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Design and Simulation of a Garlic Seed Metering Mechanism

Huiping Guo [1,2], Yazhou Cao [1], Wenyuan Song [3], Jiao Zhang [1], Changlin Wang [1], Chensi Wang [1], Fuzeng Yang [1,2,*] and Lin Zhu [1,2]

1 College of Mechanical and Electrical Engineering, Northwest A & F University, Yangling 712100, China; imguohp@nwafu.edu.cn (H.G.); cyz666@nwafu.edu.cn (Y.C.); zhangjiao27@nwafu.edu.cn (J.Z.); wangcl@nwafu.edu.cn (C.W.); wcs@nwafu.edu.cn (C.W.); zhulin@nwafu.edu.cn (L.Z.)
2 Scientific Observing and Experimental Station of Agricultural Equipment for the Northern China, Ministry of Agriculture and Rural Affairs, Apple Full Mechanized Scientific Research Base of Ministry of Agriculture and Rural Affairs, Yangling 712100, China
3 Baoji Crrc Times Engineering Machinery Co., Ltd., Baoji 721001, China; songwy@csrzic.com
* Correspondence: yangfzkm@nwafu.edu.cn

Abstract: According to the agronomic requirements of garlic sowing, the garlic morphology is studied and a garlic seed metering mechanism with excellent seeding performance is designed. Based on this design, a new garlic seeding machine with an adjustable-size seeding device is developed to realize efficient single-seed metering and seeding of different varieties of garlic. Further, the design scheme of the garlic seeder prototype is established, with the key components of the garlic seeding being designed on the basis of the garlic seeding mechanism. To achieve garlic single-seed metering for different varieties of garlic, the optimal adjustment size of the garlic seed metering device is determined through discrete element simulation analysis. A field experiment confirms the effectiveness of applying the proposed garlic planter to field sowing in terms of the metrics of missing seed and multiple seed rates. The results of the discrete element simulation test reveal that an adjustment size of 40 mm yields the best single-seed metering performance. At an operating speed of 15–35 rpm, the metering device can achieve more than an 80% qualification rate of single-seed metering, with a unit speed of 0.628–1.465 m/s. Thus, the developed garlic seeding device meets the requirements of precision sowing in China and can effectively realize the mechanized planting of garlic.

Keywords: garlic planting; seed metering device; discrete element modeling

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1. Introduction

As an important economic crop in China, garlic has the largest planting area, output, and export in the world [1,2]. In September 2015, world leaders adopted the 2030 agenda for Sustainable Development at the United Nations summit. According to the zero-hunger goal proposed in Sustainable Development, they support the increase in agricultural production and efficiency. The mechanization of garlic seeding can effectively save labor and improve production efficiency. The existing garlic sowing machines easily have high multiple seed rate, missing seed rate, and low upright rate due to the influence of the varieties and morphological characteristics of garlic seeds [3–5]. The research of single-seeding metering technology for garlic seeding is an important direction of garlic sowing mechanization, which can effectively solve the performance problems of garlic sowing machines and improve the mechanization effect of garlic planting [6,7]. The agronomic requirements of garlic planting in European and American countries require simple mechanization, wide-row-spacing random seeding, and relatively large equipment. Most of those use spoon-chain seed metering devices [8–11]. In China, garlic planting agronomy requires small-row-spacing, high-density, and single-seed and upright sowing. The degree of mechanization is low, and the equipment is miniaturized. Spoon-chain, rotary-table, and vibrating seed metering devices are widely used [12,13].

Researchers have conducted considerable studies on how to improve the quality of seed metering devices. Cui et al. [14] designed a spoon-chain-type single-seed metering device with a single-seed rate of 95%, and no statistics on the upright rate. Hou et al. [15] designed a double-filling room garlic single-seed metering device, where single-seed rate is 95.38%, however there are no statistics on the upright rate. Geng et al. [16] proposed an optimized chain-spoon-type garlic single-seed metering device. Field experiments showed that the garlic seed upright rate was 89.2%, and the missing seed phenomenon was serious during operation, and manual replanting was required. Li et al. [17] proposed using garlic seed boxes to sow garlic, which can achieve precise single-seed placement, but the garlic seeds need to be manually placed in the seed box, which makes it difficult to ensure automation. Li et al. [18] designed a wheel-spoon-type garlic single-seed metering device, using the cavity formed by the seed picking spoon and the seed picking wheel for single seeding, and the single-seed rate reached 91.10%, but the garlic was not screened and graded before sowing and the seeding spoons with different structural parameters were used for different grades of garlic, resulting in missing seed rates and multiple seed rates being slightly higher. Wang et al. [19] developed a grasping single-seed metering device, which has an upright rate of 91.3%, but it will cause blockage when the seed is picked quickly, and the missing seed rate is higher. Hou et al. designed a claw-type cyclic single-seed metering device, which has a relatively complicated structure, and the qualified rate of field trials reached 92.52%, but the upright rate was not explained. Liang et al. [20] designed an air-suction single-seed metering device, and found that the seed picking sucker could not adapt to the complex appearance characteristics of garlic seeds, and the missing seed rate of garlic seeds was relatively high.

Existing studies have provided further research on the seed metering device of garlic sowing machines, and according to simulation and field experiments, there is a good single-seed rate or a good upright rate, however, fewer machines comprehensively consider multiple factors, such as single-seed rate, multiple rate, missing seed rate, and upright rate, according to the combination of varieties of garlic-type parameters for agronomical requirements. Therefore, this article combines the morphological characteristics of garlic seeds and agronomical planting requirements, and proposes a hole-wheel-type garlic seed metering mechanism, which can better meet the single-seed qualification rate and the higher upright rate, and the lower multiple seed rate and the missing seed rate.

In this study, first, based on the size of varieties of garlic, the main distribution range of garlic seed parameters is analyzed. Then, based on the agronomic planting parameters and the technical requirements of single-seed metering, the hole-wheel design parameters of the seed metering device, the design parameters of the seed cleaning device, and the seed protection board design parameters are determined, and the structural design of the seed metering device is designed. Through the simulation analysis of garlic sowing by engineering discrete element modeling (EDEM) simulation analysis software, the working speed, n, and the adjustable size, L, of the seed metering devices are used to calculate the number of single seeds, the number of missing seeds, and the number of multiple seeds when the values are different. Further, through the field test of the prototype statistics and the analysis of the test single-seed number, the missing seed number, multiple seed number, and upright number are obtained, and compared with simulation results.

