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Performance Test of Fully Automatic Potato Seeding Machine by In-situ Process of Cutting Seeds

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Abstract

Purpose: To reduce the costs of potato seeds and labor of workers, a fully automatic in-situ seeding machine for cutting seed potatoes was developed. **Methods:** An experiment was conducted to evaluate the seeder performance of the prototype of potato planter by cutting seeds in farmlands from March to April 2017. The study tested the seeder performance at working speeds ranging from 0.28 to 0.45 m/s. The seeding rate and seeding distance were also investigated according to the planned distance between planted seeds from 20 to 30 cm, with 5 cm intervals. **Results:** Tests on the performance of the developed cutting blade on the automatic potato seeder show that whole potatoes should be used instead of half potatoes. The seeding rates were 88.8% and 82.5% for whole and half potatoes, respectively. When the tractor working speed was increased from 0.28 to 0.45 m/s, the successful seeding rate decreased from 98.8% to 96.3%, respectively. However, with planted seed distances of 20, 25, and 30 cm, the successful seeding rates were near 98%. **Conclusions:** The developed automatic potato seeder can to improve the labor productivity and cultivation environment of potato farms by the mechanization of the seeding process, which is currently associated with high-labor, -costs, and -hours. Therefore, based on this study, the developed automatic potato seeder provides the mechanization necessary for improved potato cultivation conditions in farmlands.

Keywords: Automatic seeder, Cutting seeds, Performance test, Potato, Seeding rate

Introduction

The development of agricultural machinery is essential for the cultivation of domestic agriculture because of limited labor supply and time. In order to develop an efficient agricultural system, analysis of the work involved in cultivating potatoes has been conducted (Kang et al., 2015). The traditional methods of potato cultivation in upland fields in Korea are as follows: the one-line cultivation method involves covering the seed potato with soil from rounded ridges, while the two-line cultivation method involves covering the seed potato with soil from flat-topped ridges. To apply these methods, potato planting machines currently used in Korea are tractors with attachments or semi-automatic tractors with an auxiliary worker operating the machine. The semi-automatic potato planter requires the passive cutting of potato seeds by an auxiliary worker. Thus, not only added labor costs but also worker safety should be considered.

Semi-automatic potato planters perform the metering and transfer of potatoes with the assistance of workers, instead of using a seed metering device. Types of semi-automatic potato planters include the belt cup planter, magazine type planter, cup-type automatic planter, and finger-type automatic planter. The belt cup planter (Misener et al., 1988; Buitenwerf et al., 2006; Ebrahem et al., 2011) is the most widely used machine to plant potatoes. The potato is transferred from the hopper to the

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conveyor belt with cups sized to hold one tuber. The magazine-type planter (Deppermann et al., 2010; Stehling et al., 2010) mainly consists of hoppers in a plate-type (horizontally or vertically placed) metering unit along with a ridge line in accordance with the amount of seeds to be planted at a time. The finger-type planter (Frase and O'Neil, 1972) is designed for semi-automatic planting of rooted and unrooted seedlings. In contrast, the fully automatic potato planter has an automated system, including a seed metering device for metering and transferring potatoes. Fully automatic potato planters have planting frequency of 160–200 tubers per minute, nominal forward speeds of 4–6 km/h, and working capacity of 2–8 ha per day (Ebubekir, 2005).

To reduce the costs of potato planting, farmers have planted sliced potatoes with an average of 5-7 germinated points. Therefore, the farmers have conventionally used potato slices cut into 2 to 4 parts as seeds for planting. In Korea, because the method used to cut potatoes in advance is decided by the workers, it is difficult to determine the size and shape of the cups for seeds. Therefore, in order to develop a fully automatic potato planting machine (Choi et al., 2016a; Choi et al., 2016b; Choi et al., 2017a; Choi et al., 2017b), it is necessary to consider the process of properly transferring potato seeds of various sizes and shapes in real time. The fully automatic potato planting machine has added a device that can cut seed potatoes to reduce seed potato costs. Choi et al. (2016a) developed and evaluated a cutting blade in the automatic potato seeding machine. The blade cuts the seeds into two parts, and then each sliced seed was planted on both lines. The ratio of the same weight of whole potatoes as two pieces of sliced potatoes was 44.5%; in the case of half potatoes, the ratio was 76.9%.

