Journal of Soil Sciences and Agricultural Engineering

Journal homepage & Available online at: www.jssae.journals.ekb.eg

Development of an Automated Cartesian Arm for Planting Seeds in Pots

Abo-Habaga, M. M.[1*]; Z. E. Ismail[1]; Nariman E. Moustafa[1] and M. H. Okasha[2]

[1] Agric. Eng. Dept., Fac. of Agric., Mansoura Univ., Egypt.
[2] Agric. Eng. Res. Inst., Agric. Res. Cent., El-Dokki, Giza, Egypt.

Cross Mark

ABSTRACT

This study focuses on developing an automated Cartesian arm capable of sowing seeds in pots within a greenhouse. The automated Cartesian arm comprises a seeding unit and electrical components. The Cartesian arm was successfully installed on the greenhouse frame, and the motions in the three axes were performed to sow seeds in the designated pots. The parameters evaluated were three seed suction nozzle diameters (0.5, 1.0, and 2.0 mm) and four seed types (Armenian cucumber, pepper, turnip, and okra). Performance metrics included the number of captured seeds per stroke, seed resting duration, and deviation relative to the pots' centers. Trials were conducted at the Agricultural Engineering Department, Faculty of Agriculture, Mansoura University. The results recommended that a seed suction nozzle diameter of 1 mm yielded the best outcomes for okra and Armenian cucumber seeds, with average captures of 1.0 and 1.46 seeds per pot, respectively. Conversely, a seed suction nozzle diameter of 0.5 mm was the most suitable for turnip and pepper seeds, capturing 1.46 and 1.33 seeds per pot, respectively. There was variation in the resting duration of seeds, as Armenian cucumber required 6-8 seconds while okra required 9-10 seconds. The study recommends the possibility of applying pot cultivation using the developed automated system for different seeds, choosing the diameter of the suction nozzle appropriate to the properties of the seeds. Experiments can also be applied to other types of seeds to build a database suitable for the largest number of seeds and ensure the reliability of the developed unit under study.

***Keywords*:** Automated Cartesian arm, greenhouse, pots, precision agriculture, seeding.

INTRODUCTION

The agricultural sector in Egypt necessitates a series of demanding and labor-intensive tasks. Furthermore, this sector faces challenges such as a shortage of skilled workers, high labor costs, and the disinclination of young individuals to engage in agricultural work (Abo-Habaga *et al.*, 2018). Manual seeding is considered one of the most agricultural operations that requires much labor, time, struggle, and cost (Regatti *et al.*, 2024). Hence, smart solutions like remote sensing, artificial intelligence (AI), the Internet of Things (IoT), and smart robots and vehicles. These technologies can applied by the availability of big data, and farm management systems to achieve high-precision agriculture. These technologies can potentially address the challenges faced by the sector by leveraging advanced systems in agriculture, aligning with the contemporary agricultural revolution to perform complex tasks with utmost precision, efficiency, and cost-effectiveness. In the present era, Computer Numerical Control (CNC) technology has made notable advancements in multiple domains, particularly in modern agricultural technologies that facilitate smart and precision agriculture. These encompass the systems of planting, spraying and fertilization, weeding, harvesting, and numerous other applications. Implementing smart agriculture brings various advantages, as it allows for the effortless tracking of crop conditions, enables precise and regular crop maintenance, and enhances crop yields. The functionality of CNC technology relies on randomly programmed instructions, which are stored in a storage medium. This technology enables the machine to precisely execute tasks by following designated coordinate points (Kautsar *et al.*, 2020). Furthermore, Moraitis *et al.* (2022) designed and implemented CityVeg, a 3D robotic system for lettuce plants. This system features precise actuator movement and tailored irrigation. CityVeg comprises hardware, including the robotic platform's design and construction, and software for command execution. Modeled after a 3D printer configuration for accurate three-axis movement, it includes an aluminum frame with two parallel horizontal rails, a pi (π) shaped frame traveling along these rails, and an actuator on the π frame. This setup provides three degrees of freedom (DoF): the X-axis for lateral movement, the Y-axis for vertical movement along the π frame, and the Z-axis for vertical movement of the actuator. Du *et al.* (2023) introduced a novel plugged-out transplanting end-effector with a dual-cam structure that adjusts the seedling needle's spacing and angle, addressing the challenge of picking seedlings from trays of varying sizes. They analyzed trays with 72, 128, and 200 holes using EDEM software and constructed a transplanting test platform to optimize parameters for seedling breakage rates. Optimal conditions were found for 72-hole trays (0.28 m/s² acceleration, 13° penetration angle, 40 mm insertion depth, 15% insertion margin, 2.92% breakage rate), 128-hole trays (0.28 m/s² acceleration, 12° penetration angle, 36 mm insertion depth, 15% insertion margin, 1.76% breakage rate), and 200-hole trays (0.28 m/s² acceleration, 11° penetration angle, 32 mm insertion depth, 10% insertion margin, 0.68% breakage rate). These findings demonstrate the end-effector's effectiveness and provide valuable insights for developing versatile transplanting devices.

The development and progress of air-suction seed metering devices have greatly improved precision seeding by accommodating different seed shapes and reducing seed damage (Ismail *et al.*, 2023). Karayel *et al.* (2004) focused

*** Corresponding author.**
E-mail address: mm_abohabaga@mans.edu.eg
DOI: 10.21608/jssae.2024.305809.1238

on investigating various vegetable seeds' vacuum negative pressure demands. This examination unveiled the potential of air-suction mechanisms in achieving precise seeding for small-seed crops. Further investigations focused on examining the mechanics of seed suction, conceptualizing it as a composite of differential pressure, drag force, and pressure gradient forces (Shi *et al.*, 2020; Li *et al.*, 2021).

