Original Article | Journal of Biosystems Engineering

J. of Biosystems Eng. 39(4):290-298. (2014. 12)
http://dx.doi.org/10.5307/JBE.2014.39.4.290

eISSN : 2234-1862
pISSN : 1738-1266

Development of Welsh Onion Harvester for Tractor

Sungha Hong[1], Kyouseung Lee[1], Yongjin Cho[1], Wonyeop Park[2]*

[1]*Dept. of Biomechatronics Engineering, Sungkyunkwan University, Suwon, Kyeonggi 440-746, Republic of Korea*
[2]*Dept. of Mechanical Engineering, Hankyong National University, Anseong, Kyeonggi 456-749, Republic of Korea*

Received: November 4th, 2014; Revised: November 19th, 2014; Accepted: November 20th, 2014

Abstract

Purpose: To ascertain the increase of the farm income that predominantly relies on human resources by mechanizing Welsh onion harvesting, a tractor-mounted Welsh onion harvester was developed in this study. **Method:** An experiment for evaluating harvesting performance was performed for the developed Welsh onion harvester in an actual Welsh onion farm. The harvest performance was evaluated at the tractor running speeds of 5.0 cm/s, 11.4 cm/s and 15.8 cm/s, by comparing the operating efficiency, harvest rate, and damage rate of the Welsh onion harvester. **Results:** The performance of the harvester was rated as very good, with a 100% harvest rate, regardless of tractor running speed. Furthermore, it is shown that work efficiency of the harvester is expected to increase as the running speed increases. Nonetheless, the damage rate of the harvested Welsh onions at running speeds 5.0 cm/s, 11.4 cm/s, and 15.8 cm/s, increased correspondingly and proportionally to speeds from 4.55% to 6.53% and to 11.29%. The residual amount of soil on the harvested Welsh onions was about 0.24% of their weight showing excellent soil-removal performance of the harvester. **Conclusion:** The developed Welsh onion harvester is believed to improve the labor productivity and cultivation environment of Welsh onion farmhouses by the mechanization of the harvesting process that is currently associated with the largest amount of labor hours.

Keywords: Damage rate, Harvest rate, Harvester, Tractor, Welsh onion

Introduction

The Welsh onion is an upland crop and is classified as a condiment vegetable. Nationally, on a harvest area basis, Welsh onions are grown in 7,292 ha in 40,018 households (Statistics Korea, 2010). It is known as a high-income crop since it produces 3,333 kg of main products in 10 a, which corresponds to a gross profit of 3,806,000 Won. A total of 128.4 h of labor time is expended to produce Welsh onions, from sowing to harvest, and the harvesting process occupies the highest proportion of consumed labor hours, which is 42.1 h (32.8%) (Rural Development Administration, 2013). Welsh onions can be grown almost in any soil type with minimal expected damage during the harvest. They have been grown extensively in plain areas, such as Jeollanam-do (42.5%), and Gyeonggi-do (13.1%), in spite of their characteristic as an upland crop. The ratio of the Welsh onion harvested areas per household is large compared to other upland crops, and exhibits a high tendency of large-scale farming in reference to the component ratio (Statistics Korea, 2010). To increase the farm size and productivity of Welsh onion cultivations that currently constitute 55.4% of gross profits, a reduction in the employment and self-labor charges is necessary. Thus, the mechanization of the harvesting operations associated with the largest proportion of invested labor time in comparison to the overall labor charge is required. In other words, the development of the Welsh onion harvester that will ultimately reduce the costs and improve the labor productivity is urgently required.

Since the 1970s, studies on the Welsh onion harvester have been carried out mostly in Japan. Fujii et al. (2008) evaluated the differences between the Welsh onion species

***Corresponding author:** Wonyeop Park
Tel: +82-31-670-5111; **Fax:** +82-31-670-5118
E-mail: wypark@hknu.ac.kr

by measuring their properties. Katahira et al. (2004) compared the work efficiency and accuracy in the Welsh onion cultivation between the practical method and the mechanized method. They also investigated the effect of the rotary blade type and its arrangement on the quality improvement of the Welsh onion (specifically focusing on the length of the white stems). On the domestic side, various types of research targeted the diverse range of harvesters. For example, some of these include the potato harvester using a vibration mechanism in the cultivators and tractors (Kang et al., 1989; Kang et al., 1993), the proper cabbage harvester design factor investigation (Hong et al., 2001), the cultivation method, and cutting and transporting property investigation for the development of the chive harvester (Jun et al., 2005), the development of the spinach harvester for domestic applications (Jun et al., 2007), and numerous others. However, to the best of our knowledge, studies targeting Welsh onion harvesters have not been conducted thus far.