2. Analysis of Morphological Characteristics of Garlic Seeds

Many varieties of garlic exist, including Shandong Cang garlic, Jinxiang garlic, Henan Qixian garlic, and Shaanxi Caijiapo purple garlic. Research on the shape and size of garlic species is the basis for the screening and classification of garlic species. To effectively improve the planting efficiency and quality, it is essential to provide the basic data requirements for the design of the garlic sowing machine, thereby laying a strong foundation for mechanized garlic planting.

2.1. Measurement and Analysis of Garlic Seed Shape

In this study, Shaanxi Caijiapo purple garlic with a single grain weight of more than 3 g is selected as the research object. The external shape dimensions of garlic are defined in a three-dimensional coordinate system, as shown in Figure 1. The maximum length (L), width (B), and height (H) of the garlic clove placed horizontally are represented in the x, y, and z directions, respectively.

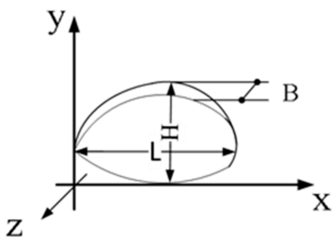

Figure 1. Overall dimensions of garlic.

In this study, 100 full garlic cloves each of 4 varieties of garlic were selected and their dimensions were measured. The measurement results are shown in Table 1 and will be used as the basic data for the design of the seed metering mechanism of a garlic planter.

Table 1. Measurement data of garlic clove specifications.

Garlic Variety	Measurement Type	Number	Average Value	Standard Deviation	Minimum Value	Maximum Value
Shaanxi Caijiapo purple Garlic	Length L (mm)	100	34.46	2.23	29.47	36.30
	Width B (mm)	100	21.76	1.94	16.02	24.90
	Height H (mm)	100	18.43	2.69	16.11	23.14
Qixian garlic	Length L (mm)	100	27.23	1.76	25.22	33.14
	Width B (mm)	100	20.84	3.11	19.14	23.08
	Height H (mm)	100	17.2	2.95	15.01	20.64
Jinxiang garlic	Length L (mm)	100	27.16	2.47	24.76	31.90
	Width B (mm)	100	21.36	2.60	20.46	22.14
	Height H (mm)	100	18.63	2.67	17.04	20.76
Shandong Cang garlic	Length L (mm)	100	29.64	1.53	27.32	32.40
	Width B (mm)	100	22.39	2.10	20.08	24.12
	Height H (mm)	100	18.63	2.67	17.02	20.76

The analysis of the experimental measurement results indicates that the length, width, and height of Shandong Cang garlic cloves mainly range within 2.9–3.1, 2.2–2.4, and 1.7–1.9 cm, accounting for 48%, 50%, and 41% of the total number of garlic cloves respectively, those of Jinxiang garlic cloves range within 2.8–3.0, 2.0–2.3, and 1.7–1.9 cm, accounting for 36%, 63%, and 38% respectively, those of Qixian garlic cloves range within 2.9–3.1, 2.0–2.3, and 1.7–1.9 cm, accounting for 46%, 66%, and 42% respectively, and those of Caijiapo purple garlic cloves range within 2.8–3.0, 2.0–2.3, and 1.7–1.9 cm, accounting for 40%, 62%, and 32%, respectively.

The heights of the four types of garlic range within 1.7–1.9 cm and the widths range within 2.0–2.3 cm, accounting for more than half of the total number of garlic cloves. That is, the maximum heights of the four garlic types barely differ from the maximum widths, and the lengths of the garlic cloves have a larger range than the ranges of the lengths and widths. Existing garlic seed metering devices cannot adjust the size of the seed spoon or hole, making them unsuitable for sowing different garlic varieties. Therefore, based on the distribution of the seed shape and size, the basic requirements for the design of a single-seed metering mechanism with size-adjusting capability are obtained.

2.2. Garlic Agronomic Planting Requirements

Garlic, an herbaceous plant, is generally planted in a particular season. The planting agronomic requirements are as follows:

(1) For planting the seeds, the soil should have low hardness and good water retention and drainage capability, as well as should be loose and fertile after rotary tillage.
(2) The best planting season is the transition period from summer to autumn, which is around September. Planting too early will result in a weak wintering ability of the plants, in turn affecting the quality of garlic, whereas planting too late will lead to weak cold resistance and higher mortality of the plants.
(3) The planting technique currently used is mainly manual sowing, and it involves the processes of land preparation, digging ditches, seed planting, and soil covering.
(4) The best time to harvest garlic is 20 days after garlic moss harvest.
(5) Planting the seeds at a reasonably close distance improves yield. In general, the density is 20 cm from row to row, and the seed spacing is 10–15 cm. The seeds should be planted shallowly in trenches having a depth of 3–5 cm and that are covered with soil up to 1–2 cm after sowing. The roots are mostly distributed in the soil layer at 5–25 cm depth, and approximately 20,000 plants per 667 m^2 is the optimum density.
(6) Row number and width: one of the main indicators to measure the quality of garlic is the garlic bulb size; the larger the bulb, the better the quality of garlic [21–25].

Suppose the row spacing of garlic sowing is l_1 and the plant spacing is l_2. The unit of them is mm. Then, the number of garlic seeds planted is calculated as follows:

$$n = \frac{667 \times 10^6}{l_1 \times l_2} \tag{1}$$

The planting density is 2500 plants per 667 m^2 of land and the number of sowing rows is 5. According to Equation (1) and the result of agronomic investigation around the region, the row spacing is 188 mm and the plant spacing is 140 mm. Therefore, the width, B, of the garlic planter is given as follows:

$$B = h \times l_1 \tag{2}$$

Accordingly, the garlic planter width, B, is 940 mm. After considering the installation of a sprocket, a seed metering regulator, and other parts in the design, the final width of the garlic planter is planned to be 970 mm.