Achieving precision seeding, specifically for crops like pepper, demands a meticulous approach to design and parameter control. This is essential because of the seeds' small size and irregular shape (Ding *et al.*, 2018). Recent research has emphasized the significant impact of seed shape and posture on the effectiveness of seed-metering devices, highlighting the necessity for more intricate designs capable of accommodating the diverse range of seed forces (Zhao *et al.*, 2023). MASCHIO's precision seeders have integrated advanced metering devices to accommodate even the tiniest seed vegetables, resulting in notable enhancements in precision planting procedures (Tawfik, 2014, Ismail *et al.*, (2014), Ismail *et al.*, (2015); Qi and Xiang, 2020). Nevertheless, further research is imperative to enhance the performance of these devices across different seed types, guaranteeing optimal efficiency and precision in seeding (Wang *et al.*, 2024a). Along the same lines, Wang *et al.* (2024b) demonstrated that the boundary of the practical suction domain directly affects seed movement in air-suction seed-metering devices, suggesting that parameters can be fine-tuned by examining this pattern. However, precise research on this boundary is still needed. This study conducted single-factor experiments to analyze the impact of key factors on the suction domain boundary. Using CFD software, numerical simulations revealed that a cylindrical suction hole's effective suction domain boundary is larger, influenced mainly by the intensity and range of pressure and velocity gradients around the seed and changes in the seed's windward area. An orthogonal experiment constructed a boundary model for suction holes with diameters of 3.5 to 5.5 mm, validated using quasi-spherical seeds (soybean, pea, Panax notoginseng), with observed relative errors within 10%.

Furthermore, various researchers addressed the optimal seeding depth for different crops. For instance, Odeleye *et al.* (2007) reported a significant decrease in seedling emergence percentage when okra was planted at depths of 4 and 5 cm. Furthermore, the vegetative growth, dry matter accumulation, and crop yield of different okra varieties experienced a significant decrease under both potted conditions and in the field. Within this context, a depth of 5 cm is the most detrimental. Despite achieving satisfactory seedling emergence at planting depths of 1, 2, and 3 cm, the highest yield and overall superior performance of okra were observed at a planting depth of 3 cm, indicating that this depth is optimal for okra cultivation. Both okra cultivars (NHAe 47-4 and LD88) employed in this study exhibited identical responses to seeding depths. Similarly, Anand *et al.* (2019) indicated that while seedling emergence at 1, 2, and 3 cm sowing depths was satisfactory, okra seeded at 5 cm had the most significant detrimental effects on seedling emergence percentage. For okra, the maximum seeding depth is 3 cm. The two okra types, Parbhani Kranti and Pusa Sawani, reacted almost identically in terms of emergence percentage in both pot and field studies at varying seeding depths. Therefore, it is recommended that okra seeds should not be planted deeper than 3 cm for optimal emergence percentage.

Hence, this study aims to develop an automated Cartesian arm capable of sowing seeds in pots within greenhouse environments to achieve precision agriculture technologies and overcome manual seeding shortcomings.

MATERIALS AND METHODS

The automated Cartesian arm's manufacturing process and trial experiments were executed in 2024 in the Department of Agricultural Engineering, Faculty of Agriculture, Mansoura University, Egypt.

The automated Cartesian arm

The automated Cartesian arm comprises a seeding unit and electrical components. The Cartesian arm was successfully installed on the greenhouse frame, and the motions in the three axes were performed to sow seeds in the designated pots.

1: Seeding unit

The seeding unit comprises a seed box, pipe, nozzle, suction motor, motor with pinion gear, a rack, servo motor, and an ultrasonic sensor, as shown in Figs. 1 and 2.

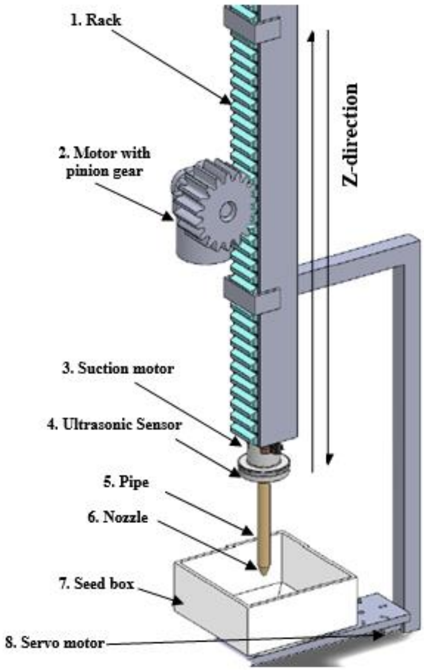
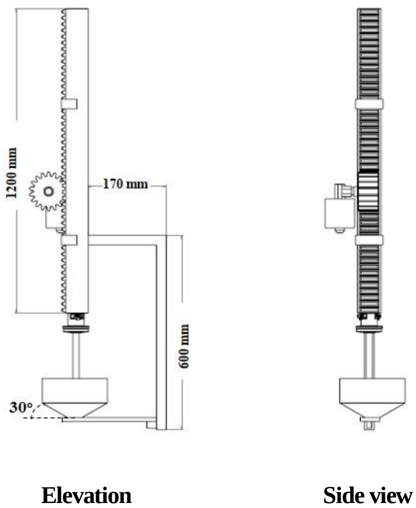


Fig. 1. 3D view of the seeding unit



Elevation **Side view**

Fig. 2. 2D view of the seeding unit

Seed box

The seed box was used to contain the seeds that were planted in the pots. It is made from acrylic and has dimensions of 133.92 × 125.92 × 80 mm, with a thickness of 2.5 mm and a slope angle of 30º. The seed box was securely held by a seed box holder made from a carbon fiber material with a length of 20 cm and a thickness of 4 mm.

Seed suction pipe and nozzles

The suction pipe is made of steel, with a length of 230 mm and an outer diameter of 22.5 mm. It has an internal thread to install the different cone diameters of air-suction nozzles. The seed's suction nozzle encompassed three cone diameters of 0.5, 1.0, and 2.0 mm, respectively, as shown in Fig. 3. The first nozzle, with a hole diameter of 0.5 mm, is made of Teflon. This is because a 0.5 mm diameter is hard to make from steel. The other two nozzles are made of steel. All nozzles have the same length of 25 mm, including the external thread length of 15 mm with a diameter of 10 mm.

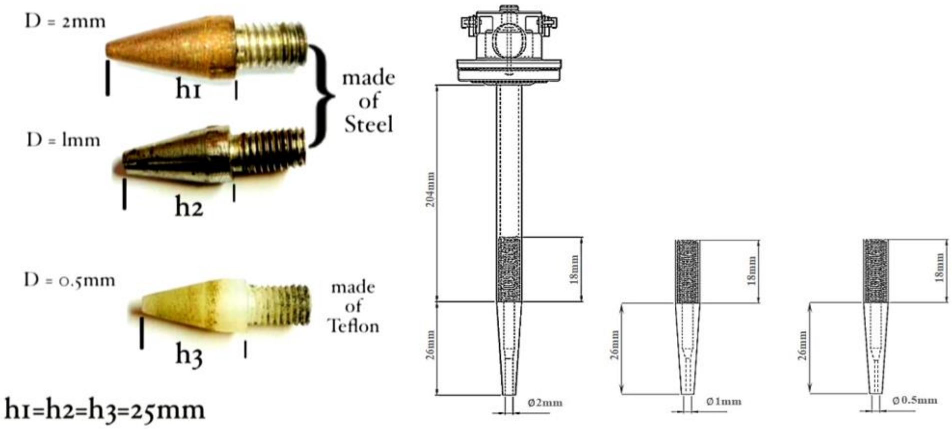


Fig. 3. Seed suction nozzle diameters

Seed suction motor

The seed's suction motor was employed to generate a suction force to suck the seeds from the seed box and hold them securely until they reached their designated planting position. This process used a brushed motor with a rated power of 1000 W, operating at a voltage of 220 V and a frequency of 50 Hz.