In this study, we developed a Welsh onion harvester that can be mounted on midrange tractors (40–60 horsepower) that are mostly owned by domestic farmers. The developed Welsh onion harvester was designed for use in a variety of growing conditions, and therefore, harvesting Welsh onions with a diverse range of ridge widths and heights was considered. The purpose of this study is to increase the labor productivity and promote the farmhouse income by mechanizing the Welsh onion harvester.

Materials and Methods

Welsh onion harvester design and development

The developed Welsh onion harvester was designed as a three-point hitch mounting type, and consisted of five major units: a) the soil destruction device, b) the Welsh onion collecting device, c) the soil-separating device, d) the Welsh onion feeding device, and e) the loading and belt conveyor (B/C) feeding device (Figure 1).

Soil destruction device

The soil destruction device reduces the uplift load on the Welsh onions and induces the Welsh onions to the collecting device placed in close proximity behind the device. This is accomplished by destroying the soils on the ridge with a nonmotorized cutting disc installed in the lower front of the harvester (Figure 2). The soil destruction device comprises a cutting disc [with a manually adjustable width, and an adjustable height with hinged self-aligning (Figure 2–①)] running wheels [inducing a furrow upon the operation of the harvester (Figure 2–②)], and a cutting disc rack [adjustable for its width and height (Figure 2–③)]. The cutting disc was placed on the lower right side and was designed to be optionally used. Its purpose is to reduce the traction resistance in the soils, such as volcanic and sandy soils, and it has a low withdrawal force on the Welsh onions.

Welsh onion collecting device

The Welsh onion collecting device, equipped with a blade-shaped digging device (Figure 3–②), is a device that supplies the clump of soils, including Welsh onion roots, to the soil separation device by braking the ridge at the lower front of the harvester. The soil cutting depth for the digging device at the contact surface of the collecting device was set to maintain a height of 5 cm above the lowest point in the ridge, to operate within a distance of 25 cm below the highest point of the ridge, and to break the

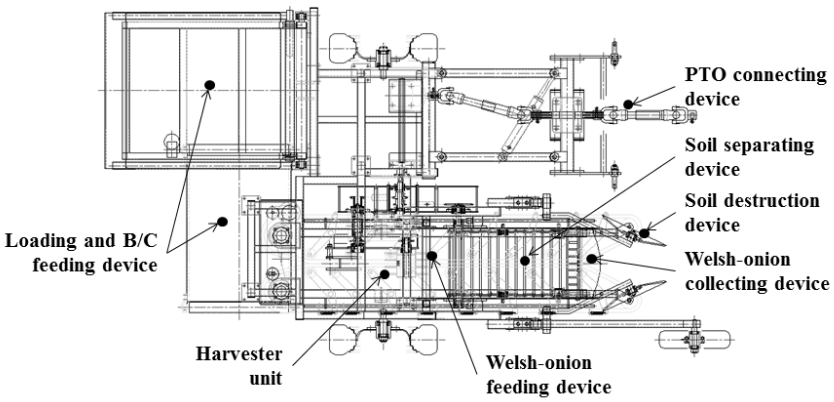
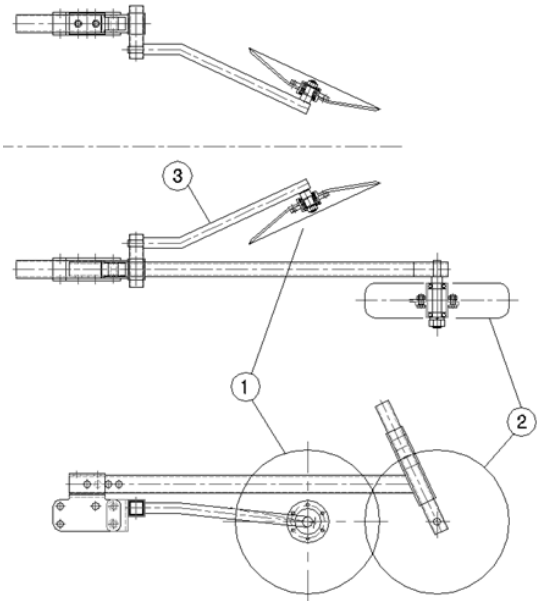