3. Design of the Seed Metering Device and Determination of Its Parameters

3.1. Design of the Hole Wheel

If d is the diameter of the hole of the seed metering device and h is the hole depth, then we have:

$$d = L_{\max} + (0.5 \sim 1) \tag{3}$$

$$h = H_{\max} - (0.5 \sim 1) \tag{4}$$

where d is the diameter of the hole and h is the depth of the hole. The hole diameter and depth thus calculated are approximately 40 and 24 mm, respectively. To ensure the requirements of single-seed metering of garlic seeds, we need to establish a certain seed filling space and time, which are related to the mold space and the linear speed of the hole wheel, respectively. In a precision sowing machinery, the maximum linear speed of the hole wheel (v_p) is given as follows:

$$v_p t = d - \frac{1}{2}\overline{L} \tag{5}$$

$$\frac{1}{2}\overline{L} = \frac{1}{2} g t^2 \tag{6}$$

where L is the average garlic seed length, d is the hole diameter, and g is the acceleration of gravity.

$$v_p = (d - \frac{1}{2}\overline{L})\sqrt{\frac{g}{L}} \tag{7}$$

Substituting d = 0.04 m, $\overline{L}$ = 0.03446 m, and g = 9.8 m/s^2 into Equation (7), the maximum linear speed of the hole wheel is obtained as v_p = 0.384 m/s.

$$v_p = 2\pi nR \tag{8}$$

where n is the speed of the garlic seed metering device, R is the hole radius, and n = 0.87 r/s (i.e., 52.3847 r/min) can be obtained. Then, n is the maximum speed.

The operating speed of the commonly used cultivator planter in China is 5–7 km/h, and the forward speed of the take-off unit is 6 km/h. A tractor pulls the ground wheel to make a linear motion, and the ground wheel drives the seed metering device. Therefore, the forward speed of the tractor affects the hole wheel, and the two must cooperate well.

When the ground wheel is in contact with the ground during operation, it will slip when the ground conditions are poor.

$$v_p = \frac{\pi D v_m}{am(1-\delta)} \tag{9}$$

where v_m is the forward speed of the unit, v_p is the linear speed of the hole wheel, a is the plant spacing, m is the number of holes on the hole wheel, D is the diameter of the hole wheel, and δ is the slip ratio of the ground wheel (generally δ = 5–12%). Therefore, we have:

$$m = \frac{\pi D v_m}{a v_p (1-\delta)} \tag{10}$$

The garlic plant spacing of a = 14 cm and δ = 12% are selected. Under the same operation speed and plant spacing, the number of shaped holes having the same diameter is inversely proportional to the linear speed. That is, when the number of shaped holes is large, the linear speed is low, and the filling performance of the shaped holes is good. By substituting the above-mentioned values in Equation (10), we obtain m = 6, and the number of shaped holes on the hole wheel is 6. The shape and size of the hole are designed by comprehensively considering the shape and size of the seed and the number of holes required; subsequently, the structure of the hole wheel is designed. According to the above calculation, the diameter of the hole wheel is 70 mm, the diameter of the hole is 40 mm, the length of the hole shaft is 32 mm, and the total width of the hole wheel is 156 mm. Figure 2 shows the three-dimensional structure of the designed hole wheel [26–29].

To meet the requirements of the precision sowing machinery, the main material of the seed metering device is often gray cast iron or engineering plastics. To reduce the total mass of the seed metering mechanism, this study considers engineering plastic material. The mechanical design course manual indicates that the commonly used engineering plastic polyoxymethylene has good friction, especially dry friction, and wear performance. Therefore, in this study, polyoxymethylene is used as the material for the vertical hole seed metering device.

3.2. Design of Seed Cleaning Device

It is necessary to design a seed cleaning device to brush the excess seeds in the hole to ensure only a single seed is metered by the vertical hole-wheel metering device. The seed cleaning device, however, often damages the seeds. Hence, the seed cleaning device must possess certain rigidity and elasticity to not only remove excess seeds but also reduce the damage of garlic seeds, which in turn improves the yield. The seed cleaning device commonly uses either a rubber scraping tongue or a brush. The rubber seed scraping tongue is made of rubber lath, and it is locally squeezed by excess seeds. The seed that does not get scraped away deforms the rubber, resulting in its increased replay rate, seed damage, and rubber damage; eventually, the rubber strip ages and fails easily. A brush is soft and elastic; therefore, it does not damage the seeds, although it wears easily. Therefore, this study used a nylon brush as the seed cleaning device. The brush is 30 mm wide, 15 mm thick, and 70 mm long, and it consists of strands of nylon placed side-by-side to achieve the seed cleaning effect. It is installed in such a way that the angle between the brush and the plumb line is 22°–45°, and the included angle is 45°. The working principle of the brush is shown in Figure 3.

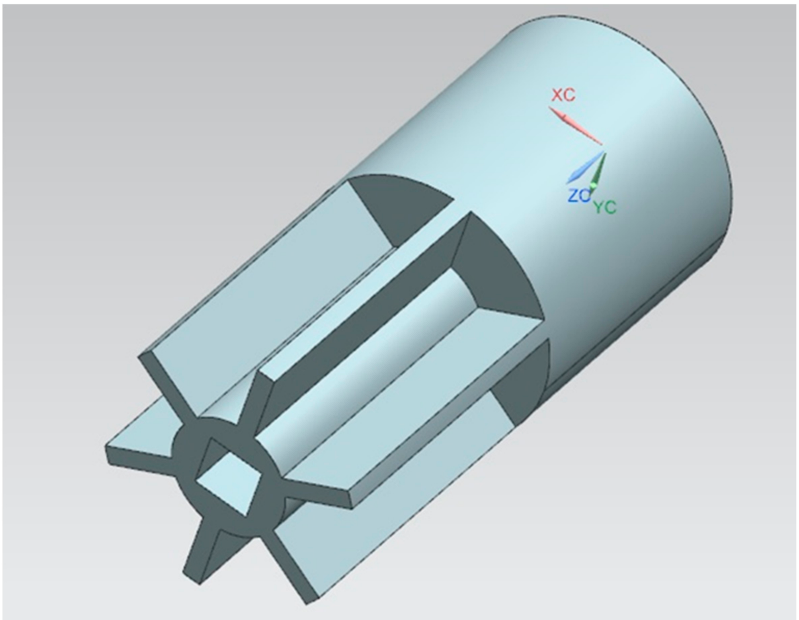

Figure 2. Structural design of the hole wheel.