Servo motor

The MG946R metal gear servo motor was used in this study to move the seed box under the seed suction nozzle to suck the seed and, after sucking the seed, move away from the path of the seeding nozzle. It features a robust metal gearbox and high torque of up to 1.27 N.m, controlled by PWM signals for 90-degree turns in either direction. Operating between 4.8 V to 6.0 V, it has a stall torque of 1.03 N.m at 4.8 V and 1.27 N.m at 6.0 V. The motor's shaft can turn 0 to 180 degrees based on pulse length, and it has interchangeable servo headers/arms for flexibility.

Ultrasonic sensor

Three HC-SR04 ultrasonic sensors were used for distance measurement and detection. The pot's in the X-direction was determined by the first sensor, the Y-direction by the second sensor, and the height of the seeding arm above the pot’s center by the third sensor (Z-direction). These devices were powered by a +5V DC supply, with a quiescent current below 2 mA and a working current of 15 mA. An effective angle of less than 15° was spanned, covering distances from 2 to 400 cm, with a resolution of 0.3 cm. The measurement angle was approximately 30°, with a pulse input trigger width of 10 µS. The sensors measured 45 × 20 × 15 mm and mass about 10 g.

2: Electrical components

Key electrical elements of the automated Cartesian arm include relays, Arduino, power supply, camera, Rasberry, and breadboard, as shown in Fig. 4.

Relays

Four relays were used in the system: Three two-channel 5V DC relay modules (SRD-05VDC-SL-C) and one one-channel 5V DC relay (JQC3F-5VDC-C). Each relay controlled a motor's forward or backward movement using an active low trigger based on Arduino Uno and Raspberry Pi board data. The relays activate at 0V and deactivate at 5V, switching up to 250V AC or 30V DC and 10A. The Arduino Uno connects to the vacuum motor via the relay, switching it on or off based on received signals.

Arduino Uno

The study used the Arduino Uno AVR variant, equipped with an ATmega328P microcontroller operating at 16 MHz, with 32 kB flash memory, 2 kB SRAM, and 1 kB EEPROM. It features 14 digital I/O pins, 6 analog input pins, an ICSP circuit, operates at 5V, and accepts DC input from 7 to 12V. The USB interface allows computer communication, and the reset button enables restarts. Arduino Uno acts as a development board that collects and stores data from connected sensors and cameras. These sensors gather information on X, Y, and Z axes. Using a specific looping algorithm, the Arduino receives real-time data from the sensors, determining the pot's location and the seeding arm's height.

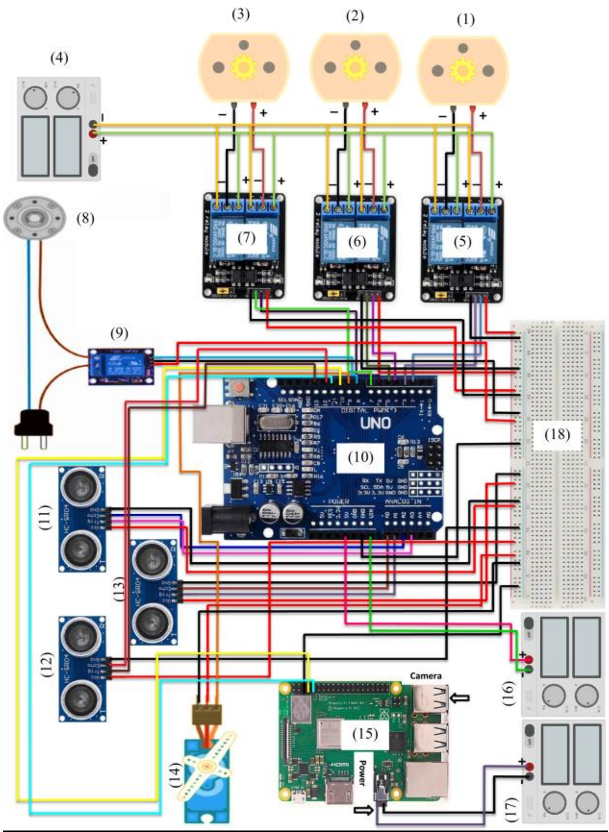
Power supply

A 24V-10A power supply provides voltage and current for the three DC motors to move along the X, Y, and Z axes. It powers the Arduino Uno with 5V at 2A and the Raspberry Pi with 5V at 2.5A, ensuring reliable and efficient operation. A consistent power supply prevents performance issues and protects the Raspberry Pi from potential damage due to incorrect currents.

Rasberry

The Raspberry Pi 4 Model B was used in this study and powered by a USB Type C supply delivering 5V at 3A. It had a 1.5 GHz quad-core Cortex-A72 processor, 4GB LPDDR4 SDRAM, and a VideoCore VI graphics processor supporting 4K video at 60 fps. Fast wireless communication was provided by dual-band Wi-Fi and Bluetooth 5.0 BLE. Connectivity included dual micro-HDMI, USB 3.0 and 2.0

ports, Gigabit Ethernet, and a combined audio/video jack. Storage was facilitated through a microSD card, and external devices were connected via the 40-pin GPIO header. The Raspberry Pi 4 was housed in a protective case with a cooling fan and aluminum heat sink to prevent thermal throttling.



No.	Description
1, 2, 3	DC Motor 24V (Directions X, Y, Z)
4	Power Supply 24V
5, 6, 7	Relay module 2 Channel 24V (Directions X, Y, Z)
8	Vacuum Motor 220V – 1000W
9	Relay module 1 Channel
10	Arduino Uno - AVR (8-bit); at 16 MHz
11, 12, 13	Ultrasonic Sensor (Directions X, Y, Z)
14	Servo Motor
15	Raspberry Pi - 4GB
16	Power Supply 5V - 2A (Direction Arduino Uno)
17	Power Supply 5V - 2.5A (Direction Raspberry Pi)
18	Breadboard

Fig. 4. Key electrical elements of the automated Cartesian arm

Breadboard

The 830-point breadboard was used to facilitate rapid electronic prototyping without soldering. Its grid pattern of interconnected points enables easy circuit creation and troubleshooting. Made from durable plastic, it provides electrical insulation and structural support.

