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Design and test of air-absorbing peanut high-speed precision seed discharger

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SUMMARY: *High-speed mechanised peanut sowing often suffers from missed and multiple seeding because seed pickup and release become unstable at elevated disc speeds. To meet agronomic requirements in Henan Province, an air-suction high-speed precision seed discharger was developed, incorporating a dual-orifice vacuum chamber with adaptive negative-pressure regulation to stabilise single-seed adsorption and enable low-impact delivery. A seed–metering-disc interaction model and kinematic analysis were established to guide the structural design and operating window. Based on force analysis of the filling and carrying stages, key parameters were determined: a 210-mm metering disc with 1.6-mm thickness, 25 suction holes, a hole diameter of approximately 7 mm, and a recommended chamber vacuum of 4–6 kPa. A three-factor, three-level combined experiment was conducted using planter forward speed, chamber negative pressure, and suction-hole diameter as factors, with qualified singulation rate, miss-seeding rate, and multiple-seeding rate as responses. Regression models were fitted and optimised, yielding an optimum at 8.617 km·h*$^{-1}$ *forward speed, 5.816 kPa chamber vacuum, and 7.02 mm suction-hole diameter. Under these conditions, the qualified seed-discharge rate reached 94.86%, while the miss-seeding and multiple-seeding rates were 3.49% and 1.65%, respectively, satisfying the requirements for high-speed precision peanut seeding.*

KEYWORDS: *Peanuts; Seed planter; High speed; Precision; Air suction; Seed tray*

1 Introduction

Peanut is a key oil and cash crop in many semi-arid and warm-temperate regions, and in countries with rapidly expanding mechanized production the demand for high-efficiency, high-quality sowing has increased markedly in recent years. For medium and large farms, high-speed precision planters are now expected to maintain qualified single-seed rates and uniform in-row spacing even when the forward speed exceeds the traditional range of 5–6 km/h, while also limiting seed damage and energy consumption. Under such conditions, the seed-metering device becomes the core subsystem that reconciles agronomic requirements with mechanical constraints: its seed-filling, carrying and discharge processes ultimately determine miss index, multiple index and the spatial distribution of plants in the field.

Conventional mechanical metering devices can achieve acceptable performance at low to moderate speeds, but their working principle-relying on pockets, cells or mechanical fingers-tends to aggravate seed bounce, blockage and damage when peripheral speed

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increases and coated or irregularly shaped seeds are involved. This limitation is particularly acute for peanuts, whose elongated, rough-shelled and size-heterogeneous seeds are more prone to breakage and to unstable positioning in purely mechanical cups. In contrast, pneumatic or air-suction systems can provide gentler, more adaptive handling by using negative pressure to pick up and carry individual seeds on a rotating disk. Wang et al.[1] designed and evaluated an inside-filling air-assisted high-speed maize precision seed-metering device, showing that carefully arranged internal air channels and seed-stirring structures can maintain a high single-seed rate and good distribution uniformity at elevated peripheral speeds, thus illustrating the potential of air-assisted architectures for high-speed operation in row crops beyond maize. Liu et al.[2] further demonstrated, in a disturbance-assisted high-speed vacuum seed-metering device, that introducing controlled airflow disturbances and optimizing the hole geometry with DEM–CFD coupling can significantly improve the stability of seed filling and reduce the sensitivity of singulation performance to speed and vacuum fluctuations.

In the area of peanut precision planting, a number of recent studies have focused on improving seed-filling quality and adapting pneumatic metering structures to the geometric particularities of peanut seeds. Guo et al.[3] developed an auxiliary air-suction seed-filling structure for a peanut high-speed pneumatic-assisted seed-metering machine, and, on the basis of a DEM–CFD coupled flow field model, analyzed how auxiliary suction paths influence seed trajectories, seed–seed interactions and pressure distribution in the filling zone. Their results indicated that properly conFig.d auxiliary suction outlets enhance the mobility of the seed bulk near the disk holes and improve qualified seed-filling performance under high-speed operation, while helping to suppress sharp increases in miss index when the forward speed is raised. Building on the same platform, Guo et al.[4] proposed a seed-pressing mechanism for precision peanut planters, in which a structured soil-covering and seed-pressing unit is coordinated with the metering device. By verifying optimal operating parameters under high-speed seeding conditions, they showed that an appropriately tuned pressing mechanism is essential to stabilizing seed depth and mitigating the variability in emergence that can otherwise overshadow the gains from improved metering.

