SIMULATION AND TEST OF FILLING PERFORMANCE OF PNEUMATIC PRECISION SEED METERING DEVICE BASED ON EDEM SOFTWARE

/

基于 EDEM 软件的气压式精量排种器充种性能模拟与试验

Wenqi GUO, Wenyi ZHANG, Yunxia WANG, Youqiang DING, Bin QI*[1]
Nanjing Institute of Agricultural Mechanization, Ministry of Agriculture and Rural Affairs, Nanjing, 210014/China
Tel: 15366092903; E-mail: qb0823521@163.com
DOI: https://doi.org/10.35633/inmateh-72-29

Keywords: *Precision seed metering device; Pneumatic type; Seed filling performance; EDEM*

ABSTRACT

In order to study the effect of population disturbance on the filling performance of the seed metering device, this paper uses the pneumatic precision seed metering device as the model, and uses EDEM software to simulate the population movement of three different seed metering devices. The bench test was carried out at different pressures at 12 km/h and at different speeds at 3.5 kPa. The results show that the designed seed disk with grooves has the most intense disturbance and the highest qualified rate. In order to verify the performance of the disk, full factor tests are carried out on the air pressure and speed, The test results show that when the operating speed is 10~12 km/h and the positive pressure is 3~3.5 kPa, the leakage rate is no higher than 5.42%, the replay rate is no higher than 0.42%, and the qualified rate is no lower than 94.58%. When the operating speed is 14 ~ 16 km/h and the positive pressure is 3.5~4 kPa, the leakage rate is not higher than 6.7%, the replay rate is not higher than 1.04%, and the pass rate is not lower than 93.12%. All the indicators are better than the national standard.

摘要

为研究种群扰动对排种器充种性能的影响，本文以气压式精量排种器为模型，运用 EDEM 软件对 3 种不同的排种盘进行种群运动仿真，以种层上方颗粒数目和种群平均运动速度作为指标，分析了各排种盘在不同转速下的种群平均运动速度和种层上方区域数量，仿真结果表明转速越快，种群运动越明显。通过台架试验对 12km/h 速度下不同气压和 3.5kPa 气压下不同速度进行试验，结果表明设计的带凹槽的排种盘扰动最激烈，合格率最高。为了验证该盘的性能对气压和转速进行全因素试验，试验结果表明针对当作业速度 10～12km/h，给定正压 3～3.5kpa 时，漏播率不高于 5.42%，重播率不高于 0.42%，合格率不低于 94.58%；当作业速度在 14～16km/h，给定正压 3.5～4kpa 时，漏播率不高于 6.7%，重播率不高于 1.04%，合格率不低于 93.12%，各项指标均优于国家标准。

INTRODUCTION

At present, high speed, high density and high efficiency are the development trend of precision seeding technology. "Quantitative and targeted" precision seeding technology has been widely used in corn, soybean and other crops in China. Single grain precision seeding is the main sowing method of corn planting in China, and the seed discharging device is the core component of the seeder, whose performance determines the efficiency and quality of seeding operation. According to its structure and working principle, it can be divided into pneumatic type and mechanical type. Pneumatic type has the characteristics of good seed adaptability and no seed damage. Pneumatic seeding has become the focus of current research.

Pneumatic precision seed metering device includes pneumatic type, air suction type, air blowing type, central collection type and so on (*Yang et al., 2016*), It has been noted that the state of seed population has a significant effect on the filling performance (*Yang et al., 2010*). The filling process of pneumatic seed metering device is the process of separating seeds from disordered groups into ordered individuals under the action of adsorption force. During this period, it is necessary to overcome the resistance of seed population to individual movement, and the filling process determines the seed placement performance. In the case of Maxima series of suction seed metering device, produced by Kuhn company of France, the disturbing button is used above the mold hole to increase the disturbance. Seed adaptability is related to seed filling performance. *Yazgi and Degirmenioglu, (2007)*, found that the diameter of the suction hole is the main factor affecting the performance of the seeder, followed by the vacuum degree and the linear speed of the seeding disk.

Among them, the diameter of the suction hole and the required vacuum degree are mainly related to the physical characteristics of the seed (*Yazgi et al., 2005*). Singh conducted a study on the linear speed of the seed disk and the shape of the suction hole inlet for cotton seeds. The experiment showed that the seeding performance was inversely proportional to the rotation speed of the seed disk. The suction hole inlet with a 120 ° chamfer had better seeding performance and required lower vacuum degree (*Singh et al., 2007*). The shape of the hole has an impact on the seeding performance.

Zhang Kaxing et al, (2021), used the CFD-DEM coupling method to obtain the optimal combination hole structure and obtained the optimal working parameters under the hole through experiments. *Zhang Xiaoshuang et al, (2021)*, conducted experiments on different hole shapes and sizes to determine the optimal hole shape, providing a basis for improving the performance of the seeder. *Wang Fenghua et al, (2020)*, designed a single row air-suction micro-potato planter to increase population disturbance by vibrating seed feeding mechanism. The air-suction seed metering device developed by Horsch, Germany, uses the chamfered asymptote hole to improve the seed adsorption capacity, and the maximum operation reaches 15 km/h. *Chen Yulong et al, (2021)*, designed a vertical disk seeding device with a seed mixer to increase the seeding probability.

Zhao Zhan et al, (2018), obtained the relationship between expansion coefficient and vibration intensity by letting the seed disk vibrate to separate the population. When the vibration intensity is 5.65, the motion state is the most ideal. *Chen and Li, (2002)*, concluded through the study of the law of seed movement that the introduction of mechanical vibration can make the seeds reach the "boiling" state and improve the seed absorption rate. *Xie Dongbo et al, (2022)*, designed a garlic seed metering device assisted by air suction with disturbed teeth, constructed the curved surface equation of disturbed teeth, and explored the influence of different disturbed teeth on the qualification rate.