Camera

The Logitech C270 Pro Stream camera, used in this study, features 720p HD resolution at 1280 × 720 pixels and 30 frames per second (fps). It has a fixed focus lens with a 60-degree field of view and connects via USB 2.0, ensuring compatibility with various operating systems. The camera captures images up to three megapixels, and its universal clip allows easy mounting on laptops and Raspberry Pi boards.

3: Greenhouse and movement installation

This study employs an even-span greenhouse made from iron pipes with an external diameter of 2.2 cm and characterized by specific dimensions, including a 2.0 m width span and a 4.0 m length. The eave height stands at 2.0 m, with a ridge height of 2.5 m and a roof slope angle of 26.5º. The chassis of the automated Cartesian arm is installed at a height of 180 cm from the ground, which is 20 cm below the height of the eave. The width of the device is 30 cm. The rail unit comprises two parallel aluminum linear rails at the X-axis with a length of 400 cm, each equipped with a rack and pinion gear for longitudinal movement, and two other parallel aluminum linear rails at the Y-axis having a 200 cm length, each with a rack and pinion gear for transverse movement (Fig. 5). A vertical bar (Z-axis) incorporates a gear rack (Fig. 1). Five racks facilitate movement in three directions (X, Y, and Z axes): two racks with a 3 mm pitch are installed on the X-axis, each 400 cm long. The X-axis movement is driven by a DC motor with a 55 mm diameter spur gear, 29 teeth, and a shaft with three spur gears (one 60 mm middle gear aligned motor and two side gears with a 60 mm diameter and 33 mm pitch). The direction motion of the Y-axis is driven by a DC motor with similar specifications to the X-axis except for a gear pitch of 8 mm and a length of 180 cm, as shown in Fig. 5. The Z-axis movement is driven by a DC motor with a 23 mm diameter pinion gear, 14 teeth, and 11 mm pitch aligned with a rack of 120 cm length and 2 cm width.

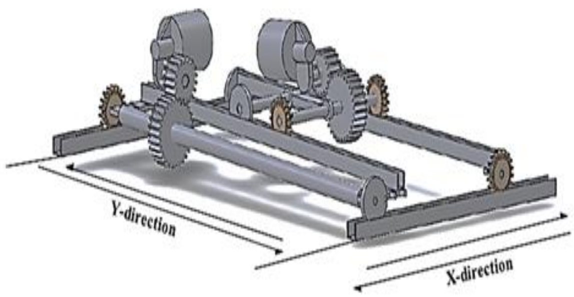


Fig. 5. 3D view of the rail system and the movement on the X and Y axes

Studied factors

The experiments were conducted to examine various factors that impact the performance of the automated seeding arm, including:

(a) Seed suction nozzle diameter: Three different seed suction nozzle diameters, i.e., 0.5, 1.0, and 2.0 mm.

(b) Seed type: Four different seed types, i.e., Armenian cucumber, pepper, turnip, and okra.

This study addressed four seed types (Armenian cucumber, pepper, turnip, and okra) with different dimensions, as listed in Table 1. The average mass of 100 seeds varies significantly among different types. The mean seed masses for okra, turnip, pepper, and Armenian cucumber were 8.08, 0.14, 0.30, and 3.06 g, respectively.

Operating the automated Cartesian seeding arm

Firstly, the Arduino card was programmed with the motor control and seed planting automation program to control multiple motors and manage seed planting actions based on sensor readings. The Raspberry Pi card was programmed with the deviation management program to send data to the Arduino and control motor movements accordingly. When the seeding arm turns on, it activates the camera to identify the locations of the planting circles (pots), and the Arduino sends coordinates in the X and Y directions. Based on these coordinates, the column moves sequentially in the X direction using transmission motors until it reaches the designated point. Then, it continues sequentially in the Y direction until the targeted planting point. Upon reaching the intersection of the circle's radii (indicating the planting point), the robot initiates the planting process.

Table 1. Dimensions of the studied seeds

Seed type	Okra	Turnip	Pepper		Armenian cucumber		
Experiments	**Diameter (mm)**	**Diameter (mm)**	**Width (mm)**	**Thickness (mm)**	**Length (mm)**	**Width (mm)**	**Thickness (mm)**
Ex.1	4.90	2.22	3.99	0.71	11.59	4.50	1.53
Ex.2	4.25	1.98	3.93	1.06	11.75	4.29	2.49
Ex.3	4.46	1.65	4.02	0.63	13.28	4.78	2.10
Ex.4	4.94	1.85	3.83	0.87	12.40	5.08	1.77
Ex.5	4.97	1.75	3.61	0.81	10.30	4.00	1.44
Ex.6	4.60	1.89	3.66	1.02	9.23	3.77	0.85
Ex.7	4.29	1.59	3.57	0.96	11.30	4.43	1.62
Average	4.63	1.85	3.80	0.87	11.41	4.41	1.69
Standard deviation (Sd)	0.31	0.21	0.19	0.16	1.33	0.44	0.52
Coefficient of variation (CV)	6.68	11.55	4.93	18.47	11.66	10.09	30.76

Initially, the seed box moves using the servo motor until it reaches a 90-degree angle, positioning it directly beneath the planting column. The suction motor responsible for catching the seed is then activated. According to measurements from the ultrasonic sensor, the robot moves downward in the Z direction until it reaches the seed box, which is positioned 31 cm below the maximum height. It collects the seed and then moves upward in the Z direction to the maximum height until the seed box returns to its original position at 0 degrees; the column then moves downward again in the Z direction to place the seed in the soil at the recommended depth (2.5 cm) based on the height of the soil surface in the pot. After placing the seed, the suction motor is disengaged to release the seed into the soil. After completing the planting process, the seeding arm ascends to the maximum height to repeat the movements until the entire greenhouse is planted.

A total of 36 pots were arranged in the 8 m² area, with 9 pots in each row longitudinally and 4 pots in a cross direction, each with a 20 cm interval between them and a 30 cm distance maintained between the pot edges and the greenhouse structure from all directions. The seeding experiments were executed at a depth of 2.5 cm throughout all pots inside the greenhouse, according to the recommendations of the literature reviews in the introduction section.

