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DEVELOPMENT OF A GARLIC SEEDER FOR TWO-WHEEL TRACTORS: A SEARCH FOR QUALITY IN DEPTH, LONGITUDINAL DISTRIBUTION, AND ORIENTATION OF BULBS

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KEYWORDS

development of agricultural machinery, two-wheel tractor, garlic seed orientation, seed singularization, seed depth adjustment.

ABSTRACT

A two-wheel tractor-drawn garlic seeder was developed. The seeder was composed of a multiple adjustment mechanism, transmission and mulching devices, a furrow opener, a ground roller, and a depth adjustment device. The problem of multiple seeds being placed in a single hole was solved through the vibration and change in volume of the seed-picking spoon. The problems with the seed orientation and sowing depth were overcome by the multi-stage cam adjustment mechanism and the depth adjustment device, respectively. After the key components of the new garlic seeder were successfully developed, product manufacturing, simulation verification, and testing were performed. The results showed that an average correct seed orientation rate of 90.97%, a missing-seed rate of 1.12%, and a single-hole repetition rate of 1.16% were achieved. The depth adjustment device ensured the required garlic sowing depth, and its sowing efficiency was 25–45 times that of manual planting, effectively meeting the needs of growers.

INTRODUCTION

Garlic is a nutritious and versatile cash crop with antibacterial and antiseptic properties, and it is an essential seasoning in cooking. According to the United Nations Food and Agriculture Organization data (Agricultural Industry Data Service Platform, 2021), in 2020, the global garlic production was approximately 32 million tons. China's garlic production was 24.028 million tons, accounting for 75.09% of the world production.

Although China plays a significant role in global garlic cultivation and production, the mechanization level of the garlic industry remains below 10%. The mechanization rate of garlic planting is below 20%, and most garlic planting is done manually. Manual planting is limiting the industrialization of garlic cultivation in China, as shown in Figure 1.

FIGURE 1. Manual planting of garlic.

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Compared with corn and wheat, garlic has strict cultivation requirements. The growth rate of garlic bulbs with the bulb facing upward is clearly higher compared to when the bulb is facing downward or to the side. The following technical routes are commonly used by garlic seeders (Wang, 2019).

Garlic spot sowing technology

During the seed delivery process, the garlic tip orientation is free. When the garlic seeds are delivered into the guide tube, the garlic tip direction is completely randomly determined through the instantaneous orientation and position of the falling seed. After the garlic is removed from the seed box, it enters the guide tube, falling freely without orientation or scape bud adjustment. This method is less efficient in terms of the germination rate and productivity (Figure 2).

Artificially assisted seeding technology

As shown in Figure 3, the artificially assisted garlic sowing machine developed by Shandong Agricultural University featured a single-row multi-cavity garlic seed box and was made of degradable material. The garlic seeds are manually placed in the box with the “roots facing down and buds facing up” and then sown in the ground, along with the box, by a garlic seeder. This method is costly due to the configuration of one garlic box per garlic bulb. The work efficiency is similar to manual planting.

FIGURE 2. Garlic spot seeder.

FIGURE 3. Artificially assisted garlic seeder.

FIGURE 4. 2BS-4 garlic seeder.

Suspended or traction garlic seeding technology

This seeder technology is currently the most widely used, and it requires external traction power, such as that provided by a tractor. The tractor directly inputs power into the ground wheel, and the friction between the ground wheel and the ground drives other components of the seeder. Figure 4 shows the 2BS-4 garlic seeder jointly developed by Shandong Wuzheng Group Co., Ltd., and Qingdao Agricultural University, with the power source of a tractor.

Self-propelled automatic garlic planting technology

This garlic sowing technology requires a self-powered seeder capable of independently driving the machine and operating components, such as the seed picker, feeder, furrow opener, and scape bud adjuster, and completing the whole process of sowing through the combined action of the parts. This seeder has yet to be successfully developed and represents the future development trend.

The four technical approaches above have advanced the development of China’s garlic seeding machinery. However, several challenges, such as the release of multiple seeds in single-hole sowing, etc., remain.

A two-wheeled tractor garlic seeder has been developed with the aim of solving the above problems and improving the planting efficiency of garlic-seeding machines.

Determination of seeder power source scheme

(1) A garlic seeder equipped with an independent power source, such as an engine or an electric motor, can be fully self-propelled and perform both movement and sowing. This type of seeder has a complex structure and large size. Additionally, it is expensive and suitable for large-area-plot operations.

(2) Another type of seeder is the suspension type. This type of seeder contains a seed box, seed meter mechanism, transmission mechanism, scape bud adjustment mechanism, slotter, and other components. It is a complete product without a power source. This seeder uses external power sources, such as a tractor, through a sprocket or pulley. The tractor drives the seeder during operation, and after seeding is completed, the power is disconnected, allowing the tractor to perform other tasks.

(3) It is also possible to have a seeder that is fully functional but lacks a power source. When the seeder operates, it relies on manual pulling or animal pulling to plant one or two rows at a time. This type of seeder is small and cost-effective and has a single function, but it is suitable for small-plot operations.