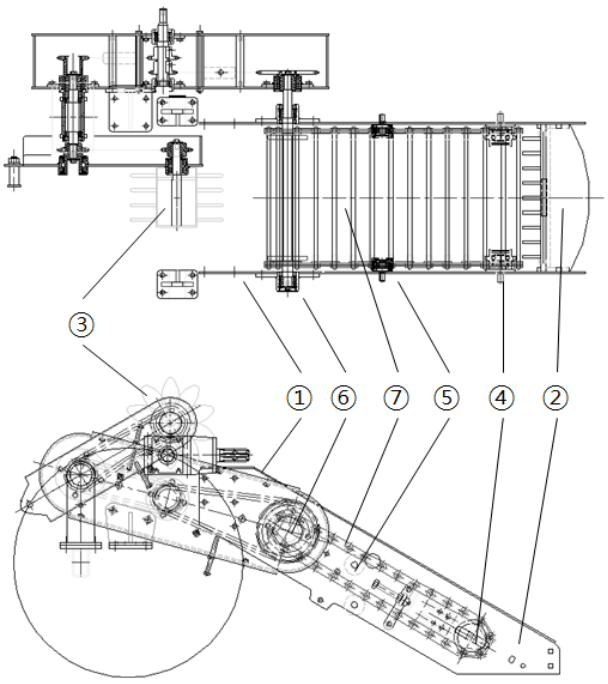
Figure 1. Schematic of the developed tractor with an attachable Welsh onion harvester.

ridge at a 30° entry angle. The body of the collecting device had an adjustable inclination angle of ±10°. In order to minimize the pull load during soil braking, the length of the contact surface of the front digging device was designed with a minimum length of 400 mm.



① Cutting disc, ② running wheels, ③ cutting disc rack

Figure 2. Soil destruction device.



① Soil-separating device, ② digging device, ③ secondary soil separating device, ④ passive roller-1, ⑤ passive roller-2, ⑥ driving roller, ⑦ round steel knife coulter

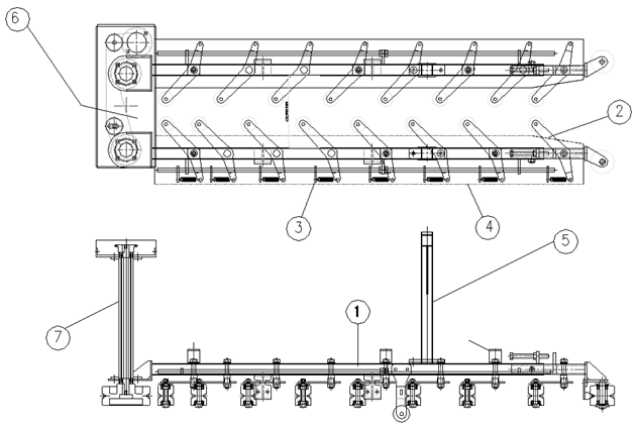
Figure 3. Welsh onion collecting device and soil-separating device.

Soil-separating device

The soil-separating device (3–①) is responsible for easing the shredding and separation of the soil attached on the Welsh onion roots during their transportation, at the lower front of the conveying device. The soil-separating device is driven by the tractor PTO power, and composed with one driving roller (3–⑥) and two of the passive rollers (3–④, ⑤) that operate the 28 round steel knife coulters [made of STS-313 (3–⑦) and having a 345 mm length]. The drive roller (Figure 3–⑥) had a secondary soil separating device attached (3–③) with a 150 mm up and down position adjustment function, thereby facilitating the removal of the soil remains from the Welsh onion roots.