Beyond the seed-metering chamber itself, researchers have also explored integrating multiple agronomic functions into the seeding system. Guo et al.[5] designed and tested a peanut seeding device capable of synchronous hole fertilization and directly-above seeding, in which the fertilizer placement, seed drop point and soil cover profile are jointly constrained so that the fertilizer band is placed below and slightly offset from the seed. Their experiments demonstrated that such integrated designs can simultaneously improve fertilizer-use efficiency and maintain acceptable in-row seed spacing for peanut, provided that the metering unit delivers seeds with sufficient positional repeatability. From the perspective of drive and control, Yu et al.[6] developed a motor-driven precision seed-metering device with an improved fuzzy PID controller for small peanut planters. By matching the rotational speed of the metering disk to machine travel speed through a closed-loop control strategy, they enhanced the adaptability of the planter under variable field conditions and widened the operating speed range over which high qualified indices could be maintained. Complementing these developments on the hardware and control sides, Zhao et al.[7] introduced a double-seed-hole peanut seed-metering device aimed at improving the stability of seed transfer and the robustness of singulation. By redesigning the hole layout and associated seed-cleaning mechanisms, they reported that the double-hole configuration can mitigate seed loss and improve the qualified index, particularly when dealing with size-graded but still geometrically irregular peanut seed lots.

With the increasing complexity of planter structures and control strategies, on-board monitoring has become an indispensable component of modern peanut precision sowing systems. Yu et al.[8] designed and tested an online monitoring system for peanut seeding parameters based on the Internet of Things (IoT), capable of tracking seed spacing, seeding rate, miss seeding, vehicle speed and environmental variables in real time and transmitting these data through industrial communication protocols. Their study showed that such monitoring can detect deviations in metering performance early and provide a data foundation for closed-loop adjustment or post-hoc quality assessment. In parallel, nutrient management has been brought into the same precision framework: Yu et al.[9] (Fan et al., in the original article) developed a peanut precision fertilization control system based on a threshold velocity algorithm, in which fertilizer application rate is dynamically adjusted according to the instantaneous forward speed to ensure that the target fertilizer dose per unit area is maintained, thus improving uniformity of fertilization and supporting higher-yield, high-density peanut cultivation. Together, these works reveal a shift from single-module optimization toward more integrated, information-rich seeding and fertilization systems.

From a methodological standpoint, theoretical modeling and numerical optimization of seed-metering performance have also advanced significantly in recent years. Da Costa and Yazgi[10] established mathematical models for a vacuum-type seed metering unit in precision peanut seeding, using a central composite experimental design on a greased-belt test bench to quantify how peripheral disk speed, vacuum pressure and seed characteristics influence the quality-of-feed index, miss index, multiple index and coefficient of precision. By fitting response surfaces and locating optimal operating points, their study provided a systematic framework for selecting operating parameters and highlighted the strong interactions among speed, vacuum and seed size distribution. In the context of high-speed maize planting, Wang et al. established a parameter-selection route by integrating analytical modelling with performance tests, and identified critical design variables for an internal-filling, air-assisted metering mechanism, such as disc size, orifice count, and the configuration of the cleaning element. These insights provide a useful reference for peanut metering systems, provided that crop-specific geometric and mechanical differences are properly accounted for. In a separate study, Liu et al. adopted a coupled DEM–CFD framework to characterise the airflow behaviour within the disc orifices of a disturbance-enhanced vacuum metering device, and subsequently refined the orifice geometry-especially entrance size and passage length-based on pressure-difference characteristics and seed-trajectory responses. Their results highlight that reliable flow-field prediction becomes essential when designing air-assisted seed pickup and release structures with complex internal passages.