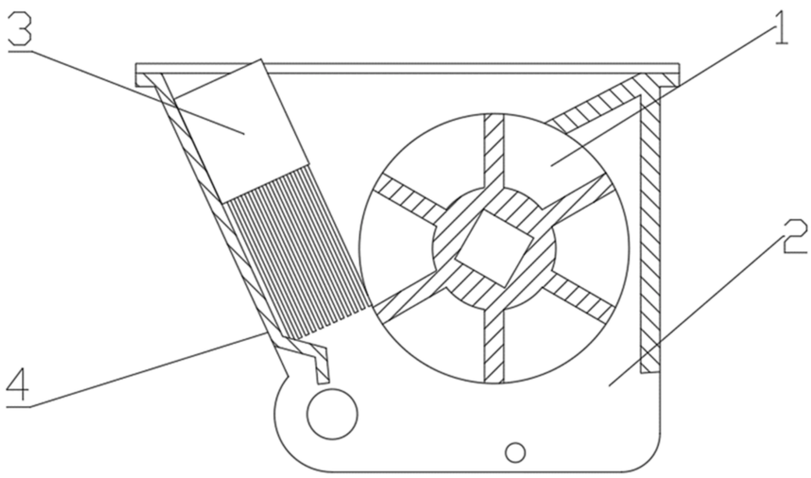

Figure 3. Working principle of brush. 1—hole wheel, 2—shell of seed metering device, 3—brush, and 4—seed protection board.

3.3. *Design of a Seed Guard Plate*

To prevent the garlic seeds in the mold hole from falling during their transportation, a seed guard plate needs to be designed. When the mold hole rotates, the seeds leave the mold hole due to their own weight, which completes the seed feeding process in the determined direction. Therefore, the seed guard plate must be close to the mold hole wheel. The seed feeding position and direction are determined by the wrapping angle of the seed guard plate.

The initial velocity of the garlic seed movement is the tangential linear velocity, V_t, along the outer edge of the hole wheel. The horizontal component of velocity, V_t, represented by V_x, throws the garlic seed back.

$$V_x = V_t \cos\theta \quad (11)$$

As shown in Equation (11), the garlic seed movement speed relative to the ground is approximately zero, which can make the angle small, even if the wrapping angle of the seed guard plate is large. Considering that there is a lag when the seed falls out of the hole, the wrapping angle, θ, should be slightly greater than zero: θ = 10°–15° is sufficient. Then, according to the overall dimension of the brush, the length of the seed guard plate is designed to be 75 mm and the thickness is 3 mm. The structural diagram and three-dimensional diagram of the seed guard plate are shown in Figures 4–6. In Figure 4, A-A and B-B are the structural diagrams of the inner baffle of the seed guard plate.

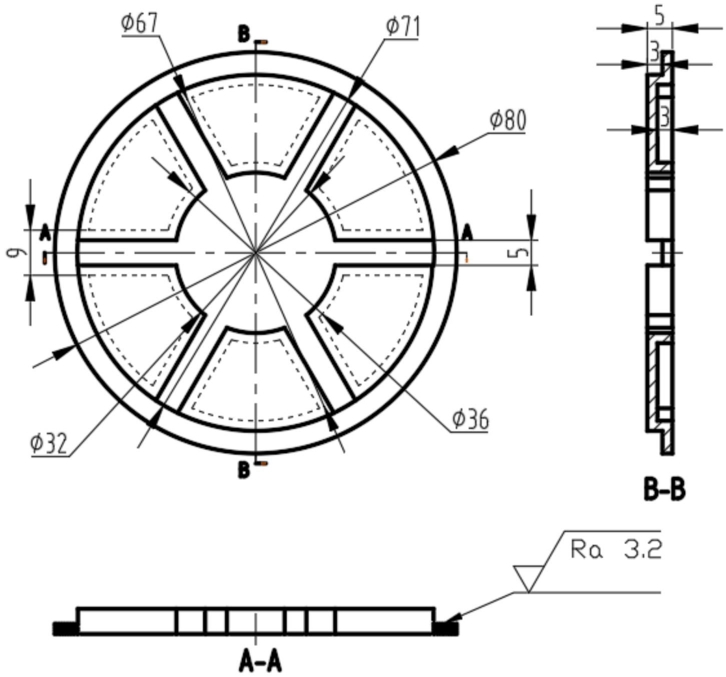

Figure 4. Structure of the inner baffle of the seed guard plate.

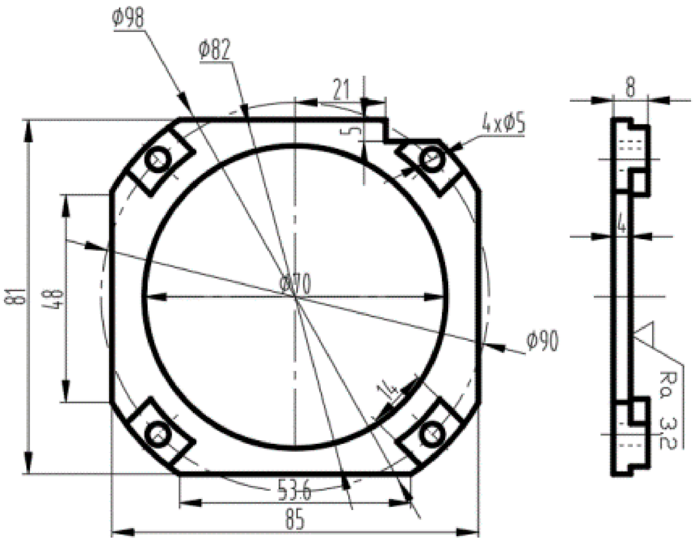

Figure 5. Structure of the outer baffle of the seed protection plate.