Welsh onion feeding device

The Welsh onion feeding device (Figure 4) mounted on the upper frame body with a 30° inclination supplies the Welsh onions transported through the soil separating device to the feed conveyor belt at the rear end. The Welsh onion feeding device operates through a power transmission unit (4–⑦) using hydraulic power and is decelerated by a gear box (4–⑥). The transfer belt was designed to operate at a speed of 67.8 cm/s. The conveyor belt had a 20 mm cushion thickness on the outer side of the rubber belt, an 80 mm width and a 4531 mm length, to reduce damage on the Welsh onions during transport. The top of the transfer belt was located higher than the loading and B/C feed device so that the Welsh onions could be dropped to the discharge unit. The conveyer belt on the Welsh onion feeding device was powered by hydraulic motors placed on the left and right, and was operated at a



① Feeding device, ② guide roller, ③ idler hinge, ④ conveyor belt, ⑤ right and left belt frame rack, ⑥ gear box, ⑦ power transmission unit

Figure 4. Welsh onion feeding device.

speed of 67.8 cm/s. The collected Welsh onions were discharged to the rear end by operating the hydraulic lift motor powered by the tractor hydraulic circuit.

Loading and belt conveyor feeding device

The Welsh onions passed through the feeding device and were transported from the right side to the left side along a horizontal direction through a flat belt conveyor (650 mm in width) that was installed at 830 mm above the ground level. The Welsh onions were transported from the belt conveyor (B/C) free-fall to the "U" shaped bag with no sidepiece located 680 mm apart from the loading space. When the bag fills at 0.3 m^3 (diameter of 700 mm, length of 800 mm) with about 40 kg (about 300 Welsh onions), it is discharged to the harvester's rear end with its own weight using a hydraulic link The drive motor of the lateral transfer belt installed in the B/C transport device requires 150 W of tractor power.

Figure 5 illustrates the developed Welsh onion harvester mounted on a tractor. The harvester was attached to a three-point hitch of the tractor. The harvester body itself was able to adjust the body angle depending on the cultivation environment by using the top hydraulic link of the tractor's three-point link. The entire harvesting process of the Welsh onion harvesting machine is as follows: 1) reduce the pull-out force that acts on the Welsh onions by cutting the soil around the ridge with the soil cutting device, 2) harvest the Welsh onions through the Welsh onion collecting device, while removing the soil around the roots with the soil separating device, and transport the Welsh onions to the feeding device, 3) remove the additional soil attached on the Welsh onion roots collected through the Welsh onion feeding device and transport using the secondary soil separation device, and 4) harvest the Welsh onions by supplying them to the loading and B/C transfer device.

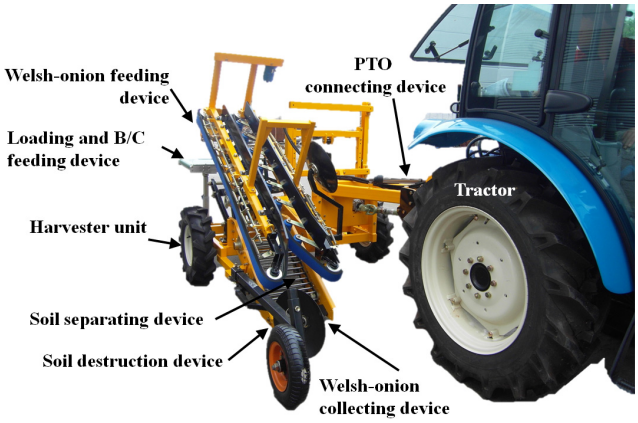


Figure 5. The developed tractor-attachable Welsh onion harvester.

Welsh onion harvesting experiment

Test environment

In order to evaluate the performance of the developed Welsh onion harvester, test packaging was performed in the major Welsh onion producer in Icheon, Gyeonggi (37°05'52.8" N, 127°31'22.08" E) (Figure 6). The farm that participated in the test was a corporate farm that grows Welsh onions in 11.7 ha. The cultivation type was spring seeding cultivation, the cultivar was single stem Welsh onion, and a three-row culture was implemented as the planting method. The soil properties of the topsoil and subsoil were sandy loam soil and sandy soil, respectively, the soil series was Nakdong series, the land slope ranged between 0–2°, and the diploid state was rated as 'very good' (RDA Soil Map, http://soil.rda.go.kr).

