STRUCTURAL DESIGN AND SIMULATION ANALYSIS OF AIR-ABSORBING VEGETABLE PRECISION SEEDER
/
气吸式蔬菜精量播种机结构设计与仿真分析

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ABSTRACT
Aiming at the problems such as low seeding qualification rate of vegetable precision seeder, this paper designs a kind of air-absorbing precision seeder. The device is mainly composed of chassis part, seed discharge device, power unit, fan, gearbox and transmission device. ADAMS software is used to simulate the kinematics and dynamics of the air-absorbent seed discharger, and the simulation results show the movement and falling process of the seeds inside the seed discharger, and at the same time analyze the movement and force of the whole machine. By building a test bench, the seeding qualified rate under different factors is obtained to meet the requirements, which verifies the rationality of the machine design.

摘要
针对蔬菜精量播种机播种合格率低等问题，本文设计了一种气吸式精量播种机。该装置主要由底盘部分、排种装置、动力装置、风机、变速箱以及传动装置等组成。利用 ADAMS 软件对气吸式排种器进行运动学和动力学仿真，仿真结果显示了种子在排种器内部运动及下落过程，同时对整机的运动及受力情况进行分析。通过搭建试验台，得到不同因素下的播种合格率均满足要求，验证了整机设计的合理性。

INTRODUCTION
With the gradual increase in the demand for vegetables in China, which caused the increase in the area of vegetable planting, under this trend, the research on vegetable seeding device to improve the performance of the seeding device has an important value *(Tian et al., 2023; Zhao et al., 2020; Yang et al., 2018)*. In mechanized seeding, the seed discharger is the core component in the mechanical seeder. The seed discharging performance of the seed discharger will directly affect the seeding quality and seeding efficiency *(Biocca et al., 2023).* Currently, the domestic seeder is mainly used for sowing corn, wheat, grains, soybeans and other common large grain size crops. Seeding devices for small-sized vegetables such as carrots are rarely developed and studied, and are still in the initial stage of development *(Zhang et al. 2021; Huang et al., 2022)*.

Common mechanical seed dischargers are prone to scratching and damaging vegetable seeds in the seed discharge process, making the efficiency and quality of seed sowing unsatisfactory. In contrast, pneumatic seed dischargers can well prevent the phenomenon of damage to the outer skin of vegetable seeds in the seed discharge process *(Li et al., 2023)*. Pneumatic precision seed dischargers began to appear in some foreign countries with advanced science and technology in the 1950's *(Zhang et al., 2022)*. *Arzu Yazgi et al*., *(2007)* in order to solve the problem of poor uniformity of seed discharge in pneumatic precision seed dischargers, applied the response surface methodology to optimize the parameters of pneumatic precision seed dischargers, and came up with the optimal parameters of the working combination of the dischargers. *Karayl et al*., *(2004),* optimized the structure and parameters of the pneumatic seed expeller on the basis of the physical properties of seeds, and at the same time established a vacuum model to improve the seed discharge performance of the discharger.

Onal et al., (2012), developed the Noetherian model to explain the mechanism of the seeds relying on the principles of fluid and aerodynamics, in response to the phenomenon of the instability of the seed suction generated in the airflow field of the pneumatic seed discharger.

Li Qichao., (2020), of Northeast Agricultural University established a stable critical transport model for non-regular small-grained vegetable seeds through a technical study on the adaptation of a variety of small-grained vegetable seeds, and clearly resolved the mechanism of seed population separation and transport.

This study aims to design and analyze an innovative air absorbing precision seeder, using ADAMS software for kinematic and dynamic simulations and conducting experimental evaluations of its performance to provide a reference basis for the research and development of vegetable precision seeder.