Due to the agronomy of garlic planting areas and the equipment configuration, farmers in garlic-producing areas, such as Jinxiang County in Jining City and Laning County in Linyi City, have two-wheel tractors. Two-wheel tractors can be used for agricultural transportation, land cultivation, and irrigation. Therefore, in this study, the power source of the garlic seeder was that described in Scheme 2 above.

Design of scheme for sowing single seeds in a single hole

Commonly used seed extraction methods

(1) Seed extraction by pneumatic suction

A high-speed fan generates negative pressure, which is transmitted to the vacuum chamber of the seeding disk. When the disk rotates, the negative pressure adsorbs the seeds, and they are rotated with the seeding disk. After the seeds are released from the vacuum chamber, they fall into the planting ditch due to their weight. This method is suitable for sowing small grains without specific directional requirements.

(2) Seed extraction by robotic arm

A robotic arm, simulating human hand movements, systematically picks garlic seeds from the seed box and places them in the planting hole or tank (Zhao et al., 2014). The movement of the robotic arm is controlled by an intelligent control system, which has high accuracy and efficiency in seed picking. However, this system has strict requirements for the working environment and is expensive.

(3) Seed-picking by seed-picking spoon

The different seed meter actions can be divided into rotary spoon-type and chain spoon-type seed meters (Li et al., 2020b, 2022). The rotating spoon-type seed pickup method operates on the principle of multiple seeds being installed on the turntable. When the turntable turns over the seed box, the spoons pick up the seeds and rotate with the turntable. The excess seeds fall freely under gravity, while the remaining seeds fall into the seed guide tube and then are discharged to the seed furrow through the outlet. At high speeds, the seed spoons may fail to pick up seeds effectively, leading to seedling shortages.

The chain spoon-type seed-picking mechanism involves seed-picking spoons mounted on a motion chain that rotates in a continuous loop. When the spooner moves toward the seed box, it picks up seeds. The seed spooner rotates to the opposite side, dumps the seeds into the guide tube, and completes the sowing process. However, this method may take more than one seed at a time.

After comparing the advantages and disadvantages of these two seed meter methods, we decided to adopt the chain spoon-type seed meter, using a combination of two schemes, that is, the vibration plus the volume change of the seed meter spoon, to achieve the placement of one seed at a time.

Single-scoop single-seed scheme

Spoon grower solution design

The key to extraction using seed scoopers lies in matching the shape and volume of the seed scoopers with the garlic seeds, the running speed of the chain, and the driving speed of the tractor.

Taking Linyi Cang Shan garlic as an example, the dimensions of garlic were studied to determine the shape and volume of the seed spooner. The external dimensions of a garlic are shown in Figure 5.

FIGURE 5. Schematic diagram of garlic clove’s external dimensions.

Three groups of 100 g of garlic were selected; their length, width, and thickness were measured, and the average was taken. The dimensions are given in Table 1.

TABLE 1. Statistical table of garlic external dimensions.

Item	Length (mm)	Width (mm)	Thickness (mm)
Maximum value	37.64	20.78	21.26
Minimum value	29.58	14.69	16.84
Average value	34.31	18.92	19.36

The average garlic dimensions are 34.31 mm in length, 18.92 mm in width, and 19.36 mm in thickness. To ensure sufficient seed pickup, the length of the seed scooper is designed to be twice the length of the garlic, measuring 70 mm in length and 25 mm in width. To avoid vibrating the seeds out of the seed scoopers, the depth is designed to be 30 mm. The bottom of the seed spooner is designed to be rounded. Nitrile rubber is used as the spooner material. Figure 6 shows a schematic diagram of the seed spooner.

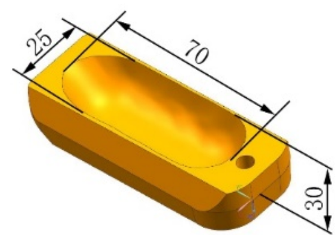


FIGURE 6. Schematic diagram of spoon structures.

Conveyor and single-cavity single-seed solution design

(1) Design scheme of transmission device

The technical solution involves a row of rails made of steel plates surrounding the ring, and the rails are designed with chain link slots at both ends and driven by four equally spaced sprockets. The rails are designed with equally spaced seed scoop extensions to facilitate the scoop extensions for picking up garlic seeds. The seed scoop is mounted on the rail by the connecting plate and rotates with the rail.

The distance between two rows of seed scoopers is 150 mm horizontally and 100 mm vertically, indicating that the garlic row spacing is 150 mm and the plant spacing is 100 mm. However, the actual plant spacing is determined by the combined transmission speed and tractor travel speed (Figure 7).

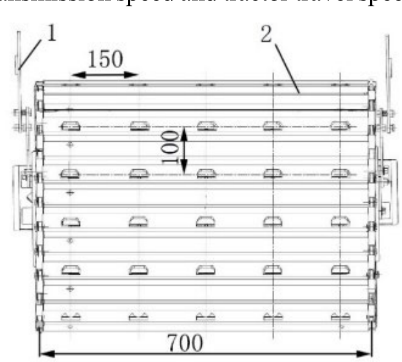


FIGURE 7. Schematic diagram of conveyor assembly

1. Adjustment of the institutional portfolio; 2. outer orbit combination

(2) Single-hole single-seed design scheme

Figure 8 shows the transfer device after the removal of the outer track combination, with the following design scheme and working principle for a single hole and single seed.

