OPTIMAL DESIGN OF EJECTOR BELT SEEDLING COLLECTING MECHANISM BASED ON EDEM

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基于 EDEM 的顶杆输送带式取苗机构优化设计

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ABSTRACT

In the seedling extraction mechanism of the ejection type, because the ejector rod is in direct contact with the seedling substrate, the fragmentation rate of the seedling is high, the success rate is low, and the seedling effect is poor. In order to solve this problem, combined with the interaction between the ejector rod and the bowl seedling, this paper analyzes the working principle of the ejector rod conveyor belt seedling harvesting mechanism, and optimizes the design of the ejector rod conveyor belt seedling harvesting mechanism. By using the method of EDEM simulation analysis and orthogonal experiment, taking the breaking rate and success rate of bowl seedling as the test response index, the effects of ejector rod end form, ejector rod diameter and seedling extraction speed were studied, and the results were analyzed by range analysis and variance analysis to analyze the influence law of the interaction of various factors on bowl seedling extraction. The simulation results show that the crushing rate of bowl seedlings increases with the increase of seedling speed and the decrease of ejector diameter. Among the three different types of ejectors, the effect of round head ejector is the best. The best parameter combination of the seedling mechanism is the diameter of the ejector rod 10mm, the seedling speed 2m/s, and the ejector rod in the form of round head ejector rod. The verification experiment shows that the seedling extraction effect of the optimized seedling extraction mechanism is better than that of the original seedling extraction mechanism. The results show that when the best combination of working parameters is used to collect seedlings, the qualified rate of seedlings is not less than 90%, the fragmentation rate is not higher than 20%, and the seedling performance is relatively stable. The optimized seedling extraction mechanism can be used in the automatic dryland bowl seedling transplanter to meet the operational requirements of the automatic transplanter.

摘 要

在顶出式取苗机构中，由于顶杆与钵苗基质直接接触，钵苗破碎率高，成功率低，育苗效果差。为解决这一问题，结合顶杆与钵苗的相互作用，分析了顶杆输送带取苗机构的工作原理，并对顶杆输送带取苗机构进行了优化设计。采用 EDEM 模拟分析和正交试验的方法，以钵苗基质破碎率和取苗成功率为试验响应指标，研究了顶杆端部形状、顶杆直径和取苗速度对取苗效果的影响，并对结果进行极差分析和方差分析，分析各因素交互作用对取苗效果的影响规律。模拟结果表明，钵苗破碎率随取苗速度的提高和顶杆直径的减小而增大。在三种不同类型的顶杆中，球头顶杆的效果最好。取苗机构的最佳参数组合为顶杆直径 10 mm，取苗速度 2m/s，顶杆形式为球头顶杆。验证实验表明，优化后的取苗机构取苗效果好于原取苗机构。结果表明，采用最佳工作参数组合取苗，取苗合格率不低于 90%，破碎率不高于 20%，取苗表现相对稳定。优化后的取苗机构可用于旱地钵苗自动移栽机，满足自动移栽机的作业要求。

INTRODUCTION

Vegetables are an indispensable food for people's daily life. According to the statistics of the National Bureau of Statistics, the national vegetable output was 770 million tons in 2021. At present, the process of urbanization in China is accelerating, and there is a shortage of labor force in agricultural production *(Liu et al., 2022)*, which has a certain impact on agricultural production and life. In order to adapt to the development of modern agricultural production, there is an urgent need to upgrade and transform the existing transplanting technology.

The technology of automatic seedling collection in hole plate is the core part of the automatic transplanting technology of vegetable seedling in hole tray. The quality of seedling collection has a direct impact on the success rate of transplanting pot seedlings *(Wang et al., 2016; Wen et al., 2021; Hu, 2021)*. At present, the main model in the market is the semi-automatic bowl seedling transplanter, which still uses manual seedling collection, which has the advantages of low working efficiency and high labor cost. The semi-automatic transplanter uses manual seedling collection, and then sends the seedling into the planting mechanism for planting, which is the most widely used and the largest existing transplanter type *(Lv, et al. 2017)*. At present, the automatic seedling extraction technology is mainly divided into two types: the clamping type and the ejection type. The pinch type seedling extraction mechanism works stably, but the mechanism is more complex, and the structure of the ejection type seedling extraction mechanism is simple, but if the working parameters are not selected properly, it is easy to penetrate the bowl seedling and the deviation rate of falling seedling position is large. Therefore, for the top-out seedling extraction device, it is necessary to optimize the working parameters of the seedling extraction device to improve the success rate and reduce the loss of bowl seedlings in the process of seedling extraction.