Using this machine, Choi et al. (2016b) evaluated the performance (e.g., sowed depth of seeds, distance of planted seeds, number of transfers to cutting blade, and misplanted rate) of a prototype automatic seed potato planter. The number of transfers from the pot hopper to the cutting blade was 1–2 and the misplanted rate was 2.5% –10%. Choi et al. (2017a) compared to costs of using conventional seeding and the prototype machine. The amount of seed potatoes required for the conventional method was 160 kg/10 a. For the prototype machine, the number seed potatoes required was 370 kg/10 a for the sowing method with two-time cutting, 204 kg/10 a for the sowing method with two- to four-time cutting, and 185 kg/10 a for the sowing method with four-time cutting. The amount of seeds needed were 231%, 127%, and 116% more than the conventional method, respectively. Choi et al. (2017b) evaluated the adaptability of the automatic potato planter in the field. When the experiment was conducted with quarter-sliced potatoes which have not sprouted, the potato seeding rate and rot rate were 18.5% and 12.2%, respectively. On the other hand, in the test with half potatoes that sprouted, the misplanted and rot rates were reduced to 10% and 4.1%, respectively, compared to the quarter-sliced potatoes which have not sprouted.

In order to improve the cutting performance of the prototype, it is necessary to modify the design of the cutting hopper's shape and the guide for positioning the seed prototype for further experiments. The developed potato seeder was mounted with the blade part for cutting the potato seeds in-situ. We evaluated the performance of the automatic potato seeder for various kinds of potatoes (i.e., spring and summer season) in field.

Materials and Methods

Automatic potato seeder design and development

The developed automatic potato seeder was designed as a three-point hitch mounting type machine consisting of two major units: a) a transfer and cutting device, and b) a soil covering device (Fig. 1). The prototype automatic potato planter was designed with AutoCAD 2016 (Autodesk INC., Mill Valley, CA, USA). The specifications of the prototype are listed in Table 1. The prototype is attached by a three-point hitch in the rear and operated by power takeoff (PTO) and hydraulics from the tractor. The prototype needs a tractor with maximum PTO output of over 50 kW.

The process of seeding potatoes involves making the ridges with a distance of 10 cm above the lowest point of surface soil; dropping seeds into rows at the desired depth and spacing from the hopper; covering the seeds with soil; and providing proper compaction over the seed. Before dropping seeds into the soil, the seed potatoes were cut in half by blade to reduce the costs. The seed spacing was controlled by controlling the speed of the transfer device. The seed spacing ranged from 700 to 900 mm (Table 1).