Measurements

a - Number of seeds captured by suction arm per stroke,

b - The seeding duration (second): It includes the total duration required for the transplant, starting with the horizontal descent of the shaft, moving upwards and then downwards to the recommended depth (2.5 cm); this period lasts for precisely 20 seconds in all experiments, in addition to the resting duration.

c - Deviation relative to the pots' centers

Instruments

a- A digital caliper was used to measure the seeds' dimensions. The digital caliper has a measurement range of 0 to 150 mm with an accuracy of 0.01 mm.

b- A digital balance was used to measure the mass of the seeds. It features a maximum capacity of 200 g with an accuracy of 0.001 g.

c- A stopwatch was used to determine the time taken for the seeding process.

RESULTS AND DISCUSSION

The following points outline the discussion of the results obtained from this study:

1: Number of seeds captured by suction arm per stroke

Table 2 explains the number of seeds captured by air suction at different seed suction hole diameters (0.5 mm, 1 mm, and 2 mm) and seed types (Okra, Turnip, Pepper, and Armenian Cucumber). The table represents data from fifteen experiments (Ex. 1 to Ex. 15) for each combination of seed type and seed suction hole diameter, presenting the average of seeds (Ex. T) for each experiment. The results reveal that a suction hole diameter of 0.5 mm captured 0.8, 1.46, 1.33, and 1.46 seed(s) for okra, turnip, pepper, and Armenian cucumber, respectively. Meanwhile, a suction hole diameter of 1 mm captured 1.0, 1.93, 2.13, and 1.46 seed(s), and a suction hole diameter of 2 mm captured 1.26, 12.6, and 3.93 seed(s) for the same seeds mentioned above. This is due to the larger seed suction hole diameter, which increases the suction area and, as a result, captures more seeds. The results recommend that a suction hole diameter of 0.5 mm is best for turnip and pepper seeds, while a suction hole diameter of 1 mm is best for okra and Armenian cucumber seeds.

Table 2. Number of seeds captured by air suction for different seed types and seed suction hole diameters.

Seed type	**Okra**			**Turnip**			**Pepper**			**Armenian cucumber**		
Seed suction hole diameter (mm)	**0.5**	**1**	**2**	**0.5**	**1**	**2**	**0.5**	**1**	**2**	**0.5**	**1**	**2**
Ex.1	1	1	1	1	1	More than 20 seeds	1	2	10	1	1	3
Ex.2	1	1	1	1	2		1	2	12	0	2	4
Ex.3	1	1	1	1	2		1	2	12	1	1	3
Ex.4	0	1	2	2	3		2	3	12	2	1	3
Ex.5	1	1	1	3	3		2	3	18	1	2	3
Ex.6	1	1	1	2	1		1	3	10	1	2	2
Ex.7	0	1	1	1	1		1	1	12	1	1	3
Ex.8	1	1	2	1	1		1	1	17	1	2	4
Ex.9	1	1	1	1	3		1	2	15	1	1	4
Ex.10	1	1	2	1	2		2	3	12	1	1	3
Ex.11	0	1	1	1	2		2	2	13	1	2	5
Ex.12	1	1	2	1	2		1	1	10	0	2	6
Ex.13	1	1	1	1	3		1	2	12	2	2	7
Ex.14	1	1	1	2	1		1	3	11	1	1	5
Ex.15	1	1	1	3	2		2	2	13	1	1	4
Ex.T	0.8	1	1.26	1.46	1.93		1.33	2.13	12.6	1	1.46	3.93

2: Resting duration

The seeding duration represents the total duration required for the transplant, starting with the horizontal descent of the shaft, moving upwards and then downwards to 2.5 cm depth. The duration of this period remains consistent across all experiments, specifically 20 seconds. The resting duration is the time needed for the seed to fall freely under the influence of its weight after the suction motor is stopped. Table 3 presents the resting duration of four seed types with a 0.5 mm suction hole diameter. Three experiments were conducted on these seeds to determine the resting duration of seeds falling into the soil at a recommended depth of 2.5 cm after the suction motor stopped, and to check if seeds fell prematurely due to vibrations from the plume movement. For Armenian cucumber seeds, the recorded resting durations were 6.05, 5.85, and 7.17 seconds for the first, second, and third experiments, respectively. In the initial and third trials with pepper seeds, two seeds were suctioned and fell into the soil at 5.40, 6.61, 5.25, and 5.40 seconds, respectively. In the second experiment, one seed fell prematurely after 3 seconds, and the second after 7.20 seconds. For turnip seeds, one seed fell into the soil after 8.84 seconds in the first experiment, while in the second trial, two seeds fell prematurely at 4.48 seconds, with another falling at 9 seconds. In the third trial, three seeds fell at 7, 7.2, and 7.55 seconds. For okra, one seed fell prematurely at 15.2 seconds in the first experiment, none in the second, and one prematurely at 2.83 seconds in the third experiment.

Table 3. Resting duration for different seed types at a seed suction nozzle diameter of 0.5 mm.

	Suction nozzle diameter = 0.5 mm						
Seed type Experiment	**Armenian cucumber**	**Pepper**		**Turnip**			**Okra**
Ex.1	6.08s	Seed Number 1 5.40s	Seed Number 2 6.61s	8.84s			1seed feel after 15.2s
Ex.2	5.85s	1seed feel after 3s	Seed Number 2 7.20s	1seed feel after 4.48s without closing		Seed Number 2 9s	No seeds sucked
Ex.3	7.17s	Seed Number 1 5.25s	Seed Number 2 5.40s	Seed Number 1 7s	Seed Number 2 7.2s	Seed Number 3 7.55s	1seed feel after 2.83s

Table 4 presents the resting time for four different seed types using a 1 mm seed suction hole diameter. For Armenian cucumber seeds, in the first experiment, one seed fell into the soil after 8.27 seconds. In the second experiment, two seeds fell at 5.26 and 9.18 seconds; in the third experiment, two seeds fell at 5.30 and 7.11 seconds. For pepper seeds, in the first experiment, five seeds fell; the first two at 5.20 seconds and the remaining three at 7.30 seconds. In the second experiment, five seeds were captured; the first fell after 10 seconds, the next two at 6.30 seconds, the fourth at 7.50 seconds, and the last at 8 seconds. In the third experiment, three seeds fell at 4.30, 7.30, and 7.45 seconds. In the first trial, three seeds fell at 6.30, 7.40, and 8.20 seconds for turnip seeds. In the second trial, three seeds fell at 6, 7, and 9.10 seconds. In the third trial, three seeds fell at 6.20, 7.40, and 9.20 seconds. In the first trial, one seed fell at 8.42 seconds for okra seeds. In the second and third trials, seeds fell at 9.20 and 9.40 seconds, respectively.