At present, there are many types of dryland transplanters in China, but most of them use foreign machines for reference, and the situation at home and abroad is quite different. Foreign transplanting machines are not matched with the situation of our country, and the cost is high *(Wen et al., 2020; Yu et al., 2014; Choi et al., 2016; Karayel, D., 2023; Porteus, Sc.,1988; Kornecki, TS., 2022)*. Many scholars at home and abroad have applied discrete element simulation technology to the field of agricultural machinery *(Wang et al., 2022; Zhang et al., 2022; Yan et al., 2022; Yu et al., 2020; Liu et al., 2022; Zhou et al., 2022; Feng et al., 2016)*, which has greatly reduced the cost of research and development. Wen Yongshuang *(Ren et al., 2011)* designed a kind of plug-in type seedling extraction device, analyzed the force of the ejection process of the bowl seedling from the seedling plate, and the kinematics analysis of the motion process after the bowl seedling was thrown out. The influence factors of the bowl seedling rolling were obtained, and the force analysis and parameter optimization were carried out on the plate feeding mechanism and seedling picking mechanism of the structure.

Feng Tianxiang *(Yao et al., 2019)* and others designed the existing transplanting claws, measured the physical and mechanical property parameters of Anthurium andraeanum seedling substrate through matrix mechanical test and physical test, used different oblique insertion methods to clamp seedlings, and compared the seedling clamping effect. Combined with discrete element method, the model was established by EDEM software, and the damage of steel needle to substrate was simulated. The damage of matrix with different insertion angle, depth and position of insertion point is analyzed, and the experimental verification is carried out. At present, China's transplanting machinery has developed some transplanting equipment, mainly semi-automatic vegetable seedling transplanter, but its seedling extraction link is still completed manually, which cannot really solve the problems of high labor cost and high labor intensity. The automatic seedling collecting device of transplanter is the key to solve the above problems.

In order to further improve the working performance of the automatic seedling harvesting mechanism, this paper first measured the basic physical parameters of the seedling and analyzed the movement of the seedling in the process of seedling extraction. Secondly, the EDEM simulation analysis is used to analyze the seedling extraction mechanism with different structure, different seedling speed and different ejector diameter, and the optimal working parameters are determined. Finally, the optimal working parameters of the seedling harvesting mechanism are verified by bench test. In this study, aiming at the top-out seedling harvesting mechanism, the working performance of the seedling harvesting mechanism can be improved through the optimization analysis of modern simulation technology.

MATERIALS AND METHODS

Determination of basic parameters

- **Determination of moisture content of potted seedlings**

The bowl seedling matrix is similar to the soil, the moisture content is different, and the physical properties are quite different. Soil shows bonding characteristics due to the interaction of ion molecules and water film, which is an important factor of soil strength *(Zhang et al., 2008)*.

Because it is necessary to overcome the friction and adhesion between the acupoint plate and the seedling, the friction force is related to the material of the burrow plate and the physical characteristics of the seedling matrix, and the adhesion force is mainly related to the type of substrate, texture, water content and soil surface state, and varies greatly with the moisture content.

According to the relevant literature, in a certain range, the higher the moisture content of the matrix is, the greater the bonding force between the disk and the matrix is, and the subsequent simulation parameters need to select the bonding radius of the particles according to the moisture content of the seedling matrix. Therefore, the moisture content of the bowl seedling matrix was measured before the forward compression test to ensure the consistency of the moisture content.

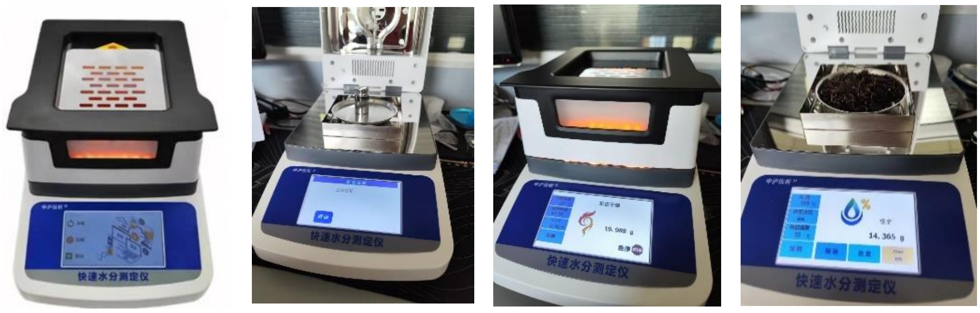


Fig. 1 - Rapid moisture meter

First of all, the weight calibration and preheating of the rapid moisture measuring instrument are carried out. Put the weight, tray and triangle bracket on the measuring instrument to calibrate the standard weight. Select the automatic mode, set the heating time to 30 minutes, and preheat the rapid moisture meter. In order to improve the testing accuracy of moisture content and shorten the drying time, the seedling matrix was mashed and laid flat on the tray as far as possible. Set the drying temperature and choose the end mode automatically. The measurement results are shown in Table 1.