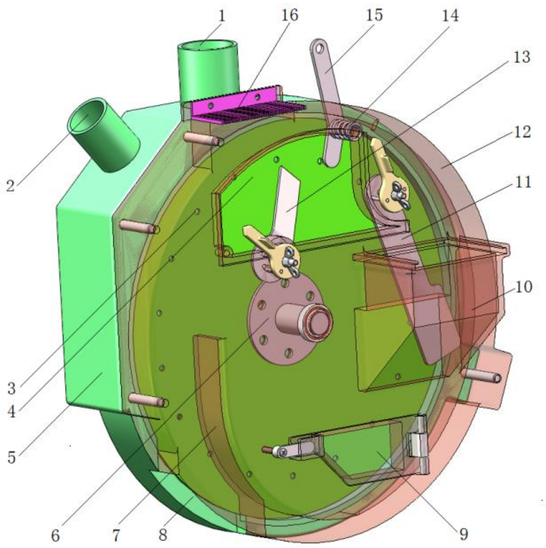
Despite these advances, several technical contradictions remain unresolved for peanut high-speed precision sowing. First, most existing peanut metering studies emphasize either seed-filling enhancement through auxiliary suction or mechanical agitation, or downstream stabilization via seed-pressing and soil-covering mechanisms, but relatively few focus on the complete chain from air-assisted seed picking through zero-speed seed discharge and transfer to the furrow. In particular, the interaction between the auxiliary air-absorbing structure, the geometry of the seed tray and disk, and the instantaneous velocity of seeds at the moment of release has not been systematically investigated, even though this interaction strongly affects both miss and multiple indices at high forward speeds. Second, as Yu et al. showed, motorized drives and IoT-based monitoring can significantly broaden the controllable operating envelope of planters, but they do not eliminate the intrinsic sensitivity of seed flow in the metering chamber to variations in vacuum pressure, seed bulk properties and machine vibration. At very high speeds typical of modern peanut production, fluctuations in pressure distribution and seed–wall friction within the seed tray can still cause abrupt deterioration of performance, especially for seed lots with large size dispersion. Third, while the modeling framework of Da Costa and Yazgi and the DEM–CFD analyses of Liu et al. provide powerful tools for parameter optimization, they have primarily been applied to generic vacuum plates or to maize rather than to peanut-specific air-absorbing structures with auxiliary suction channels and highly asymmetric seed geometries.

To address these gaps, the present study focuses on the design and testing of an air-absorbing high-speed precision seed discharger specifically tailored to peanut seeds. Building on preliminary domestic work on pneumatic peanut seed-metering devices and the force analysis of seeds on rotating disks, we revisit the mechanics of seed adsorption, carrying and release under high-speed conditions and use this understanding to guide the structural design of an air-absorbing seed tray and auxiliary suction system. The objectives are threefold: (i) to establish a mechanically consistent design of the air-absorbing seed discharger that balances disk diameter, hole layout, auxiliary suction channels and vacuum level so as to stabilize single-seed adsorption over a wide speed range; (ii) to develop a laboratory test protocol that quantifies qualified index, miss index and multiple index of peanut seeding under representative combinations of forward speed, vacuum pressure and structural parameters; and (iii) to identify optimal parameter regions and operating recommendations for achieving high qualified indices with low miss and multiple indices while keeping the device structure and energy consumption suitable for medium-sized planters. The insights gained are expected not only to enhance the performance of peanut high-speed precision sowing, but also to inform the design of air-absorbing seed dischargers for other large-seeded crops where seed shape and flowability present similar challenges.