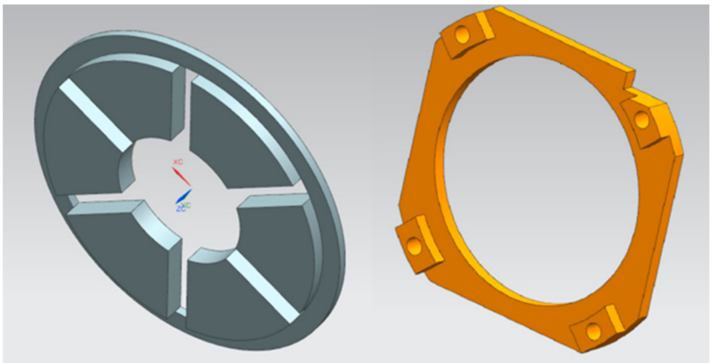

Figure 6. Three-dimensional diagram of the seed guard plate.

The seed protection plate is usually made of iron sheet or plexiglass. To reduce the total weight of the garlic planter and improve work efficiency, in this study we used a seed protection plate made of engineering plastic, specifically polyformaldehyde, based on the mechanical design course manual [30–33].

4. Discrete Element Simulation Analysis of the Seed Metering Device

The seed metering device uses a mechanism for sorting seed particles (discrete materials), and its working process involves the interaction between seeds and between seeds and the seed metering device. Traditionally, the optimal design of a seed metering device is analyzed, and its working principle is improved by obtaining repeated experimental observations and summarizing them. However, such traditional research methods only study the macro-motion law of seed particles and cannot analyze the motion law of a single particle. Based on the seed metering device design described in the previous sections, in this section, the discrete element simulation software is used to analyze the working of the seed metering device to improve the basis for the optimal design of the seed metering device.

4.1. EDEM Simulation Parameter Setting

The main parameters used in EDEM simulation include density, elastic modulus, static friction coefficient, and collision recovery coefficient. Before performing the simulation, to obtain accurate simulation results, these parameters need to be calibrated to eliminate measurement errors and the errors caused by the difference between the shape of the simulated particle model and the actual seed shape.

4.1.1. Determination of Friction Coefficient

The experimental setup includes a working face, an angle measuring instrument, and an angle adjusting mechanism. The coefficients of static friction between the garlic clove and the stainless-steel plate and between the garlic clove and the polyoxymethylene plate were measured by the inclined method. The experimental device is shown in Figure 7.

According to Coulomb's law, the static friction factor is obtained by dividing the static friction by the normal pressure. The inclined plane method is a common method for measuring static friction factors. In this method, the garlic clove is allowed to rest on an inclined plane set at an angle θ, called the static friction angle. The garlic clove has a static friction force of $f_s = \mu mg\cos\theta$ and tends to slide on the plane. The relationship between the static friction factor and the static friction angle is as follows:

$$\mu = \tan\theta \tag{12}$$

where f_s is the static friction force, m is the mass of the garlic clove, and υ is the static friction. Based on the above test principle, the static friction factors between the garlic clove and the steel plate, between the garlic clove and the polyformaldehyde plate, and between garlic cloves were measured and analyzed by the inclined plane method. The measurement results show that the average static friction coefficient between the garlic clove and the steel plate is 0.50, the average static friction coefficient between the garlic clove and the polyformaldehyde plate is 0.46, and the average static friction coefficient between the garlic clove and garlic is 0.43.

Figure 7. Static friction coefficient measuring device.

4.1.2. Determination of Collision Recovery Coefficient

Collision recovery means that object 1 moving at an initial speed of v_1 collides with object 2 moving at an initial speed of v_2 and separates after collision. The speed of object 1 after collision is $v_1{}'$ and the speed of object 2 after collision is $v_2{}'$. Then, the collision recovery coefficient, e, is given by Equation (13):

$$e = \frac{v_2 - v_1}{v_1{}' - v_2{}'} \tag{13}$$

The collision recovery coefficient was measured by a free-fall collision method. The drop table was set at heights of 10 and 20 cm, thus releasing garlic seeds from different heights. The steel plates, polyoxymethylene plates, and seed plates were placed at the bottom of the drop table for multiple tests to ensure the vertical upward movement of the seeds after rebound. A total of 50 measurements were made. Finally, the abnormal data were removed, the average values were calculated, and the collision recovery coefficient was calculated according to Equation (13). The results are shown in Table 2.

Table 2. Collision recovery coefficient.

Collision Material	Falling Height/mm	Collision Coefficient
Garlic	100	0.34
	200	0.32
Steel plate	100	0.38
	200	0.34
Polyoxymethylene plate	100	0.36
	200	0.33

Table 2 indicates that the collision recovery coefficient varies for different materials at different heights. The collision recovery coefficient in the decreasing order is that of steel plate, polyoxymethylene plate, and garlic.

The collision recovery coefficient was then calibrated by comparing the free-fall experiment result with the actual measurement. The height of the free fall was set to 20 cm. The virtual experiment process is shown in Figure 8.

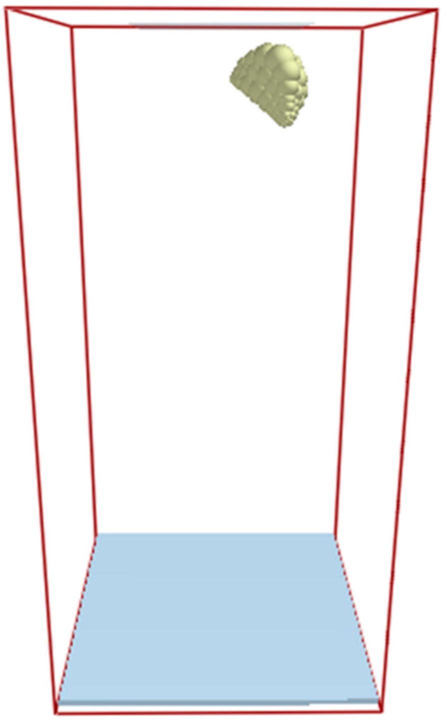

Figure 8. Collision recovery coefficient test.

