Design and experiment of conical diversion virus-free potato minituber precision seed-metering device

Zhaomei Qiu[1], Shanshan Jin[1], Xin Jin[1,2*], Jiangtao Ji[1], Tengfei Ma[1]

(1. *College of Agricultural Equipment Engineering, Henan University of Science and Technology, Luoyang 471003, Henan, China*;
2. *Science & Technology Innovation Center for Completed Set Equipment, Longmen Laboratory, Luoyang, Henan, China*)

Abstract: In order to accelerate the development of sowing mechanization of virus-free potato minituber, a conical diversion virus-free potato minituber precision seed-metering Device was designed according to the structural characteristics and agronomic requirements of virus-free potato minituber. The device is mainly composed of conical turntable, transmission shaft, outer baffle of seed-metering Device, baffle, seed outlet, seed cleaning device, type hole, etc. The working principle of conical diversion precision seed-metering device for virus-free potato minituber was expounded, and the stress analysis of virus-free potato minituber in each region was carried out. By EDEM discrete element simulation software, the structure of the type hole is optimized to determine the optimal structure of the type hole and according to the physical characteristics of virus-free potato minituber, the single factor experiments of the effects of length of type hole, cone disc speed and cone disc angle on seed filling performance were completed. The orthogonal regression test was carried out with the length of type hole, cone disc speed, and cone disc angle as the test objects, and the leakage rate and qualified rate as the response indexes. The regression models of leakage rate, replay rate, and qualified rate were established, and the parameters of the regression model were optimized. The optimal parameter combination is that the length of type hole is 33.61 mm, the cone disc speed is 6.35 r/min, and the cone disc angle is 26.59°. Bench test was carried out under the optimal conditions, the leakage rate was 3.80%, the replay rate was 0.80%, and the qualified rate was 95.40%, which was basically consistent with the prediction results of the regression model, and met the requirements of precision sowing of virus-free potato minituber.

Keywords: virus-free potato minituber, conical diversion, seed-metering device, type hole, discrete element method
DOI: 10.25165/j.ijabe.20231603.7682

Citation: Qiu Z M, Jin S S, Jin X, Ji J T, Ma T F. Design and experiment of conical diversion virus-free potato minituber precision seed-metering device. Int J Agric & Biol Eng, 2023; 16(3): 85–95.

1 Introduction

At present, most of the potato planting in China is still based on manual planting after potato chips, with high labor intensity and low production efficiency. Cut potatoes as seed are susceptible to virus infection, leading to lower yields per unit area and hindering the development of the potato industry. Virus-free potato minituber is bred under sterile conditions, which have higher yield, better quality, and higher commodity rate than ordinary potatoes[1]. However, the production and breeding level of virus-free potato minituber in China is low, and its supply is far less than the market demand. Therefore, it is necessary to increase the planting area of virus-free potato minituber, and the mechanization of virus-free potato minituber sowing is imperative[2-4].

The existing mechanized seeding techniques of virus-free potato minituber mainly focus on air-suction metering device and mechanical seeding device. Mcleod et al.[5] developed an air-breathing virus-free potato minituber precision seeding device, using negative pressure suction seed, positive pressure seed metering, and equipped with a spray gun, with seed picking function, to improve the seeding qualified rate. Lu et al.[6] designed an air-suction potato metering device to improve the performance of large-scale seed crops sowing equipment and solve the problems of high replay index, high leakage index, and low qualification rate of potato mechanical seeder. The main structure and operating parameters of the device are determined by theoretical analysis. The working performance of the device meets the requirements of precision sowing. Lai et al.[7,8] designed a single-row air-suction virus-free potato minituber precision seeder to meet the needs of small plots in hilly and mountainous areas in China, and solved the problems of serious seed injury and poor filling effect of mechanical virus-free potato minituber seeder. The seeder was tested and optimized, and verified by field experiments. Meet the agronomic requirements of virus-free potato minituber seeding. Lv et al.[9,10] developed a pneumatic precision potato seeder to solve the problems of slow operation, low precision, and high rate of heavy and missed seeding of potato seeders in China. The machine used negative pressure suction, positive pressure seeding, and zero-speed seeding to optimize the performance. The machine could complete multiple functions such as potato ditching, side-deep stratified fertilization, high-speed seeding, and soil covering.

For mechanical type, in order to improve the efficient and accurate seeding of potato, Zhang et al.[11] designed a new type of vacuum spoon belt combined metering device. The structure and parameters of key components of metering device were studied. The bench test verified the efficient and precise performance of the seed-metering Device, which provided theoretical and technical reference

Received date: 2022-05-16 **Accepted date:** 2023-02-20
Biographies: Zhaomei Qiu, PhD, Professor, research interest: modern agricultural equipment and intelligence, Email: qzm381@126.com; **Shanshan Jin**, MS candidate, research interest: modern agricultural equipment and intelligence, Email: jss971010@163.com; **Jiangtao Ji**, PhD Professor, research interest: modern agricultural equipment and intelligence, Email: jjt0907@163.com; **Tengfei Ma**, MS candidate, research interest: agricultural mechanization engineering, Email: mtf20032004@163.com.
***Corresponding author: Xin Jin**, Associate Professor, research interest: agricultural equipment and intelligent technology. Science & Technology Innovation Center for Completed Set Equipment, Longmen Laboratory, Luoyang 471003, Henan, China. Tel: +86-379-64877817, Email: jx.771@163.com.

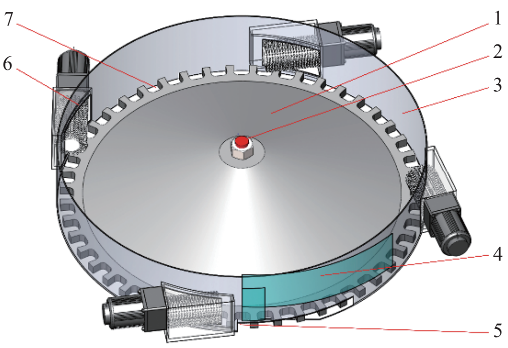
for improving the efficient and precise seeding of potato. Lv et al.[12] designed a scoop potato metering device to solve the problems of high heavy missing sowing rate, high labor intensity and poor universality of potato seed-metering Device. The seed metering performance of the seed-metering Device was tested on the bench, and the seed metering quality was good. The field experiment showed that the seed metering performance of the seed-metering Device under the combination of operating parameters met the seeding performance requirements of potato seeder. Liu et al.[13] put forward the single row sequencing mechanized sowing technology based on forced vibration principle, designed the potato micro seed potato vibration sequencing sowing device, and optimized the sowing performance to meet the requirements of potato seeder sowing performance. The above two sowing methods provide technical support for mechanized sowing of virus-free potato minituber. However, for the pneumatic seeding device, because the virus-free potato minituber is a large particle, the air tightness and supporting power of the seeding device put forward higher requirements[14-17]. The mechanical potato sowing device is simple in structure, but the sowing pass rate needs to be improved[18-22].

In this paper, a conical diversion virus-free potato minituber precision seed-metering device is designed according to the sowing demand of small plots in mountainous and hilly areas of China and the agronomic requirements of virus-free potato minituber. The working principle of conical diversion type virus-free potato minituber precision seed-metering Device is expounded, and the size range of the hole is determined according to the physical characteristics of the virus-free potato minituber. EDEM discrete element simulation software was used to simulate and analyze the seed collection process and conical turntable parameters[23-25]. The experimental scheme was designed by Box-Benhnken central composite design theory[26,27], and the bench verification test was carried out to provide reference for the design of virus-free potato minituber single seed-metering device.

2 Structure and working principle of seed-metering device

2.1 Seed-metering Device structure

The conical diversion virus-free potato minituber precision seed-metering device is mainly composed of conical turntable, type hole, seed cleaning device, baffle, outer baffle of seed-metering device, transmission shaft, and so on. The structure is shown in Figure 1.