Su Wei et al, (2023), designed a kind of gas-suction broad bean precision seed metering device with flat belt auxiliary seed filling device, and carried out dynamic analysis on its working state. The flat belt auxiliary seed filling device transformed the population resistance to the adsorbed seeds into a favorable supporting force for seed filling, so as to improve the seed filling performance. *Ding Li et al, (2018)*, designed the disturbance population of the shaped hole head according to the size of corn, which played an auxiliary role in seed filling. The average distance between the population particles and the seed disk, the average speed of the population and the average speed under different angular speeds were selected as indicators.

In this paper, the pneumatic precision seed metering device was used as the research carrier, and the EDEM simulation software was used to test the disturbed species of different seed metering devices. The indexes of population disturbance degree were established with different rotational speed and the number of seeds generated as variables, and the effects of different disturbed seed metering devices on population disturbance size and disturbance degree on filling performance were obtained through bench verification.

MATERIALS AND METHODS

Population index analysis

Although existing studies have proposed that seed population state has a significant impact on seed filling performance, and developed a variety of mechanisms to improve seed population state, the research on the mechanism of seed population state impact on seed filling performance is not deep enough, and most of them remain in the stage of experimental research and qualitative description, lacking a clear quantitative model to accurately describe the characteristics of reasonable seed population state. The guidance for the design and optimization of seed metering device is limited.

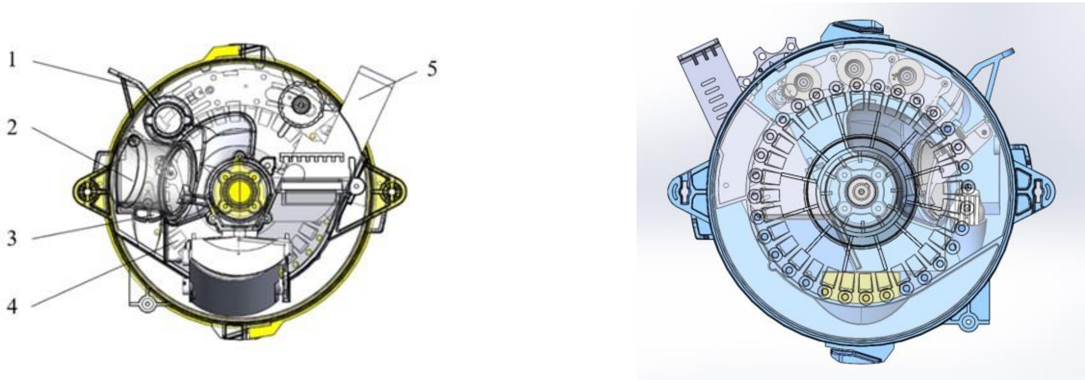
In this paper, two indicators are created according to the obvious degree of seed disturbance. In the display option function of the data analysis interface, the transparency of the geometry is changed to make the particles appear. The target particles are selected, and the particle display type is adopted as default. The speed is colored by the attribute coloring in the color identification TAB, which can distinguish the speed of different particles. The more intense the disturbance, the larger the particle motion speed, and the more obvious the filling effect.

The function of grid cell group is to divide the entire model area into grid cells with the same volume. Right-click on the setting options in the data analysis interface and select Add option, select Grid Bin Group, set the center position of the cell group and the dimensions in three directions XYZ, set the grid cell group to 1, and the bottom of the grid cell region just exceeds the layer. The number of seeds in the cell reflects the degree of disturbance. The more intense the disturbance, the more the number of seeds will be driven to the cell, and the less intense the disturbance, the less the number of seeds.

Structure principle of Seeding device

On the basis of the previous research conducted by Nanjing Institute of Agricultural Mechanization, Ministry of Agriculture and Rural Affairs, this paper adopted the pneumatic precision seed metering device developed in the earlier stage to carry out the research. The structure of the seed metering device is shown in Figure 1.

The working process of the seed metering device includes seed filling, seed clearing, seed carrying and seed casting. During operation, the air flow enters the inside of the seed metering device through the air inlet, and seed filling is carried out under positive pressure. When the seed disk rotates, the internal and external pressure difference makes the seeds press to the mold hole, and then reach the position of the seed drop mouth. The air pressure difference is eliminated under the air blocking device, and the seeds fall into the seed drop tube.



a. Front view of the seed metering device b. Rear view of seed metering device

Fig. 1 - Schematic diagram of seed metering device structure

1. Front housing;2. Air inlet;3. Seed port;4. Feed disk;5. Baffle plate.

Disturbance comparison and mechanical analysis

As shown in Fig. 2a, in the case of grooves, seeds were disturbed and showed a discrete state in the seed filling area of the seed layer with the rotation of the seed disk, while populations without grooves showed a stacked state, as shown in Fig. 2b.

a. Grooved population disturbed state b. Ungrooved population state

Fig. 2 - Effects of different types of disks on populations

The filling process of seeds is actually a process in which the air drag overcomes the population movement resistance (*Qi et al., 2013*). With the rotation of the seed disk during filling, the seeds were separated from the population by the disturbed seed disk, and the seeds were only affected by their own gravity and air compression force, as shown in Fig. 2a.

a. Disturbance force analysis b. Undisturbed force analysis

Fig. 3 - Comparison of force analysis under two different states

Therefore, when disturbed, seeds that do not come into contact with the population only need to meet the airflow pressure greater than their own gravity to be adsorbed, as shown in equation 1.

$$F_d \geq G \tag{1}$$

In Equation (1): F_d is the Airflow pressure, N. G is seed's own gravity, N.