The free-fall collision between the garlic seeds and the steel and polyoxymethylene plates was simulated with the collision recovery coefficients of the materials set to 0.21, 0.22 . . . 0.50. The rebound heights after collision were recorded and compared with the data obtained from the actual experiment. The virtual verification test results show that the rebound height obtained for the collision recovery coefficients 0.35–0.34 agrees well with the actual experiment results. Therefore, a collision recovery coefficient of 0.35 is selected for the steel plate and 0.34 is selected for the polyformaldehyde plate [34–38].

4.2. Establishment of a Discrete Element Model of the Seed Metering Device

In this simulation process, 300 seed grains were selected and based on the simulation requirements, the physical and mechanical parameters of the garlic seeds were measured. The simulation parameters of the mechanical model of garlic seeds were obtained, as shown in Table 3.

Table 3. Simulation parameters of the mechanical model.

Parameters	Value
Quality (g)	5.3
Collision recovery coefficient (e)	0.35
Static friction coefficient between garlic seeds (μ)	0.43
Static friction coefficient between garlic seed and seed metering device (μ)	0.46

4.2.1. Global Variable Settings

The setting of global variables of EDEM involves five steps: (1) Select units: millimeter is usually selected in the design of agricultural machines and tools, (2) enter the title of the model and make an appropriate description, (3) set the contact type: six contact models can be selected in EDEM software, and the non-sliding contact type is selected according to the physical characteristics of garlic species, (4) set the gravity and define the material properties: the direction of gravity is set as the positive downward direction of the seed metering outlet, and the gravity acceleration is set as 9.81 m/s^2, and (5) define parameters between materials.

4.2.2. Garlic Seed Model

Taking Caijiapo purple garlic as an example, in this study, the garlic seed particle model was established and the center of gravity of the garlic seed was calculated, as shown in Figure 9 and Table 4.

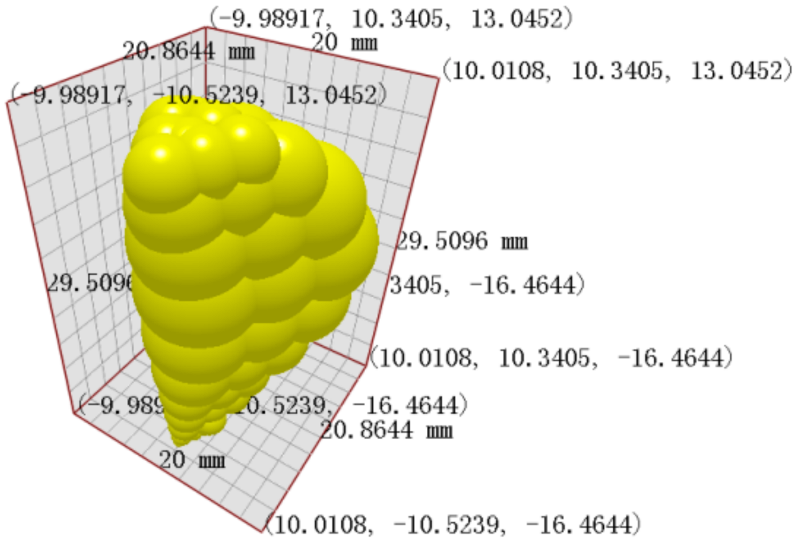

Figure 9. Modeling of garlic seed particle model.

Table 4. Calculation of the center of gravity of the garlic seed.

Parameters	Value	Unit
Mass	9.22310×10^{-4}	kg
Volume	4.64310×10^{-6}	m^3
Moment of Inertia X	5.45310×10^{-8}	kg m^2
Moment of Inertia Y	5.05310×10^{-8}	kg m^2
Moment of Inertia Z	3.35310×10^{-8}	kg m^2

4.2.3. Seed Metering Model

In the discrete element simulation process, UG 3D software is used to draw the simplified seed metering device model. It is saved as a ". stp" format file, which is convenient to import into EDEM software. The seed metering shaft is set as a rotating part as required, while other parts are simplified as fixed parts, and the garlic grain generation area is set above the seed box.

4.2.4. Pellet Plant Settings

As the initial conditions of the simulation, the number of particles selected is 300, the time step of the simulation test is 1.69310^{-6} s, the simulaton time is set to 10 s, and the particle factory setting is as shown in Figure 10.

4.2.5. Simulation Calculation

In the discrete element simulation calculation, the display mode is set to mesh mode, in which the movement of seeds in the seed box and seed metering device can be clearly seen. The simulation result is shown in Figure 11.

The post-processing module of EDEM software has a powerful function for extracting the velocity, acceleration, displacement, and other data of any particle in the simulation process. In addition, the change curves of particle force chain and particle energy are output.

4.3. Virtual Experiment of Seed Metering Mechanism

A virtual test of seed metering performance was conducted by using EDEM software to study the effects of adjustment size, L, of the seed metering device regulator and working speed on seed metering performance. This will provide a reference for the optimal design of the seed metering device and its key components. The adjustment size, L, of the regulator is shown in Figure 12.

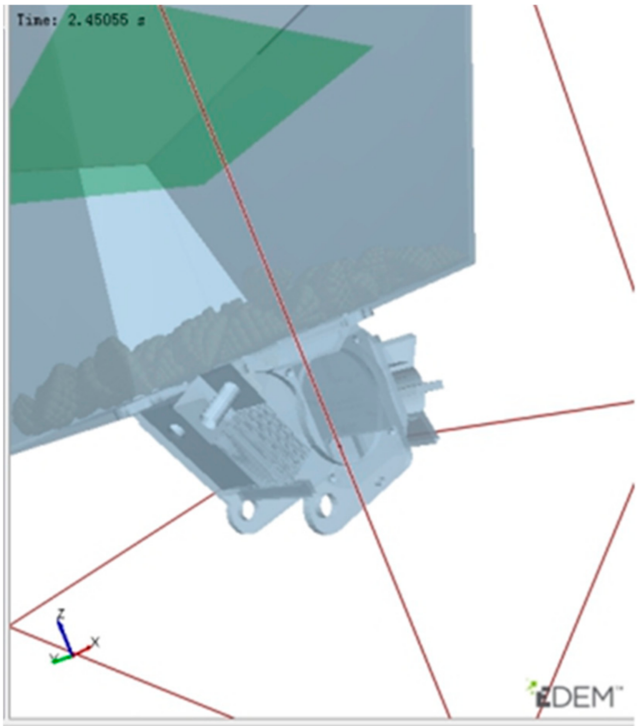

Figure 10. Particle factory setting.