The seed spooner assembly is driven by the sprocket and the outer slide, and its rotation is driven by rollers inside the inner slide. The left-hand handle is used to adjust the distance L between the left and right inner slides. When the limit block is stuck in different slots on the main frame, the compression of the left spring and right spring changes. As a result, the distance L between the two inner slides continuously changes under the tension of the spring, and the change in the size of the inner slide causes the seed scoopers to swing from side to side to swing off the excess seeds.

The right-hand handle is used to adjust the distance between the linkage mechanism combination and the outer slide, and the inside of the right-hand handle has a limiting block. When the limiting block is stuck in different slots on the main frame, the linkage mechanism assembly rotates outward around the rotating support. The closer the linkage mechanism rotates toward the top, the larger the angle rotation. The outward rotating linkage mechanism assembly pushes the outer slide outward, shortening the extension length of the seed scoop, thereby pushing out the excess seeds. Thus, single-hole single-seed planting can be achieved.

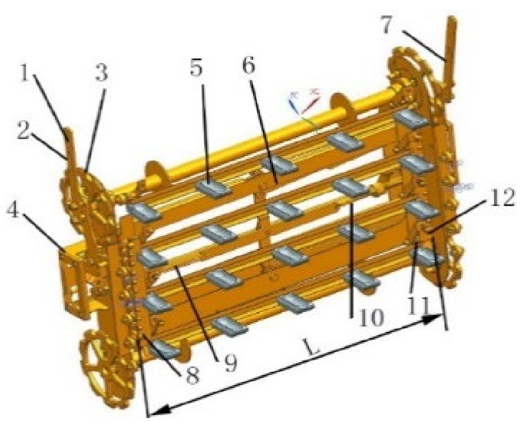


FIGURE 8. Detailed structural diagram of the conveyor device. 1. Left-hand handle; 2. limit block; 3. sprocket; 4. mounting bracket; 5. seed spoon; 6. linkage mechanism combination; 7. right-hand handle; 8. left inner slide; 9. left spring; 10. right spring; 11. rotation support; 12. right inner slide

Scheme design for reorientation of garlic tips

The control of the scape bud orientation during the sowing of garlic is a difficult point of research. Many researchers have proposed various solutions. Chong et al. (2015) invented a multi-layered conical bowl structure to control the direction of garlic scape shoots. The structure was moderately adaptable for specific varieties but not universally applicable. Huang (2020) proposed a double duckbill-type head-righting mechanism. The mechanism has a better head-righting effect but is only applicable to varieties with long, downy hairs at the tip of the scape buds. Han et al. (2016) achieved head-turning using the center of gravity of garlic and the friction with the guide tube during the fall of the garlic. However, the head-turning was not satisfactory. Li et al. (2020a) and Geng et al. (2020) successively proposed the use of image processing pattern recognition technology and photoelectric recognition technology for garlic scape bud direction control.

Development of a garlic tip orientation adjustment program

As the seed scooper picks the seeds from the seed box, it is continuously raised by the outer track assembly. When the seed scooper reaches the highest point, it flips down and then enables the seeds to fall into the seed guide slot. However, the direction of the garlic tip remains undefined at this stage.

When the garlic is released from the seed spoon, it can undergo any of the following three states: horizontal drop, tip facing down, or tip facing up. The adjustment structure uses a multi-stage inverted cone adjuster. When the garlic falls into the first adjuster and hits the inclined side wall of the adjuster, the garlic has a tendency to slide down the side wall. Because the barycenter of garlic is in the middle-down position, the garlic root speed is faster when it slides down. As the adjuster is an inverted cone, the lower the taper, the more pointed it becomes. When the bottom of the adjuster is reached, the garlic seed lies flat at the bottom of the first adjuster.

When the first adjuster is turned on, the roots will automatically adjust to face downward during the free fall of the garlic due to the closeness of the barycenter to the roots. When the garlic reaches the second adjuster, the angle of the inverted cone of the second adjuster will be smaller and steeper than that of the first-stage adjuster. When the garlic roots slide down the side wall of the adjuster to the bottom, the scape buds will lean upward diagonally against the side wall of the cone. After the adjustment is completed, the second adjuster opens and allows the garlic to fall into the third adjuster. This process repeats until the garlic scape buds are adjusted to the basic upward-facing state. Figure 9 shows the structure of the adjuster, and Figure 10 shows the multi-stage adjustment mechanism.