2 Structure and operating principle

2.1 Overall configuration

The air-suction seed metering unit consists of a housing, sealing brush, suction inlet, sealing gasket, metering disc, seed-cleaning scraper, seed box, and drive shaft, among other components. A schematic of the overall assembly is presented in Fig. 1. During operation, a high-speed fan supplies suction to the vacuum chamber of the metering unit. As the disc rotates, seeds are captured at the orifices under the pressure differential and are transported with the disc. Once the orifices move beyond the effective vacuum region, the holding force diminishes and the seeds are released by gravity and/or by the scraper, after which they enter the furrow to complete the delivery process. The air chamber is equipped with double air channels, when sucking seeds, the auxiliary suction port can increase the vacuum degree of one week, which helps to increase the pressure of the negative pressure chamber, and can better adsorb the peanut seeds.

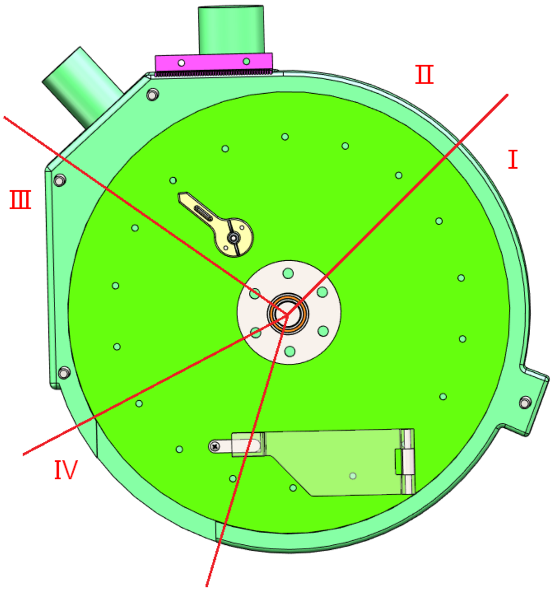


1. Inhalation port; 2. Auxiliary suction port; 3. Fill the seed empty; 4. Seed tray; 5. Negative pressure end shell 6. Central axis; 7. Curved scraper; 8. Planting mouth; 9. Observation window; 10. Seed box; 11. Seed box baffle; 12. Seed planter casing; 13. Scraper; 14. Adjust the spring; 15. Seed clearing board; 16. Sealing brush.

Figure 1: Structure diagram of seeding device

2.2 Working principle

As shown in Fig. 2, the air-suction seed dispenser is partitioned into four functional zones: Zone II (pickup–filling), Zone III (singulation), Zone IV (transport) and Zone I (release). During operation, suction generated by the planter fan is conveyed to the metering unit through a vacuum hose, creating a sealed, concave negative-pressure chamber between the housing and the rotating disc. Peanut seeds enter the vicinity of the disc in Zone II and are captured at the suction orifices by the pressure differential. The disc then passes through Zone III, where a scraper removes surplus seeds around each orifice and returns them to the seed mass, thereby preventing multiple pickup and reducing reseeding. The retained single seed is conveyed under sustained suction through Zone IV. When the orifice reaches Zone I, the seed contacts an internal curved guide/plate; the effective holding condition is disrupted and gravity completes detachment from the orifice. The released seed falls into the guide channel and is delivered to the furrow opener for in-furrow placement, completing the metering and delivery process.



I. Seed filling zone II Qingzhong District III Carrying Seed Zone IV Planting area

Figure 2: Schematic diagram of seeding disk partitioning

3 Key components design and parameter determination

3.1 Peanut seed filling force analysis

The rowing stability of peanut seed expeller and the degree of seed damage are closely related to the structure of the rowing disc and the force characteristics of the seed [11-13]. Peanut seeds have been kept in motion during the process of adsorption on the seed discharge disc, and are subject to the adsorption force, centrifugal force and own gravity of the seed discharge disc and friction, respectively [14-16], so the analysis of the force on peanut seeds can provide a reference to the structural design of the seed discharge disc. The relationship between velocity and acceleration of peanut seeds during their rotation on the seed discharge disc is shown in Fig. 3.