When there is no disturbance, seeds come into contact with other seeds on the surface of the seeds, the seed is subjected to the horizontal component of population movement resistance and the vertical component of population movement resistance. At this point, the seed filling condition is reached as shown in equation 2.

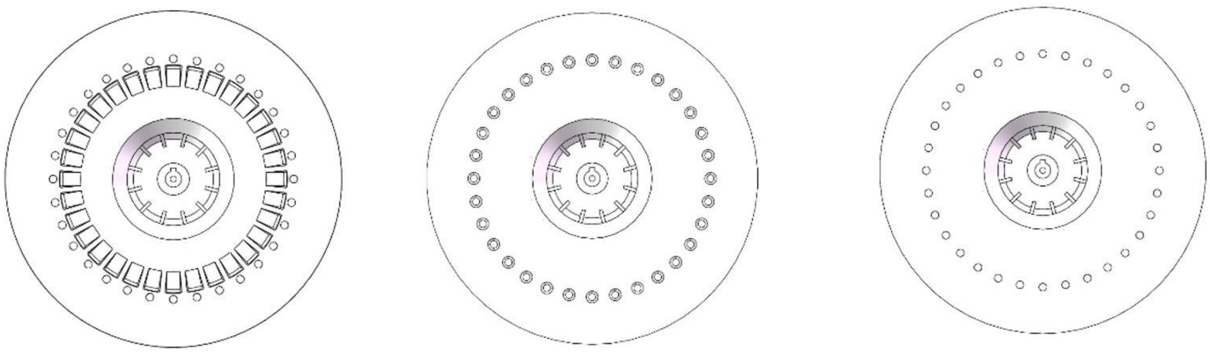
$$F_d \geq G + F_{fi} + F_{fj} \tag{2}$$

In Equation (2): F_d is the airflow pressure, N. F_{fi} is the horizontal component of group movement resistance; F_{fj} is the vertical component of population movement resistance.

Through the comparison of whether there is disturbance or not, it can be concluded that when there is disturbance, the seed can be pressed to the mold hole by overcoming its own gravity, and the air compression force is smaller than that when there is no disturbance, the required pressure value is also small, and the efficiency is high.

Seed disk structure

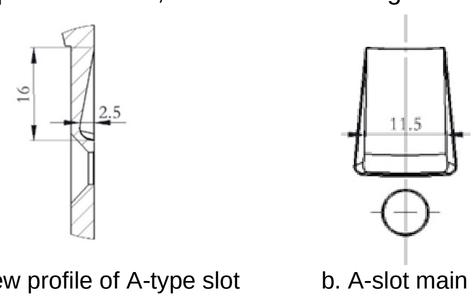
According to the working principle, the seed disk is the key structure responsible for seed carrying in the seed disk, and its important parameters include the size of the mold hole, the number of the mold hole and the distance from the center hole of the disk. The friction in the population increases when the seed layer accumulates, and the rotation of the seed disk causes the disturbed seed groove to disturb the population and reduce the friction, which is conducive to seed adsorption during the filling. In this paper, three kinds of seed disks are compared. The hole size of all disks is 5.5 mm, the number of holes is 32, and the distance from hole center to disk center is 90 mm. Disk A is designed as a trapezoidal inclined groove, disk B has a circular groove with a diameter of 9.5 mm and a depth of 1 mm around the hole, and disk C has no groove. The three types of seed rows are shown in Figure 4.



a. Disk A b. Disk B c. Disk C

Fig. 4 - Three types of seed disk structure

According to the literature, the maximum length and width of Zhengdan 958 corn seeds are 14 mm, 11.3 mm, and the minimum thickness is 3.3 mm, respectively. The size of corn seeds should be considered when designing the disturbed seed tank, and the length and width of the tank should be greater than the maximum size of corn, so that the seeds can completely enter the disturbed seed tank, and the length and width of the tank are 16 mm and 11.5 mm, respectively. The depth of the groove is smaller than the minimum seed thickness to prevent the seeds from being completely trapped in the groove affecting the disturbance performance, and the groove depth is 2.5 mm, as shown in the Figure 5.



a. Left view profile of A-type slot b. A-slot main view

Fig. 5 - Partial schematic diagram

As shown in Figure 6, the disturbed seed slot has a certain slope. When the seeds are in contact with the seed disk, they slide into the slot and close to the shaped hole under the influence of centrifugal force and gravity, and a certain slope can guide the seed flow.

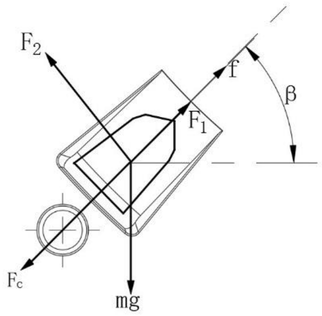


Fig. 6 - The seeds are subjected to force in the groove

$$\begin{cases} F_c = f + F_1 \\ mg = \dfrac{F_2}{\cos\beta} \end{cases} \tag{3}$$

In Equation (3): F_c is the centrifugal force on the seeds in the tank, N. F_1 is the supporting force of the bottom of the tank on the seed, N; F_2 is the supporting force of the groove side to the seed, N; β is the angle between the groove and the center of the disk and the horizontal line, (°); f is the friction between seed and tank, N; m is the quality of the seed, kg; g is the gravitational acceleration, m/s^2.