The ridge on the experimental field was round shaped with a row spacing of 828 mm and a hill spacing of 89 mm. The ridge height was 346 mm, the ridge width was 493 mm, and the furrow width was 287 mm (Figure 7).

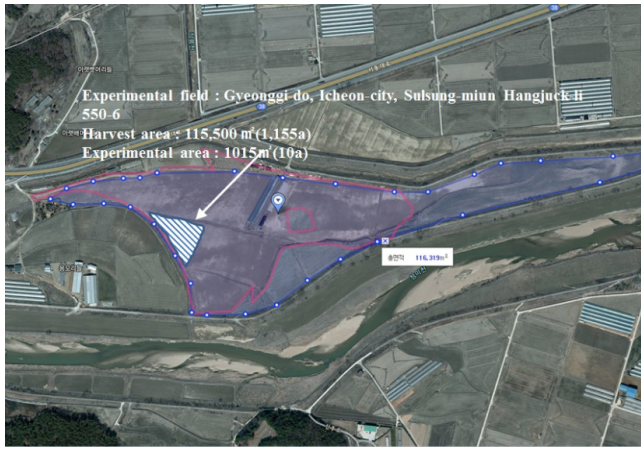


Figure 6. Satellite picture of the experimental field (Daum map, 2014).

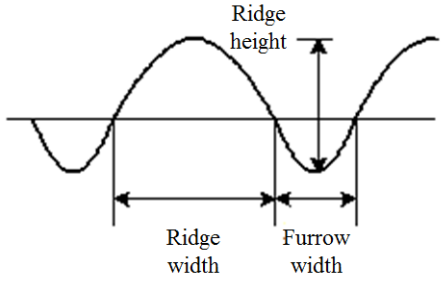


Figure 7. Ridge shape of the Welsh onion plantation.

Tractor used for experiment

The tractor used to test the Welsh onion harvester performance is one of the most widely used tractors in farmlands (Model U-43, LS Mtron, Jeonju, Jeollabuk-do, Republic of Korea) with a 40–60 horsepower. The rated tractor engine output was 43 ps (32 kW), at a rated 2600 rpm of engine speed, and a range of running speeds of 0.05 m/s–7.49 m/s.

Field experiment method

The field experiment of the Welsh onion harvester was performed in the fixed ultra-low-speed tractor operation mode (rated engine speed of 2400 rpm and PTO rotation speed of 540 rpm) at which the field work capacity, damage rate, harvest rate, and soil scrape rate were investigated. The field work capacity was recorded at three levels of tractor working speeds, namely, 5.0 cm/s, 11.4 cm/s, and 15.8 cm/s, at three respective times for a segmentation task of 10 m, and the average value was calculated. The damage rate and the harvest rate were also evaluated in the same way as that used in the field work capacity experiment, and the number of harvested Welsh onions with fair quality (before and after the experiment) was measured. During the quality evaluation, immature and aging Welsh onions were excluded. The selection or exclusion criteria for the immature Welsh onions included the assessment of the white stem thickness with a threshold set to a value equal to or less than 10 mm. Furthermore, the selection or exclusion criteria for the aging of the Welsh onions that have no commercial value owing to the leanness of the leaf sheath tip were based on simple visual inspection.

The classification criteria in relation to the thickness of the Welsh onions were based on the total quantity of the Welsh onions harvested in the 10 m areas during the three times the segmentation task was performed. The sample size for the assessment of the itemized material properties was selected in consideration of the standard for the composition ratio of the total amount. The major properties of the measured Welsh onions were: a total length (d_1) of 805.3 mm, leaf sheath (d_2) of 311.9 mm, white stem (d_3) of 208.4 mm, and white stem width (d_4) of 18.02 mm (Figure 8). The measured Welsh onions were samples from an outdoor, spring seeding, plant cultivar, and the cultivation method was a three-row culture. The Welsh onion planting date was June 5th, and the measurement date was October 7th with 124 days of cultivation period.