Table 4. Resting time for different seed types at a seed suction nozzle diameter of 1 mm.

	Suction nozzle diameter = 1 mm								
Seed type Experiment	**Armenian cucumber**		**Pepper**			**Turnip**			**Okra**
Ex.1	Seed Number 1		Seed Number 1:2		Seed Number 3:5	Seed Number 1	Seed Number 2	Seed Number 3	8.42s
	8.27s		5.20s		7.30s	6.30s	7.40s	8.20s	
Ex.2	Seed Number 1	Seed Number 2	1seed feel after 10s without closing			Seed Number 1	Seed Number 2	Seed Number 3	9.20s
			Seed Number 2:3	Seed Number 4	Seed Number 5				
	5.26s	9.18s	6.30s	7.50s	8s	6s	7s	9.10s	
Ex.3	Seed Number 1	Seed Number 2	Seed Number 1	Seed Number 2	Seed Number 3	Seed Number 1	Seed Number 2	Seed Number 3	9.40s
	5.30s	7.11s	4.30s	7.30s	7.45s	6.20s	7.40s	9.20s	

Table 5 illustrates the resting time for the four seed types with a seed suction hole diameter of 2 mm. In the initial experiment, three Armenian cucumber seeds fell into the soil after the suction motor closed, reaching a depth of 2.5 cm at 7.58, 8.41, and 9.10 seconds, respectively. In another trial, four Armenian cucumber seeds fell at 5.30, 7.20, 8.40, and 9.02 seconds. In a third trial, three seeds fell at 7.50, 8.69, and 9.19 seconds. Three experiments were conducted on pepper seeds. In the first experiment, 18 seeds were captured. The first and second seeds fell after 15 seconds and 17 seconds, respectively, but did not reach the soil surface. The subsequent seeds fell after the suction motor closed and reached the desired depth (2.5 cm). The third seed fell after 6.28 seconds. Seeds 4 and 5 fell after 7.45 seconds, seeds 6 and 7 fell after 8.28 seconds, and seeds 8 to 12 fell after 9.58 seconds. In the second trial with pepper seeds, 12 seeds were picked up. The first seed fell after 18.27 seconds without reaching the designated planting place. The next seeds fell after the suction motor closed and reached the designated planting place as follows: seeds 2 and 3 fell after 6.23 seconds, seeds 4 and 5 fell after 7.10 seconds, seeds 6 and 7 fell after 8.13 seconds, and seeds 8 to 12 fell after 9.40 seconds. In the third trial with pepper seeds, 12 seeds were picked up. The first seed fell after 2.13 seconds without reaching the planting place. The next seed fell after the suction motor closed and reached the designated planting place as follows: seeds 2 and 3 fell after 4.30 seconds, and seeds 4 and 5 fell after 5.40 seconds. As for the turnip experiments, a suction hole diameter of 2 mm is excluded because it sucked more than 20 seeds. For okra seeds, in the first and second trials, one seed fell at 9.98 and 9.77 seconds, respectively. In the third experiment, the first seed fell at 6.72 seconds and the second at 9.30 seconds.

3: Deviation relative to the pots' centers:

Fig. 6 details the variations in X and Y coordinates observed in a camera system designed to align a seeding arm precisely with the pot's center. The system aims to reach the pot's center (0,0) for seeding. Deviations from this target, measured in millimeters, indicate the system's accuracy and precision. The table shows multiple readings of deviations, with the desired position at (0,0). Minimal deviations, such as (0 mm, 0 mm) and (0 mm, -0.6 mm), indicate high accuracy. In contrast, larger deviations, such as (1.4 mm, 0.8 mm) and (1.2 mm, -1.2 mm), suggest occasional precision issues, possibly due to mechanical misalignments or sensor errors. The clustering of deviations at (1.2 mm, 0.8 mm) and (1.2 mm, -1.2

mm) points to a systematic bias that could be corrected through calibration. Mechanical factors, environmental conditions, and precise positioning are crucial for successful seeding. Depending on system tolerance, deviations within ±0.5 mm might be acceptable, but larger deviations could affect seed placement and yield (Pradhan *et al.*, 2024). Regular calibration, improved mechanical stability, and advanced error-correction algorithms can enhance accuracy.

Table 5. Resting time for different seed types at a seed suction nozzle diameter of 2 mm.

<table>
<tr><th colspan="12">Suction nozzle diameter = 2 mm</th></tr>
<tr><th>Seed type
Experiment</th><th colspan="4">Armenian cucumber</th><th colspan="4">Pepper</th><th>Turnip</th><th colspan="2">Okra</th></tr>
<tr><td rowspan="3">Ex.1</td><td rowspan="2">Seed Number 1</td><td rowspan="2" colspan="2">Seed Number 2</td><td rowspan="2">Seed Number 3</td><td colspan="4">1seed feel after 15s without closing
1seed feel after 27s without closing</td><td rowspan="3">Excluded</td><td rowspan="3" colspan="2">9.98s</td></tr>
<tr><td>Seed Number 3</td><td>Seed Number 4:5</td><td>Seed Number 6:7</td><td>Seed Number 8:18</td></tr>
<tr><td>7.58s</td><td colspan="2">8.41s</td><td>9.10s</td><td>6.28s</td><td>7.45s</td><td>8.28s</td><td>9.58s</td></tr>
<tr><td rowspan="3">Ex.2</td><td rowspan="2">Seed Number 1</td><td rowspan="2">Seed Number 2</td><td rowspan="2">Seed Number 3</td><td rowspan="2">Seed Number 4</td><td colspan="4">1seed feel after 18.27s without closing</td><td rowspan="3">Excluded</td><td rowspan="3" colspan="2">9.77s</td></tr>
<tr><td>Seed Number 2:3</td><td>Seed Number 4:5</td><td>Seed Number 6:7</td><td>Seed Number 8:12</td></tr>
<tr><td>5.30s</td><td>7.20s</td><td>8.40s</td><td>9.02s</td><td>6.23s</td><td>7.10s</td><td>8.13</td><td>9.40s</td></tr>
<tr><td rowspan="3">Ex.3</td><td rowspan="2">Seed Number 1</td><td rowspan="2">Seed Number 2</td><td rowspan="2" colspan="2">Seed Number 3</td><td colspan="4">1seed feel after 2.13s without closing</td><td rowspan="3">Excluded</td><td rowspan="3">1seed feel after 6.72s without closing</td><td rowspan="2">Seed Number 2</td></tr>
<tr><td>Seed Number 2:3</td><td>Seed Number 4:5</td><td>Seed Number 6:7</td><td>Seed Number 8:12s</td></tr>
<tr><td>7.50s</td><td>8.69</td><td colspan="2">9.19s</td><td>4.30s</td><td>5.40s</td><td>7.40s</td><td>9.82s</td><td>9.30s</td></tr>
</table>