MATERIALS AND METHODS

Overall design of the seeder

Composition of the whole machine

The seeder is mainly composed of two parts, the first part is the chassis movement part, the second part is the seeder sowing part, the specific structure is shown in Figure 1. The machine consists of a frame platform carried by four wheels as well as an engine drive module, the motor output power is transmitted to the gearbox, after the gearbox speed change, a part of the power is transmitted to the gears of the rear wheels of the chassis in order to drive the total device forward, which can be adjusted by adjusting the transmission ratio to control the forward speed of the machine. The seeding device adopts air-absorbing seed discharge disk, which is powered by another part of the gearbox. The suction holes on the vertical disk in the seed discharge disk use the negative pressure formed on both sides of the disk to suck the seeds. As the seed discharge disk rotates, it reaches a certain angle where the differential pressure no longer exists, causing the suction to disappear. At this moment, the seeds previously held on the seed discharge disk fall.

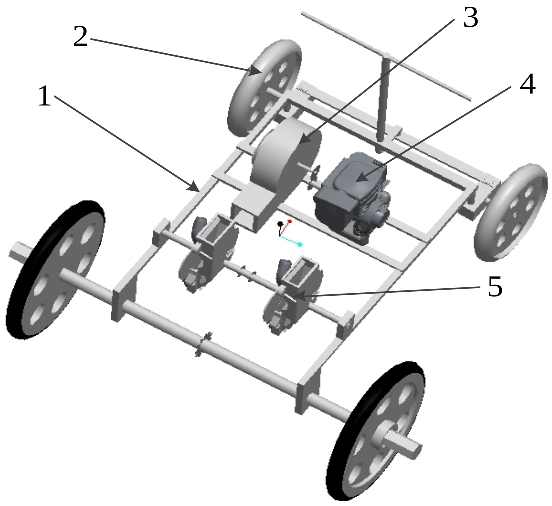

Fig. 1 - Overall structure of seeder

1.chassis; 2.tire; 3.fan; 4.gear box; 5.precision seed-metering device

Working principle

At working, the fan starts and gets a certain angular rotation speed. At the same time, the air inside the seed discharge disk sucked out. Thus, there is a certain pressure difference between the inside and outside of the two sides of the formation of suction on the seeds. The seeds in seed box fall because of gravity. At the same time, the seeds are sucked by suction onto the holes in the seed discharging disk and rotate with the disk. And in a certain range of angles, the negative pressure has always existed. This process is called seed taking and seed carrying process. When the seed discharge disk rotates at a certain angle, the negative pressure disappears, and the seeds fall back to the seed chamber or are discharged under the action of self-weight, vibration and friction. This process is called seed clearing and seed discharge process *(Li et al., 2024)*. The seed discharger keeps doing circular motion, and this process is continuously circulated to complete the seeding operation, and different specifications of seed discharging disk can be selected according to the different vegetable crops sown.

Adams virtual experiment

The kinematics and dynamics simulation is mainly carried out for the seeder in the model to analyze the influence of the rotational speed of the seed discharge disk on the trajectory of the seed drop, as well as the changes of the seed velocity, angular velocity and the force situation, to validate the stability of the rotation of the seed discharge disk *(Yu et al., 2024; Li et al., 2021)*.

The model of air-aspirated vegetable precision seeder created in SolidWorks was imported into ADAMS. According to the size of the model, adjust the size and density of the grid. According to past experience, in order to get more accurate simulation results, set the range of grid activity in the X, Y direction at 6000 mm and 5000 mm, respectively. The grid size in the X, Y direction is 50 mm. The units were chosen according to the standard MMKS. The Cartesian coordinate system is selected as the ground coordinate system. After the model is imported into ADAMS, the attributes of each component should be defined, including the component name, material properties, etc. *(Shi et al., 2019)*. ADAMS can automatically calculate the mass and center of gravity position of each component, and the frame is 87 kg, and the seed discharger is 20.8 kg.