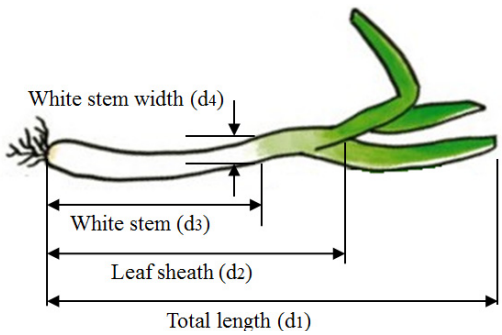


Figure 8. Physical properties of Welsh onion.

Results and Discussion

A sample survey of welsh onion

The quality of Welsh onions was evaluated based on several factors, such as the length and width of the white stem. However, the length of the white stem could not be measured until harvest since the white stem was dispersed under the soil. In order to measure the weight of the Welsh onion relative to its thickness, the weight was divided into eight different levels from 10 mm to 26 mm, with a 2 mm interval, and one with a length of over 26 mm. The unit weight of the Welsh onion for each level of the white stem width was calculated on the basis of the 1276 Welsh onion samples. All the collected samples were categorized into nine levels. The thicknesses and weights of the Welsh onion samples collected are shown in Table 1. Figure 9 shows the correlation of the Welsh onion's white stem

Table 1. The distribution of the thickness and weight of the collected Welsh onion samples

White stem width (mm)	Number based classification		Weight based* classification		Unit weight**
	(ea)	(%)	(kg)	(%)	(g/ea)
10–12	62	4.9	3.30	1.9	53
12–14	181	14.2	12.69	7.3	70
14–16	274	21.5	25.89	15.0	94
16–18	259	20.3	31.52	18.3	122
18–20	210	16.5	34.42	19.9	164
20–22	158	12.4	31.32	18.1	198
22–24	78	6.1	18.60	10.8	238
24–26	35	2.7	9.46	5.5	270
>26 mm	19	1.5	5.50	3.2	289
Total	1,276	100	172.7	100	135.3

* This category represents the total weight of samples at each level
** The unit weight is the average weight

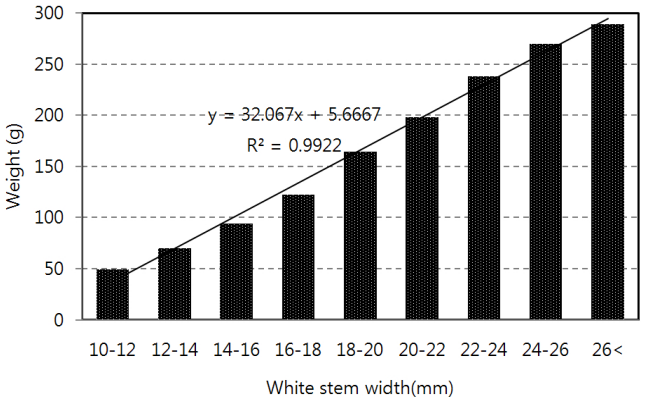


Figure 9. Correlation plot of Welsh onion's white stem width and weight.

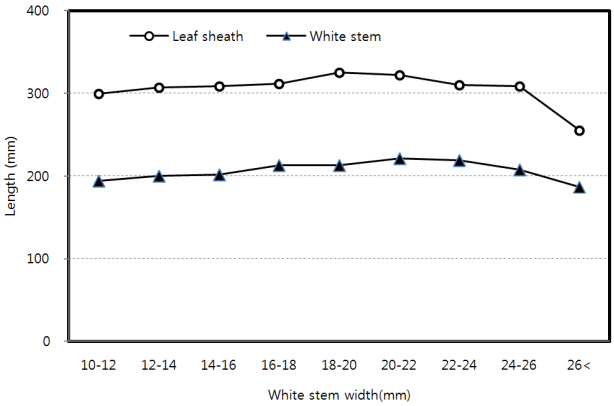


Figure 10. Variation of the leaf sheath length according to the thickness of the white stem.

