Develop the Precise Vacuum Seeder for Nursery Plug Tray Sowing by Using the Vacuum Cleaner

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Abstract. The manual sowing of vegetable seeds is the general practice of vegetable nurseries in Thailand. It is the slow and labour-intensive process that causes the low production capacity. This study aims to design and develop a vegetable seed sowing machine for 200-cell plug tray plantings to substitute human labor. The prototype utilizes the vacuum cleaner to develop the suction head pressure that simultaneously offers the 200 seeds-planting per tray. The vacuum seeder mechanism is composed of the suction head unit and seeds tray unit. The prototype is operated and controlled by the automation system for continuous planting. Cantonese vegetable seed is selected to evaluate the planting precision of the prototype. Based on the design parameters obtained in laboratory experiments, the optimal condition for planting the Cantonese vegetable seeds in the 200-cell plug tray is verified by adjusting two parameters - the suction pressures and the nozzle implement type. On the other hand, the planting precision is indicated by the single seed sowing index. The results showed that the average quality of feed index is 70.53% when utilizing the large nozzle implement type with a vacuum pressure of 1019 Pa. The average working cycle time per tray and the machine capacity per hour are 51.0 seconds and 70 trays, respectively. Moreover, the prototype machine costs about 43% of the average cost of the existing commercial seeders in terms of cost-effectiveness.

1 Introduction

Sowing seed is one of the important steps for planting after preparing the soil. Among various techniques, sowing in a plug tray is an efficient and reliable method. This method saves seeds, produces a large yield per unit area, induces independent seedling growth, and ensures uniform quality [1]. However, sowing of the small seed in a plug tray is tedious and time consumption work for human labor. According to [2], about eight man-hours are required to sow 100 plug trays for raising 9800 seedlings. This leads to a low production capacity and quality due to human error and fatigue.

To increase the production capacity and quality, automatic seeder machines into the plug trays have been introduced. A pure mechanical seeder has been proposed in [3]. While the machine in [4,5] utilize the electric motor and robot for the seedling, respectively. Pneumatics seeder is another type of machine and has been introduced in [6,7]. Moreover, the sowing

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precision measurement has been added to the machine in [8,9] for the quality control by using vision technique. Among the seeder machine, the pneumatic type has various advantages over others such as uniform seed placement, high operational speed, robustness and reliability [10]. However, the cost of the machine is still high, especially the vacuum unit so that the small and medium enterprises (SME) section can hardly handle. In this paper, the vacuum cleaner is adopted as a pressure unit to lower the machine cost. The optimal condition is obtained by varying the nozzles implement and the vacuum pressure. Finally, the planting precision is evaluated by four indices call quality of feed, double, multiple and missing index.

2 Methodology

The development of the vacuum seeder using the vacuum cleaner consists of four stages. Firstly, the mechanism of the plug trays feeder, vacuum and seedling units are designed and implemented. Secondly, the control system and devices are installed to the prototype. Thirdly, the experiments for the maximum planting precision criterion are conducted by varying two parameters – suction pressure and nozzle type. Finally, the analysis and verification of the results are discussed.

2.1 Sowing seed machine and working sequence

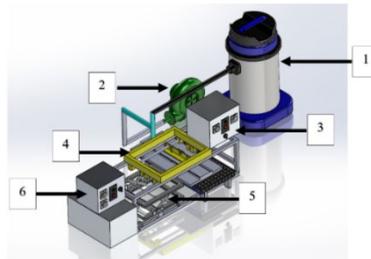Major parts of the sowing seed machine are shown in Fig. 1. - Fig. 3.
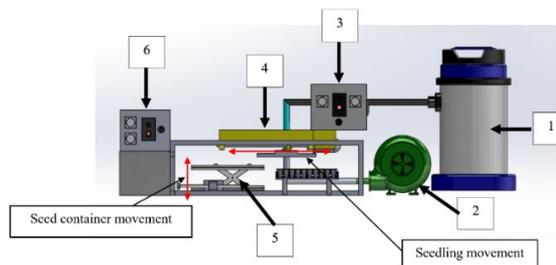

Fig. 1. Sowing seed machine (3D).
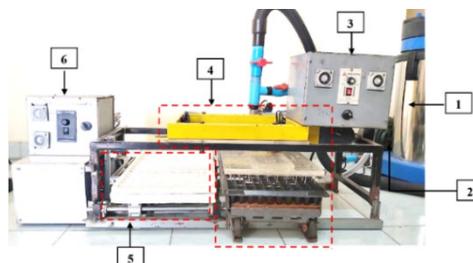

Fig. 2. Sowing seed machine (Side view).

Fig. 3. Sowing seed machine (Prototype).

The machine is constructed of the following units.