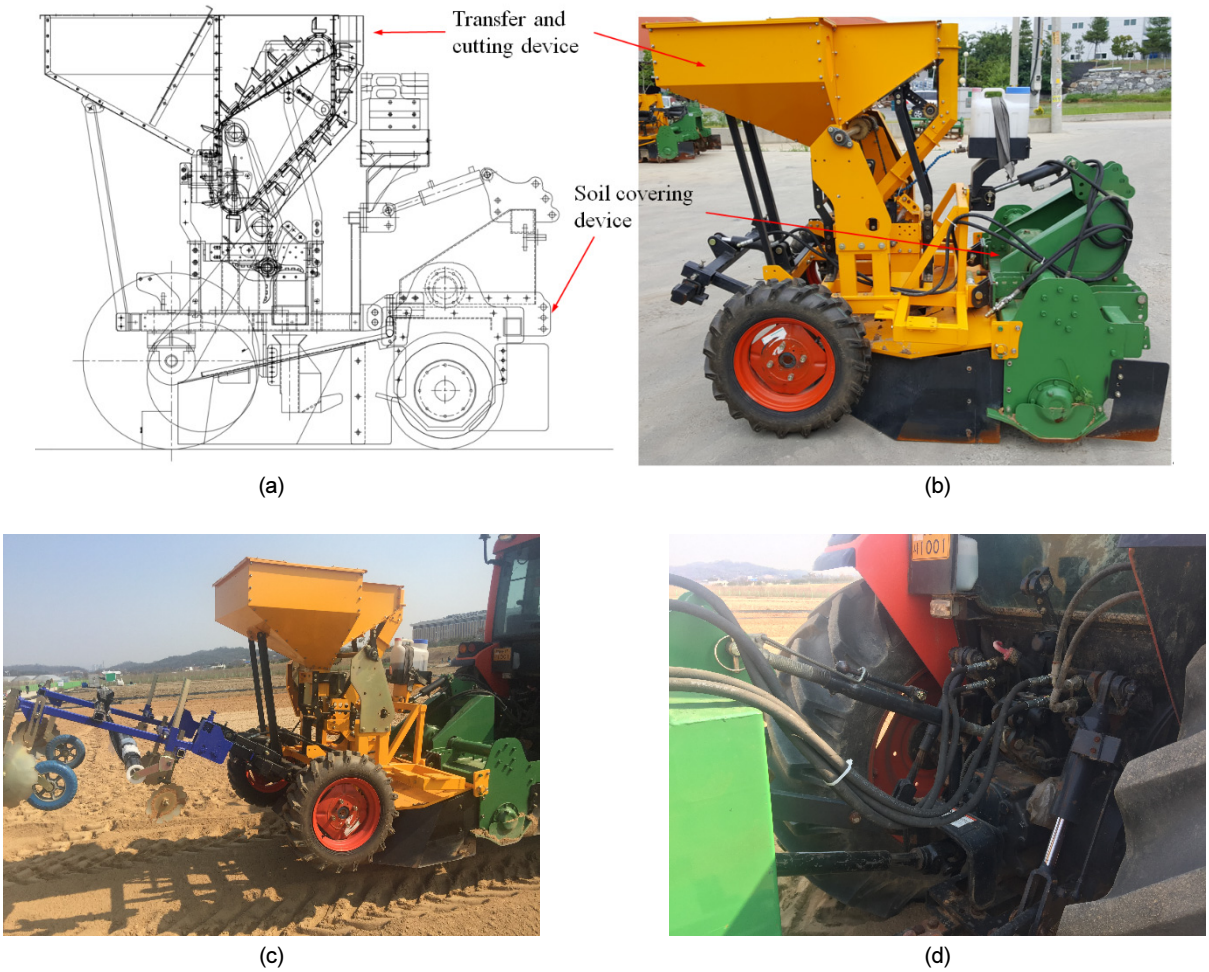

Figure 1. The developed automatic potato seeder with a three-point hitch mounting. (a) schematic view, (b) picture of prototype, (c) picture of prototype mounted on tractor, and (d) picture of prototype connected by three-point hitch.

Table 1. Specifications of the prototype automatic potato seeder

Type		Two-row seeding
Dimension	Length × Width × Height (mm)	3850 × 2240 × 1520
	Weight (kg)	1250
	Power	PTO and hydraulic
Transporting device	Operating type	Hydraulic
	Transporting type	Chain
	Type of seed transport	Elevator
	Shape of transporting device	Bucket
	Adjustment spacing of row seeding (mm)	700–900
Rotavotor	Shape of rotavotor blade	L-type
	Width of tillage (mm)	1850
	Power	PTO
Soil digging device	Shape of digging device	Blade-shaped
	Angle	30°
Soil covering device	Shape of covering device	Circle with sawtooth
	Diameter (mm)	330

(a) (b) (c)

Figure 2. The transporting device of potato with bucket (a), the potato cutting device of the automatic seeding machine (b), and the cut potatoes after the cutting process (c).