1. Conical turntable 2. Transmission shaft 3. Outer baffle of seed-metering device 4. Baffle 5. Seed outlet 6. Seed cleaning device 7. Type hole

Figure 1 Schematic diagram of the seed-metering device structure

2.2 Working principle of seed-metering device

The process of single seed collection of virus-free potato minituber was divided into three stages, as shown in Figure 2, which were filling stage, cleaning stage, and seeding stage.

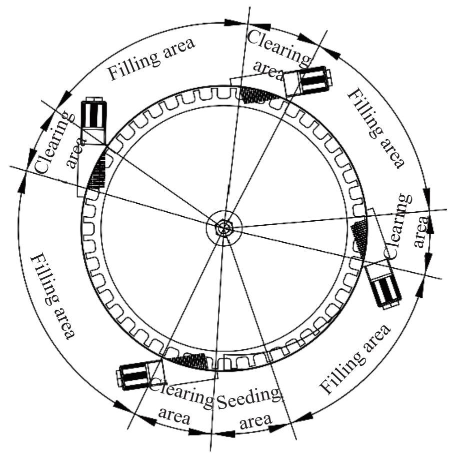


Figure 2 Working principle diagram of the seed-metering device

When working, the virus-free potato minituber on the conical turntable rotates with the conical turntable driven by the speed regulating motor. The virus-free potato minituber is stirred by the centrifugal force, conical component force, and seed cleaning device generated by the rotation of the conical turntable. Under the action of centrifugal force and inclined force, the virus-free potato minituber moves to the edge of the outer baffle of seed-metering device and falls into the type hole at the edge of the conical turntable to complete the filling process. The virus-free potato minituber will accumulate above the edge type hole of the turntable and rotate with the conical turntable. Four seed cleaning devices are fixed on the outer baffle of seed-metering device, which consists of a seed cleaning motor and a seed cleaning cylindrical brush. In the seed-metering device, the virus-free potato minitubers that fail to enter the type hole will accumulate in large quantities above the type hole and on the edge of the conical turntable, and rotate together with the conical turntable to reach the position of the seed clearing device. The seed clearing device will push the excess virus-free potato minitubers above the type hole back to the cone of the conical turntable to avoid replay phenomenon. At the same time, the seed cleaning device and the conical turntable rotate and cooperate with each other, which can also push the excess virus-free potato minitubers into the mold hole that has not been filled in time to play the role of reseeding. The virus-free potato minituber in the type hole fall after reaching the outlet to complete the seed feeding process, while the more virus-free potato minitubers will be blocked by the baffle of the outlet to start the seed filling process again.

Analysis of seed filling process: the virus-free potato minituber falls on the conical turntable and flows to the surrounding type hole under the action of conical surface. Taking the location of virus-free potato minituber as the center, the spatial rectangular coordinate system was established. The x-axis was perpendicular to the generatrix of the conical turntable through the seed. The y-axis was perpendicular to the x-axis and parallel to the generatrix of the conical turntable. The z-axis was perpendicular to the generatrix of the conical turntable through the contact point between the virus-free potato minituber and the conical surface. The force of the virus-free potato minituber on the conical surface is shown in Figure 3.

$$\begin{cases} f_1 = \mu N_1 \\ F = 2m\omega v_r \cos\theta \\ I = m\omega^2 r \end{cases} \tag{1}$$

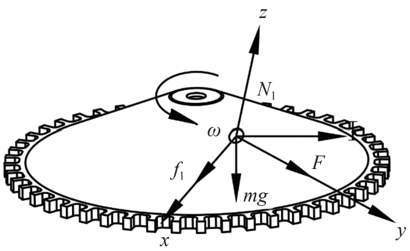


Figure 3 Stress analysis of virus-free potato minituber on conical turntable

where, f_1 is the friction force between the conical turntable and the virus-free potato minituber, N; N_1 is the supporting force of the conical turntable to the virus-free potato minituber, N; μ is the static friction factor between virus-free potato minituber and conical turntable; F is for Koch force, N; v_r is the speed of virus-free potato minituber movement, m/s; m is the quality of virus-free potato minituber, N; θ is the cone angle of a conical turntable, (°); ω is the angular velocity of conical turntable, r/min; r is the radius of the location of the virus-free potato minituber, mm; I is the centrifugal force on the virus-free potato minituber, N.

Whether virus-free potato minitubers fall into the type hole depends on the relative movement along the type hole. The kinematic analysis of a single virus-free potato minituber, when it is about to enter the hole, is shown in Figure 4. O is the seed centroid, and the long-axis direction of the virus-free potato minituber is x-axis direction. The relative limiting velocity $v_{r\max}$ of the seed filling the type hole and the limiting speed $n_{\max}$ of the Conical turntable are:

$$\begin{cases} v_{r\max} \leq (E+L-D)\sqrt{\dfrac{g}{2D}} \\ n_{\max} \leq (E+L-D)\sqrt{\dfrac{g}{2D}} \end{cases} \tag{2}$$

where, L is the length of type hole, mm; D is the distance between the virus-free potato minitubers mass center and the conical turntable, mm; E is the width of the upper chamber, mm; R is the radius of a conical turntable, mm.

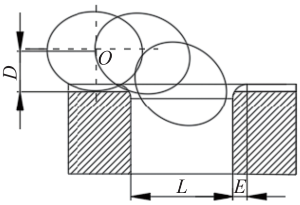


Figure 4 Kinematics analysis of virus-free potato minituber filling the length of type hole

The mechanical analysis of virus-free potato minituber on the conical turntable and the kinematics analysis of virus-free potato minituber filling hole show that the cone disc speed, cone disc angle and type hole parameters of the conical turntable affect the filling process of virus-free potato minituber.

Seed cleaning process analysis: In order to solve the problem that virus-free potato minituber is easy to damage in the cleaning stage of mechanical seed-metering device, the rotating brush is used for seed cleaning, and the rotating brush is driven by the speed regulating motor. The brush adopts wear-resistant and uniform nylon material to reduce the clamping, knocking, and friction of virus-free potato minitubers during seed cleaning. When the seed-metering device works, the virus-free potato minitubers are arranged along the long-axis direction driven by the conical turntable, and move together with the conical turntable. The virus-free potato minitubers move to the front layer of the rotating brush, and the relative velocity of the horizontal virus-free potato minituber layer decreases from bottom to top. The dragging speed of the bottom virus-free potato minituber is the largest, and the force to drill into the type hole is the largest. The virus-free potato minituber moving to the edge of the conical turntable allows only one virus-free potato minituber to fall into the type hole under the barrier of the seed cleaning device, while more virus-free potato minitubers will continue to rotate with the conical turntable above the type hole. The force is shown in Figure 5.

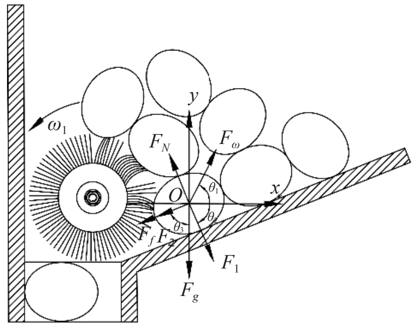


Figure 5 Force analysis of brush cleaning device

The centroid O of the virus-free potato minituber contacting with the brush was selected as the origin, and the xoy coordinate system was established along the tangential and normal directions of the brush rotation direction. The virus-free potato minituber was mainly affected by its own gravity, the support force on the bevel surface of the conical turntable, the friction force on the bevel surface of the conical turntable, the support forces F_1 and F_2 between adjacent virus-free potato minitubers, and the force on the virus-free potato minituber when the brush was rotated. When the brush rotates, the force on the virus-free potato minituber pushes back the micro-tuber accumulated on the type hole back to the bevel of the conical turntable, so that the virus-free potato minituber continues to rotate with the conical turntable and starts the filling process again. Through the force analysis, the force balance equation of miniature potato during seed cleaning is:

$$\begin{cases} F_\omega\cos\theta_1 + F_1\cos\theta_2 - F_N\cos\theta_2 - F_f\sin\theta_3 - F_2\sin\theta_3 = 0 \\ F_\omega\sin\theta_1 + F_N\sin\theta_2 - F_f\cos\theta_3 - F_2\cos\theta_3 - F_1\sin\theta_2 - F_g = 0 \end{cases} \tag{3}$$

where, F_ω is the force on brush rotation on virus-free potato minituber, N; F_1 is the support between adjacent virus-free potato minitubers, N; F_2 is the support between adjacent virus-free potato minitubers, N; F_N is the support of the conical turntable to virus-free potato minituber, N; F_f is the friction between the conical turntable and the virus-free potato minituber, N; F_g is the gravity of virus-free potato minituber itself, N.