(1) The vacuum generator (Vacuum cleaner) (4) Nozzles and seedling mechanism
(2) Blower   (5) Seed container and mechanism
(3) Seedling controller   (6) Seeder container controller

The vacuum pressure is distributed to the grid like chambers and the nozzles which are equally perpendicular attached to each chamber. The arrangement of the 200 nozzles is aligned to the layout of the 200 plugs tray via the vacuum chambers as shown in Fig. 4.
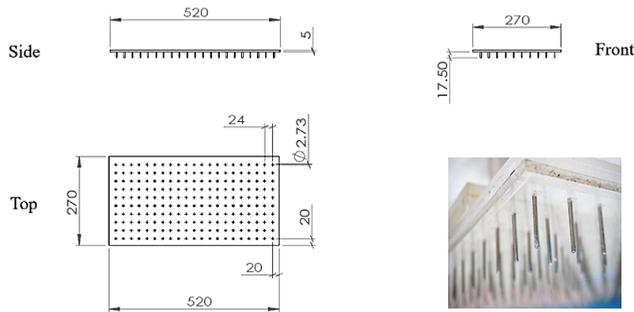

Fig. 4. Arrangement of the nozzles.

A single working cycle consists of five steps. Firstly, the user places a 200 plugs tray under the nozzles chamber unit then pushes the start bottom. Secondly, the nozzles chamber unit moves to the design position until hit the proximity switch then the vacuum cleaner develops the negative pressure. At the same time, the seeds container lifts to provide seeds to the nozzles chamber unit. Thirdly, seeds container lifts until hit the proximity switch then seed container stay still to let the nozzles pick up seeds for a while by counting with timer. Fourthly, the seed container moves down after timer-off and the nozzles chamber return to the position over the plug tray. Finally, the nozzles chamber unit move back and hit the proximity switch to turn-off the vacuum cleaner and turn-on the blower at the same time to let the seeds are dropped into the plug tray for a while by counting with timer. The working cycle of the machine is controlled by the programmable logic controller (PLC) with feedback signals from timers and proximity switches. The movement of nozzles chamber and seeds container depict in Fig.2.

2.2 Planting precision

Planting precision is an index showing the quality of the seeder. Four indices are used to evaluate the planting precision of the prototype machine. The requirement of planting into the 200 plugs tray is distributed a single seed per plug and provide it through 200 plugs simultaneously.

2.2.1 Quality of feed index

Quality of feed index (A) is the ratio between the number of plugs that contain exactly a single seed to the total number of plugs in a single tray. It can be calculated by the equation.

$$A = 100 \left(\frac{\sum n_A}{N} \right) \tag{1}$$

when n_A is the number of plugs containing a single seed and N is the total number of plugs in a tray.

2.2.2 Double index

Double index (B) is the ratio between the number of plugs that contain two seeds to the total number of plugs in a single tray. It can be calculated by the equation

$$B = 100 \left(\frac{\sum n_B}{N} \right) \tag{2}$$

when n_B is the number of plugs containing two seeds and N is the total number of plugs in a tray.

2.2.3 Multiple index

Multiple index (C) is the ratio between the number of plugs that contain more than two seeds to the total number of plugs in a single tray. It can be calculated by the equation

$$C = 100 \left(\frac{\sum n_C}{N} \right) \tag{3}$$

when n_C is the number of plugs containing more than two seeds and N is the total number of plugs in a tray.

2.2.4 Missing index

Missing index (D) is the ratio between the number of plugs that contain non seeds to the total number of plugs in a single tray. It can be calculated by the equation

$$D = 100 \left(\frac{\sum n_D}{N} \right) \tag{4}$$

when n_D is the number of plugs containing non seeds and N is the total number of plugs in a tray.

2.3 Nozzle mechanism

The nozzle mechanism is shown in Fig. 5. This force produced by the nozzle must be greater than the gravitational force acting to the seed (F_{seed}).
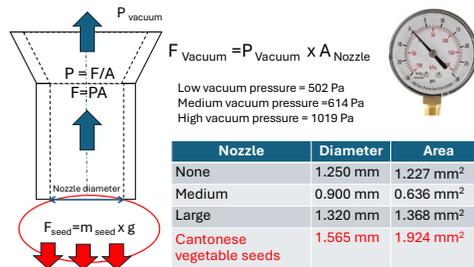

$F_{Vacuum} = P_{Vacuum} \times A_{Nozzle}$

Low vacuum pressure = 502 Pa
Medium vacuum pressure = 614 Pa
High vacuum pressure = 1019 Pa

Nozzle	Diameter	Area
None	1.250 mm	1.227 mm²
Medium	0.900 mm	0.636 mm²
Large	1.320 mm	1.368 mm²
Cantonese vegetable seeds	1.565 mm	1.924 mm²

$P = F/A$
$F = PA$

$F_{seed} = m_{seed} \times g$

Fig. 5. Pressure in nozzle and its dimensions.

Vacuum force is proportional to the vacuum pressure and the nozzle open area by the equation

$$F_{vacuum} = P_{vacuum} A_{nozzle} \tag{5}$$

when F_{vacuum}, P_{vacuum} and A_{nozzle} are the force produced by the nozzle, the vacuum pressure and the nozzle open area, respectively.