(a) (b)

Figure 3. The rotavator and digging device for soil cutting (a) and soil covering device after seeding process (b).

Transfer and cutting device for potatoes

The transfer and cutting device for potatoes was mounted on the upper frame body with a hopper for transporting the filled potatoes. The transfer and cutting device operates through a power transmission unit using hydraulic power (Table 1). The transfer chain was designed to operate at speeds of 0.24–0.72 m/s. The transferred potatoes were cut by operating the hydraulic motor powered by the tractor hydraulic circuit.

The potatoes were transported to the cutting device (Fig. 2a) by the bucket (Fig. 2b) mounted on the frame chain with a 30° inclination. After the cutting process, the sliced potatoes were dropped into the soil (Fig. 2c).

Soil breaking and covering device

The soil breaking device is equipped with a rotavator and a blade-shaped digging device (Fig. 3a, Table 1). The soil cutting depth for the digging device at the contact surface of the covering device was set to maintain a height of 5 cm above the lowest point in the ridge and to make ridges with distance of 10 cm above the lowest point of the surface soil (Fig. 3b).

Experiment on potato seeder

In order to evaluate the performance of the developed automatic potato seeder, a field test was conducted at Gangneung, Gangwon, in March 2017, and at Pyeongchang, Gangwon, in April 2017. The properties of the topsoil and subsoil in the Gangneung field were silt loam soil and sandy loam soil, respectively; the soil series was Samgag series, the land slope ranged between 2° and 7°, and the diploid state was rated as “good.” In the Pyeongchang field, the properties of the topsoil and subsoil were loam soil and sandy loam soil, respectively; the soil series was

(a)

(b)

Figure 4. The preparation of two kinds of seeds: (a) whole potatoes and half potatoes, and (b) the investigation of quantity and condition of planted potatoes.

Mui series, the land slope ranged between 7° and 15°, and the diploid state was rated as "very good" (RDA Soil Map, http://soil.rda.go.kr).

The potato used in this experiment was the "Sumi" potato, which is widely consumed in Korea. The Sumi is usually planted in the spring and summer seasons. The average weight of the seed was 80 g. Two kinds of seed potatoes were prepared: whole potatoes and half potatoes (Fig. 4a).

Tractor used for experiment

The tractor used to test potatoes seeding performance is one of the most widely used in farmlands (Grandmax GM56, Kubota INC., Naniwa-ku, Osaka, Japan) with a 40–60 HP engine. The rated engine output was 56 ps (41 kW), at a rated engine speed of 2500 rpm, and working speed range of 0.07–10.5 m/s.

Field experiment method

The experiment was conducted in the fixed ultra-low-speed tractor operation mode (rated engine speed 2500–3000 rpm) at which the seeding performances were investigated. The seeding rate, seeding distance, and seeding depth were recorded at tractor working speeds 0.28, 0.35, and 0.45 m/s, respectively, at three respective times for a segmentation task of 5 m, and the average values for each were calculated.

The classification criteria for the seeding rate of potatoes were based on the quantity of potatoes planted at the each point in the 5-m areas during the three times that the segmentation task was performed. Figure 4b shows that the potatoes were dug from the soil before these were counted at each point. The seeding rate was classified into three conditions: no seed planted, one seed planted, and two or more seeds planted. The distance in the rows between one potato to the next was investigated at three respective times for a segmentation task of 5 m, and the average distances and standard deviations were calculated.