According to the connection between the components of the seeder, the corresponding fixed joint, moving joint, cylindrical joint, etc. were created in turn. Mainly create the motion joint of the internal structure of the seed discharger. The seed discharger and the frame are the fixed joint, the rotary disk inside the seed discharger and the seed discharger shell are the rotary joint; the seed inside the seed discharger and the shell are the contact joint. The specific constraints are shown in Fig. 2.

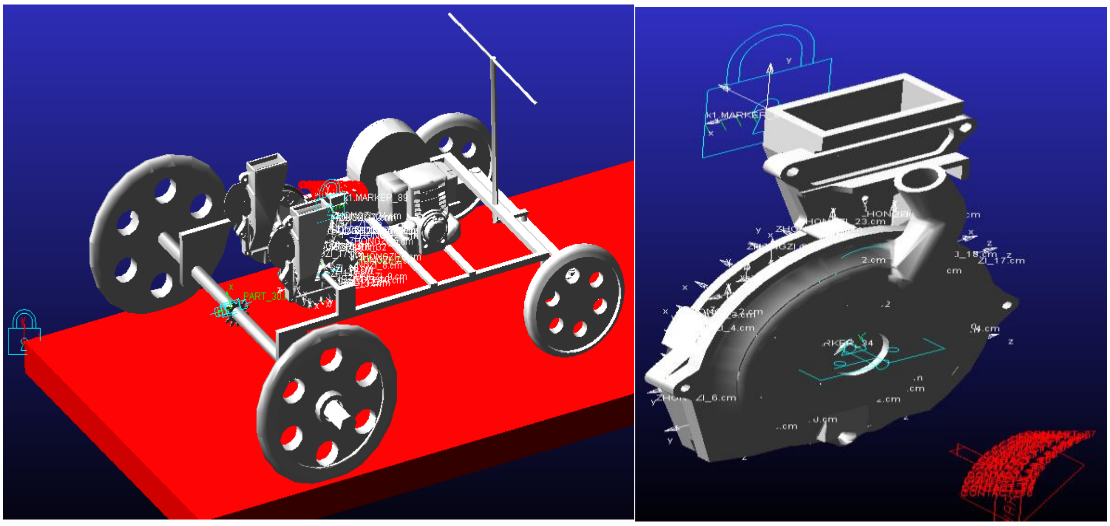

Fig. 2 - The constraints of hoisting system

Applied load and drive: This study primarily examines the relationship between the seed discharger and the speed of the seeding machine, considering two key factors: the speed of the seeder and the seed discharge rate at a given rotational speed of the seed discharger. The relationship between these factors is analyzed through simulation. The drive is applied to the mobile joint of the planter, while the rotary drive is applied to the rotational joint of the seed discharger. The traveling speed of the machine relative to the seeding speed is considered uniform. The main calculations for several operational groups are shown in Table 1.

Table 1

Working conditions of each group

operation	rotational speed of the seed discharger	speed of the seeder
1	30 d/s	0.3 m/s
2	30 d/s	0.2 m/s
3	30 d/s	0.1 m/s
4	60 d/s	0.1 m/s

Verification test of carrot seeder

Yellow Sword No. 1 pelletized carrot seeds of Shouhe Company with less than 8% moisture content were used as the test material in the experiment *(Wang et al., 2015).*

The whole test bench is shown in Fig. 3, which is mainly powered by a 190F gasoline engine with a continuous output of 7.0 kw. Other test supporting pieces of equipment are a rotational speed tester (3402, TACHO Hi Tester, Japan), wind pressure tester, camera, stopwatch, and meter scale.