3 Design and simulation of key structures

3.1 Physical properties of virus-free potato minitubers

The physical characteristics of virus-free potato minitubers are the important basis for the design of seed-metering device. In this paper, ' Xisen ' virus-free potato minitubers (6-8 g) were selected as the research object, and 300 grains were randomly selected. The three-axis size, quality, and angle of repose of virus-free potato minitubers were measured by vernier caliper (precision 0.02 mm), electronic balance (precision 0.001g), and angle of repose measuring instrument.

The mass of virus-free potato minitubers was 6-8 g, the average particle size was 24.57 mm, the sphericity was 0.84, and the rest angle was 25.17°, the average mass was 7.32 g. The three-dimensional size distribution of virus-free potato minitubers is shown in Figure 6, and the three-dimensional size of virus-free potato minitubers is listed in Table 1.

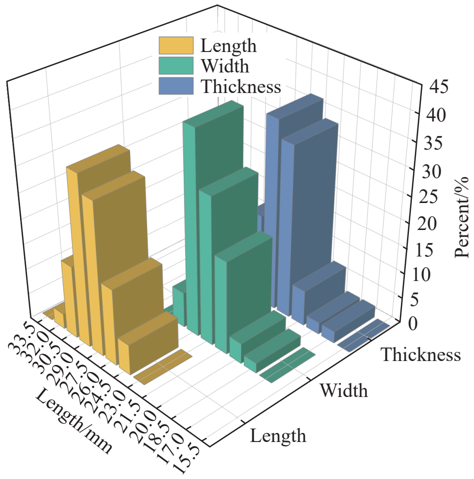


Figure 6 3D size probability distribution diagram of virus-free potato minituber

Table 1 Three-axis size distribution of virus-free potato minituber

Parameter	Average/mm	Standard deviation/mm	Coefficient of variation/%
Length	28.13	1.43	5.07
Width	23.34	1.81	7.76
Thickness	22.24	3.07	13.8

3.2 Structure design of conical turntable

3.2.1 Diameter determination of conical turntable

As the core component of the seed-metering device, the diameter of the conical turntable determines the overall structure of the seed-metering device, the number of type holes, and the structural parameters of the type holes, which has a direct impact on the leakage and reseeding rate of virus-free potato minituber.

In general, the longer the seed filling time, the lower the number of leakage seeds and therefore the better the seed filling performance. The relationship between the diameter of the conical turntable and the seed filling time is as follows:

$$t_0=\frac{L_0}{v_0}=\frac{\delta(D-\Delta h)}{\pi n_s\frac{D-\Delta h}{30}}=\frac{30\delta}{n_s\pi} \tag{4}$$

where, t_0 is the filling time, s; L_0 is the filling area arc length, mm; v_0 is the centreline speed of the conical turntable type hole, m/s; δ is the radius of the filling area, rad; Δh is the difference between the diameter of the conical turntable and the diameter of the distribution circle of the type hole, mm; n_s is the rotational speed of conical turntable, r/min.

It can be seen from the above formula that the filling time t_0 is related to the rotation speed of the conical turntable and the radian of the filling area. Because the number of type holes in the planting area is certain, increasing the diameter of the conical turntable can increase the radian of the filling area and the number of type holes in the filling area, thus increasing the filling time and improving the filling performance. However, considering the sowing speed, seed-metering device quality, virus-free potato minituber size, and shape size of seed-metering device, the conical turntable diameter D = 0.8 m is selected.

3.2.2 Determination of type hole Size

Type hole parameters are the key to seed-metering device design. Hole type length A, width B, groove depth *C*. In order to ensure the success rate of single seed, the seed size should be within the appropriate range. The length of virus-free potato minituber is larger than the width, and the width is slightly larger than the thickness. According to the probability method, the probability of virus-free potato minituber lying flat and lying side is much larger than that of standing. At the same time, according to the principle of minimum potential energy, the lying flat state is determined as the most stable filling method, as shown in Figure 7.

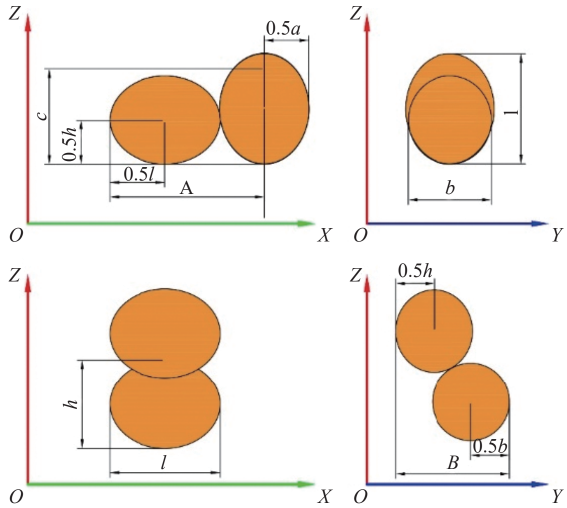


Figure 7 Diagram for calculating the size of the type hole

The type hole can only contain one virus-free potato minituber and cannot contain two virus-free potato minitubers:

$$\begin{cases} l_{\max}<A<l+0.5h \\ b_{\max}<B<b+h \\ B<l \\ h_{\max}<C<h+0.5b \\ C<B \end{cases} \tag{5}$$

where, A is the length of the type hole, mm; B is the width of the type hole, mm; C is the depth of the type hole, mm; l is the maximum length of the virus-free potato minituber, mm; b is the maximum width of the virus-free potato minituber, mm; h is the maximum thickness of the virus-free potato minituber, mm.

During the rotation of conical turntable, the virus-free potato minituber long axis was driven to be aligned along the tangential direction of the circumference and moved in a concentric circle. Therefore, the length of the type hole had the greatest impact on the seed filling ability, while the thickness and width of the type hole had little impact on the seed filling ability. Therefore, the long circular holes arranged along the circumferential tangential direction were designed, and the ‘Xisen’ virus-free potato minituber was taken as the research object. The average values of length, width, and thickness were 28.13 mm, 23.34 mm, and 22.24 mm, respectively. The length of type hole should not be less than 30 mm, so the design length of type hole should be changed in the range of 30-50 mm, the height should be 25 mm, and the width should be 30 mm, so as to reduce the leakage and replay phenomenon in the process of seeding. The supporting force of the virus-free potato minituber near the type hole on the conical turntable comes from the upper edge of the type hole, as shown in Figure 8. The gravity G, the horizontal component force F_x and the vertical component force F_y of the virus-free potato minituber force are applied to the virus-free potato minituber. Due to the existence of a small round angle of 45° with a radius of 5 mm. at the upper edge of the type hole, the support force N_0 of the micro potato obliquely upwards through the normal direction of the small round angle, that is, N_0 has a horizontal component, and the horizontal component of N_0 forward must be greater than the horizontal component of the friction F_f backward, acting on the seeds in front of it, will inevitably accelerate the front of the micro potato into the type hole, so as to improve the filling rate of the hole and reduce the breakage.