a) *b)*

Fig. 2 - Seedling matrix granule

a) Before drying *b) After drying*

Table 1

Measurement results of moisture meter

Parameter	drying temperature (℃)	standby temperature (℃)	initial weight (g)	Drying weight (g)	drying time	water loss (%)	drying rate (%)	wet weight (%)	moisture regain (%)
Numerical value	105	56	14.355	4.036	48min32s	71.88	28.12	355.67	255.67

Analysis of ejection time and conveyor belt speed of seedling

The seedling collecting mechanism is composed of synchronous belt pulley, bottom plate, customized synchronous belt, guide rod, seedling guide plate side plate, seedling top rod, horizontal conveyor belt, seedling guide bucket, etc., which is installed at the back of the transplanter through the frame, as shown in Fig 3. The custom conveyor belt is fixed on the frame through the synchronous belt pulley, and the guide rod is fixed on the base plate, which is used to fix the synchronous belt pulley. The seedling ejector rod is located on the back of the base plate, and the seedlings in the hole plate are taken out. The point plate is placed through the limit block on the custom synchronous belt, the side plate is fixed on both sides of the frame by screws, and the horizontal conveyor belt is fixed under the base plate. It is used to send the removed seedlings to the seedling guide bucket.

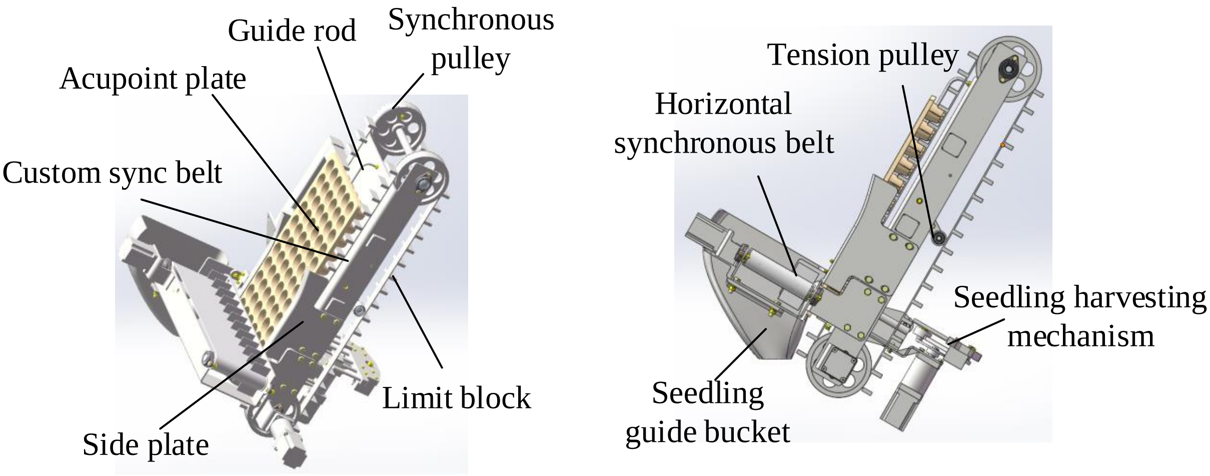


Fig. 3 - Overall structure of transplanter
a) Transplanting machine axonometric map b) transplanting machine side view

- **Establishment of Model of Seedling Mechanism**

In the process of ejecting the seedling from the seedling plate by the ejector rod, the matrix of the seedling will be broken to a certain extent under the action of ejection force. Because there are many kinds of particles in the matrix and the structure is complex, it is difficult to obtain various crushing parameters of the bowl seedling, so the discrete element analysis software is used to simulate and analyze the ejection process of the bowl seedling, which provides the basis for the parameter optimization of the ejection process.

When the seedling is ejected by the ejector rod, the force and breaking rate of the seedling will be affected due to the difference of the structure, ejection speed and diameter of the ejector rod. In this study, three kinds of ejector rod structures are designed, namely, flat head ejector rod, round head ejector rod and cone head ejector rod. The specific structure is shown in Fig 4.