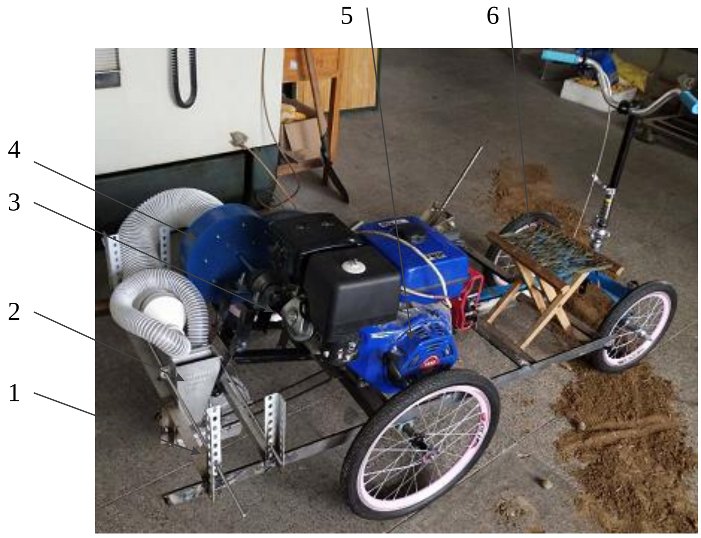

Fig. 3 -Test bench of air-suction carrot seeder
1.chassis; 2.precision seed-metering device; 3.gear box; 4.fan; 5.petrol engine; 6.tire

Test indexes and test methods

Precision seeder adopts the national standard *GB/T 6973-2005*. The adoption of this standard can make the test results of different types of single grain (precision) seeders comparable. In in this standard, the three major performance indexes of precision seeders are the qualified rate of seeding, the miss-seeding rate, and the reseeding rate.

Test design

The key components of the air-absorbent seeder lie in the structure and installation position of the seeder, etc. However, there are various factors affecting the seeding of the seeder, among which the key influencing factors are the vacuum degree of the air chamber produced by the fan, the rotational speed of the seeding disk driven by the engine, the seeding height, the thickness of the seeder and the angle of the seeder when it is installed, and the number, size, layout and so on of each suction hole of the seeding disk when it is designed *(*Abdolahzare *et al., 2018)*. Since the minimum size of the triaxial dimensions of the carrot seeds for sowing is greater than 2 mm, the diameter of the suction holes in the clock discs designed during the test was 2 mm. Using the control variable method, the pitching height was adjusted separately while keeping all other conditions unchanged. Several groups of different test results were recorded, and the obtained data were processed to determine the average value for the air-absorbent carrot planter. The study examined the effects of three factors—the vacuum degree of the air chamber, the rotational speed, and the pitching height—on the performance of seed placement. The test factor levels are shown in Table 2.

Table 2

Factors and level of orthogonal test

Level	Factors		
	A. Vacuum degree pa	**B. Rotational speed of the seeding disk r/min**	**C. seeding height mm**
1	2000	36	20
2	3000	60	30
3	4000	96	40

Through the simulation test, the trajectory and speed of the seed can be obtained, while the bench test provides data on the seed discharge performance of the seeder. Combining both methods allows for a comprehensive analysis of the seeder's operational performance.

RESULTS AND DISCUSSION

Simulation results analysis

Seed movement trajectory analysis

When the seeder is in operation, the seeds make a circumferential motion in the seed discharger and are finally discharged in a certain form of motion. The trajectory of the seed i.e. the actual curve of the seed falling on the ground. The dynamics of the seed movement is simulated using the ADAMS/ view module with a simulation time of 10 s and a simulation step count of 200 steps. The trajectory curves of the seeds under different working conditions are shown in Figure 4-7.