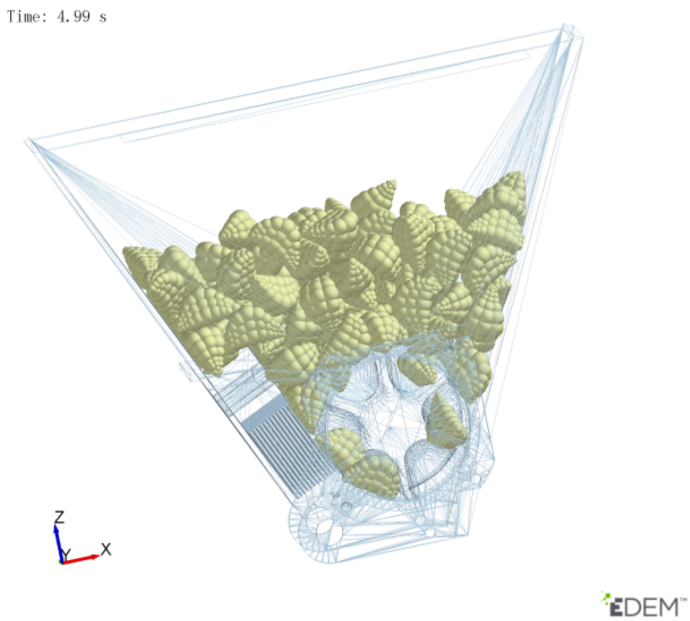

Figure 11. Simulation of the seed metering device.

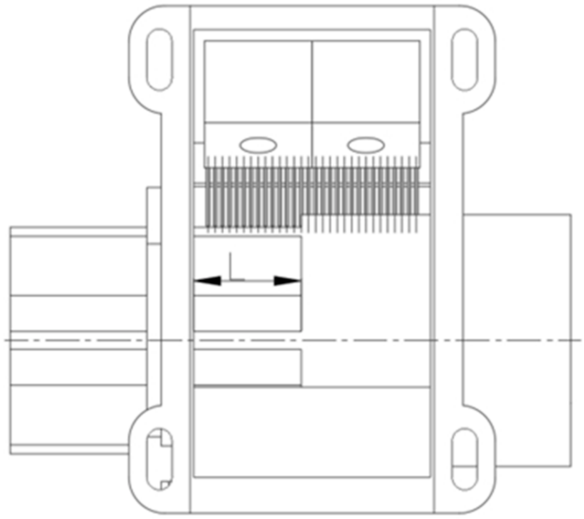

Figure 12. The structural design drawing of the brush.

Based on the actual operation in the field, for the simulation test, the working speed of the seed metering device was set to 15, 25, 35, and 45 r/min, and three groups of adjustment size, L, were selected, namely 35, 40, and 45 mm. The seed metering device was set to be displayed in the mesh mode. In the simulation process, the operation effect of the seed metering device was mainly manifested in three states: single seed, multiple seed, and missing seed. According to GB/T6973-2005 "test methods for single-grain (precision) planters", the qualification index, s, multiple seed index, D, and missing seed index, M, are selected as the virtual test indexes, which are calculated as Equations (14)–(16), respectively:

$$S = \frac{n_1}{N} \times 100\% \tag{14}$$

$$D = \frac{n_2}{N} \times 100\% \tag{15}$$

$$M = \frac{n_0}{N} \times 100\% \tag{16}$$

where N is the number of theoretical rows, n_0 is the number of empty and missing seeds, n_1 is the number of single seeds, and n_2 is the number of multiple seeds.

4.4. Simulation Results and Analysis

The adjustment size, L, ranged from 0 to 75 mm. In the actual production process, for different varieties of garlic, the process of selecting the adjustment size is more complex and requires several experiments and a long time. Therefore, a simulation experiment is beneficial to determine the operating parameters, speed, and adjustment size of the mechanism. When the adjustment length is 35 mm (a), 40 mm (b) and 45 mm (c) respectively, the virtual simulation experiment results of the seed metering mechanism at different speeds are as shown in Figure 13.

According to the simulation test results, when the operating speed of the seed metering device was 15–35 r/min, the qualification index of single-seed feeding of the seed metering device is greater than 80%. When the operating speed of the seed metering device is greater than 45 r/min, severe missing seed rates occur, thereby not meeting the requirements of precision sowing. According to the transmission ratio of the designed transmission device, the speed of the seed metering device is 0.628–1.465 m/s, and the sowing performance is the best. For Caijiapo purple garlic, an adjustment size, L, of 40 mm is more suitable for efficient seed metering. In addition, using the virtual simulation results, the adaptive adjustment size, L, for different varieties of garlic can be obtained and recorded to facilitate the application and operation of the designed machine in the future [39–42].