The process of ejecting the bowl seedling from the seedling plate by the ejector rod was simulated, and through the comparison of the number of connecting bonds between the bowl seedling particles before and after the ejector rod ejection, the fragmentation rate and stress condition of the bowl seedling were obtained. Thus, the end structure, ejection speed and diameter of the ejector rod are selected and determined.

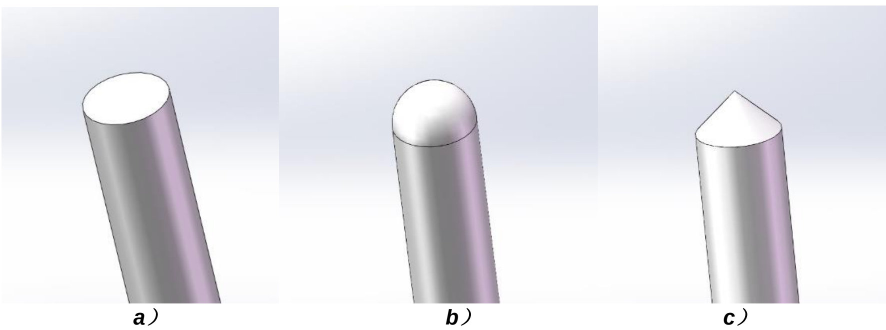


Fig. 4 - Ejector rods with different end types
a) Flat head ejector rod; b) Round head ejector rod; c) Conical ejector rod

- **Test factors and indicators**

Ejector rod diameter: the diameter of the ejector rod is too small, which will lead to penetration in the ejection process, damage the seedling matrix, cause the seedling adhesion to fall off smoothly at the end of the ejector rod, and the ejector rod diameter is too large, so that the ejector rod cannot smoothly pass through the drainage hole at the bottom of the hole plate. Easy to rub with the drainage hole. Therefore, the diameter of the ejector rod plays a key role in the success rate of seedling extraction.

The shape of the jacking rod: the overall shape of the bowl seedling is round table, and the flat head jacking rod form can basically meet the requirements of taking seed-lings, but the simulation shows that the force of the bowl seedling is mainly concentrated in the edge part of the ejector rod, relative to the bottom center position. The root effect of the edge position is poor, the breaking rate is high, and the stress state is un-reasonable, so the end form of the ejector rod is optimized, and different end structures are selected for ejection test.

Ejection speed: the seedling extraction mechanism is the ejector rod conveying belt type, and the ejection process of the bowl seedling from the point plate is a collision process, the ejection speed is too large, and the collision between the ejector rod and the bowl seedling is intensified, which can easily lead to a high fragmentation rate of the bowl seedling and serious damage to the bowl seedling; the ejection speed is too small, so that the initial speed of the bowl seedling is not enough, which cannot be thrown to the ideal position, resulting in the waste of the bowl seedling.

Based on the above analysis, the diameter, end form and ejection speed of the ejector rod in the seedling harvesting mechanism were tested. According to the leaf growth and root condition of pepper, the seedling age was selected as 33 days. The level of moisture content will affect the adhesion between the pot and the bowl seedling and the position of the center of gravity, too low moisture content will lead to the survival rate of the bowl seedling substrate is low, too high will lead to the reduction of the compressive capacity of the bowl seedling, and it is difficult to maintain the original shape, so the bowl seedling with 40% moisture content is selected.

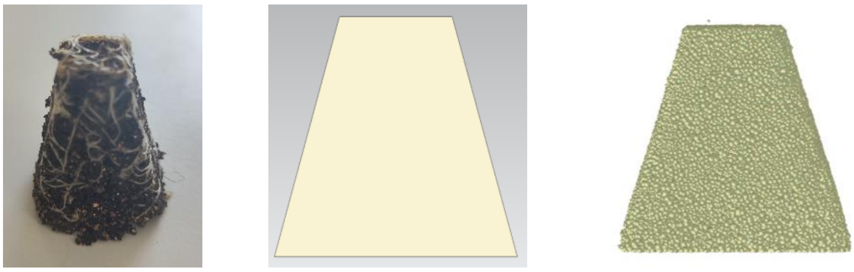
According to the overall performance of the seedling extraction device, the pepper seedling was taken as the seedling object, the ejection speed, diameter and structure of the ejector rod as the influencing factors, and the qualified rate of the seedling was taken. The orthogonal experiment of three factors, three levels and two indexes were carried out to explore the effects of different parameters and structural combinations of the ejector rod on the seedling harvesting effect. The factor level table is shown in Table 2.