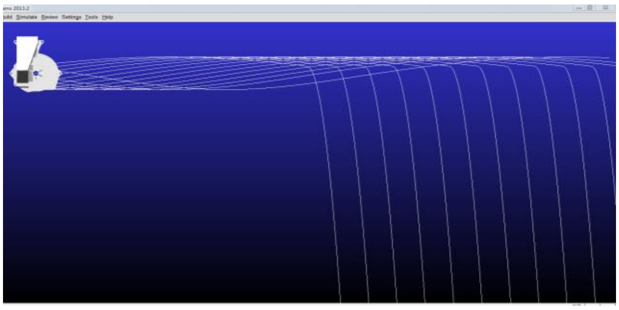

Fig. 4 - The trajectories of seeds in operation 1

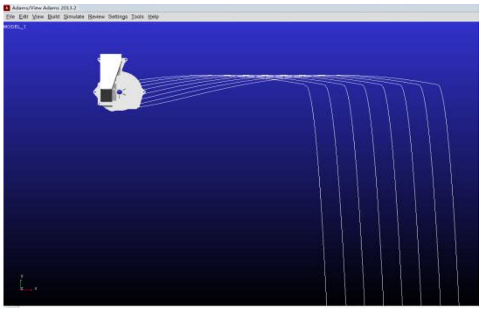

Fig. 5 - Trajectory of seeds in operation 2

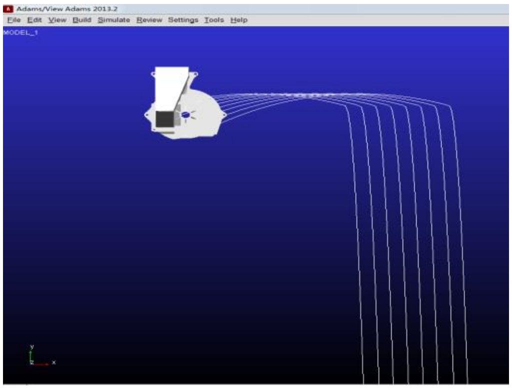

Fig. 6 - Trajectory of seeds in operation 3

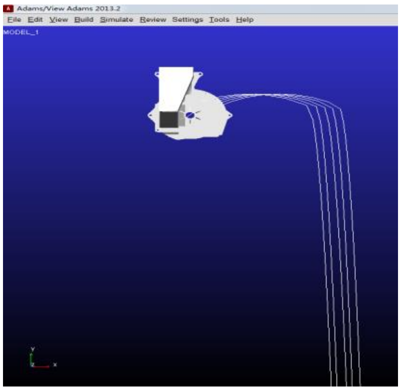

Fig. 7 - Trajectory of seeds in operation 4

In case of operation 1, the landing distance of the seeds is 100 mm, in case of operation 2, the landing distance of the seeds is 150 mm, in case of operation 3, the landing distance of the seeds is 200 mm, in case of operation 4, the landing distance of the seeds is 250 mm, and the results of the statistical calculations are shown in Table 3.

Table 3

Calculations

Operation	Rotational speed of the seed discharger	Seeder speed	Sowing spacing
1	30 d/s	0.3 m/s	100 mm
2	30 d/s	0.2 m/s	150 mm
3	30 d/s	0.1 m/s	200 mm
4	60 d/s	0.1 m/s	250 mm

By simulating the situation of seeding spacing under different operating conditions, the ideal seeding distance can be determined. The desired seeding spacing can be obtained by adjusting the self-propelled speed of the whole machine and the speed of the upper shaft of the seed discharger.

Simulation result curve of seed under virtual prototype

In the case of the seed discharger under working operation 1, i.e., the speed of the seeder is 0.3 m/s and the rotational speed of the seed discharger is 30 d/s, the curves of the seed velocity changes during sowing are shown in Fig. 8, and the angular velocity changes of different seeds are shown in Fig. 9.