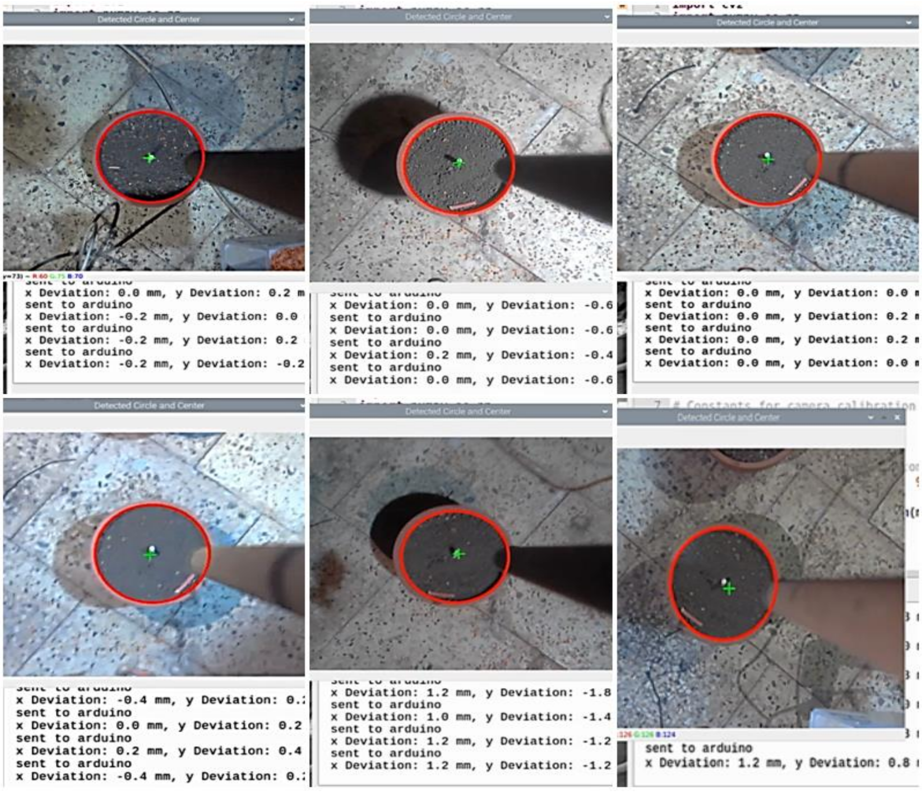


Fig. 6. Deviation relative to the pots' centers.

CONCLUSION

The study aimed to automate seed sowing in pots in the protected crops, tackling the labor-intensive manual process in Egypt's agriculture. The results revealed notable findings regarding the number of seed captures and the optimal configurations for various types of seeds. Okra and Armenian cucumber showed optimal seed capture with a 1 mm nozzle diameter, recorded in an average of 1.0 and 1.46 seed(s) per pot, respectively. The most effective nozzle for capturing turnip and pepper seeds was 0.5 mm, with an average of 1.46 and 1.33 seeds, respectively. The nozzle diameter positively influenced the capture efficiency, with variations observed depending on the seed type. The resting duration of the seeds' fall into the soil varied based on the nozzle diameter and seed type. Armenian cucumber seeds exhibited a duration range of approximately 6-8 seconds, while okra seeds required 9-10 seconds. Based on the results, for precise single-seed capture, it is recommended to apply a 1 mm nozzle diameter for okra and Armenian cucumber seeds and a 0.5 mm nozzle diameter for turnip and pepper seeds.

REFERENCES

Abo-Habaga, M.M.; Z.M. Imara and M.H Okasha (2018). Development of a Combine Hoeing Machine for Flat and Ridged Soil. Journal of Soil Sciences and Agricultural Engineering, Mansoura University, 13(7), 231-235. http://dx.doi.org/10.21608/ jssae. 2018. 36548

Anand, S.K.; R. Baitha and M.P. Mandal (2019). Effects of Sowing Depth on Emergence of Abelmoschus esculentus by Modified Mechanical Equipment. International Research Journal of Engineering and Technology, 6(3), 7426-7430.

Ding, L.; L. Yang; D.H. Wu; D. Li; D. Zhang and S. Liu (2018). Simulation and experiment of corn air suction seed metering device based on DEM-CFD coupling. Journal of Transactions of the Chinese Society of Agricultural Machinery, 11(49), 48-57. http:// dx. doi. org/10.6041/j.issn.1000-1298.2018. 11.006

Du, X.; Z. Yun; X. Jin; P. Li and K. Gao (2023). Design and Experiment of Automatic Adjustable Transplanting End-Effector Based on Double-Cam. Agriculture, 13(5), 987. https://doi.org/10.3390/ agriculture 13050987

Ismail, Z.E. (2015). Seeder equipped with seeds delivery mechanism depending on an oscillating motivation unit. Misr J. Ag. Eng., 32(4), 1761-1774. https://doi. org/ 10.21608/mjae.2015.97872

Ismail, Z.E.; A.E. Abo El-Magd; E.B. Elbanna; Amaal A. Ibrahim (2014). Vacuum pressure device as affected by suction tube characteristics. J.Soil Sci. and Agric. Eng., Mansoura Univ., Vol. 5 (12), 1635-1644. https://dx .doi.org/10.21608/jssae.2014.49796

Ismail, Z.E.; Kh. A.A. Khdar and Marwa S. Shawky (2023). Connection of the Radish Seed's Physical Characteristics with the Bottom Holes Design of the Seeder Device. Journal of Soil Sciences and Agricultural Engineering, Mansoura University, 14(7), 203-207. https://dx.doi. org/ 10.21608/ jssae. 2023. 216279.1166