Table 2. Measured physical properties of Welsh onions

White stem width (mm)	Total length (d_1) (mm)	Leaf sheath length (d_2) (mm)	White stem length (d_3) (mm)
10–12	746	300	194
12–14	763	307	200
14–16	770	309	202
16–18	821	312	213
18–20	831	325	213
20–22	826	322	221
22–24	880	310	219
24–26	841	309	208
>26 mm	850	255	187
Average	805.3	311.9	208.4

width and weight.

The average thickness of the onion's white stem was 18 mm, with an average weight of 135.3 g, based on the 1276 Welsh onions harvested, as shown in Table 1. The weight of the Welsh onions relative to the thickness of the white stem is shown to increase linearly with respect to the thickness of the white stem. In addition, the value of R^2 for the correlation plot of the weight and white stem width was found to be 0.99. This value is significantly high and indicates that the thickness of the white stem is closely related to the weight of the Welsh onion. The analysis of texture of the Welsh onions was based on the nine different white stem thickness levels, with a reported average value for each cohort of ten samples, for the total length of the Welsh onion, leaf sheath, and white stem. The measurement results are shown in Table 2.

Figure 10 shows the variation of the length of the white stem and the leaf sheath according to the thickness of the white stem. Interpreting these results implies that increasing the thickness of the white stem leads to increases in the length of the white stem and the leaf sheath. However, the length of the white stem and the leaf sheath tend to decrease when the thickness of the white stem exceeds 20–22 mm. Therefore, the thickness of white stem needs to be considered before making a decision for the quality and harvest time.

Performance test for tractor for harvesting welsh onion

Operating efficiency of tractor

To investigate the rate of the tractor for harvesting Welsh onions, a harvest experiment was performed at three different running tractor speeds at 5.0 cm/s, 11.4 cm/s, and 15.8 cm/s. As a result, the times to harvest a 10 a area at each different tractor running speed were 27,000 s, 10,524 s and 7,596 s, respectively. Therefore, the operation area per total harvesting time at the three different speeds were 1.3 a/h, 2.7 a/h, and 3.4 a/h, respectively. Consequently, when the running speed of the tractor increased, the efficiency of harvesting the Welsh onions also increased.

In addition, the harvest rate was also investigated at the three different running speeds. Therefore, for the tractor used for harvesting Welsh onions in this study, the harvest rate was 100%, regardless of the tractor speed. These are truly outstanding results. The harvest processing and the conditions of packing after the Welsh onion harvest are shown in Figure 11.

Examination of the rate of damages

The quality of Welsh onions is affected by the level of damage. Welsh onions that are damaged while harvesting

Figure 11. Photographs depicting the execution of the harvest rate experiments.

Leaf sheath amputation | White stem amputation | White stem fracture | Root amputation

Figure 12. The most typical damage patterns.

Table 3. Welsh onion damage rate

Parameter (%)	Tractor working speed		
	5.0 cm/s	11.4 cm/s	15.8 cm/s
Leaf sheath amputation	0.0	0.11	0.1
White stem fracture	1.61	2.89	7.39
White stem amputation	0.27	1.82	0.94
Root amputation	2.68	1.71	2.96
Total	4.55	6.53	11.29

have a lesser market value. Therefore, the condition of harvested Welsh onions is a very important factor for evaluating the tractor performance for Welsh onion harvesting. The most typical patterns of Welsh onion damages that raise serious concerns to their marketability are shown in Figure 12. The most significant damages encountered relate to the amputation of the leaf sheath, white stem, and root, and the fracture of the white stem. Therefore, in this research, three different levels of working speeds are considered relative to the rate of damage for Welsh onions.

Table 3 shows the rate of damage results for the principal parts of the Welsh onions after harvesting, using the Welsh onion harvesting tractor at three different working speeds. With respect to the three different working speeds studied (5.0 cm/s, 11.4 cm/s, and 15.8 cm/s), the damage rate of Welsh onions increases from 4.55%, to 6.54%, and to 11.29%, respectively. Welsh onions were mostly damaged because of hitting that was caused by soil scraper on the secondary soil-separating device. These results can be attributed to the changes of the angles of the transporting device at increasing speeds, to the fracture of the white stem, and to the amputation of the root.