Among them, the centrifugal force F_c is affected by the speed and centrifugal radius, and the centrifugal radius is 90 mm, the centrifugal force can be shown in equation (4).

$$F_c = 0.36\pi^2 n^2 \tag{4}$$

In Equation (4): n is the rotational speed of the seed disk, r/min.

As shown in Figure 7, when seeds enter the tank, the population will have a vertical and disk pressure on the seeds in the tank, and the positive pressure of the population on the seeds can be found as shown in equation (5).

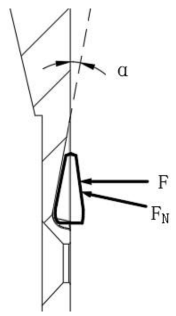


Fig. 7 - Left view of seeds under force in the groove

$$F_N = F\cos\alpha \tag{5}$$

In Equation (5): F_N is the positive population pressure, N; F is the Total population pressure, N; α is the angle between the groove bevel and the disk surface (°)

The friction force is shown by equation (6):

$$f = \mu F\cos\alpha \tag{6}$$

In Equation (6): μ is the Friction coefficient.

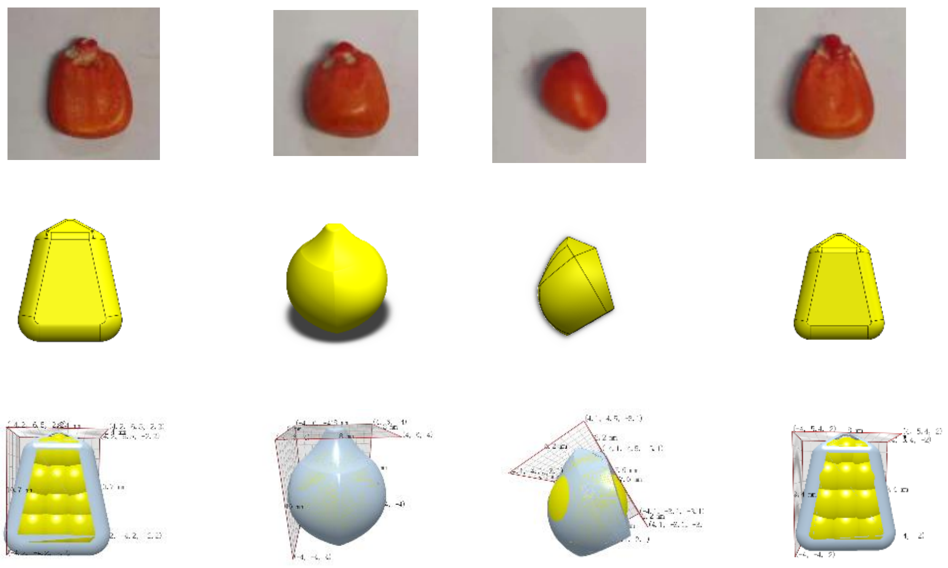
Substitute formula (4)(5)(6) into formula (3), it is obtained:

$$\begin{cases} 0.36m\pi^2 n^2 = \mu F\cos\alpha + F_1 \\ mg = \dfrac{F_2}{\cos\beta} \end{cases} \tag{7}$$

Force analysis through formula (7), the seeds in the tank are mainly affected by the rotation speed of the seed disk itself. When the height of the seed baffle is adjusted, the seeds move from the bottom to the surface when the height of the seed layer is fixed, the total pressure of the population on the seeds in the tank becomes smaller, the angle β becomes smaller, the seeds are subjected to greater force by the wall of the tank, the surface velocity of the seed layer increases, the number of seeds in the set area increases, and the disturbance becomes more obvious.

Particle seed modeling and motion simulation

In this paper, Zhengdan 958 corn seed was used for simulation. After preliminary screening, the seed was divided into four shapes: big circle, big flat, small circle and small flat. After modeling in SolidWorks, the seed was imported into EDEM for multi-spherical particle filling, the modeling and filling effects are shown in the figure 8.



a. Large flat b. Large circle c. Small circle d. Small flat

Fig. 8 - Zhengdan 958 maize seed model

The relevant mechanical properties and characteristic parameters of corn seeds and seed disks are shown in Table 1 with reference to relevant literatures (*Liu et al., 2015*).

Table 1

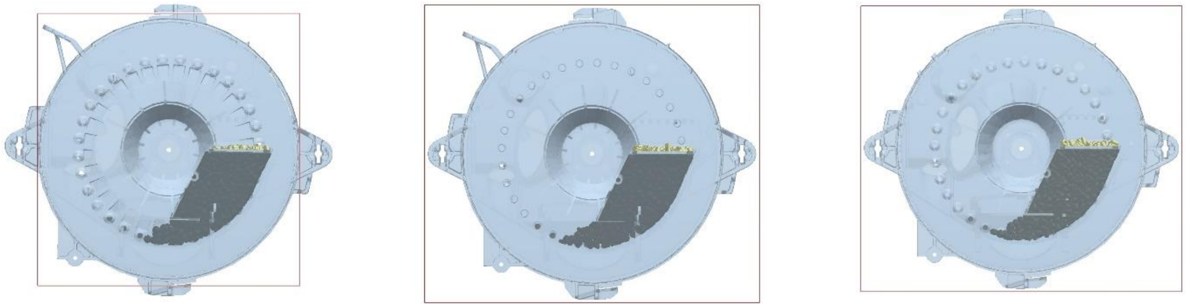
Physical characteristics and contact parameters of maize seed and seed disk

Contact form	Collision recovery coefficient	Coefficient of static friction	Coefficient of dynamic friction
Seed and seed	0.182	0.431	0.0782
Seed disk and seeds	0.621	0.459	0.178

Due to the irregular shape of corn seeds and the lack of adhesion on the surface of grains, the Hertz-Mindlin (no slip) model was chosen (*Shi et al., 2015*).