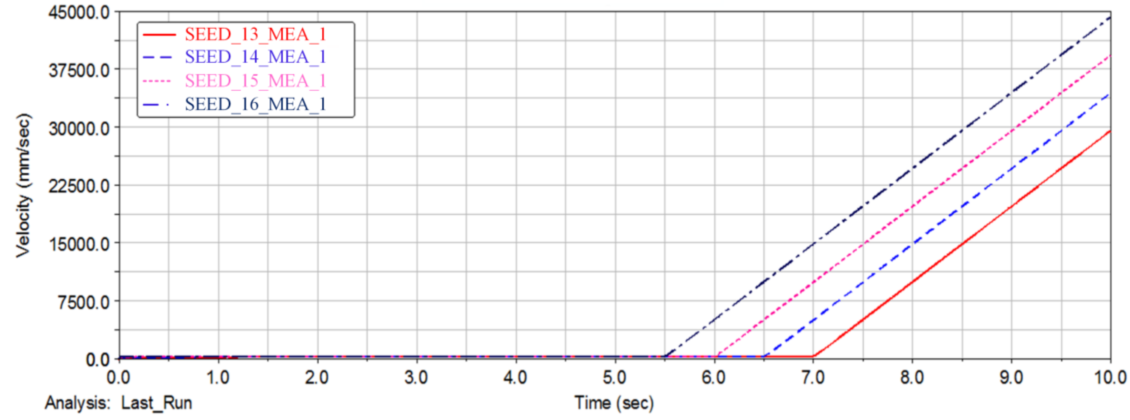

Fig. 8 - Velocity map of four seeds

As can be seen from the seed velocity change curve in Fig. 8, the seeder sequentially releases seeds from the seed discharge tray, after which they accelerate downward with constant acceleration during sowing. The time interval between the fall of every two seeds was approximately 0.5 s. The time interval between the fall of each seed is roughly the same, which shows that the seed discharger is installed more firmly. There is a small vibration which has a negligible effect on it. The simulation was carried out under ideal conditions, without the influence of external wind speed, etc. In addition, there is friction to be taken into account, but compared to the traditional coated seed, this seed is adsorbed on the seed discharging disk, and friction also has a small effect on it. Therefore, based on the time interval between seed falls, it can be concluded that the seeds are sown at relatively uniform spacing, and the emergence of the seedling is neat and tidy.

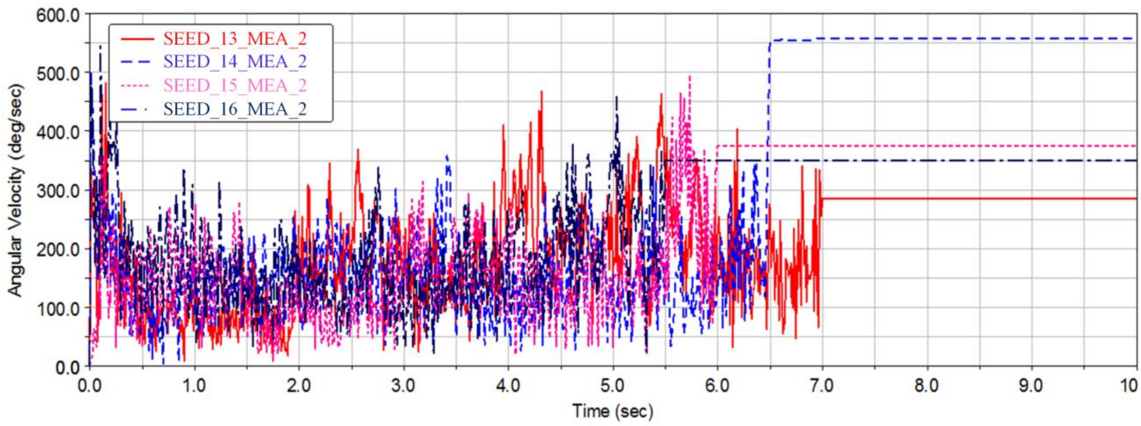

Fig. 9 - Angular velocity diagram of four seeds

Through the angular velocity of different seeds in Fig. 9, it can be seen that the seeds inside the seed discharger are rotating together with the seed discharger, and finally detach from the seed discharger from the seed casting mouth due to their own gravity and the seed scraping device. There is a certain fluctuation of the seeds inside the seed discharger, which is caused by the vibration of the whole machine and its own movement due to the seed discharger being installed on the rear axle of the frame. The angular velocity of all the seeds is basically the same as the angular velocity of the seed discharging disk, and when the seeds are discharged from the seed discharger, they will complete the later work with constant angular velocity.