Table 2

Level table of test factors

level	Factors		
	Ejector rod diameter /mm	Ejector rod speed /m/s	Ejector rod end form
1	6	1.5	Plane type
2	8	2	Cone type
3	10	2.5	Arc type

- **Establishment of discrete element simulation model of bowl seedling**



a) b) c)

Fig. 5 - Rapid moisture meter

a) The physical picture b) Three-dimensional map c) Potted seedling granule bond diagram.

First of all, we need to establish the geometric model of the seedling plate and the geometric model of the ejector rod. Model the seedling plate and ejector rod by SolidWorks, then save the model in x_t format and import it into EDEM. The Poisson's ratio, shear modulus and density of ejector rod and seedling plate are set, and with reference to the previous literature, the static friction coefficient, rolling friction coefficient and collision recovery coefficient between geometry and particles are set.

In order to carry out the discrete element simulation of the bowl seedling ejection process, it is necessary to model the particles that make up the bowl seedling matrix, as shown in Fig 5, which is followed by the physical map of the bowl seedling matrix, the 3D diagram and the particle bonding diagram from left to right. The main materials of the existing matrix are peat, perlite and vermiculite at the proportion of 3:1:1. According to the relevant literature *(Pan, 2019)* and particle test, the basic structure of peat particles is mainly massive particles, nuclear particles and columnar particles, the main structure of perlite is spherical particles, and the main structure of vermiculite is flake particles.

Table 3

Simulation parameter

Parameters	Numerical value
Matrix density (kg·m^{-3})	790
Matrix shear modulus (Pa)	1.59×10^6
Matrix Poisson's ratio	0.25
Density of ejector rod and hole plate (kg·m^{-3})	1380
Shear modulus of ejector rod and hole plate (Pa)	1.28×10^8
Poisson's ratio of ejector rod to hole plate	0.35
Static friction coefficient	0.40
Rolling friction coefficient	0.44
Collision recovery coefficient	0.27

To carry out the generation of matrix particles, we should set up a particle factory, adjust the size and position of the generated particles, and set it to virtual, the generation speed is set to 10000 per second, the generation position is randomly generated, and the initial velocity is generated in the direction of -z. The purpose of setting the initial velocity is to make the soil particles move downward and prevent the formation of accumulation too fast. In the solver, the time integral is set to Euler, and the total simulation time is 3s. When the bowl seedling is ejected from the seedling plate by the ejector, the bowl seedling is subjected to gravity, the ejection force of the ejector rod to the bowl seedling, the adhesion between the seedling plate and the bowl body, and the supporting force of the seedling plate to the bowl seedling.

Because of the adhesion between soil particles, the contact model between soil particles is Hertz-Mindlin with bonding model, and the bonding parameters are shown in Table 4.

The best parameters obtained in the previous calibration are used to bond the particles. The bonding start time is set to 0.5s, and the total bonding time lasts about 0.2s. In the setting of the simulation environment, all models are subject to gravity, and the displayed area is set to the area where the model exists, and a large space should be left above the model to show the damage and bonding after the seedling is ejected.

Table 4

Bonding bond parameters

Parameters	Numerical value
Normal stiffness per unit area (N/m^3)	2.6×10^6
Shear stiffness per unit area (N/m^3)	2.6×10^6
Critical normal stress (Pa)	710000
Critical shear stress (Pa)	710000
Bonded disk radius (m)	0.001

Bench test method

In order to test the seedling harvesting mechanism and verify the simulation experiment, and to test the influence of three types of ejector on the seedling harvesting mechanism, the seedling extraction experiment was carried out in the State key Laboratory of soil Plant Machinery system of Chinese Academy of Agricultural Mechanization on December 10, 2022. The experimental seedlings were pepper seedlings, and the pepper burrow plates with seedling age of 35 days were used for the experiment. The experimental seedlings were cultivated in Beijing Zhongnong Futong Horticultural Co., Ltd., the seedling substrate was imported substrate, the proportion of peat, perlite and vermiculite was 3:1:1, and the experimental seedlings grew evenly.

In the control system of the seedling collecting mechanism, the experiment is carried out with the optimal working parameters. The stm32f407 chip is used as the main controller and the stepper motor is used as the driving part. After the seedlings were evenly watered, they were placed in a cool and ventilated place, and the moisture content of the bowl was measured with a moisture meter. When the moisture content of the bowl was reduced to 40%, the seedling extraction test was carried out. When picking up the seedlings, the links such as sending the plate, collecting the seedlings and sending the seedlings were completed successively. After the completion of each group of experiments, they were repeated five times and the experimental data were counted.

