | | | 60 | 80 | 85 | |
| 20 | Before | Back & forth | 43 | 48 | 45 | 45.3 |
| | | Side | 19 | 17 | 17 | 17.7 |
| | After | Back & forth | 38 | 40 | 41 | 39.7 |
| | | Side | 19 | 16 | 17 | 17.3 |
| | Removing ratio | Back & forth | 11.6 | 16.7 | 8.9 | 12.4 |
| | | Side | 0 | 5.9 | 0 | 2.0 |
| 70 | Before | Back & forth | 43 | 46 | 43 | 44.0 |
| | | Side | 20 | 17 | 18 | 18.3 |
| | After | Back & forth | 2 | 0 | 2 | 1.3 |
| | | Side | 14 | 17 | 14 | 15.0 |
| | Removing ratio | Back & forth | 95.3 | 100 | 95.3 | 96.9 |
| | | Side | 30 | 0 | 22.2 | 17.4 |

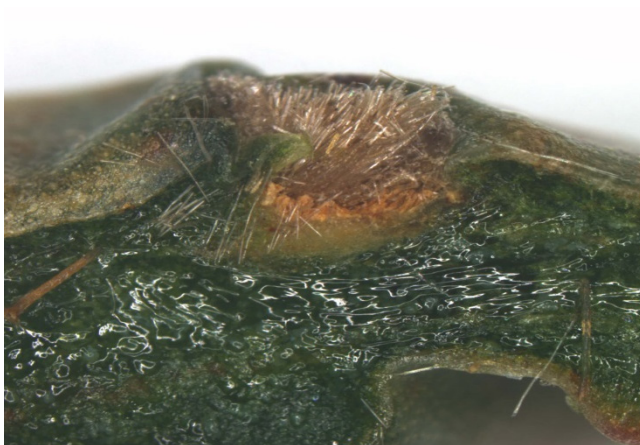


Figure 6. Shot of the spine-removed stem taken with an electron microscope.

removing spines on the side was needed.

However, a shot of the spine-removed stem taken with an electron microscope showed that glochids were embedded on the epidermis though the spines on the surface were removed. When the brush was rotated more to remove the glochids, the epidermis of the stem was damaged and the glochids were nail deeply. Therefore, the rotating method was not suitable for removing spines from the stem.

Performance result of the water spray device

Performance result in accordance with the water spray pressure and the conveyor speed

The performance result in accordance with the water spray pressure and the conveyor speed is shown in Table 2. The performance results showed the spine removal

Table 2. Spine removal ratio in accordance with the water spray pressure and the conveyor speed (Unit : %)

| Water injection pressure (kgf/cm ²) | Conveyor speed (cm/s) | | | Remarks |
|---|-----------------------|----|----|---------|
| | 5 | 10 | 15 | |
| 15 | 88 | 80 | 76 | - |
| 20 | 98 | 97 | 92 | - |
| 25 | - | - | - | Damage |

ratio of 98% with the water spray pressure of 20 kgf/cm² and the conveyor speed of 5 cm/s. But in terms of work efficiency, the conveyor speed of 10 cm/s was considered the best though the ratio was 97%. The water spray pressure of 25 kgf/cm² damaged the stem, so it was not suitable for removing the spines.

Since optimal water spray pressure was 20 kgf/cm², there should be regulator to maintain the water spray pressure 20 kgf/cm².

Performance result in accordance with the number of water spray and the stem size

Table 3 shows the spine removal ratio in accordance with the number of water spray and the stem size. When the spines and water spray direction were at right angles to each other, they were removed 100%. However, the spines on the curvy stems were not completely removed because the spines and water spray direction were not at right angles to each other. There was a tendency that small size of the stem had high spine removal ratio, but it showed no significant difference ($P > 0.05$). However, the

Table 3. Thorn removing ratio by the size and number of injection(Unit : ea, %)

| Number of cycles ^{a)} | Thorn bundles | Size of stem (mm) | | | Average |
|--------------------------------|----------------|-------------------|------|----|---------|
| | | 72 | 83 | 94 | |
| 1 | Before | 21 | 22 | 25 | 22.7 |
| | After | 8 | 9 | 8 | 8.3 |
| | Removing ratio | 61.9 | 59.1 | 68 | 63.0 |
| 2 | Before | 21 | 22 | 25 | 22.7 |
| | After | 3 | 4 | 5 | 4.0 |
| | Removing ratio | 85.7 | 81.8 | 80 | 82.5 |
| 3 | Before | 21 | 22 | 25 | 22.7 |
| | After | 0 | 1 | 2 | 1.0 |
| | Removing ratio | 100 | 95.5 | 92 | 95.8 |

^{a)} Significantly different parameter between number of cycles

Table 4. Reversal efficiency of Opuntia humifusa (Unit : %)

| Angle ^{a)} (°) | Drop height (mm) | Conveyor speed (cm/s) | | |
|----------------------------|---------------------|-----------------------|----|----|
| | | 5 | 10 | 15 |
| 15 | 330 | 76 | 79 | 77 |
| | 380 | 78 | 81 | 79 |
| | 430 | 75 | 77 | 76 |
| 20 | 330 | 91 | 94 | 92 |
| | 380 | 96 | 97 | 95 |
| | 430 | 90 | 93 | 91 |
| 25 | 330 | 73 | 75 | 73 |
| | 380 | 74 | 76 | 73 |
| | 430 | 72 | 73 | 70 |

^{a)} Significantly different parameter between angle

number of water spray was correlated with the spine removal ratio ($P < 0.001$). Three cycles of water spray showed the best result (95.8%), but it damaged the surface of the stem. Thus, no more than three cycles of water spray should be arranged when developing the process with spines removal devices.