Results and Discussion

Table 2 shows the samples collected and calculated data (i.e., seeding distance, seeding depth, and seed count at each point). By investigation of the quantity and condition of the planted potato (Fig. 4b), each data was calculated at one point on each side. The calculation method was based on Choi et al. (2016b). The conditions of the planted seeds were cllassified into three (i.e., no

Table 2. The example of seeding distance, seeding depth, and seed count at each point in one row with 28-cm distance between planted seeds and 0.24 m/s tractor working speed

Point number	Left side in one row			Right side in one row		
	Seeding distance[a] (cm)	Seeding depth (cm)	Count of seeds at each point	Seeding distance[a] (cm)	Seeding depth (cm)	Count of seeds at each point
1	-[b]	9.0	1	-[b]	7.0	1
2	31.5	9.5	1	20.5	7.0	1
3	32.5	11.5	1	23.5	7.5	1
4	27.5	11.5	1	34.0	8.0	1
5	27.0	10.5	2	40.0	6.5	2
6	46.5	9.0	1	48.5	6.0	1
7	35.0	10.0	1	30.0	8.0	1
8	35.5	8.0	2	24.5	10.0	2
9	36.5	10.0	1	32.5	6.5	1
10	31.0	9.5	1	--[c]	--[c]	0
11	26.5	10.5	1	59.0	7.5	1
12	36.5	11.0	1	43.0	7.5	1
13	19.5	10.5	1	44.5	8.5	1
14	40.0	10.0	1	11.0	6.5	1
15	24.5	8.0	1	38.5	9.0	1
16	27.5	8.5	1	33.0	7.5	1
17	19.5	9.5	1	14.0	9.5	1

[a]The seeding distance is the value of the distance from previous point to this point.
[b]This means that there is no distance value because there is no previous point.
[c]This means that there are no values because there are no planted seeds at this point.

Table 3. The mean seeding rate (%), seeding distance (cm), and seeding depth (cm) at each side in one row

Each side in one row	Mean seeding rate (%)			Mean seeding distance (cm)	Mean seeding depth (cm)
	No seed	One seed	Two or more seeds		
Left side	0.0	88.2	11.8	31.1 ± 7.3[a]	9.8 ± 1.1[a]
Right side	5.9	82.4	11.8	33.1 ± 13.1[a]	7.7 ± 1.2[a]
Both side	2.9	85.3	11.8	32.0 ± 10.4[a]	8.8 ± 1.6[a]

[a]Values are presented as mean ± SD.

seed, one seed, and two or more seeds). The seeding rate was calculated by the ratio of the three conditions (Table 3). The calculated data, such as seeding distance and depth, were averaged in Table 3. Because the segmentation task was performed three times in one experiment, the data from the three-time task was also averaged. The seeding rate was calculated from the ratio of the three conditions.

Performance test for developed cutting blade on the potato seeder

To compare the seeding rate of whole potatoes and half potatoes using the potato seeder with the developed cutting blade, a seeding experiment was performed at working tractor speed 0.2 m/s and the same seeding distance. The results show that the successful seeding rate of one seed per point for half and quarter potatoes averaged 88.8% and 82.5%, respectively. After two weeks, the sprouting rate of half potatoes (82.3%) was greater than that of quarter potatoes (79.9%). The seeding distance and depth were similar for half and quarter potatoes (Table 4). Consequently, when the developed cutting blade was used in the experiment, the whole potato might be recommended for use instead of the half potato.

Table 4. The mean seeding rate (%), sprout rate after two weeks (%), seeding distance (cm), and seeding depth (cm) of half potato and quarter potato

Items	Mean seeding rate (%)			Mean sprout rate after 2 weeks (%)	Mean seeding distance (cm)	Mean seeding depth (cm)
	No seed	One seed	Two or more seeds			
Half potato	6.3	88.8	5.0	82.3	25.4 ± 8.6[a)]	8.7 ± 1.6[a)]
Quarter potato	5.8	82.5	10.7	79.9	25.9 ± 8.0[a)]	8.2 ± 1.3[a)]

[a)]Values are presented as mean ± SD.