RESULTS

Determination of substrate ratio of bowl and seedling

a) *b)*

Fig. 6 - Screening of substrate by soil sieve

a) Soil sieves with different grids; b) 10g Matrix sample

By consulting the data, it was found that the main components of the seedling matrix were peat, perlite and vermiculite at the ratio of 3:1:1 *(Gao et al., 2017)*. In order to simulate the real composition of pot seedlings and provide data support for follow-up simulation, the particle size composition of bowl seedlings was screened by new standard soil sieve. Because the substrate of the bowl seedling is soft and contains a certain amount of water, in order to facilitate the screening of the substrate by the soil sieve, the substrate of the bowl seedling is crushed and dried in the sun, and then the substrate of the pot seedling is screened by using soil sieves with different meshes (as shown in Fig 7), and the distribution of the substrate in each screen is obtained. 10.02g matrix is selected to weigh on the electronic scale, and the particle size distribution is shown in Table 5.

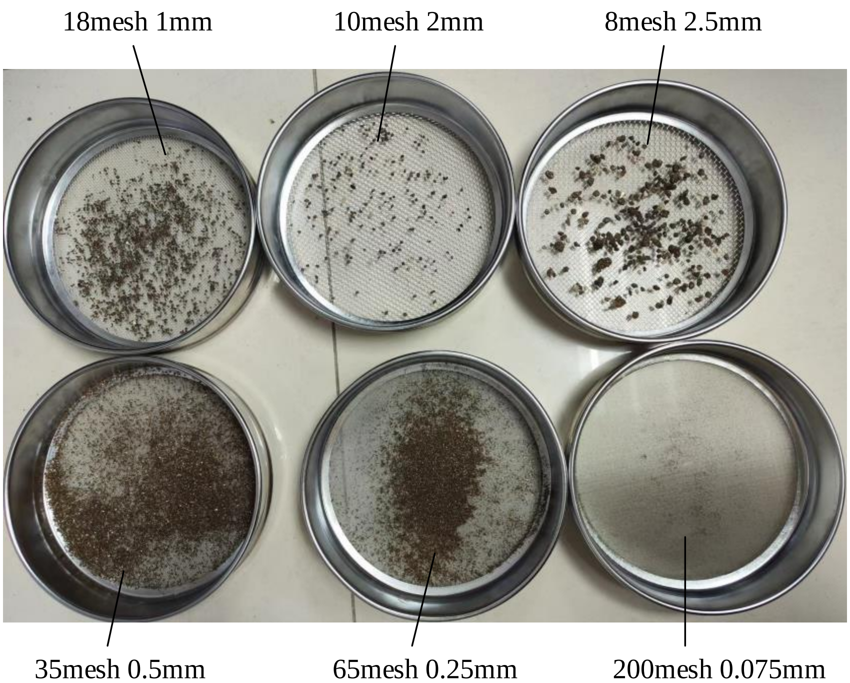


Fig. 7 - Screening results

From Table 5, it can be seen that the matrix particle size is mainly distributed between 0.25mm - 1.0mm.

Particle size distribution of matrix **Table 5**

Aperture size [mm]	Particle mass [g]	Mass proportion [%]
2.5	2.62	0.262
2	0.50	0.050
1	2.16	0.216
0.5	3.41	0.341
0.25	1.29	0.129
0.075	0.02	0.002

Simulation result

When the particle bonding is completed, the number of connection bonds between the particles can be obtained through the bonds module in the data browser of the software itself. After the bowl seedling is ejected from the bowl seedling plate, the number of connection bonds between the particles is recorded again. The ratio of the number of connection bonds reduced after ejection to the number of connection bonds between the particles before ejection is the breaking rate of the bowl seedling. According to the flight track after taking out the seedling and the distance between the center of gravity of the seedling and the hole plate, the qualified rate of the seedling is determined. The simulation is shown in Fig 8. Each group of simulation is repeated five times, taking the average value, and the experimental results are shown in Table 6.

In the simulation, the method for calculating the qualified rate of seedlings n_1 is as follows：

$$n_1 = \frac{a}{A} \times 100\% \tag{1}$$

a is total number of connection keys after ejection, A is total number of connection keys before ejection.