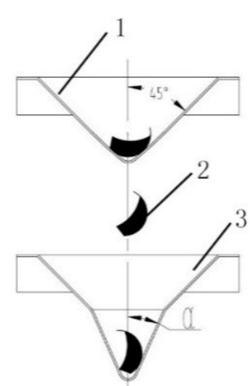


FIGURE 9. Schematic diagram of two-stage adjuster structure. 1. First adjuster; 2. garlic; 3. second adjuster

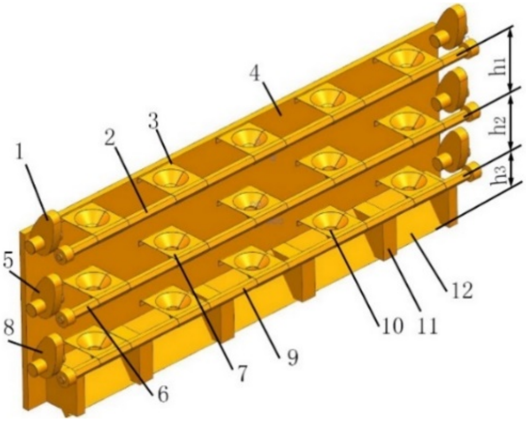


FIGURE 10. Multi-stage adjustment mechanism.

1. Cam ①; 2. hexagonal shaft ①; 3. first adjuster; 4. main frame; 5. cam ②; 6. hexagonal shaft ②; 7. second adjuster; 8. cam ③; 9. hexagonal shaft ③; 10. third adjuster; 11. guide slot; 12. third adjuster plate

Principles and key parameters of the scape bud orientation adjustment program

Working principle

The seed spoon is flipped over to pour the garlic into the guiding slot, and the garlic falls into the first adjuster. When the garlic is adjusted in the adjuster, cam ① pushes the round roller at one end of hexagonal shaft ①, and hexagonal shaft ① causes half of the adjuster to rotate. When the adjuster is turned on, the garlic falls into the second adjuster. When the same adjustment in the adjuster is completed, cam ② pushes the round roller at one end of hexagonal shaft ②. Then, hexagonal shaft ② drives half of the adjuster to rotate, causing it to open and allowing the garlic to fall into the third adjuster. This process repeats, and the garlic falls into the groove. The mulching device covers the soil, and the ground roller compacts the soil to complete the sowing process.

Key parameters

(1) Tapered adjuster angle for each stage

The tapered adjuster is designed to be split into two halves from the middle, with one half connected to the main frame and the other connected to the hexagonal shaft. The adjuster is designed as a multi-stage tapered adjuster, with a 45° taper angle at the top and a decreasing angle at the bottom. The lower diameter of the first adjuster is designed to ensure that the garlic seeds lie flat within it. The lower diameter of the first adjuster is determined to be 40 mm. Generally, the greater the number of adjuster stages, the better the garlic is adjusted. Based on previous studies, we set the tapered semi-top angles of the adjuster to 45°, 40°, and 30° and observed that the rates of scape buds facing up and down were 95.65% and 3.77%, respectively. As a result, three adjusters were used to adjust the scape buds so that they were facing up (Geng et al., 2018; Liu et al., 2019). The fourth-level adjusting plate is designed as a forward-tilting hard rubber plate, with an inclination angle of 8–15° relative to the vertical plane. The distance between the third and fourth adjusters must be from 15–30 mm. The distance is designed to be 25 mm.

(2) Design of the heights between the adjusters

When the seed scoopers release the garlic seeds into the first adjuster, the seeds fall free to the second adjuster after the adjustment is performed. Height h_1 is satisfied:

$$h_1 = \frac{1}{2} g h t_1^2 \tag{1}$$

Where:

h_1 is the distance between the first and second adjuster in mm;

g is the acceleration of gravity, taken to be 9.8 m/s^2, and

t_1 is the time of the seed drop in s.

Three kinds of cone adjusters with cone top half-angles of 45°, 40°, and 30° were made with plastic pipes and glue, and the cones were divided in two and mounted on shafts made of PPR（Abbreviation for Polypropylene Random Polymer） pipes, which were placed at different heights to verify the orientation and inclination of the seeds when they fell. The workbench is shown in Figure 11.

FIGURE 11. Test bench.

The falling height was increased by 100 mm. The tilt change in the garlic as it fell was examined through several methods, including visual inspection and a camera. The results are shown in Table 2.

TABLE 2. Relationship between the tilt change and height of garlic as it fell.

Serial No.	Height range (mm)	Test results		
		Tilt	Bounce	Falling time (s)
1	0–300	No visible tilt	No visible bounce	0–0.25
2	300–400	Slight changes	No visible bounce	0.25–0.29
3	400–500	Slight changes	Slight bounce	0.29–0.32
4	500–800	Visible tilt	Visible bounce	0.32–0.4

The test showed that when the falling height exceeded 500 mm, the tilt angle changed, and the seeds bounced as they fell into the next adjuster. The lighter the seed mass, the more pronounced the tilt change. Due to the forward speed of the machine during field operation, the seeds gain forward inertia as they fall. The height between the two adjusters is designed to be 400 mm, and the fall time is 0.29 s.