Analysis of bench test results

Effect of air chamber vacuum on seeding performance

For different vegetable crop seeds, the required vacuum pressure is different, in general, the larger the vacuum degree of the air chamber, the stronger the seeds are adsorbed, and it is not easy to cause missing sowing phenomenon, but the large pressure difference inside the air chamber causes the seed discharge tray to adsorb more than one seed in one type of hole, and the phenomenon of reseeding is obvious, which makes it difficult to realize the precision sowing. Therefore, this experiment was conducted to study the effect of different vacuum degrees on the performance, to find the optimal vacuum degree and range. The wind pressure generated by the fan at work was 2000 Pa, 3000 Pa, 4000 Pa, and the grain spacing under different vacuum degrees was measured and calculated when the traveling speed of the seeder was stable. The results are shown in Table 4.

Table 4

Effect of vacuum degree in air chamber on seeding performance

Test No.	Vacuum degree of air chamber (pa)	Qualification rate (%)	Reseeding rate (%)	Miss-seeding rate (%)	Average seed spacing (mm)
1	2000	61.25	12.71	27.62	8.4
2	3000	80.71	8.01	12.34	10.1
3	4000	71.44	14.27	15.71	22.6

From Table 4, it can be concluded that as the vacuum degree inside the seed chamber increases, the qualified seed rate rises, the reseeding rate increases, and the miss-seeding rate decreases. In this test, increasing the vacuum degree of the air chamber led to a higher qualified rate; however, it also inevitably resulted in a higher reseeding rate. Considering these three performance indexes comprehensively, the air pressure in the seed chamber should be controlled within the range of 3000–4000 Pa. When the vacuum degree in the seed chamber is at the minimum setting of 2000 Pa, the seed discharge performance is the worst—the qualified rate is relatively low, and the occurrence of empty holes is severe. However, as the air pressure increases, various performance indexes gradually improve. Once the vacuum in the seed chamber reaches a certain level, further increasing the air pressure no longer enhances the qualified rate, while the reseeding phenomenon becomes more pronounced.

Effect of seeding disk's rotational speed on seeding performance

The rotational speed of the seeding disk is another important factor affecting seeding performance. If the rotational speed is too high or too low, it may result in inefficient seeding. Therefore, when selecting the seeding disk's rotational speed, it is essential to ensure that the three key seeding performance indexes remain optimal. This test quantitatively examines the impact of the seeding disk's rotational speed on these three major performance indexes. The rotational speeds were set at 36 r/min, 60 r/min, and 96 r/min, respectively. The seed spacing at different rotational speeds was measured under stabilized conditions, and the results are presented in Table 5.

Table 5

Effect of seeding disk's rotational speed on seeding performance

Test No.	Seeding disk's rotational speed (r/min)	Qualification rate (%)	Reseeding rate (%)	Miss-seeding rate (%)	Average seed spacing (mm)
1	36	65.20	17.49	5.52	7.8
2	60	77.02	9.14	3.48	15.3
3	96	88.74	7.48	2.73	40.3

From Table 5, it can be seen that the rotational speed and the qualified rate have a non-linear relationship. When the rotational speed is constantly increasing, the qualified rate of the seed discharger first increases and then decreases, and when it increases to a certain peak, the re-seeding rate decreases, but the miss-seeding rate increases. This occurs because when the rotational speed increases, the linear velocity of the seed discharging disk increases continuously, and the time for the seeds to be adsorbed in the seed chamber becomes shorter, resulting in the phenomenon of empty cavities, which leads to the increase of the leakage rate. When the rotational speed is 60-96 r/min, the three major performance indexes of the seed discharger are higher.