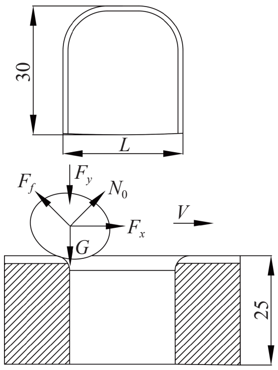


Figure 8 Diagram of type hole dimensions

3.2.3 Determination of the number of type holes

When the operating speed and plant spacing are determined, the increase in the number of type holes on the conical turntable can reduce the linear speed of theconical turntable and increase the seed filling time, which is conducive to improving the seed filling performance. However, the excessive number of type holes will increase the diameter of the conical turntable, and the quality, and size of the seed-metering device. According to the agronomic requirements, virus-free potato minituber for a type hole one seed sowing, plant spacing is consistent, so the unit time seeder operating speed and metering device conical turntable speed match. Therefore, the number of conical turntable type holes and the rotational speed of conical turntable should be reasonably selected. The number of type holes in the conical turntable N and the rotational speed of the conical turntable n_s should satisfy:

$$N = \frac{60v_m}{L_b n_s(1-\varepsilon)} \tag{6}$$

where, v_m is the operating speed of the seeder, m/s; L_b is sowing spacing, m; ε is the ground wheel slip coefficient, %.

The diameter of the conical turntable D = 0.8 m, the operating speed of the seeder v_m = 1 m/s, the planting spacing of virus-free potato minituber is 0.15-0.25 m, according to agronomic requirements, L_b = 0.20 m, the rotational speed of the conical turntable, n_s = 7 r/min, and the slip rate of the ground wheel ε = 3%, thus determining the number of type holes as N = 48.

3.3 Discrete element simulation model

In order to shorten the test time and improve the pertinence of the test, the discrete software EDEM was used to simulate and analyze the performance of the seed-metering device. Taking 'Xisen' virus-free potato minitubers as the simulation object. Hertz-Mindlin (no slip) model is used in the contact model between particles and between particles and equipment. The simulation parameters are listed in Table 2.

Table 2 Simulation parameters of virus-free potato minitubers

Item	Attribute	Value
Virus-free potato minituber	Poisson ratio	0.4
	Shear modulus/Pa	3.34×10^7
	Density/kg·m^-3	1.06
Seed-metering device	Poisson ratio	0.3
	Shear modulus/Pa	7×10^7
	Density/kg·m^-3	7800
Between virus-free potato minitubers	Restitution coefficient	0.452
	Coefficient of kinetic friction	0.412
	kinetic friction	0.01
Between virus-free potato minituber and seed-metering device	Restitution coefficient	0.52
	Coefficient of static friction	0.64
	Coefficient of kinetic friction	0.02

3.4 Determination of the type hole structure

The structure of the type hole directly affects the seeding quality. In order to improve the qualified rate of seeding, three kinds of optimal type hole structures were selected for discrete element simulation analysis under the same conditions of conical turntable diameter, cone disc angle, cone disc speed and number of type holes, as shown in Figure 9.

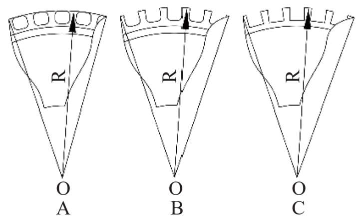


Figure 9 Schematic diagram of the preferred type hole structure

In order to facilitate the simulation, remove the irrelevant components in the process of virus-free potato minituber movement, and simplify the seed-metering device model, the three-dimensional software Solidworks was used to model the seed-metering device entity. The seed-metering device simulation model was imported into EDEM in stl format. The three-axis average value of virus-free potato minituber was set to generate 300 virus-free potato minituber models. In order to ensure the continuity of simulation, the fixed time step was set to be 15% of the Rayleigth time step, and the total simulation time was 20 s (the particles were generated in the first 1 s), as shown in Figure 10.

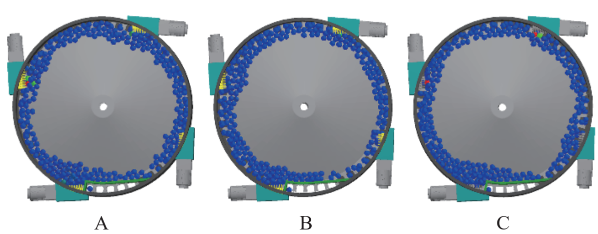


Figure 10 Optimum structural simulation schematic

The filling simulation results of the seed-metering device with type A, type B and type C hole structure are listed in Table 3.

Table 3 Simulation results of three type of holes seed-metering device

Type hole	Leakage rate/%	Replay rate/%	Qualified rate/%
A-type	10.3	0.5	89.2
B-type	6.4	1.2	92.4
C-type	7.6	3.7	88.7

The EDEM discrete element analysis software was used to simulate and analyze the three type holes with different structures. The comparative analysis shows that the leakage rate and qualified rate of B-type holes are lower than those of the other two structures under the same conditions, as listed in Table 3. From the EDEM output under different type holes of virus-free potato minituber speed changes over time as shown in Figure 11, it can be seen that the B-type hole speed changes with time the smallest fluctuation, A-type and C-type hole speed changes with time fluctuations, is not conducive to virus-free potato minituber into the type hole and filling instability, resulting in lower qualified rates. Although the shape and structure of A-type hole is similar to that of virus-free potato minituber, it is easy to fail to take virus-free potato minituber due to its small volume and arc shape on both sides of the length direction, resulting in high leakage rate. Type C hole is rectangular, easy to seed, but the volume is large, may appear two virus-free potato minituber stuck in a type hole at the same time, resulting in more leakage and angular seed damage; the B-type hole adopts an end arc, which combines the advantages of A and C, and avoids the disadvantages of too large or too small volume. Therefore, the B-type hole has a relatively low seed leakage rate.

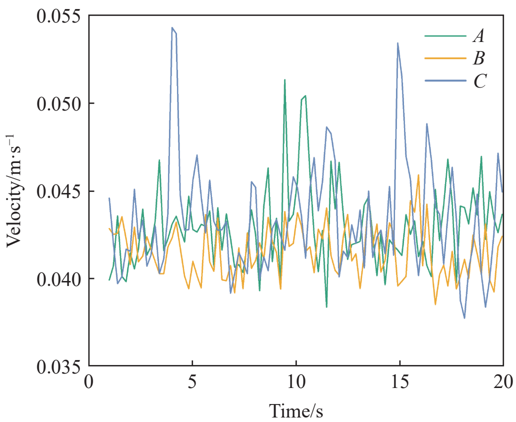


Figure 11 Curves of virus-free potato minituber speed changing with time under different type hole types

3.5 Analysis of virus-free potato minituber seeding process

When the seed-metering device was just started, the energy change of virus-free potato minitubers in the seed-metering device is shown in Figure 12. When the virus-free potato minituber just fell into the conical turntable, the virus-free potato minituber was completely in a state of disorder. Under the rotation of the conical turntable, the virus-free potato minituber is arranged along the tangential direction of the conical turntable with a long axis. The virus-free potato minituber in the type hole is limited by the type hole in a stable state, so the energy fluctuation is small and the energy consumption is small, which meets the requirements of filling.

The energy change of virus-free potato minituber in seed-metering device is shown in Figure13. The virus-free potato minituber stacked above the type hole and the virus-free potato minituber at the edge of the type hole are subjected to the force of the conical turntable and the virus-free potato minituber inside the type hole, resulting in a certain energy fluctuation, but the movement trend and direction are stable. The virus-free potato minituber moving to the seed cleaning device will change the movement direction of the virus-free potato minituber under the combined action of the seed cleaning device and the conical turntable, and will also produce certain energy fluctuations. However, the energy fluctuation of the virus-free potato minituber here is relatively stable, and the energy consumption is not large, so it can play the purpose of seed cleaning. The virus-free potato minituber located at the seeding outlet will change its movement direction under the action of the baffle and the seed cleaning device, and produce large energy fluctuations to ensure that there is no replay phenomenon.