The crushing rate n_2 is calculated as follows：

$$n_2 = \frac{b}{B} \times 100\% \tag{2}$$

b is the number of seedlings ejected in a specified range, B is the total number of seedlings ejected from the bowl.

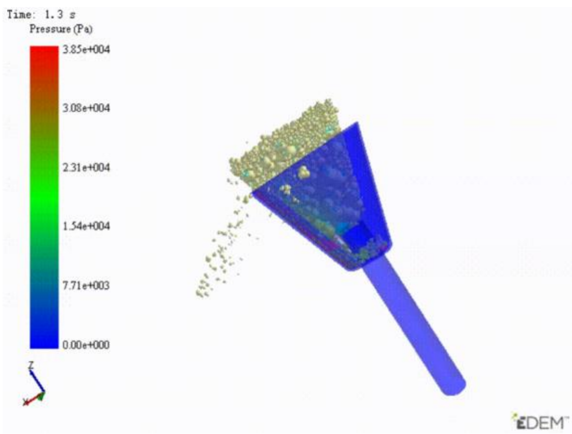


Fig. 8 - Seedling ejection process

Table 6

Simulation Scheme and results of orthogonal experiment of Seedling Mechanism

Serial number	Ejector rod diameter (mm)	Ejector rod form	Ejector rod speed (m/s)	Breakage rate n1 (%)	Qualified rate of seedling n2 (%)
1	6	Plane type	1.5	16.5	88.3
2	6	Cone type	2	20.2	94.5
3	6	Arc type	2.5	22.1	89.6

Table 6
(continuation)

Serial number	Ejector rod diameter (mm)	Ejector rod form	Ejector rod speed (m/s)	Breakage rate n1 (%)	Qualified rate of seedling n2 (%)
4	8	Plane type	2	14.8	95.3
5	8	Cone type	2.5	18.6	91.2
6	8	Arc type	1.5	16.3	89.3
7	10	Plane type	2.5	12.3	93.2
8	10	Cone type	1.5	13.6	87.5
9	10	Arc type	2	10.3	96.4

Range analysis and variance analysis were used to analyze the experimental results. The results were shown in Table 7 and Table 8. The range of fragmentation rate and qualified rate of seedling collection were R_1 and R_2, respectively. As can be seen from Table 7, for crushing rate $R_{1A} > R_{1C} > R_{1B}$, the primary and secondary factors of crushing rate are A, C, B, the optimal scheme of crushing rate is $A_1B_2C_3$, the qualified rate of seedling is $R_{2A} > R_{2C} > R_{2B}$, the factor of qualified rate of seedling is A, C, B, and the optimal scheme of qualified rate of seedling is $A_3B_3C_2$.

Table 7

Range analysis

Index	Factors	K1	K2	K3	Extreme difference R	Optimal scheme
n1	A	19.60	14.50	15.40	7.50	A1
	B	16.56	17.46	15.10	2.90	B2
	C	12.06	16.23	17.66	2.50	C3
	Primary and secondary				A>B>C	
n2	A	90.80	92.26	88.36	1.60	A2
	B	91.93	91.07	95.40	1.20	B3
	C	92.36	91.76	91.33	7.00	C1
	Primary and secondary				C>A>B	

The three optimization schemes are not exactly the same. The better parameters are selected by using the basic principle of comprehensive balance method, and each factor is analyzed.

The diameter of ejector rod A: for the crushing rate, the range of A is the largest, so A is the biggest factor affecting the crushing rate, A1 is the best for the crushing rate, A3 is the best for the seedling qualified rate, and A3 is the best for the comprehensive effect of seedling qualified rate and crushing rate on transplanting effect. The form of ejector rod B: for the breaking rate and the qualified rate of seedlings, the range of B is the smallest, which is the least influencing factor. Select B3. Ejector speed C: for the crushing rate, the range of C is smaller, which is a smaller influencing factor. For the qualified rate of seedlings, the range of C is larger, which is the larger influence factor of the crushing rate.

Table 8

Analysis of variance

Index	Variance source	Sum of squares of deviation	Degree of freedom	Mean square	F value	P value
n1	A	86.20	2.00	43.10	19.17	0.05
	B	13.02	2.00	6.51	2.90	0.26
	C	11.56	2.00	5.78	2.57	0.28
	D（Error）	4.50	2.00	2.25	1.00	0.50
	Summation	115.28	8.00			
n2	A	3.93	2.00	1.96	1.02	0.49
	B	2.18	2.00	1.09	0.57	0.64
	C	74.81	2.00	37.40	19.45	0.05
	D（Error）	3.85	2.00	1.92	1.00	0.50
	Summation	84.76	8.00			

Note: $P \le 0.01$ means extremely significant, $P \le 0.05$ means significant, $P \le 0.1$ means significant, $P > 0.1$ means not significant.