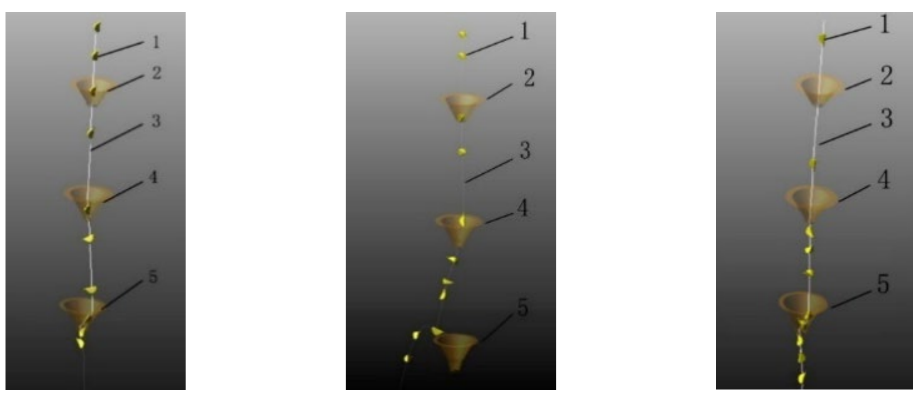
That is, $h_1 = h_2 = 400\ mm$ (2)

(3) Design requirements for drive cam mounting angle

The cam is suitable for intermittent opening due to its resting angle. The opening and closing times of the regulator are not exactly the same. For example, when the first adjuster is turned on, the second adjuster and the third adjuster need to be closed. That is, they are opened and closed alternately to ensure that the time between opening and closing is greater than the time that the seed is falling.

Simulation validation of the orientation adjustment scheme for garlic bulb buds

The Adams2021 software was used to simulate and verify the adjustment of scape buds when the garlic was falling. The models of the garlic and three adjusters were established using UG12.0 software, and the .x_t file was exported and imported into the Adams2021 software to set the direction of gravity and the friction parameters. The simulation results are shown in Figure 12.



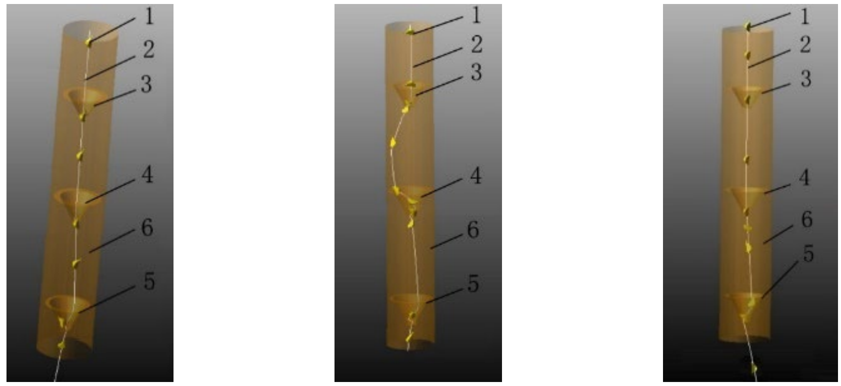
(a) Bulb buds facing up (b) Bulb buds horizontal (c) Bulb buds facing down

FIGURE 12. Scape bud adjustment simulation results (without guide groove).

1. Garlic; 2. first adjuster; 3. garlic center of gravity trajectory; 4. second adjuster; 5. third adjuster

The simulation results revealed that when the garlic bulb shoots fell in an upward state, after the first, second, and third adjusters, the bulb shoots remained in the upward state when they fell to the ground. When the garlic bulb shoots fell horizontally, they were initially oriented diagonally upward after passing through the first adjuster. When they passed through the second adjuster, the bulb shoots were basically in an upward state. However, when the garlic arrived at the third adjuster, it fell onto the edges of the adjuster and bounced to the side. In the process of bouncing, the direction of the bulb buds was uncertain. When the garlic bulb buds fell downward, the direction of the bulb buds changed after the first and second adjusters. When they reached the third adjuster, the bulb buds basically faced upward due to the center of gravity moving downward. After the third-level adjuster, the bulb buds faced upward as they fell to the ground, and the adjustment was more effective.

To address the issue of garlic falling to the edge of the adjuster and bouncing out during the fall, we considered designing a guiding groove on the outside of the whole adjusting mechanism to direct the garlic. The optimized adjustment mechanism was re-simulated, and the results are shown in Figure 13.



(a) Bulb buds facing up (b) Bulb buds horizontal (c) Bulb buds facing down

FIGURE 13. Scape bud adjustment simulation results (with guide slots).

1. Garlic; 2. first adjuster; 3. garlic center of gravity trajectory; 4. second adjuster; 5. third adjuster; 6. guide groove

As shown in Figure 13, the bulb-up situation is similar to that shown in Figure 12a. The bulb-down situation is similar to that shown in Figure 12c. After three adjusters, the bulb is adjusted so that it is in the upward state for sowing. The most significant change occurs when the bulb is level. The garlic passes through the first adjuster into the second adjuster, and the garlic angle is basically adjusted in place. After the garlic is released from the second adjuster, it smoothly enters the third adjuster due to the existence of the guiding groove. By the time the garlic drops to the ground, the bulb buds are generally oriented upward, indicating an excellent adjustment effect. After simulation verification using Adams software, the adjustment mechanism scheme with a guiding groove was adopted.