Effect of seeding height on seeding performance

Seeding height (the distance between the falling position of the seed and the furrow) is also an important parameter that has a great influence on the seeding performance, and it is an important factor in achieving precision seeding. Due to the light weight of carrot seeds, air resistance during the falling process cannot be ignored. Additionally, friction and collisions within the seed guide tube cause deviations in the falling trajectory, preventing the seeds from following the expected path precisely. Therefore, when selecting the seeding height, the optimal working height should be determined while ensuring that the three major seed discharge performance indexes remain within a reasonable range. This study quantitatively examines the effect of seeding height on these performance indexes. The selected seeding heights were 20 mm, 30 mm, and 40 mm. Once the seed falling process stabilized, grain spacing was measured, and the performance indexes within the grain spacing were calculated. The results are presented in Table 6.

Table 6

Effect of seeding height on seeding performance

Test No.	Seeding height (mm)	Qualification rate (%)	Reseeding rate (%)	Miss-seeding rate (%)	Average seed spacing (mm)
1	20	87.35	16.49	2.75	69.7
2	30	78.62	10.62	3.47	90.3
3	40	70.28	9.13	5.53	105.4

From Table 6, it can be observed that seeding height and the qualified rate exhibit a generally linear relationship. As seeding height increases, both the qualified rate and reseeding rate of the seed discharger gradually decrease, while the miss-seeding rate increases. When the seeding height is 20 mm, the three major performance indexes show the best results. The reason is that a lower seeding height results in a shorter seed drop distance, reducing the impact of wind on the seeds. Thus, the following conclusion can be drawn: the higher the seeding height, the greater the seed drop distance, leading to increased influence from wind, inter-seed friction, collisions, and other external factors, ultimately reducing seeding accuracy. To ensure optimal seed discharge, the seeding height should be minimized as much as possible to reduce the falling distance of the seeds.

In summary, as the vacuum inside the chamber increases, the seed spacing gradually decreases, indicating a reduction in the miss-seeding rate. This occurs because an increase in vacuum pressure leads to more carrot seeds being adsorbed onto the disk, thereby increasing the number of discharged seeds and reducing seed spacing. However, if the vacuum pressure becomes too high, multiple seeds may be discharged simultaneously, leading to an increased reseeding rate. When the rotational speed of the seed discharge disk increases, the seed spacing increases. However, at very low rotational speeds, the increase in seed spacing is slower, whereas at higher rotational speeds, seed spacing increases more significantly. The reason for this phenomenon is that at higher speeds, the seed discharge disk has less time to properly adsorb enough seeds, resulting in larger seed spacing and a higher miss-seeding rate. When the seeding height is increased, seed spacing also increases, leading to a higher miss-seeding rate. This occurs because carrot seeds are very lightweight, and as the seed discharge height increases, seeds fall a greater distance and are more affected by wind, causing uneven seed distribution. Therefore, when determining the installation height of the seed discharger, it should be kept as low as possible while ensuring it does not come into contact with uneven ground.

CONCLUSIONS

(1) An air-absorbing precision seeder was designed, and its overall structure was developed. The device mainly consists of a chassis, seed discharging device, power unit, fan, gearbox, and transmission system. The working principle of the entire machine and the four seed discharge processes of the seed discharger were introduced, providing a theoretical basis for subsequent simulations to analyze the trajectory and movement process of seeds.

(2) Using ADAMS software, kinematic and dynamic simulations of the air-absorbing seed discharger were conducted. The seeding process was simulated, and the seeding speed curve was generated. The simulation results illustrate the movement and falling process of seeds within the seed discharger, while also analyzing the motion and forces acting on the entire machine.

（3）The influence of three factors—vacuum degree of the air chamber, rotational speed, and seeding height—on seed discharge performance was investigated through a test bench. The reasons for variations in test results were explained by analyzing the data. The effects of different factor levels on seed discharge performance were determined, verifying the validity and reliability of the test results.

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