The particle size distribution was normal, and the mean value of the normal size distribution parameter was 1 and the standard deviation was 0.05. The particle factory was set to generate four kinds of particles respectively. In order to improve the solving calculation speed, the model was simplified when imported, the redundant parts were deleted, and key contact parts such as shell and seed disk were retained. Set the rotation speed of the seed disk to 20.7, 24.9, 29.1 and 33.3 r/min respectively.

Set the number of corn seeds in Figure 2 according to the total number of 800 and the ratio of 5:3:1:1, respectively, and generate them according to the total number of 500 per second, ensuring that the number of seeds generated can fill the seed inlet, as shown in Figure 9.



a. disk A b. disk B c. disk C

Fig. 9 - The simulation process of each seed disk

The solution setting adopts Euler time integration, with a Rayleigh time step of 2×10^{-6} seconds, the total simulation time is 7 seconds, and the particle generation time is less than 1 second. The generation is completed, and the seeding disk is set to start rotating at 1 second. Therefore, in the analysis interface, only the particle motion speed of 1 to 7 seconds and the number of seeds in the divided area need to be extracted.

Summary of simulation results

The disturbed seed tank can break the static state of population accumulation, and the seeds at the bottom can be moved upward in the process of movement, and the seeds near the seed layer can leave the surface of the seed layer through the disturbed seed tank, increasing the degree of seed dispersion. Therefore, the average velocity of seeds and the number of seeds entering the area above the seed layer were used as indicators to reflect the degree of species disturbance of the population. As shown in Figure 10, this article analyzes each disk at a speed of 19 r/min when the forward speed of the implement is 12 km/h.

In the post-processing, the simulation data of 1~7 s is extracted at a time interval of 0.4 s. The results show that the average speed of different kinds of disks fluctuates greatly, and the average speed of A disk mainly ranges from 0.005 to 0.02 m/s, while the average speed of B and C disks does not fluctuate.

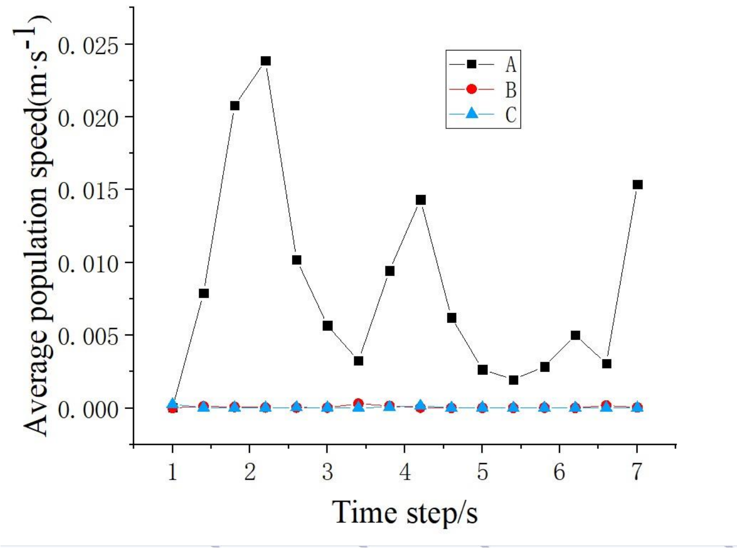


Fig. 10 - The fluctuation of the average velocity of the population of each seed disk with time

As time changes, it can be seen that the number in disk B and disk C is 0, indicating that the seed disk cannot bring the seeds into the area above the seed layer, and there is no obvious disturbance. As shown in Figure 11, the number of seeds above the seed layer of disk A fluctuated from 18 to 24, and there was obvious disturbance above the seed layer and the number was relatively stable, maintaining a stable filling state in the filling area.

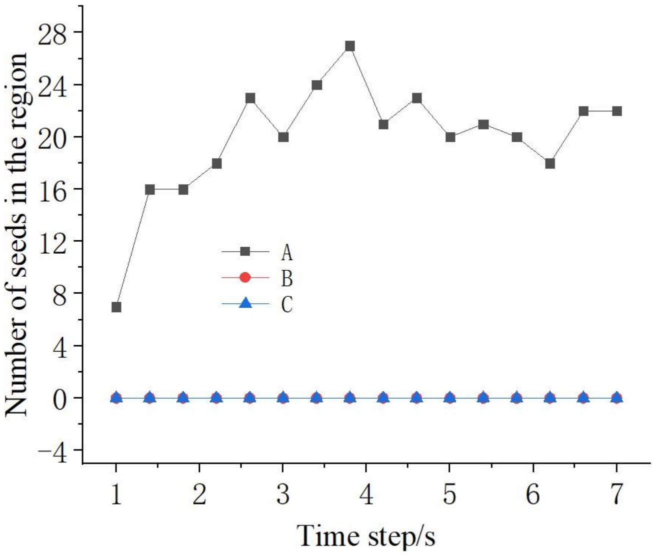


Fig. 11 - Number of seeds in each disk area at a speed of 12km/h

In general, with the increase of the rotation speed of the seeding disk, the average speed of the overall population increased. As shown in Figure 12, the average speed of the population of disk A was greater than $5\times10^{-3}m\cdot s^{-1}$at each rotation speed, and could reach more than 0.01 m/s at high speed, and the population speed increased gently, while the speed of disk B was not much higher than that of disk C. Compared with disk A, it is found that the disturbance condition is disk A > disk B > disk C.