Design of adjustment scheme for sowing depth for different varieties of garlic

The planting depth for garlic varies by garlic variety, with an optimal range of 40–60 mm. Therefore, it should be possible to easily adjust the sowing depth of the seeder during operation to meet the requirements of different users for the sowing depth.

A common method used to adjust the seeding depth of traditional seeders is using hydraulic cylinders to push the slotter or the whole machine. This method requires the configuration of a complete hydraulic system, making it more costly and resulting in a larger seeder size. In this work, the garlic seeder depth was adjusted through a mechanical linkage, which was easy and cost-effective to operate.

Depth adjustment program design

The depth adjustment structure is shown in Figure 14. The adjustment mechanism is assembled by connecting rods through a hinge to form a movable mechanism. Consequently, adjusting the length of one of the connecting rods will cause the angles and pivot points of the remaining connecting rods to move accordingly to realize the depth adjustment of the furrow opener. The adjusting mechanism is connected to the seeder body through supports ①, ②, and ③. The sowing depth is set by adjusting the height of the ground roller.

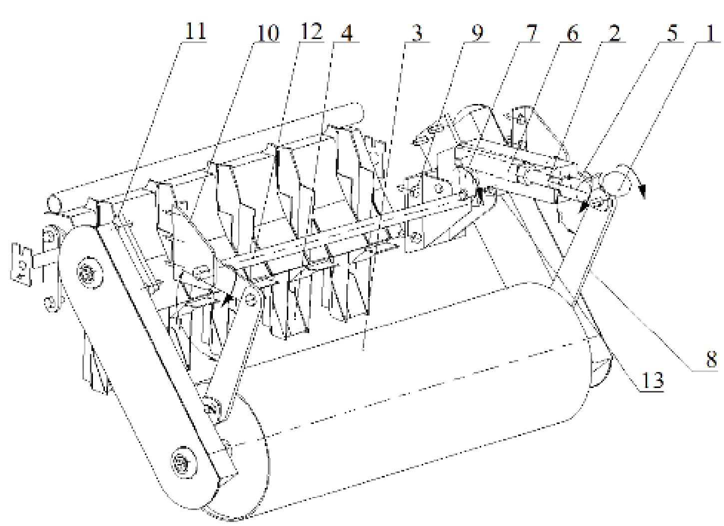


FIGURE 14. Depth adjustment mechanism.

1. Handle; 2. stud; 3. ground roller; 4. trencher; 5. linkage ①; 6. linkage ②; 7. linkage ③; 8. linkage ④; 9. standoff ①; 10. standoff ②; 11. standoff ③; 12. semi-major axis; 13. semi-minor axis

Depth adjustment mechanism working principle and key parameters

Working principle

The depth can be adjusted using the following method: the clockwise rotation of the handle shortens the distance between connecting rod ② and the handle. Connecting rod ② drives connecting rod ③ in the direction of the arrow shown, and in turn connecting rod ③ drives the semi-major axis and semi-minor axis rotation. The two axes respectively drive the two ends of connecting rod ①, causing them to rotate in the direction of the arrow shown. Connecting rod ① drives the rotation of connecting rod ④. Then, the angle β between connecting rod ① and connecting rod ④ gradually becomes larger. Connecting rod ④, through the pivot point, pushes the ground roller down. As the ground roller contacts the ground, the distance between the opener and the ground increases, resulting in a shallower sowing depth. When the depth needs to be increased, the handle is turned in the opposite direction.

Key parameters

Figure 15 shows the length and installation angle of the connecting rod. After the verification of the limit position, the results showed that the lowest position of the ground roller was 66.33 mm, and the highest position was 60.62 mm. When the ground roller was in the lowest position, the furrow opener was in the highest position. When the ground roller was in the highest position, the furrow opener was in the lowest position, indicating that the depth of the seeder was at its highest value (66.33 mm).

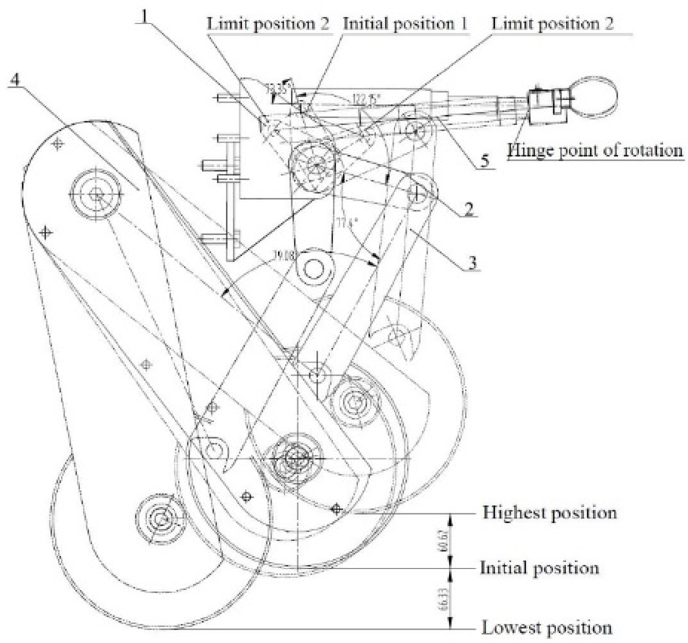


FIGURE 15. Limit position of the depth adjustment mechanism.
1. Connecting rod ①; 2. connecting rod ②; 3. connecting rod ③; 4. connecting rod ④; 5. screw ⑤

Table 3 shows the design length of each connecting rod and the installation angles of adjacent connecting rods. The following considerations should be made in the design of the connecting rod: (1) avoid the dead spot position; and (2) use ball bearings for the connection of two connecting rods (Ji, 2014).