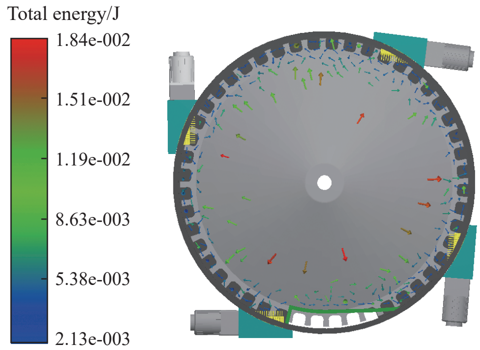


Figure 12 Energy diagram of miniature potato in seed-metering device

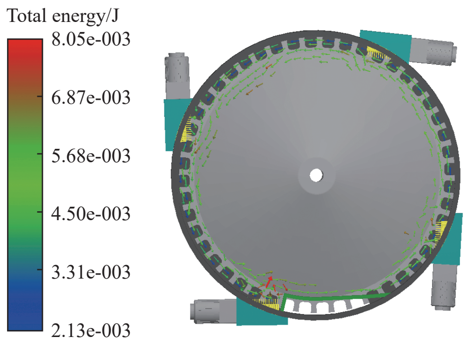


Figure 13 Energy variation of virus-free potato minituber in seed-metering device

3.6 Single factor simulation test and result analysis

In order to facilitate the parameter design, the single factor simulation analysis of the length of type hole, cone disc speed and cone disc angle was carried out. The diameter of the conical turntable was 80 mm, the number of type holes was 48, and the fixed values of each factor were 35 mm, 7 r/min, and 25°, respectively. The test performance evaluation indexes included leakage rate, replay rate and qualified rate.

3.6.1 Influence of length of type hole selection on seeding performance

The virus-free potato minituber enters the type hole with the long axis arranged along the tangential direction of the conical turntable circle, and the reasonable configuration of the length and size of the hole is conducive to the virus-free potato minituber entering the type hole. In order to study the influence of the length of type hole on the filling performance, the simulation analysis of the filling situation of the seed-metering device is carried out when the length of the type holes are 30 mm, 35 mm, 40 mm, 45 mm and 50 mm, respectively. The results are listed in Table 4.

Table 4 shows that reducing the length of type hole can reduce the replay rate, but increase the leakage rate; increasing the length of type hole can reduce the leakage rate, but increase the replay rate. In order to further analyze the effect of the length of type hole on seed filling process, the variation of virus-free potato minituber velocity with time under different the length of type hole is output from EDEM, as shown in Figure 14. When the length of type hole is large, the motion velocity fluctuation of the virus-free potato minituber is large, and the motion of the virus-free potato minituber is unstable, and the phenomenon of accommodating two virus-free potato minitubers in the same type hole is easy to occur. When the length of type hole is small, the motion velocity fluctuation of the virus-free potato minituber is small, and the motion velocity of the virus-free potato minituber is small, which reduces the probability of the virus-free potato minituber entering type hole, but the qualified rate of seeding does not decrease significantly. Based on the analysis of seed exclusion rate and velocity stability, it is suitable to select the length of type hole in the range of 30-40 mm.

Table 4 Simulation results of different length of type holes

The length of type hole/mm	Leakage rate/%	Replay rate/%	Qualifiedrate/%
30	7.1	0.2	92.7
35	5.7	0.7	93.6
40	4.9	2.7	92.4
45	3.5	5.7	90.8
50	2.2	10.7	87.1

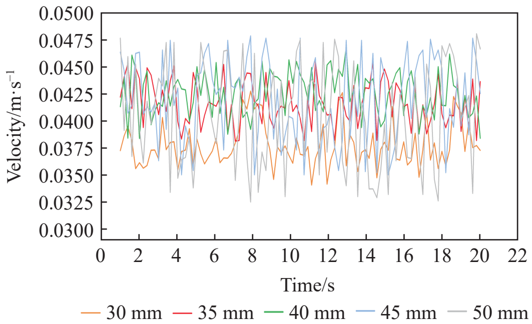


Figure 14 Curves of virus-free potato minituber velocity versus time under different length of type holes

3.6.2 Influence of cone disc speed selection on seeding performance

The cone disc speed has an important influence on the filling process of virus-free potato minituber. According to the operating speed of the seeder in the field, the cone disc speed was obtained as 5, 6, 7, 8, and 9 r/min for simulation, and the results are listed in Table 5.

Table 5 Simulation results of different cone disc speed

Cone disc speed/r·min^{-1}	Leakage rate/%	Replay rate/%	Qualified rate/%
5	4.3	0.5	94.2
6	4.5	0.5	94.0
7	7.2	0.6	92.2
8	9.4	0.4	90.2
9	10.1	0.7	89.2

It can be seen from Table 5 that the leakage rate increases significantly with the increase of the cone disc speed, the qualified rate decreases, and the replay rate changes little. The change of virus-free potato minituber speed with time under different cone disc speed in EDEM is shown in Figure 15. When the cone disc speed is low, the velocity fluctuation of the virus-free potato minituber in the seed platter is small; when the cone disc speed is low is high, the velocity fluctuation of the virus-free potato minituber in the seed platter is increased, which leads to the increase of the leakage rate of the virus-free potato minituber. Although the cone disc speed is low, it can ensure a higher qualified rate of seeding, but in order to improve the working speed of the cone disc speed planter in the field and the uniformity of seeding spacing, the cone disc speed should be increased appropriately. In general, 6-8 r/min is the appropriate speed for cone turntable.

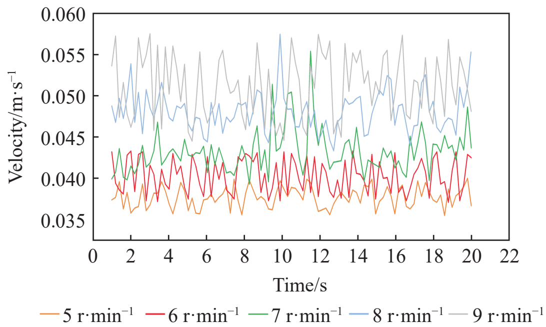


Figure 15 Curves of virus-free potato minituber speed versus time under different cone disc speed

3.6.3 Influence of cone disc angle selection on seeding performance

The cone disc angle has an important influence on the filling performance of virus-free potato minitubers. The cone disc angle affects the oblique force and then affects the seed filling force on the circumferential filling ring. Small cone disc angle will reduce the filling ability, and too large cone disc angle will cause a large number of virus-free potato minitubers to accumulate above the type hole. According to the rolling stability angle, repose angle, and physical characteristics of virus-free potato minituber, the cone disc angle was determined to be 15°, 20°, 25°, 30° and 35° for simulation, and the results are listed in Table 6.

Table 6 Simulation results of different cone disc angle

Cone disc angle/(°)	Leakage rate/%	Replay rate/%	Qualified rate/%
15	8.4	0.8	90.2
20	7.5	0.5	92.0
25	6.5	0.6	92.9
30	7.4	0.4	92.2
35	8.1	0.7	91.1

With the increase of cone disc angle, the leakage rate first decreases and then increases, and the replay rate is stable at about 0.6%. From Figure 16, it can be seen that the speed of virus-free potato minitubers with different cone disc angles fluctuates around 0.04 m/s, but the larger the cone disc angle, the virus-free potato minitubers accumulate above the type hole, resulting in the greater the fluctuation of virus-free potato minitubers speed, the instability of filling leads to the decrease of qualified rate and the increase of leakage rate. The smaller the cone disc angle, the smaller the filling

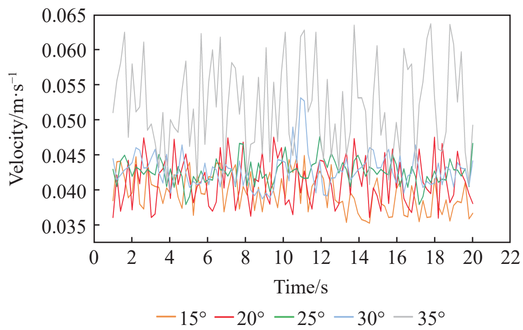


Figure 16 Curves of virus-free potato minituber velocity versus time under different cone disc angles

capacity of virus-free potato minitubers, but also increases the leakage rate. Therefore, it is more appropriate to choose the cone disc angle of 20°-30°.