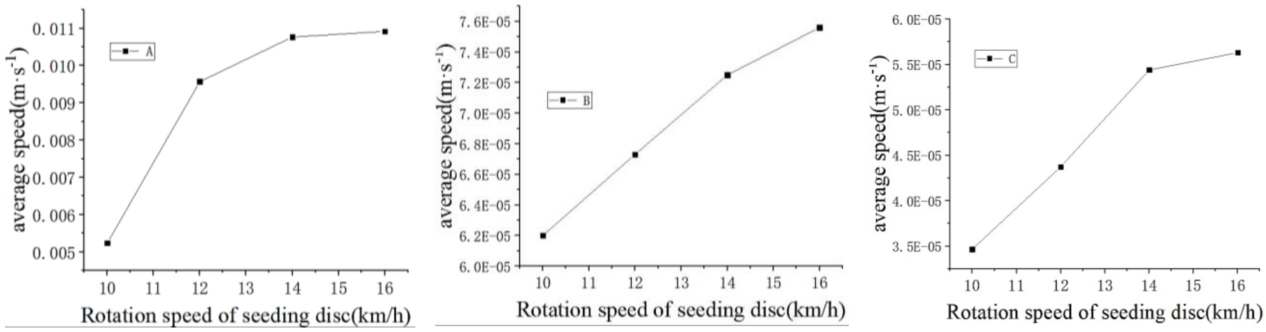


Fig. 12 - The average speed of the population at different seed disk speeds

In summary, the seed disturbing tank of disk A has a large disturbance ability, which can significantly increase the average speed of the population, reduce the internal friction of the seeds, drive the seeds away from the seed layer, and the seed disturbing effect is stable, which is conducive to the seed adsorption on the mold hole, and the seed filling performance of disk A is the best.

RESULTS

Bench test

Test materials and equipment

The selected seed was ungraded Zhengdan 958 corn seed with a 1000-grain weight of 330 g and a water content of 12%. In order to facilitate observation, the seed metering device is processed with a transparent shell, and the trial-produced seed metering disk is installed on the pneumatic high-speed precision seed metering device. The seed metering device is installed on the seed metering test bench of JPS-12, Nanjing Institute of Agricultural Mechanization, Ministry of Agriculture and Rural Areas. The plant distance and forward speed are set by the self-developed intelligent monitoring system of the seeder, and the speed is adjusted by the motor, The device is shown in the figure 13.

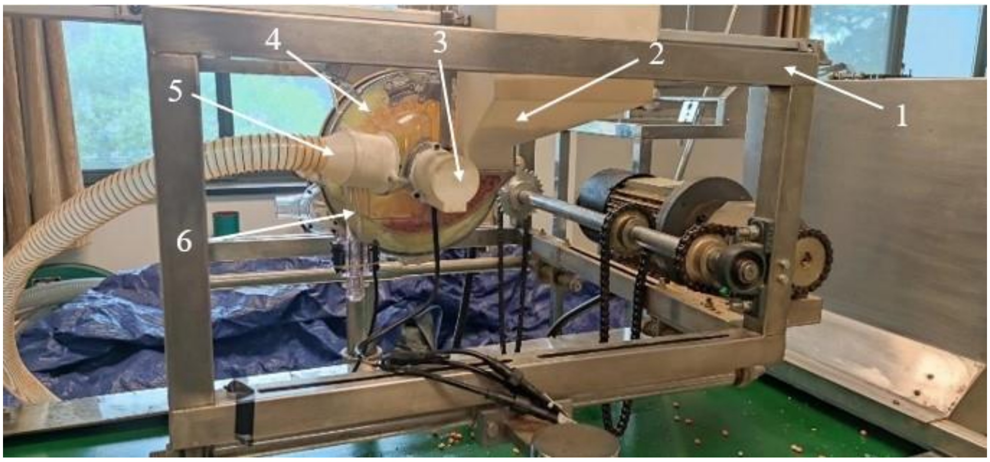


Fig. 13 - Seeding test bench

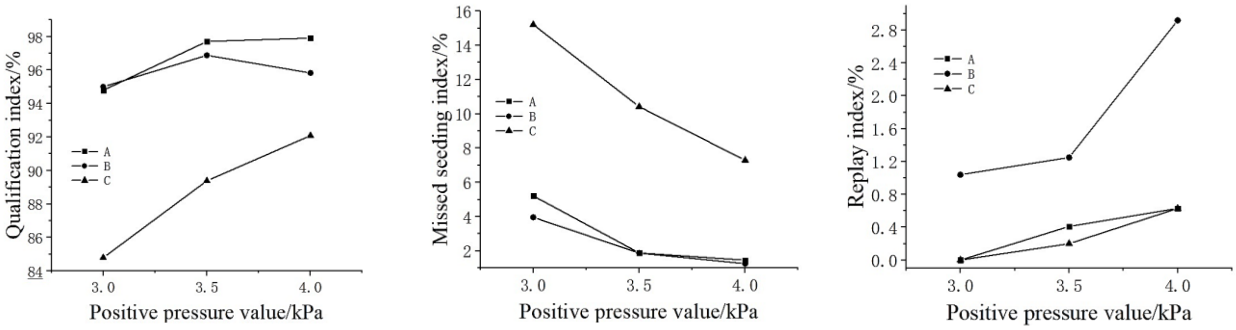
1. Profile racks; 2. Seed box; 3. Electrical machinery; 4. Seed metering device; 5. Air inlet port; 6. Seed feeding port

Test method

In the performance test of the seeding disk, Operation forward speed setting 10, 12, 14, 16km/h, and the working positive pressure was set to 3, 3.5, 4kPa. Marks were marked on the seeding disk to record the number of laps. The recording area started when the mold hole left the seed layer and ended at the highest position of the seeding position. The average value was repeated for 3 times as the test result.