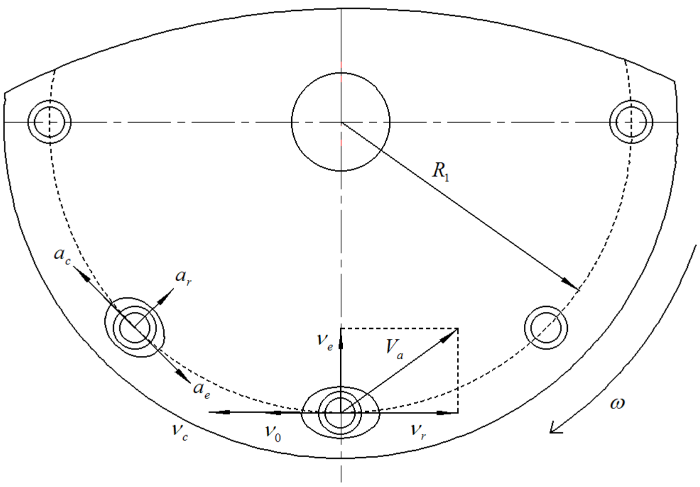


Figure 3: Schematic diagram of peanut seed velocity analysis

From Fig. 3, the seed implication velocity is

$$v_e = R_1\omega \tag{1}$$

where: v_e is the traction speed (m/s);

R_1 -radius (s) of the circumference where the seed-sucking hole is located.

ω -Rotational speed of the seed discharge disc (rad/s).

The relative speed is

$$v_r = v_e - v_0 - a_r t_1 \tag{2}$$

where: v_r -relative velocity of peanut seeds (m/s);

v_0 -initial velocity of peanut seeds (m/s);

a_r -acceleration of peanut seeds (m/s-2);

t_1 -acting time of rowing disc on peanut seeds (s).

The synthetic velocity of the implicated and relative velocities is

$$V_a = \sqrt{(v_e - v_0 - a_r t_1)^2 + (R_1\omega)^2} \tag{3}$$

The relative acceleration in the graph is

$$\begin{cases} L_1 = \dfrac{1}{2} a_r T_1^2 \\ v_e - v_0 = a_r T_1 \end{cases} \tag{4}$$

where, L_1 the effective distance of the adsorption force acting on the peanut seed;

T_1 is the time acted by the adsorption force.

Equation (4) can be organised as

$$a_r = \frac{2L_1}{T_1^2}\ ,\quad T_1 = \frac{2L_1}{R_1\omega - v_0} \tag{5}$$

The implicated acceleration a_e is

$$a_e = \sqrt{(a_e^\tau)^2 + (a_e^n)^2}$$

$$a_e^\tau = R_1(\omega t_1)'' = 0\ \ ,\ \ a_e^n = R_1\omega_2 \tag{6}$$

where a_e is the implicated acceleration (m/s2); a_e^τ is the tangential acceleration (m/s2); and a_e^n is the normal acceleration (m/s2).

From this, the Koch acceleration a_c can be calculated as

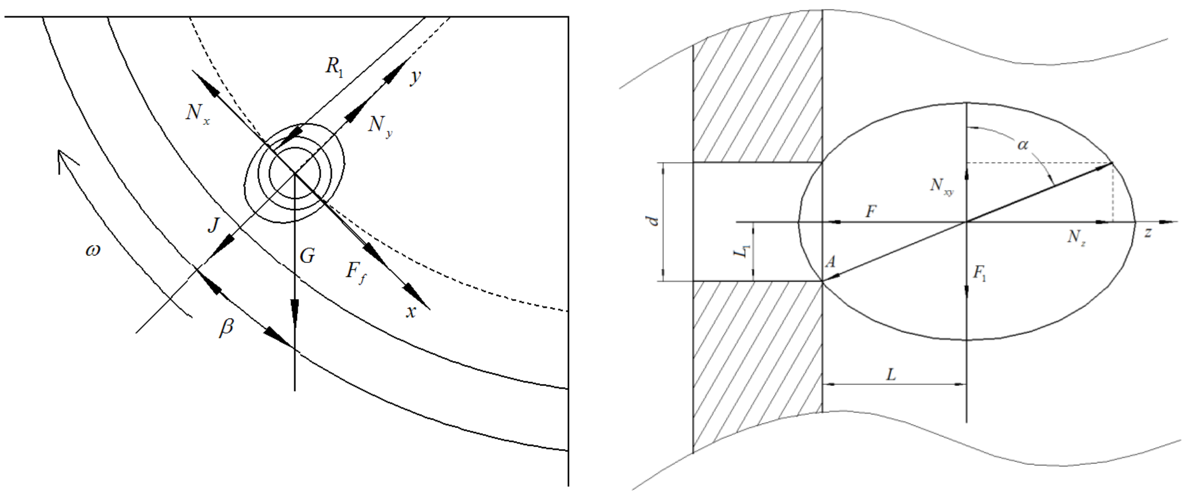
$$a_c = 2\omega(v_c - v_0 - \frac{2L_1t_1}{T_1^2}) \tag{7}$$