3.7 Multi-factor simulation test and analysis

The working parameters of the optimal seed-metering device were determined, and the length of type hole L, the cone disc speed n, and the cone disc angle α of the conical turntable that had a great influence on the seed collection performance were selected as the test factors, and the leakage rate, replay rate, and qualified rate were the response indexes. According to the previous theoretical calculation and simulation analysis, the range of each factor is determined: the length of type hole L is 30-40 mm, the cone disc speed n is 6-8 r/min, and the cone disc angle α is 20°-30°. According to the Box-Benhnken central composite design theory, the experimental design is carried out. The experimental factors are encoded as listed in Table 7.

Table 7 Code of test factors

Code	Factor		
	Length oftype hole x_1 L/mm	Cone disc speed $x_2 n$/r·min^{-1}	Cone disc angle x_2 α/(°)
–1	30	6	20
0	35	7	25
1	40	8	30

3.7.1 Test Results and analysis

The experimental design and results are listed in Table 8, where, x_1, x_2, x_3 denote the encoding values of each factor.

3.7.2 Regression model establishment and significance test

Multiple regression fitting analysis was performed on the test results in Table 5 using Design-Expert 8.0.6.1 data analysis software to obtain the regression equation of Leakage rate y_1, Replay rate y_2, and qualified rate y_3.

$$y_1 = 4.6 + 1.39x_1 + 2.54x_2 - 1.03x_3 + 0.37x_1x_2 - 0.15x_1x_3 - 0.15x_2x_3 + 2.16x_1^2 + 1.86x_2^2 + 1.44x_3^2 \quad (7)$$

$$y_2 = 0.56 + 0.24x_1 - 0.075x_2 + 0.013x_3 - 0.075x_1x_2 - 0.05x_1x_3 + 0.075x_2x_3 + 0.095x_1^2 - 0.08x_2^2 - 0.055x_3^2 \quad (8)$$

$$y_3 = 94.84 - 1.62x_1 - 2.46x_2 + 1.01x_3 - 0.3x_1x_2 + 0.2x_1x_3 + 0.075x_2x_3 - 2.26x_1^2 - 1.78x_2^2 - 1.38x_3^2 \quad (9)$$

Table 8 Test design and results

No.	Factor			Response value		
	x_1	x_2	x_3	Leakage rate y_1/%	Replay rate y_2/%	Qualified rate y_3/%
1	–1	1	0	9.30	0.3	90.40
2	–1	0	–1	7.60	0.3	92.10
3	0	0	0	4.70	0.5	94.80
4	0	0	0	4.80	0.6	94.60
5	0	1	1	9.20	0.4	89.40
6	0	0	0	4.90	0.5	94.60
7	–1	–1	0	5.10	0.3	94.60
8	0	–1	–1	6.30	0.6	93.10
9	–1	0	1	6.10	0.5	93.40
10	1	0	–1	10.60	0.8	88.60
11	1	0	1	8.50	0.8	90.70
12	0	0	0	4.10	0.6	95.30
13	0	0	0	4.50	0.6	94.90
14	1	–1	0	7.20	1.0	91.80
15	0	–1	1	4.30	0.4	95.30
16	1	1	0	12.90	0.7	86.40
17	0	1	–1	11.80	0.3	87.90

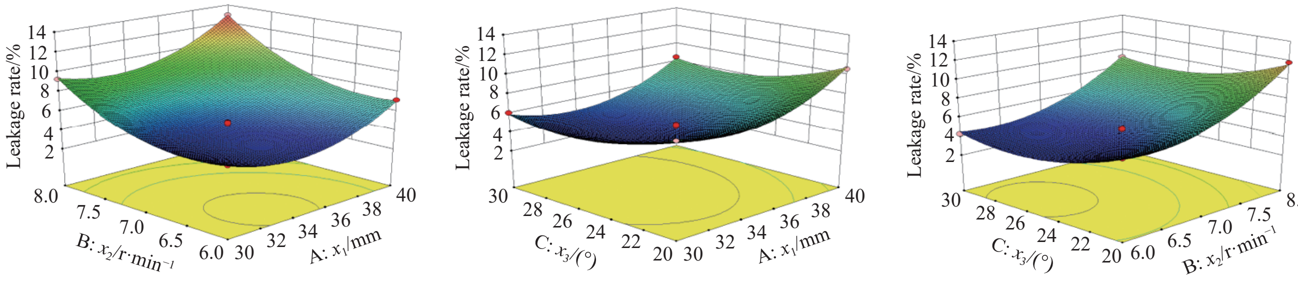
The analysis of Table 9 showed that the models of miss rate, reseed rate and qualified rate of virus-free potato minituber were all p<0.01, indicating that the regression models of leakage rate, replay rate, and qualified rate of virus-free potato minituber were highly indigenous. The missing items of the regression models are all p>0.05, the missing items are not obvious, and the fitting degree of the experiment is high. Through the p value, it can be obtained that the regression terms x_1, x_2, x_3 and x_1x_2, x_1^2, x_2^2, x_3^2 in the leakage rate model have extremely obvious influence on the model, and the primary and secondary order of the factors affecting the leakage rate is the length of type hole x_1, the cone disc speed x_2, and the cone disc angle x_3. The regression term x_1 in the replay rate model has a very significant influence on the model, and the regression terms x_2 and x_1^2 have a significant influence on the model, so the length of type hole is the main reason for affecting the replay rate. The regression items x_1, x_2, x_3 and x_1x_2, x_1^2, x_2^2, x_3^2 in the qualified rate model have significant influence on the model. The regression item x_2x_3 has significant influence on the model. The primary and secondary order of factors affecting the qualified rate is the length of type hole x_1, the cone disc speed x_2, and the cone disc angle x_3.

Table 9 Variance analysis of regression model

Source	Leakage rate				Replay rate				Qualified rate			
	Sum of squares	df	F-value	p-value	Sum of squares	df	F-value	p-value	Sum of squares	df	F-value	p-value
Model	123.93	9	169.85	<0.0001	0.63	9	14.13	0.001	126.04	9	158.24	<0.0001
x_1	15.40	1	189.97	<0.0001	0.45	1	91.56	<0.0001	21.12	1	238.70	<0.0001
x_2	51.51	1	635.38	<0.0001	0.045	1	9.13	0.0193	48.51	1	548.15	<0.0001
x_3	8.41	1	103.67	<0.0001	0.0125	1	0.25	0.63	8.20	1	92.67	<0.0001
x_1x_2	0.56	1	6.94	0.0337	0.023	1	4.57	0.07	0.36	1	4.07	0.0835
x_1x_3	0.09	1	1.11	0.3271	0.01	1	2.03	0.1973	0.16	1	1.81	0.2207
x_2x_3	0.09	1	1.11	0.3271	0.023	1	4.57	0.07	0.02	1	0.25	0.6296
x_1^2	19.69	1	242.87	<0.0001	0.038	1	7.71	0.0274	21.46	1	242.46	<0.0001
x_2^2	14.61	1	180.16	<0.0001	0.027	1	5.47	0.052	13.38	1	151.17	<0.0001
x_3^2	8.70	1	107.32	<0.0001	0.013	1	2.58	0.152	8.05	1	90.93	<0.0001
Residual	0.57	7			0.035	7			0.62	7		
Lack of fit	0.17	3	0.56	0.6701	0.023	3	2.5	0.1985	0.29	3	1.15	0.43
Error	0.40	4			0.012	4			0.33	4		
Total	124.5	16			0.66	16			126.66	16		

3.7.3 Effect of factors on leakage rate

The horizontal value of one of the three factors is set to zero, and the influence of the interaction of the other two factors on the leakage rate is analyzed. The response surface is shown in Figure 17.