Analysis of test results

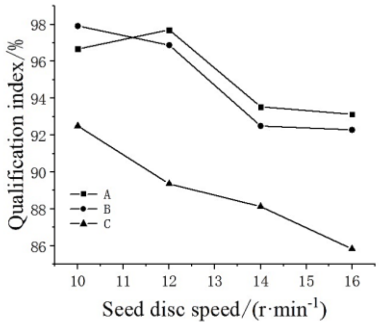
It can be seen from Figure 14(a) that at the speed of 12km/h, the pass rate of disk A increases with the increase of air pressure, while the leakage rate of disk A decreases with the increase of air pressure in Figure 14(b). There is little difference between disk A and disk B within the range of 3.5~4 kPa, and the performance of disk A is higher than that of disk B, and the leakage rate of disk C is the largest. It can be seen from Figure 15(b) and (c) that with the increase of speed, the leak rate of disk C is the largest. When the rotation speed is 16 km/h, the leak rate of disk C is more than 8 percentage points higher than that of other disks, while the replay rate is the smallest. The reason for the above test results is that the groove disturbance performance of disk A is the best, which is conducive to the seed filling of mold holes.



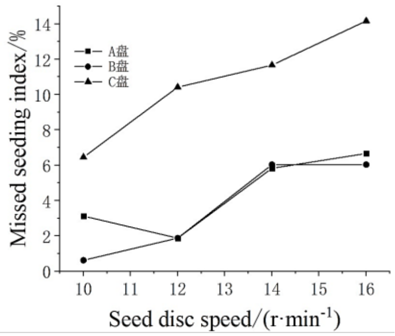
a. Qualification index b. Missed seeding index c. Replay index

Fig. 14 - Filling performance under different positive pressure at speed of 12 km/h

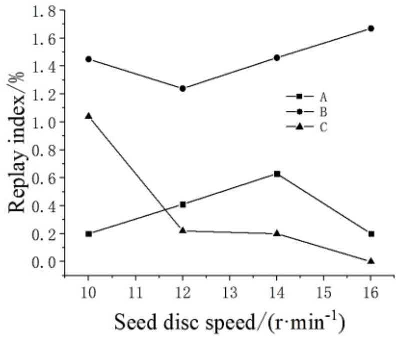
It can be seen from Figure 15(a) that the pass rate of disk A increases at the speed of 10~12 km/h, while the pass rate of disk C decreases at the speed of 12~16 km/h, among which the pass rate of disk C is the least. The result is that in a certain speed range, the appropriate increase of the speed makes the disturbance larger, and the seed disk can be better filled, so the pass rate is higher. Under high-speed operation, the centrifugal force on the seeds becomes larger, and it is easy to miss sowing, resulting in an increase in the miss sowing rate and a decrease in the qualified rate. Because there is no seed disturbing effect, the seeds are immovable under high-speed operation, and the interaction force between the populations is greater, and the seeds are difficult to adsorb. Therefore, the qualified rates of the seeds are much different from those of disk A and disk B.



a. Qualification index



b. Missed seeding index



c. Replay index

Fig. 15 - Seed filling performance under different seed disk rotation speed of 3.5kPa

Validation test

In order to verify the seeding performance of the installation of A disk seeding device, according to GB/T6973-2005 "Test Method for Seeder", the qualified rate, missing seeding rate and reseeding rate of seeds were taken as test indexes, and the full factor test of the rotation speed of the seed disk and the given positive pressure were carried out. The test results are shown in Table 2.

Table 2

Full factor test results

Operating speed km/h	Barotropic value /kPa	Miss seeding rate/%	Replay rate/%	Pass rate/%
10	3	5.42	0	94.58
10	3.5	5.13	0.21	96.66
10	4	1.25	0.63	98.12
12	3	5.21	0	94.79
12	3.5	1.88	0.42	97.7
12	4	1.46	0.63	97.91
14	3	11.25	0.21	88.54
14	3.5	5.83	0.63	93.54
14	4	3.96	1.04	95
16	3	11.88	0	88.12
16	3.5	6.67	0.21	93.12
16	4	4.17	0.42	95.41

According to the test results of the A-type seed disk, when the operating speed is 10~12 km/h and the positive pressure is 33.5 kPa, the leakage rate is no higher than 5.42%, the replay rate is no higher than 0.42%, and the qualified rate is no less than 94.58%. When the operating speed is 14~16 km/h and the positive pressure is 3.5~4 kPa, the leakage rate is not higher than 6.7%, the replay rate is not higher than 1.04%, and the pass rate is not lower than 93.12%. All the indicators are better than the national standard.

CONCLUSIONS

(1) In order to investigate the effect of population disturbance on the leakage of seed metering device, two indexes were established for population disturbance. Through simulation, it was found that the population velocity of disk A was the largest, the number of seeds entering the area above the seed layer was the largest, and the degree of disturbance was the largest.

(2) The comparative test of the three seed arrangement disks used in the simulation with the same speed and different pressures and the same pressure and different speeds found that the seed disturbing performance of disk A was the best, which made the seeds more easily pressed on the mold hole, and the disturbance performance of disk A > disk B > disk C.

(3) The full factor test of speed and pressure was carried out on the best designed seed disk. At the operating speed of 16 km/h, by adding grooves to increase the disturbance, the leakage rate was reduced by 8 percentage points compared with the smooth disk without any disturbance. When the operating speed is 10~12 km/h and the positive pressure is 3~3.5 kPa, the leakage rate is no higher than 5.42%, the replay rate is no higher than 0.42%, and the qualified rate is no lower than 94.58%. When the operating speed is 14~16 km/h and the positive pressure is 3.5~4 kPa, the leakage rate is not higher than 6.7%, the replay rate is not higher than 1.04%, and the pass rate is not lower than 93.12%. All the indicators are better than the national standard.