The amount of residual soil on Welsh onion

The weight of the residual soil on Welsh onions after harvest will increase the volume and the weight of the Welsh onion thereby causing inefficiencies in their packaging, transportation, and storage. Therefore, in this study, the weight of the residual soil of the harvested Welsh onions is investigated at three different working speeds. The result of the measurements indicated insignificant differences in the weight of residual soil, irrespective of the working speed. The average weight of the residual soil for each Welsh onion was 0.33 g that represents 0.24% of the total weight of the Welsh onion. Based on these findings, such results can be ignored. Therefore, the newly developed soil-separating device for the Welsh onion harvester is regarded to have an excellent performance (Figure 13).

Figure 13. Harvested Welsh onion after the soil separation process.

Conclusions

In this research, mechanization of harvesting Welsh onions, a process that has traditionally depended on labor, will increase productivity and household income through the development and use of a Welsh onion harvester mounted on a tractor. The performance of the newly developed Welsh onion harvester was tested in an actual Welsh onion cultivation farm. At three different tractor speeds of 5.0 cm/s, 11.4 cm/s, and 15.8 cm/s, we have investigated the operating efficiency, harvest rate, damage rate, and residual soil, in order to test the harvesting performance of the Welsh onion harvester. The harvest rate was 100% regardless of the speed of the tractor that represents outstanding results. Therefore, when the working speed increases, the efficiency of harvesting Welsh onions will also increase. From the elicited results at the three different working speeds, the damage rate of harvested Welsh onions seems to increase proportionately from 4.55% to 6.53% and to 11.29%. The residual soil on harvested Welsh onions was 0.24% of the total weight of the Welsh onions indicative of the high performance of the harvester in removing soil. Therefore, based on this study, the newly developed Welsh onion harvester will allow the mechanization of the harvest operation that currently requires a substantial amount of labor, thereby contributing to improved conditions in our Welsh onion cultivation farms.

Conflict of Interest

The authors have no conflicting financial or other interests.

Acknowledgements

This study was conducted with the support of "State-of-the-art production technology development project (Project No. 111167033SB010)", from the Institute of Planning & Evaluation for Technology in Food, Agriculture Forestry & Fisheries, Republic of Korea.

References

Fujii, H. M. Kitada. M. Nuome and H. Horie. 2008. Method of evaluating physical properties with cutter on welsh onion. Toyama Prefectural Agricultural, Forestry & Fisheries Research Center 25:43-49 (In Japanese, with English abstract).

Hong, J. T., Y. Choi, J. H. Sung, Y. K. Kim and K. M. Lee. 2001. Design factors for chinese cabbage harvester attachable to tractors. Journal of Biosystems Engineering 26(4): 337-354 (In Korean, with English abstract).

Jun, H. J., S. H. Kim, J. T. Hong and Y. Choi. 2005. Cutting and conveying characteristics for development of Chinese leek harvester. Journal of Biosystems Engineering 30(4):220-228 (In Korean).

Jun, H. J., Y. Choi, C. K. Lee, Y. M. Cho and S. B. Hong. 2007. Development of a spinach root-cutter for the greenhouse spinach, Proceedings of the KSAM 2007 Winter Conference 12(1):10-14 (In Korean).

Kang, W. S., S. H. Kim and Y. C. Hahm. 1989. Development of an oscillating potato harvester. Journal of Biosystems Engineering 14(1):16-23 (In Korean, with English abstract).

Kang, W. S., Y. B. Shin, S. H. Kim and Y. C. Hahm. 1993. Development of a potato harvester for tractors. Journal of Biosystems Engineering 18(1):21-29 (In Korean, with English abstract).

Katahira, M., T. Ota, T. Niiyama, M. Masuya, S. Ogasawara, K. Kumekawa, I. Shibuya and Y. Kamada. 2004. Mechanical working technology for vegetables cultivation in upland field converted from a heavy paddy (Part 2) –Farm work labor-saving using the multiple management vehicle–. Journal of the Japanese Society of Agricultural Machinery 66(5):97-106 (In Japanese, with English abstract).

Rural Development Administration. 2013. 2012 Revenue book of agricultural and livestock products income base for agricultural management improvement. RDA.

Statistics Korea. 2010. Agriculture, fishery & forestry census.