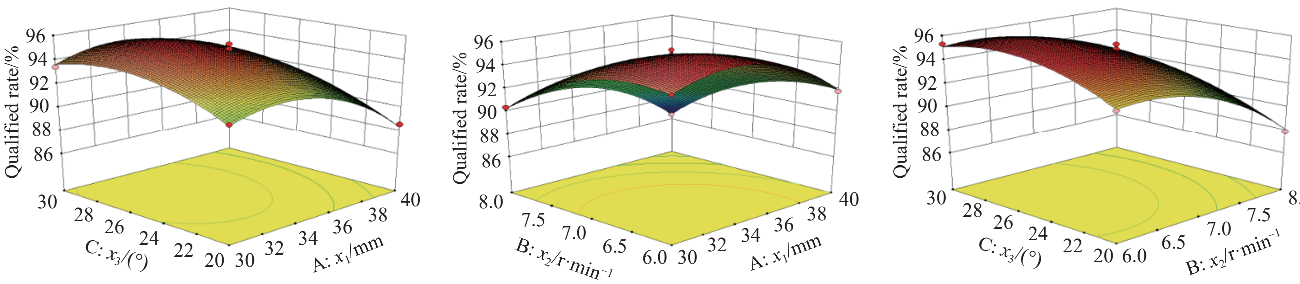
a. x_1 and x_2 b. x_1 and x_3 c. x_2 and x_3

Figure 17 Effects of various factors on leakage rate

Figure 17a shows the effect of the interaction between the length of type hole x_1 and the cone disc speed x_2 of the conical turntable on the leakage rate when the cone disc angle x_3 of the conical turntable is at the central level. When the length of type hole x_1 is fixed, with the decrease in cone disc speed x_2, the leakage rate gradually decreases and tends to be stable. When the cone disc speed x_2 is large, the time of the hole passing through the filling area is shortened, and the seed does not have enough filling time, resulting in a higher leakage rate. Figure 17 shows the effect of the interaction between the length of type hole x_1 and the cone disc angle x_3 of the conical turntable on the leakage rate when the cone disc speed x_2 is at the central level. When the cone disc angle x_3 of the conical turntable is constant, with the increase of the hole length x_1, the leakage rate decreases first and then increases. When the length of type hole x_1 is constant, with the increase of the cone disc angle x_3 of the conical turntable, the leakage rate decreases first and then increases. When the cone disc angle x_3 of the conical turntable is small, the oblique force of the conical turntable is small, and the ability of the flow direction type hole of the micro potato is weak, resulting in high leakage rate. When the cone disc angle x_3 of the conical turntable is large, the bevel force of the conical turntable is large, resulting in a large accumulation of virus-free potato minitubers in the type hole position, and the interference between virus-free potato minitubers, resulting in increased leakage rate. Figure 17c shows that when the length of type hole x_1 is at the central level, when the cone disc speed x_2 of the conical turntable is constant, with the increase of the cone disc angle x_3 of the conical turntable, the leakage rate decreases first and then increases. When the cone disc angle x_3 of the conical turntable is constant, with the decrease of the cone disc speed x_2 of the conical turntable, the leakage rate gradually decreases and tends to be stable.

3.7.4 Effect of factors on qualified rate

Figure 18a shows the effect of the interaction between the length of type hole x_1 and the cone disc speed x_2 of the conical turntable on the qualified rate when the cone disc angle x_3 of the conical turntable is at the central level. When the cone disc speed x_2 of the conical turntable is constant, the qualified rate increases first and then decreases with the increase length of type hole x_1. When the length of type hole x_1 is fixed, with the increase of the cone disc speed x_2, the qualified rate increases first and then decreases. Figure 18b shows the effect of the interaction between the length of type hole x_1 and the cone disc angle x_3 of the conical turntable on the qualified rate when the cone disc speed x_2 of the conical turntable is at the central level. When the cone disc angle x_3 of the conical turntable is constant, the qualified rate increases first and then decreases with the increase of the length of type hole x_1. When the length of type hole x_1 is fixed, with the increase of cone disc angle x_3, the qualified rate increases first and then decreases. Figure 18c shows that when the length of type hole x_1 is at the central level, when the cone disc speed x_2 of the conical turntable is constant, the qualified rate increases first and then decreases with the increase of the cone disc angle x_3. When the cone disc angle x_3 of the conical turntable is constant, the qualified rate increases first and then decreases with the increase of the cone disc speed x_2.



a. x_1 and x_2 b. x_1 and x_3 c. x_2 and x_3

Figure 18 Effects of various factors on qualified rate

3.7.5 Parameter optimization and experimental verification

Taking the maximum values of leakage rate y_1, replay rate y_2, and qualified rate y_3 as the objective function, and the length of the type hole x_1, the cone disc speed x_2 and cone disc angle x_3 of the conical turntable as the constraint conditions, a mathematical model for the working parameters planning of the conical diversion virus-free potato minituber precision seed-metering device was established.

$$\begin{cases} \min y_1 \\ \min y_2 \\ \max y_3 \\ -1 \leq x_1 \leq 1 \\ -1 \leq x_2 \leq 1 \\ -1 \leq x_3 \leq 1 \end{cases} \tag{10}$$

The software Design-Expert Optimization Numerical module is used to optimize the parameters. The optimal parameters are as follows: the length of the type hole x_1 is 33.61 mm, the cone disc speed x_2 is 6.35 r/min, and the cone disc angle x_3 is 26.59°. At this time, the leakage rate predicted by the model was 3.45%, the replay rate 0.49% and the qualified rate was 96.06%.

4 Seed-metering device test and result analysis

4.1 Test materials and equipment

The test equipment is a conical diversion virus-free potato minituber precision test bench with the structure as shown in Figure 19. It mainly includes bracket, conical turntable, type hole, seed cleaning device, baffle, driving motor, etc. Drive motor speed is continuously adjustable at 0-30 r/min.

1. Type hole 2. Baffle 3. Seed outlet 4. Conical turntable 5. Transmission shaft 6. Outer baffle of seed-metering device 7. Seed cleaning device

Figure 19 Conical diversion virus-free potato minituber precision test bench

4.2 Test method

The test methods refer to the test methods and indexes specified in GB/6242-2006 potato planting machine test method and NY/T990-2006 potato planting machine operation quality. Performance evaluation indexes include leakage rate, replay rate, and qualified rate. The sum of the leakage rate, replay rate, and qualified rate is 100%. Therefore, leakage rate y_1, replay rate y_2, and qualified rate y_3 are the evaluation indexes. The data on leakage rate, replay rate, and qualified rate are obtained through the test process. During the stable seeding stage of seed-metering device, the seeding effect of 300 virus-free potato minitubers was continuously measured as a group of tests. A total of 5 groups of tests were carried out, each group of tests was repeated 3 times, and the average value of each group of tests was taken.

4.3 Test results and analysis

In order to verify the accuracy of the optimization results, the working parameters were set as follows: the length of the type hole x_1 was 34.0 mm, the cone disc speed x_2 was 6.5 r/min, and the cone disc angle x_3 was 27.0°. The test results are listed in Table 10.

Table 10 Seed-metering device seeding test

No.	Leakage rate y_1/%	Replay rate y_2/%	Qualified/ rate y_3/%
1	3.7	0.9	95.4
2	3.9	0.8	95.3
3	3.8	0.8	95.4
4	3.7	0.8	95.5
5	3.9	0.7	95.4
Average	3.8	0.8	95.4

The test results showed that the leakage rate was 3.80%, the replay rate 0.80% and the qualified rate was 95.40%. The experimental value is very close to the theoretical optimization value, and the regression model is reliable.

4.4 Discussion

The research object of this paper is the virus-free potato minituber without strict screening and grading, and the structural parameters of seed-metering device are designed by statistical calculation theory. Due to the large variation coefficient of virus-free potato minituber size, the compromise scheme was adopted to meet the successful seed selection rate of all virus-free potato minituber, so the leakage was high. There is a small amount of virus-free potato minituber volume is small, which will lead to the occurrence of reseeding phenomenon. If virus-free potato minitubers were screened and graded before sowing, and conical turntables with different structural parameters were used for different grades of micro-tubers, the qualified rate of sowing would be further improved. Conical turntables with different structural parameters are also suitable for other large seeds.