ACKNOWLEDGEMENT

We greatly appreciate the careful and precise reviews by the anonymous reviewers and editors. This research was funded by the Jiangsu Provincial Natural Science Foundation of China (Grant No. BK20211021), the Jiangsu Province Agricultural Science and Technology Independent Innovation Fund (Grant No. CX(21)3143), and the Innovation Program of Chinese Academy of Agricultural Sciences (CAAS-SAE-202301).

REFERENCES

[1] Chen Jin, Li Yao Ming, (2002). Study on Seeds Movement Lawin Sowing Test Stand with Suction and Vibration (气吸振动式播种试验台内种子运动规律的研究). *Transactions of the Chinese Society for Agricultural Machinery*, Vol.(01), pp. 47-50.

[2] Chen Yulong, Zhang Meng, Liu Zeqi, et al., (2021). Design and experiment of seed agitator for vertical disk seed metering device. *INMATEH-Agricultural Engineering*, Vol.63(01), pp.178-188.

[3] Ding Li, Yang Li, Liu Shourong, et al., (2018). Design of air suction high speed precision maize seed m etering device with assistant seed filling plate (辅助充种种盘玉米气吸式高速精量排种器设计). *Transact ions of the Chinese Society of Agricultural Engineering*, Vol.34(22), pp.1-11.

[4] Liu Rui, Liu Zhongjun, Liu Lijing et al., (2022). Design and Experiment of Corn High Speed Air Suction Seed Metering Device with Disturbance Assisted Seed-filling (玉米扰动辅助充种高速气吸式排种器设计与试验). *Transactions of the Chinese Society for Agricultural Machinery*, Vol.53(09), pp.50-59.

[5] Qi Bing, Zhang Dongxing, Cui Tao, et al., (2013). Design and experiment of centralized pneumatic see d metering device for maize (中央集排气送式玉米精量排种器设计与试验). *Transactions of the Chinese Soc iety of Agricultural Engineering*, Vol.29(18), pp.8-15.

[6] Singh R.C., Singh, G., Saraswat D.C., (2005). Optimisation of design and operational parameters of a pneumatic seed metering device for planting cottonseeds. *Biosystems Engineering*, Vol.92(4), pp.429-438.

[7] Shi Song, Zhang Dongxing, Yang Li, et al., (2015). Simulation and verification of seed-filling performan ce of pneumatic-combined holes maize precision seed-metering device based on EDEM (基于 EDEM 软件的气压组合孔式排种器充种性能模拟与验证). *Transactions of the Chinese Society of Agricultural Enginee ring*, Vol.31(03), pp. 62-69.

[8] Su Wei, Zhao Qinghui, Lai Qinghui, et al., (2023). Design and Experiment of Air-suction Broad Bean S eed Metering Device with Flat Belt Auxiliary Seed-filing (辅助充种带气吸式蚕豆精量排种器设计与试验). *Tra nsactions of the Chinese Society of Agricultural Engineering*, Vol.54(07), pp.144-155.

[9] Wang Fenghua, Sun Kai Lai, Qinghui, et al., (2020). Design and Experiment of Minituber Precision Sin gle-row Air-suction Planter (单行气吸式微型薯精密播种机设计与试验). *Transactions of the Chinese Society for Agricultural Machinery*, Vol.51(01), pp.66-76.

[10] Xie Dongbo, Zhang Chunling, Wu Xiaoqing et al. (2022). Design and Test of Garlic Seed Placer with S eed Disturbing Tooth Assisted Air Suction (扰种齿辅助气吸式大蒜排种器设计与试验). *Transactions of the Chinese Society for Agricultural Machinery*, Vol.53(02), pp.47-57.

[11] Yang Li, Yan Bingxin, Zhang Dongxing, et al., (2016). Research Progress on Precision Planting Techn ology of Maize (玉米精密播种技术研究进展). *Transactions of the Chinese Society for Agricultural Mach inery*, Vol.47(11), pp. 38-48.

[12] Yang Mingjin, Qiu Bing, Yang Ling, et al., (2020). Metering performance of the vibrational vacuum prec ision tray seeder (振动气吸式精密穴播机的排种性能). *Transactions of the CSAE*, Vol.26(9), pp.139-143.

[13] Yazgi A., Degirmencioglu A., (2007). Optimisation of the seed spacing uniformity performance of a vac uum-type precision seeder using response surface methodology. *Biosystems engineering*, Vol.97(3), pp. 347-356.

[14] Zhang Kaixing, Zhang Lan, Ding Yang, et al., (2021). Design and experiment of seed agitatro for vertic al disk seed metering device. *INMATEH-Agricultural Engineering*, Vol.64(02), pp.345-354.

[15] Zhang Xiaoshuang, Zhu Dequan, Xue Kang, et al., (2021). Parameter optimization and experiment of s lider-hole-wheel seed-metering device based on discrete element method. INMATEH-Agricultural Engi neering, Vol.65(03), pp.410-420.

[16] Zhao Zhan,Tian Chunjie, Wu Yafang, et al. (2018). Dynamic simulation of seed pick-up process and p arameter optimization on vacuum plate seeder for rice (盘吸式水稻排种器吸种动力学过程模拟及参数优化). *Transactions of the Chinese Society of Agricultural Engineering*, Vol.37(07), pp.38-44.