3 Experiments

Firstly, the maximum planting precision condition is experimentally obtained by varying two parameters - the vacuum pressure and the nozzle implement type. In the second step, the average cycle and machine capacity are evaluated. Three levels of the vacuum pressure are categorized as Low, Medium and High with the pressure of 502 Pa, 614 Pa and 1019 Pa, respectively. The nozzle implement types are also categorized as None, Medium and Large with their inner diameter of 1.25 mm, 0.90 mm and 1.32 mm, respectively. The prototype are tested with Cantonese vegetable seeds which has an average diameter of 1.565 mm and frontal project area of 1.924 mm^2.

3.1 Vacuum pressure and nozzle implement variation

The 200-cell plug tray of 27 cm wide, and 53 cm long is used in the experiments. Five plug trays are continuously seedling by the prototype machine with variation of vacuum pressure and nozzle implement.

3.1.1 Low vacuum pressure

A low vacuum pressure of 502 Pa is applied to the nozzle unit while varying the nozzle type. The average values of each index are shown in Table 1.

Table 1. Planting precision indices from the low vacuum pressure (502 Pa).

Nozzle	Quality of feed index (%)	Double index (%)	Multiple index (%)	Missing index (%)
None	26.36 ±3.92	3.97 ±0.77	2.37 ±0.5	67.30 ±2.44
Medium	48.03 ±1.24	3.66 ±1.69	5.5 ±1.66	42.81 ±2.75
Large	60.2 ±2.35	10.34 ±0.94	9.63 ±2.29	19.83 ±2.8

3.1.2 Medium vacuum pressure

A medium vacuum pressure of 614 Pa is then applied to the nozzle unit while also varying the nozzle type. The average values of each index are shown in Table 2.

Table 2. Planting precision indices from the medium vacuum pressure (614 Pa).

Nozzle	Quality of feed index (%)	Double index (%)	Multiple index (%)	Missing index (%)
None	32.27 ±1.24	3.33 ±1.69	4.37 ±1.66	60.03 ±2.75
Medium	46.17 ±1.75	7.87 ±1.19	4.9 ±1.08	41.06 ±2.52
Large	64.51 ±1.76	6.03 ±1.02	6.43 ±0.97	23.03 ±2.18

3.1.3 High vacuum pressure

Finally, a high vacuum pressure of 1019 Pa is applied to the nozzle unit with the nozzle type variation and the average values of each index are shown in Table 3.

Table 3. Planting precision indices from the high vacuum pressure (1019 Pa).

Nozzle	Quality of feed index (%)	Double index (%)	Multiple index (%)	Missing index (%)
None	38.57 ±1.08	4.47 ±1.02	5.63 ±1.32	51.33 ±2.63
Medium	60.00 ±1.82	7.94 ±1.96	5.83 ±0.67	26.23 ±3.04
Large	70.53 ±0.22	7.34 ±0.81	3.10 ±0.35	19.03 ±1.28

The results in Table 1. - Table 3. show that the large nozzle implements with a vacuum pressure of 1019 Pa yield the maximum average quality of feed index and minimum average missing index of 70.53% and 19.03%, respectively. The large nozzle provides the maximum efficiency since it has the highest suction force, which is proportional to the vacuum pressure and the cross-sectional area of the nozzle. In addition, the Cantonese vegetable seed size is suitable to the large nozzle type. Therefore, the large nozzle type gives the highest accuracy and planting precision indices in all vacuum pressure levels.

3.2 Cycle Time and Machine Capacity

The working cycle time and machine capacity are measured by continuously turning on the prototype machine with 25 trays. Each working cycle time and the average time are shown in Table 4.

Table 4. Continuous working cycle time of 25 trays.

Cycle	Time (s)	Cycle	Time (s)	Cycle	Time (s)
1	50.8	**10**	51.5	**19**	50.8
2	51.1	**11**	51.2	**20**	51.1
3	51.3	**12**	50.6	**21**	51.4
4	50.8	**13**	51.3	**22**	50.7
5	50.5	**14**	51.4	**23**	50.9
6	51.4	**15**	51.2	**24**	50.7
7	50.9	**16**	50.7	**25**	51.4
8	51.3	**17**	50.5	**Average**	**51.0**
9	51.1	**18**	50.7		

From Table 4. the average working cycle time is 51.0 seconds, which is equivalent to the machine capacity of 70 trays per hour.

4 Conclusions

The automated seeder for the plug tray using the vacuum cleaner is introduced in this paper to reduce the cost of the prototype. The maximum average quality of feed index is 70.53%, which is obtained from the large nozzle implement type with a vacuum pressure of 1019 Pa. The average planting time per tray and the machine capacity per hour are 51 seconds and 70 trays, respectively. Moreover, the quality of feed index could be improved by rearrangement of the nozzles, installation of the pressure sensor and the controllable proportional valves in each chamber together with the feedback control algorithm instead of the timers. The cost of this prototype is about 2580 USD. It is only 43% of the average cost of the existing commercial seeders which vary from 1100 USD to 10945 USD.

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