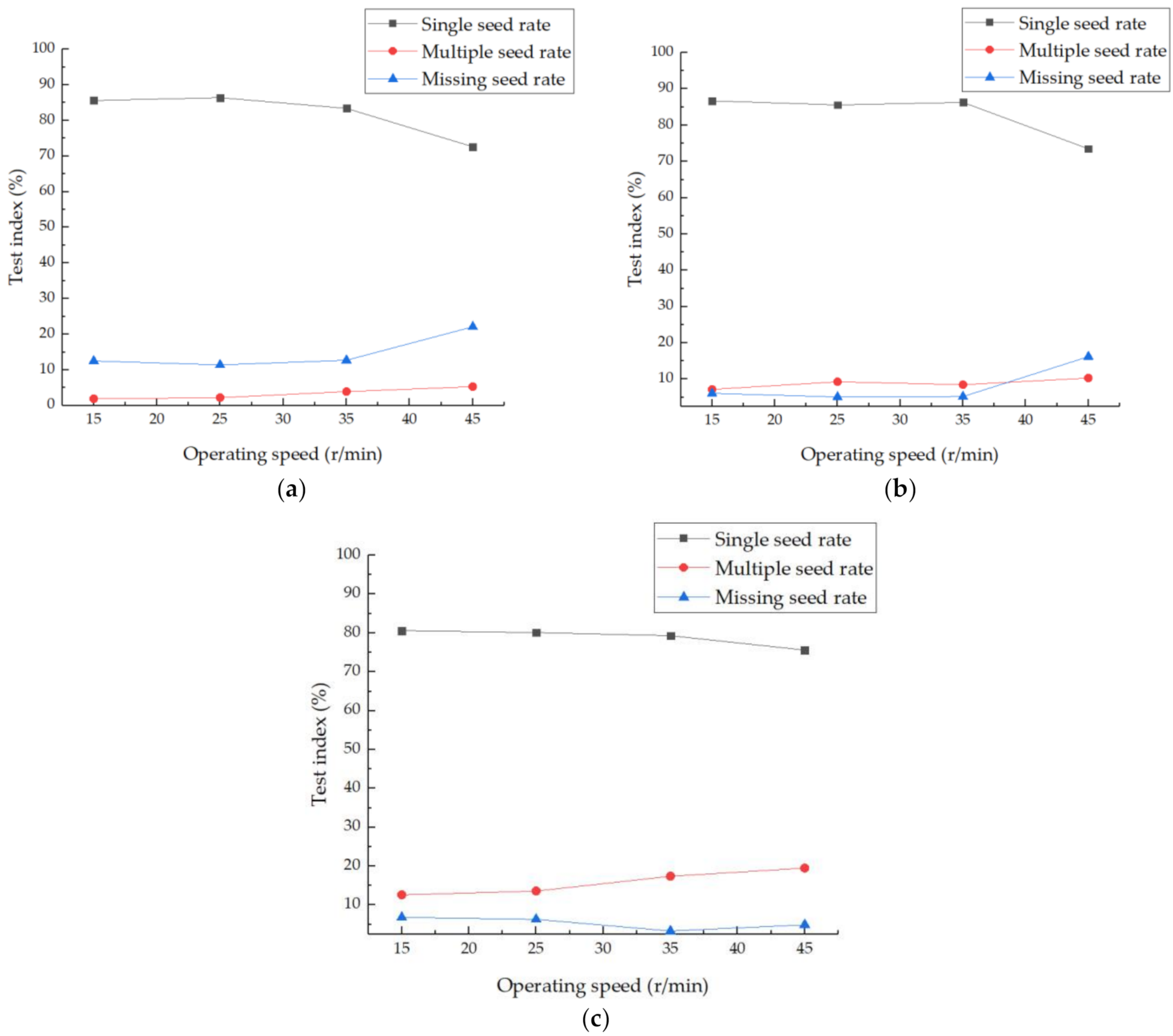

Figure 13. Virtual simulation experiment results of the seed metering mechanism. (**a**) When the adjustment length is 35 mm. (**b**) When the adjustment length is 40 mm. (**c**) When the adjustment length is 45 mm.

5. Field Experiment

To further test the application of the designed garlic planter in sowing on actual fields, a field test was conducted in September 2018 in the west of the school of mechanical and electronic engineering of Northwest University of agriculture and forestry science and technology, China. This test mainly included the measurement of soil moisture and hardness of the garlic planting site and the planting test using a garlic planter prototype. The working environment is expected to affect the field work of the prototype; therefore, before the test, the working environment was checked, and results were recorded. In the planting area, the soil conditions were ensured to meet the planting requirements, the terrain was flat, and the moisture content was preferably 8–16%, yielding soil that is not too hard or too soft.

Diagonal sampling in the test area was performed, with sampling depths of 0–50, 50–100, and 100–150 mm. The weighing accuracy was not less than 0.1 g, and the moisture content of the sample was obtained in each test: the average soil moisture content was 8.4%.

The Shaanxi Caijiapo purple garlic seed was selected for the field experiment. The data of garlic seed physical properties are the average values of 10 measurements, and the seed size for the test is shown in Table 5.

Table 5. Seed size.

	Length (mm)	Width (mm)	Height (mm)
Shaanxi Caijiapo Purple Garlic	34.46	21.76	18.43

The garlic seeding metering machine prototype and seeding process are shown in Figure 14. The Chinese in this figure means developed by Northwest A & F University.

Figure 14. Seeding process using the prototype.

From the experiment, the multiple seed rate, missing seed rate, qualification index of single-seed feeding, plant spacing, and upright rate of the garlic seeding prototype were obtained, as shown in Table 6.

Table 6. Garlic seeding prototype.

Serial Number	Inspection Items	Unit	Result
1	Multiple seed rate	%	5.5
2	Missing seed rate	%	8
3	Single-seed rate	%	86.5
4	Plant spacing	mm	13.6
5	Upright rate	%	79.2

The results show that the qualification index of single-seed collection and sowing was greater than 80%, which meets the requirements of precision sowing in China. Compared with the existing research, the single-seed rate was slightly lower, the missing seed rate and multiple seed rate were also lower, and the upright rate was better. Thus, the whole machine can better realize the mechanized planting of garlic.

6. Conclusions

(1) According to the specifications of the garlic clove, a garlic seed metering device was designed such that the hole of the hole wheel can accommodate only a single garlic clove at a time in order to realize single-seed metering.

(2) The existing seed metering structure cannot adjust the seed metering process according to different garlic species, which affects the planting performance. To overcome this limitation, a single-seed metering device was designed with simple adjustment capability according to the shape and size of garlic cloves.

(3) For the selection of the adjustment size of existing seed metering devices, the traditional test method is used, whose design optimization cost is high, test cycle is long, and test range and times are limited. Therefore, in this study, the EDEM discrete element simulation software was used to simulate the movement process of garlic cloves in the designed seed metering and sowing device. Moreover, a virtual test of seed metering performance was conducted to determine the best adjustment size of the seed metering device.
(4) According to the three-dimensional model design and theoretical analysis, the core components of the planter were designed and processed, the assembly of the garlic planter was completed, and the garlic sowing experiment was successfully conducted.

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