Performance result of the reversal device

Table 4 shows the reversal efficiency of the stem with the reversal device. The reversal ratio was high with 97 % when the inclination angle was 20° with drop height of 380 mm and speed of 10 cm/s.

Reversal ratio was not correlated with the conveyor speed and the drop height ($P > 0.05$), but the conveyor speed of 10 cm/s was suitable considering the optimal speed of the spine removal ratio. Inclination angle of 20° was suitable ($P < 0.001$), but the stems were slipped back with the angle of 25°. In addition, the stem arranged

in the middle of the conveyor was not landed at the same position after dropping and reversing. Considering the water spray range and angle, the stems should be placed on the middle of the conveyor to remove the spines effectively. Therefore, a device for inducing the stem to the center was needed to remove the spines on the back side of the stems.

Conclusions

Opuntia Humifusa has excellent effective components, so it is used in the food and beauty industry after spines and glochids were removed clearly. This study compared the methods used in removing spines and glochids. The results of the analysis about the design factors for developing a spine removal device are as follows:

- (1) The spine removal device with 70 mm long bristle showed 96.9% on the front and back, but 18.3% on the side. This study found that the brush method was not appropriate because it did not remove glochids at all. Furthermore, it needs another device for removing spines on the side.
- (2) The performance result showed the spine removal ratio of 96.9 % with the water spray pressure of 20 kgf/cm² and the conveyor speed of 10 cm/s. However, when the brush was rotated more to remove the glochids, the epidermis of the stem was damaged and the glochids were nail deeply. Therefore, the rotating method was not suitable for removing spines from the stem.
- (3) Performance result of the spine removal ratio in accordance with the number of water spray and the stem size showed that the number of water spray was correlated with the spine removal ratio. Three cycles of water spray showed the best result 95.8%.
- (4) The reversal ratio of the stem was high with 97 % when the inclination angle was 20° with drop height of 380 mm and speed of 10 cm/s.

The water spray method was effective in removing spines of Opuntia Humifusa. Further studies on appropriate arrangement of spray nozzles, maintaining the optimal water spray pressure, the speed and angle control of the feeding conveyor, and devices for inducing the stem to the

center after reversing will be needed in combining the water spray device and the reversal device.

Conflict of Interest

The authors have no conflicting financial or other interests.

Acknowledgement

This research was supported by Kyungpook National University Research Fund, 2012.

References

- Charles, E. R and P. Felker. 1987. The Prickly-pears (*Opuntia* spp., Cactaceae): A Source of human and animal food in Semiarid Regions. *Economic Botany* 41(3):433-445.
- Kim, D. S. 2011. *Opuntia humifusa* cultivation and storage technology. Seoul: Pubple (in Korean).
- Kim, J. K and M. G. Kim. 2012. Slice of Multipurpose Slice Cactus. Korean Patent Publication No.1020120078227 (In Korean).
- Kwon, D. K and Y. J. Song. 2005. Effect of *Opuntia humifusa* supplementation on endurance exercise performance in rats fed a high-fat diet. *The Korean Journal of Exercise Nutrition* 9(2):183-188 (in Korean).
- Lee K. S., M. G. Kim and K. Y. Lee. 2004. Antimicrobial effect of the extracts of cactus Chounnyouncho (*Opuntia humifusa*) against food borne pathogens. *Journal of the Korean Society Food Science and Nutrition*. 33(8):1268-1272 (in Korean).
- Lee, M. I and J. S. Oh. 2011. A manufacturing process of a slice pack for beauty of a raw cactus stem (leaf). Korean Patent Publication No.1020110030047 (In Korean).
- Lim, 2012. Development of small packaging juice powder with *Opuntia* spp. Goyang Agriculture Technology Center (in Korean).
- Lydakis, D., N. Pompodakisa, E. Markelloub and S.M. Lionakisa. 2005. Storage response of cactus pear fruit following hot water brushing. *Postharvest Biology and Technology* 38(2):145-151.
- Moon, Y. I. 2000. Device for removing a thorn of a falm cactus fruit. Korean Patent Publication No.1020010090192 (In Korean).
- Moon, Y. I. 2003. Studies on cultural practices, composition and functional effect of *Opuntia ficus-indica* var. savoten. PhD diss. Cheju: Cheju national University, Department of Horticulture (in Korean).
- Park, M. K., Y. J. Lee and E. S. Kang. 2005. Hepatoprotective effect of Cheonnyuncho (*Opuntia humifusa*) extract in rats treated carbon tetrachloride. *Korean Journal of Food Science and Technology* 37(5):822-826 (in Korean).