TABLE 3. Design length and initial installation angle of each connecting rod.

Connecting rod serial number	Length (mm)	Initial mounting angle (°)
Connecting rod ①	60	① and ⑤: 73.35°
Connecting rod ②	113	① and ②: 122.15°
Connecting rod ③	225	② and ③: 77.4°
Connecting rod ④	360	③ and ④: 79.08°
Screw ⑤	150	——

The whole machine transmission scheme and modeling of the garlic seeder

A two-wheel tractor is used to power the garlic seeder, and the power is transmitted to the garlic seeder through the output sprocket to provide both moving and operating power.

The whole machine transmission solution

The whole machine transmission system is designed according to the transmission and functional requirements of each working part of the garlic seeder, as shown in Figure 16.

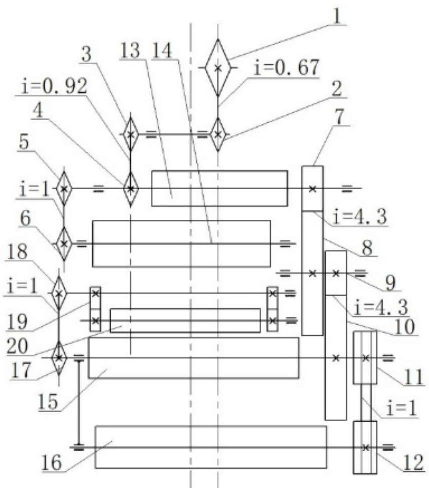


FIGURE 16. Transmission system diagram of garlic seeder.

1. Sprocket ①; 2. sprocket ②; 3. sprocket ③; 4. sprocket ④; 5. sprocket ⑤; 6. sprocket ⑥; 7. gear ①; 8. gear ②; 9. gear ③; 10. gear ④; 11. pulley ①; 12. pulley ②; 13. trencher; 14. mulching device; 15. transfer device combination; 16. ground roller; 17. sprocket ⑦; 18. sprocket ⑧; 19. cam; 20. multi-stage adjustment mechanism

The power of the seeder is supplied by sprocket ①, which is mounted on the power turn-out shaft of the transmission of the tractor.

3D model of the garlic seeder

A three-dimensional model of the garlic seeder is shown in Figure 17.

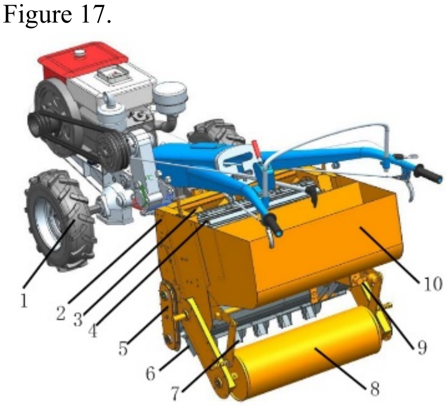


FIGURE 17. 3D model of garlic seeder.

1. Tractor; 2. main frame; 3. multi-stage adjustment mechanism combination; 4. transmission device combination; 5. transmission system; 6. mulching device; 7. furrow opener; 8. ground roller; 9. depth adjustment device; 10. seed box

The working principle of the seeder is as follows: the driver operates the two-wheeled tractor, the transfer case of the tractor causes sprocket ① to rotate, and sprocket ① drives the seeder through the transmission system.

Calculation of seeder productivity

The standard speeds of the power output shaft of the two-wheel tractor are 32,400 r/s and 60,000 r/s for the high and low speeds, respectively (Machinery Industry Standards of the People's Republic of China, 2007), i.e., the speed of input sprocket ①.

The productivity of the seeder depends on the slewing speed of the conveyor, which is determined by the rotation speed of gear ④. According to the drive system diagram, the calculation is as follows:

$$\begin{cases} n_2 = \dfrac{n_1}{0.67} \\ n_3 = n_2 \\ n_4 = \dfrac{n_3}{0.92} \\ n_5 = n_7 = n_6 = n_4 \\ n_8 = \dfrac{n_7}{4.3} \\ n_9 = n_8 \\ n_{10} = \dfrac{n_9}{4.3} \end{cases} \tag{3}$$

Where:

n_1 is the rotational speed of input sprocket ①;

n_2 is the rotational speed of sprocket ②;

n_3 is the rotational speed of sprocket ③;

n_4 is the rotational speed of sprocket ④;

n_5 is the rotational speed of sprocket ⑤;

n_6 is the rotational speed of sprocket ⑥;

n_7 is the rotational speed of gear ①;

n_8 is the rotational speed of gear ②;

n_9 is the rotational speed of gear ③, and

n_{10} is the speed of gear ④.