5 Conclusions

1) In order to realize the precision sowing of virus-free potato minituber, a conical diversion virus-free potato minituber precision seed-metering device was designed, and the parameter design and theoretical analysis were completed. Single seed collection was carried out by using the type hole filling at the edge of conical turntable and the seed clearing device.

2) The force analysis of the virus-free potato minituber with seed filling, seed cleaning, and seed seeding was carried out, and the seed metering principle of the cone conical single-row filling virus-free potato minituber precision seed-metering device was expounded. The EDEM discrete element simulation analysis was used to compare the structure shapes of different length of the type holes, and the optimal structure of the length of the type hole was determined. The single factor test and analysis were carried out to analyze the energy change law of virus-free potato minituber during filling.

3) The Box-Benhnken central composite method was used to carry out the three-factor and three-level regression orthogonal test, and the multiple regression models of leakage rate, replay rate, and qualified rate were established respectively. With the leakage rate, replay rate, and qualified rate as the objectives, the parameters of each influencing factor were optimized. The optimal parameter combination is as follows: the length of the type hole is 34.0 mm, the cone disc speed is 6.5 r/min, and the cone disc angle is 27.0°. The bench test is carried out under the optimal parameter combination. At this time, the leakage rate is 3.80%, the replay rate 0.80% and the qualified rate is 95.40%, which is consistent with the model prediction results. To meet the requirements of virus-free potato minituber sowing operation.

Acknowledgements

This work was financially supported by the National Key Research and Development China Project (Grant No. 2022YFD2001205), the Henan Province Higher Education Reform Research and Practice Project (Grant No. 2021SJGLX138Y), and the University Scientific Innovation Team Projects of Henan Province (Grant No. 23IRTSTHN015).

[References]

[1] Hassanpanah D, Azimi J. Mini-tuber production potential of potato cultivars in repeated and conventional harvesting under in vivo condition. Journal of Food Agriculture and Environment, 2011; 9(1): 398–403.

[2] Lü J Q, Zhu M F, Zhu X X, Li J C, Su W H, Liu Z Y. Optimal design and experiment of integrated fan of air suction potato planter. Transactions of

the CSAM, 2022; 53(3): 80–90. (in Chinese)

[3] Lai Q H, Ma W P, Su W, Hu Z W, Xing J L. Design and experiment of pneumatic disc seed-metering device for mini-tuber. Transactions of the CSAM, 2016; 47(12): 30–37. (in Chinese)

[4] LI Z H, Wen X Y, Lü J Q, Li J C, Yi S J, Qiao D. Analysis and prospect of research progress on key technologies and equipment of mechanization of potato planting. Transactions of the CSAM, 2019; 50(3): 1–16. (in Chinese)

[5] Mcleod C D, Misener G C, Tai G C C, Caissie R. A precision seeding device for true potato seed. American Potato Journal, 1992; 69(4): 255–264.

[6] Lü J Q, Yang Y, Li Z H, Shang Q Q, Li J C, Liu Z Y. Design and experiment of an air-suction potato seed metering device. Int J Agric & Biol Eng, 2016; 9(5): 33–42.

[7] Lai Q H, Ma W P, Liu S, Su Wei, Zhang Z H. Simulation and experiment on seed-filling performance of pneumatic disc seed-metering device for mini-tuber. Transactions of the CSAM, 2017; 48(5): 44–53. (in Chinese)

[8] Wang F H, Sun K, Lai Q H, Dong J Y, Su W, Yu Q X. Design and experiment of minituber precision single-row air-suction planter. Transactions of the CSAM, 2020; 51(1): 66–76. (in Chinese)

[9] Lü J Q, Yang Y, Shang Q Q, Li Z H, Li J C, Liu Z Y, Wang Y B. Performance optimization test on air-suction potato seed metering device with positive pressure airflow and zero-speed seeding. Transactions of the CSAE, 2016; 32(20): 40–48. (in Chinese)

[10] Lü J Q, Yi S J, Tao G X, Mao X. Design and experiment of precision air-suction type planter for potato. Transactions of the CSAE, 2018; 34(10): 16–24. (in Chinese)

[11] Zhang W Z, Liu C L, Lü Z Q, Lü H Y, Hou J L. Optimized design and experiment on novel combination vacuum and spoon belt metering device for potato planters. Mathematical Problems in Engineering. 2020, Article ID 1504642. doi: 10.1155/2020/1504642.

[12] Lü J Q, Yang Y, Li Z H, Tian Z E, Shang Q Q, Wu J E. Design and experiment of cup-belt type potato seed-metering device. Transactions of the CSAE, 2016; 32(16): 17–25. (in Chinese)

[13] Liu W Z, He J, Li H W, Li X Q, Wei Z C, Liu P. Design and experiment of vibration-arranging based seeder for potato micro-seed. Transactions of the CSAM, 2019; 50(8): 70–80. (in Chinese)

[14] Yang W C, Kan C L, Zhang X W, Wu C, Du Q, Pan W J. Design and test of precision seed metering device for Panax notoginseng seedling and seeding by air suction. Transactions of the CSAM, 2021; 52(6): 95–105. (in Chinese)

[15] Hou J L, Liu W, Zhang W Z, Lü J Q, Lü Z Q, Zhang Z L. Design of precision pneumatic cup seed-metering device for potato. Transactions of the CSAE, 2018; 34(24): 18–28. (in Chinese)

[16] Zhang K X, Li J F, Song Z H, Liu X X, Liu L. Optimum design and test of variable diameter double disc air suction precision seeder. Transactions of the CSAM, 2019; 50(6): 52–63. (in Chinese)

[17] Liu K, Yi S J. Design and experiment of seeding performance monitoring system for suction corn planter. Int J Agric & Biol Eng, 2019; 12(4): 97–103.

[18] Wang G P, Sun W, Chen L D, Zhang H, Liu X L, Li H L, et al. Realization of an integrated seeding and compensating potato planter based on one-way clutch. Int J Agric & Biol Eng, 2020; 13(3): 79–87.

[19] Zhan Z, Jin M Z, Tian C J, Fang Q. Simulation and experiment on prediction of total rice seeds mass in vibrating tray for vacuum plate seeder. Int J Agric & Biol Eng, 2019; 12(5): 81–86.

[20] Jin X, Li Q W, Zhao K X, Zhao B, He Z T, Qiu Z M. Development and test of an electric precision seeder for small-size vegetable seeds. Int J Agric & Biol Eng, 2019; 12(2): 75–81.

[21] Kang J M, Peng Q J, Zhang C Y, Zhang N N, Fang H M. Design and testing of a punching-on-film precision hole seeder for peanuts. Transactions of the ASABE, 2020; 63(6): 1685–1696.

[22] Cho Y J, Choi I S, Dong K J, Oh J, Hoon L D. Performance test of fully automatic potato seeding machine by in-situ process of cutting seeds. Journal of Biosystems Engineering, 2017; 42(3): 147–154.

[23] Shi S, Zhang D X, Yang L, Cui T, Li K H, Yin X W. Simulation and verification of seed-filling performance of pneumatic-combined holes maize precision seed-metering device based on EDEM. Transactions of the CSAE, 2015; 31(3): 62–69. (in Chinese)

[24] Wang L J, Li R, Wu B X, Wu Z C, Ding Z J. Determination of the coefficient of rolling friction of an irregularly shaped maize particle group using physical experiment and simulations. Particuology, 2018; 38: 185–195.

[25] Liu H X, Guo L F, Fu L L, Tang S F. Study on multi-size seed-metering device for vertical plate soybean precision planter. Int J Agric & Biol Eng, 2015; 8(1): 1–8.

[26] Cheng X P, Li H W, He J, Wang Q J, Lu C Y, Wang Y B, et al. Optimization of operating parameters of seeding device in plot drill with seeding control system. Int J Agric & Biol Eng, 2021; 14(3): 83–91.

[27] Zhang K F, Zhang Z, Wang S, Yang C, Yu Y C, Li H. Design and experiment of electronic seeding system based on response surface method. International Journal of Computer Integrated Manufacturing, 2020; 33(10-11): 982–990.