From Table 7 and Table 8, it can be seen that the significant order of the factors of range analysis and variance analysis on each index is basically the same. The comprehensive balance valve is used to analyze each factor, and it is concluded that the better seedling selection scheme is A3B3C2, that is, the diameter of the ejector rod is 10mm, the end form is round head, and the seedling speed is 2 m/s. In order to verify the rationality of the optimization scheme, the optimization scheme is selected for verification experiment.

Bench test result

In order to further verify the results of the above simulation test, the bench test of the seedling harvesting mechanism was carried out, and the ejection mechanism with the optimal working parameters was used to carry out the top seedling experiment, and the qualified rate and breaking rate of the seedling extraction mechanism were calculated and analyzed.

The method for calculating the qualified rate of seedlings N_1 is as follows:

$$N_1 = \frac{W - W_1 - V_1 - V_2}{W} \times 100\% \tag{1}$$

where:

W is the total number of plants, W_1 is the number of seedlings without ejection, V_1 is the number of damaged or broken stems and leaves, and V_2 is the number of loose dunes.

The crushing rate N_2 is calculated as follows:

$$N_2 = \frac{P - M - N}{P} \times 100\% \tag{2}$$

where:

P is the total quality of seedling plate before seedling collection, N is the sum of seedling quality after seedling collection, kg; M is the mass of pot seedling after seedling collection, kg.

a) b) c)

Fig. 9 - Seedling extraction process test

a) Before taking seedlings *b) When collecting seedlings* *c) After the seedling is taken*

The experiment shows that under the optimal working parameters, the qualified rate of seedling collection mechanism is 91.2%, and the breaking rate is 18.3%, which meets the working standard of seedling collection mechanism. Through the experiment, it can be found that the loss of the seedling matrix is mainly caused by the collision between the seedling collecting mechanism and the substrate, and between the horizontal conveyor belt and the substrate, and the loss part is mainly peat and perlite outside the matrix.

Basically, damage was not caused to the main part of the internal matrix-root complex. In order to reduce the damage rate, the diameter of the ejector rod can be increased as much as possible, the speed of seedling extraction can be reduced, and the impact and pressure of the ejector rod on the bottom of the seedling can be reduced.

However, the bottom space of the hole plate is relatively small, in order to ensure that the ejector rod can smoothly pass through the bottom hole plate for normal work, the diameter of the ejector rod cannot be set too large, and the decrease of seedling speed plays a significant role in reducing the breaking rate of the matrix. However, too small seedling speed will affect the qualified rate of seedling extraction. The end form has a certain effect on the matrix fragmentation rate, but has little effect on the qualified rate of seedlings.

CONCLUSIONS

In view of the problems of high breaking rate and low qualified rate of the existing top-out seedling extraction mechanism, this paper optimizes the design of the top-out automatic seedling extraction device, measures the moisture content and particle size distribution of bowl seedlings, calculates and analyzes the speed of bowl seedling movement and conveyor belt, and simulates the effects of seedling extraction speed, ejector rod diameter and end type on seedling collection qualified rate and fragmentation rate by using EDEM discrete element simulation method. The following conclusions are drawn:

(1) the speed of seedling collection, the diameter of ejector rod and the type of end of ejector rod have important influence on the crushing rate and qualified rate of seedling. Too high or too small seedling speed will lead to the seedling not being able to fall to a reasonable position, and the qualified rate of seedling will be reduced. Increasing the diameter of ejector rod in a certain range and selecting the end form with better effect can effectively reduce the breaking rate of bowl seedling matrix and the effect is better.

(2) through the design of orthogonal experiment, the ejection process of the seedling was simulated and analyzed, and the crushing rate of the seedling was evaluated by using the number of connecting bonds between particles, and the best working parameters of the seedling mechanism were obtained, so as to improve the seedling quality.

(3) the verification test of the seedling harvesting mechanism was carried out, and the verification test of seedling ejection was carried out by using the optimal parameter combination in the simulation. The test results show that when the round head ejector rod is used, the ejection speed is 2m/s, and the diameter of the ejector rod is 10mm, the fragmentation rate of the seedling is 80%, and the qualified rate of the seedling is 90%, which meets the requirements of the dryland transplanter.

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