Karayel, D.; Z.B. Barut and A. Özmerzi (2004). Mathematical Modelling of Vacuum Pressure on a Precision Seeder. Journal of Biosystems Engineering, 4(87), 437-444. https://doi.org/10.1016/ j.biosystemseng.2004.01.011

Kautsar, S.; E. Rosdiana; B. Widiawan; D.P.S. Setyohadi; H.Y. Riskiawan and R. Firgiyanto (2020). Farming Bot: Precision Agriculture System in Limited Land Based On Computer Numerical Control (CNC). IOP Conference Series Earth and Environmental Science, 411(1), 012059. https://iopscience.iop.org/ article/ 10.1088/1755-1315/ 411/ 1/012059

Li, J.H.; Q.H., Lai; H. Zhang; Z.G. Zhang; J.W. Zhao and T.T. Wang (2021). Suction force on high-sphericity seeds in an air-suction seed-metering device. Biosystems Engineering, 211, 125-140. https://doi. org/ 10.1016/j. biosystemseng.2021.08.031

Moraitis, M.; K. Vaiopoulos and A.T. Balafoutis (2022). Design and Implementation of an Urban Farming Robot. Micromachines, 13(2), 250. https://doi.org/10.3390/mi13020250

Odeleye, F.O.; O.M.O. Odeleye; A.O. Olaleye and F.B. Yakubu (2007). Effect of sowing depth on emergence, growth and yield of okra (*Abelmoschus esculentus* (L.) Moench). Journal of Food, Agriculture & Environment, 5(1), 205-209.

Qi, Y.Z.; S.N. Xiang (2020). Research Status and Development Trend of Vegetable Planter at Home and Abroad. Journal of Chinese Journal of Agricultural Mechanization, 1(41), 205-208.

Pradhan, N.C.; M.A. Naik; M. Chowdhury; A. Kushwah; K.R. Asha; T. Dhar; K.P. Gavhane; S.B. Urhe and A.N. Satpute (2024). Robotic Seeding or Sowing System in Smart Agriculture. In: Pandey, K., Kushwaha, N.L., Pande, C.B., Singh, K.G. (eds) Artificial Intelligence and Smart Agriculture. Advances in Geographical and Environmental Sciences. Springer, Singapore. https://doi. org/ 10.1007/978-981-97-0341-8_23

Regatti, V.; S. Sai Mohan; S. Rahaman; M. Vinayak; B. Hari Babu and K.V.S. Rami Reddy (2024). Energy Assessment of Manual Transplanting Rice and Dry Direct Seeding Rice Production Systems in Combined Nalgonda District, Telangana. Indian Journal of Agricultural Research, 58(1), 95-100. http://dx.doi. org/ 10.18805/IJARe.A-5912

Shi, S.; H. Liu, G.J. Wei; J.L. Zhou; S.C. Jian and R.F. Zhang (2020). Optimization and experiment of pneumatic seed metering device with guided assistant filling based on EDEMCFD. Transactions of the CSAM, 51(5), 54-66. http://nyjxxb.net/index. php/journal/article/view/987

Tawfik, H.A.H (2014). Developing an automatic mechanism for precision seeder. MSc thesis, Agric. Eng. Department, Faculty of Agriculture, Mansoura University, Egypt.

Wang, Y.; W. Zhang; X. Luo; Y. Zang; L. Ma; W. Zhang; J. Liu and S. Zeng (2024a). Effect of Vibration Conditions on the Seed Suction Performance of an Air-Suction Precision Seeder for Small Seeds. Agriculture, 14(4), 559. https://doi.org/10.3390/ agriculture14040559

Wang, Z.; W. Su; Q. Lai; J. Li and X. Gao (2024b). Boundary modelling of the effective suction domain of an air-suction seed-metering device for quasi-spherical seeds. Biosystems Engineering, 238(2), 212-226. http://dx.doi. org/10.1016/ j.biosystemseng. 2024.01.012

Zhao, X.; T. Zhang; F. Liu; N. Li and J.R. Li (2023). Sunflower seed suction stability regulation and seeding performance experiments. Agronomy, 13(1), 54. https://doi.org/ 10.3390/ agronomy13010054

تطوير ذراع ديكارتي آلي لزراعة البذور في أصص

محمد مصطفى أبوحباجة[1]، زكريا ابراهيم اسماعيل[1]، ناريمان السيد مصطفى[1] و محمود محمد هشام عكاشة[2]

[1] قسم الهندسة الزراعية – كلية الزراعة – جامعة المنصورة – ج.م.ع.
[2] معهد بحوث الهندسة الزراعية – مركز البحوث الزراعية – الجيزة – ج.م.ع.

الملخص

تهدف هذه الدراسة إلى تطوير ذراع ديكارتي آلي لزراعة البذور في أصص داخل البيوت المحمية. يتكون الذراع من وحدة الزراعة ومكونات كهربائية. تم تركيب الذراع على إطار البيت المحمي، وتم تنفيذ الحركات في المحاور الثلاثة لزراعة البذور في الأواني المخصصة. تناولت الدراسة متغيرات تمثلت في ثلاثة أقطار لفوهة شفط البذور (0.5 و1.0 و2.0 مم) وأربعة أنواع من البذور (القثاء والفلفل واللفت والبامية). تم تقييم الأداء من حيث عدد البذور الملتقطة في المشوار الواحد، مدة سقوط البذور في التربة، والانحراف بالنسبة لمنتصف الأصيص. أُجريت التجارب في قسم الهندسة الزراعية، كلية الزراعة، جامعة المنصورة. أظهرت النتائج أن قطر فوهة شفط البذور 1.0 مم كان الأفضل لزراعة بذور البامية والقثاء، حيث بلغ متوسط عدد البذور الملتقطة 1.0 و1.46 بذرة لكل أصيص على التوالي. على العكس من ذلك، كان قطر فوهة شفط البذور 0.5 مم هو الأنسب لبذور الفلفل واللفت، حيث التقطت الفوهة 1.33 و1.46 بذرة لكل أصيص على التوالي. كان هناك تفاوت في مدة سقوط البذور في التربة، حيث استغرق القثاء 6-8 ثوانٍ بينما استغرقت البامية 9-10 ثوانٍ. توصى الدراسة بإمكانية تطبيق الزراعة للأصص باستخدام النظام الآلي المطور لعديد من البذور مع اختيار قطر فوهة الشفط المناسبة لمواصفات البذور. كما يمكن تطبيق التجارب على أنواع أخرى من البذور لتوثيق قاعدة بيانات تناسب أكبر عدد من البذور لرفع فعالية الوحدة تحت الدراسة.