Table 5. The mean seeding rate (%), seeding distance (cm), and seeding depth (cm) for whole potato depending on tractor working speeds

Planted time	Tractor working speed (m/s)	Planned distance of planted seeds (cm)	Mean seeding rate (%)			Mean seeding distance (cm)	Mean seeding depth (cm)
			No seed	One seed	Two or more seeds		
Spring season	0.24	25	2.5	96.2	1.2	25.6±5.9[a)]	10.1±0.6[a)]
Summer season	0.28	25	1.3	98.8	0.0	25.2±4.5[a)]	-
	0.35	25	2.5	97.5	0.0	25.8±6.4[a)]	-
	0.45	25	2.5	96.3	1.3	25.9±7.1[a)]	-

[a)]Values are presented as mean±SD.

Performance test for the potato seeder depending on working speed and planned distance of planted seeds

Depending on tractor working speeds

To investigate the seeding rate of the prototype depending on tractor working speeds, experiments were performed at three working tractor speeds of 0.28 m/s, 0.35 m/s, and 0.45 m/s (Table 5). The seeding rates for one seed at each speed were 98.8%, 97.5% and 96.3%, respectively. Consequently, when the working speed of the tractor increased, the seeding rates of the prototype decreased.

The seeding rate in the spring season was also investigated at working speed of 0.24 m/s. The seeding rate for one seed in the spring was 96.2%. The difference in seeding rates between the spring and summer seasons may be hard to determine because of varying conditions such as climate and soil. However, for the tractor used to plant potatoes in this study, the harvest rate was over 96%, regardless of the working speed. The seeding distances (25.2–25.9 cm) were close to the planned distance of 25 cm.

Depending on the planned distance of planted seeds

The resulting seeding rate and seeding distance slightly increased or decreased depending on the planned distance of planted seeds at the same working speed with of 0.28 m/s (Table 6). At three different distances between planted seeds (20, 25, and 30 cm), the seeding rates of the potato seeder was 98.6%, 98.8%, and 97.9%, respectively. The results of the measurements indicate insignificant differences in seeding rate (> 97%), irrespective of the planned distance between the planted seeds.

The mean seeding distances were similar to the planned distance of planted seeds at 20 and 25 cm. When the planned distance between planted seeds increased, the difference between the average seeding distance and the seeding distance gradually increased. At planned distance of planted seeds of 25, 28, and 30 cm, these differences were 0.2 cm, 2.1 cm, and 3.3 cm, respectively. Based on these findings, the recommended distance between planted seeds is less than 25 cm.

Conclusions

This research showed that the development and use of an automatic potato seeder mounted on a tractor can decrease costs and increase household income. The performance of the developed prototype automatic potato seeder was tested in a potato farm. For performance testing of the developed cutting blade on the automatic potato seeder, the seeding rate for whole and half potatoes

Table 6. The mean seeding rate (%), seeding distance (cm), and seeding depth (cm) in whole potato depending on spacing of planted seeds

Planted time	Tractor working speed (m/s)	Planned distance of planted seeds (cm)	Mean seeding rate (%)			Mean seeding distance (cm)	Mean seeding depth (cm)
			No seed	One seed	Two or more seeds		
Spring season	0.28	28	1.1	98.2	0.7	30.1±8.0[a)]	8.9±2.0[a)]
Summer season	0.28	20	1.4	98.6	0.0	20.5±5.1[a)]	-
	0.28	25	1.3	98.8	0.0	25.2±4.5[a)]	-
	0.28	30	0.0	97.9	2.1	33.3±4.9[a)]	-

[a)]Values are presented as mean±SD.

were compared. The whole instead of half potato is recommended for use in the developed automatic seeder. The average successful seeding rate of whole and half potatoes were 88.8% and 82.5%, respectively. When the tractor working speed was increased from 0.28 to 0.45 m/s, the successful seeding rate decreased from 98.8% to 96.3%. However, with planned distance between planted seeds of 20, 25, and 30 cm, the successful seeding rates were near 98%. Therefore, based on the results this study, the developed automatic potato seeder can improve potato cultivation conditions in farmlands.

Conflict of Interest

The authors have no conflicting financial or other interests.

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