If n_1 = 32,400–60,000 r/s is substituted into formula (3), the result is n_{10} = 2842.8–5264.4 r/s.

Gear ④ rotates the large-pitch gear through the square shaft, and the large-pitch sprocket rotates the conveyor. Then, the area sown by the five-row seeder per hour is expressed as follows:

$$S = \frac{60(4\pi D n_{10} L_1)}{10^7}, \tag{4}$$

Where:

D is the diameter of the large-pitch sprocket indexing circle (155 mm), and

L1 is the row spacing of the seeder (150 mm):

$$S = (0.083 - 0.1537) hm^2/h \quad (5)$$

The sowing efficiency is 0.083–0.1537 hectares/hour, meaning that 0.83–1.537 hectares can be sown in 10 hours each day, meeting the user's demand for sowing efficiency.

The power of the seeder is supplied by the tractor and transmitted to the seed spooner. The theoretical row spacing is 100 mm. In actual operation, the gear speed of the tractor is 1.4–2.1 km/h, and the second seed starts to fall t seconds after the first seed is dropped:

$$h = v_0 t + \frac{1}{2} g \quad (6)$$

$$v_0 = n_{10} \cdot \tau \cdot D \quad (7)$$

Where:

h is the theoretical plant spacing (100 mm);

v_0 is the initial velocity of the seed falling under the action of the outer orbital transport in m/s;

D is the diameter of the sprocket (150 mm), and

t is the interval time between two seeds falling in s.

The results are given as follows:

$$v_0 = (0.37 - 0.69)\ m/s \quad (8)$$

$$t = (0.09 - 0.11)\ s \quad (9)$$

Then, after the first seed is dropped, the increase in the plant distance due to the different forward speed of the tractor when the second seed is dropped is L:

$$L = V \cdot t = (1.4\ km/h - 2.1\ km/h) \cdot t \quad (10)$$

The result is L = 35–64.2 mm.

The actual line spacing is L'' = 135–164.2 mm.

This plant spacing is large for garlic varieties with both shoots and heads, which affects the yield. Therefore, by correcting the theoretical plant spacing to 80 mm, the time t' is calculated as

$$t' = (0.075 - 0.09)\ s \quad (11)$$

The plant spacing increment is L':

$$L' = 35\ mm - 52.5\ mm \quad (12)$$

That is, the actual line spacing is

$$L'' = 115\ mm - 132.5\ mm \quad (13)$$

The plant spacing is generally between 120 and 130 mm, so the actual row spacing is reasonable.

Prototype production and field trials

Testing conditions

On February 19, 2023, a field trial was conducted on a plot in Weifang City, Shandong Province. The test site, located on land previously used for shed cultivation, had loamy loose soil suitable for garlic cultivation agronomy, and the test garlic variety was Linyi Cang Shan garlic.

Test method and test results

The test was conducted in accordance with GB/T6973-2005, "Test methods for single grain (precision) seeders," and DB37/T3705-2019, "General technical specifications for garlic seeders" (Cui et al., 2022). The operating plots were marked to create a starting zone (15 m), testing zone (20 m), and stopping zone (15 m). The tractor was operated at a speed of 1.4 km/h. The rate of scape shoots oriented upwards and the number of missed sowings were separately counted (Sun et al., 2023).

The soil on top of the garlic was cleaned with brushes, and the state of the garlic was observed. The garlic scape buds were considered to be facing up when they were tilted at an angle ≤11°. The slip rate was not considered (Standardization Administration of China, 2005). The data are recorded in Table 4.

TABLE 4. Summary of test data.

Item	No. of garlic buds	Rate of scape buds facing upward	No. of missed sowings	No. of multiples
The first time	149	91.47%	1	0
	151	89.36%	2	3
	152	90.46%	0	2
	151	90.79%	2	3
	149	92.87%	3	2
The second time	151	88.26%	1	2
	148	92.39%	2	0
	147	92.21%	4	1
	151	91.35%	1	2
	152	92.43%	0	2
The third time	147	87.99%	3	0
	150	89.68%	2	2
	152	90.25%	2	4
	153	93.36%	0	3
	148	91.72%	2	0

The data analysis revealed that on average, for the new garlic seeder, 90.97% of the scape buds were facing upward, 1.12% of the seeds were not sown, and the single-hole repetition rate was 1.16%. The disparity in the average percentage of scape buds facing upward and that of the theoretical value is due to the large clods in the soil. The overall scale of the upward rate was high, and it met the requirements of the DB37/T3705-2019 standard. That is, at least 85% of the scaled buds were facing upward, at most 5% of the seeds were not sown, and the single-hole repetition rate was less than or equal to 4%.

CONCLUSIONS

In this study, the new garlic seeder, which has five rows of synchronous sowing, is powered by a tractor. It can adjust the direction of the scape buds and the sowing depth, eliminating the problem of multiple seeds being placed in a single hole. The sowing efficiency of the device was 25–45 times that of manual planting, ensuring timely sowing, high germination rates, and increased profit for garlic farmers, thereby meeting the planting requirements of growers.

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