The absolute acceleration a_a is

$$a_a = \sqrt{(\frac{2L_1}{T_1^2})^2 + (R_1\omega)^2 + \left[2\omega(v_e - v_0 - \frac{2L_1t_1}{T_1^2})\right]^2} \tag{8}$$

The relationship between the initial velocity v_0 of peanut seeds and the absolute acceleration a_a can be seen from formula (8), that is, the increase of the initial velocity v_0 will make the absolute acceleration a_a decrease, and thus the design of the peanut seed discharge disc structure can be used to reduce the acceleration of peanut seeds in the process of movement by increasing the initial velocity v_0 of peanut seeds to reduce the damage of peanuts and ensure that the purpose of the suction of the negative pressure of the seed. In the process of seed filling, peanut seeds will be close to the suction hole attachment under the action of negative pressure, and in the case of precision sowing, generally only one seed is adsorbed on the suction hole. Establish a three-dimensional coordinate system to analyse the force of the seed filling process on the seed suction hole.

Peanut seeds in the role of adsorption force with the seed discharge disc for uniform circular motion, ω is the angular velocity of rotation, G is the seed itself vertically downward gravity, J is the centrifugal force on the seed rotation, the seed in the suction hole adsorption force for F, the reaction force for N at the same time by the resistance, gravity, the centrifugal force of the combined force for F_1, as shown in Fig. 4.



(a) (b)

Figure 4: Force analysis of peanut seed filling process

From Fig. 4(a), it can be seen that the moment of force out of the point A is 0, and the combined force on the seed in the adsorption process is also 0. Therefore, it can be obtained that

$$\begin{cases} N_x - F_f - G\sin\beta = 0 \\ N_y - J - G\cos\beta = 0 \\ N_z - F = 0 \\ FL_1 - F_1 L = 0 \end{cases} \tag{9}$$

Middle - N_x peanut seed is subjected to the reaction force component of the suction hole in the direction of x, N

N_y - Peanut seed is subjected to the reaction force component of the suction hole in the direction of y, N

N_z - Peanut seed is subjected to the reaction force component of the suction hole in the direction of z, N

J - peanut seed is subjected to the centrifugal force, N

F_f - inter-seed resistive force, N

L - horizontal distance from the seed centre of gravity to point A, mm

L_1 - vertical distance from the seed centre of gravity to point A, mm

β - angle between the line connecting the centre of gravity of the seeds and the centre of the row of seed discs and the vertical direction, (°)

From Fig. 4(a) It can be seen that in the plane of xy

$$N_{xy} = \sqrt{N_x^2 + N_y^2} \tag{10}$$

where: N_{xy} -seed reaction force in the xy-plane combined force, N

ω-exhaust disc angular velocity, rad/s

From Fig. 4(b) on the z -plane force analysis can be seen

$$F_1 = N_{xy} \tag{11}$$

$$\tan\alpha = \frac{L}{L_1} \tag{12}$$

α - chamfer of suction hole of seed discharge disc, (°)

From equations (8) to (13), we can get

$$F = \frac{F_1 L}{L_1} = \frac{N_{xy} L}{L_1} = N_{xy}\tan\alpha \tag{13}$$

Seek

$$F = \sqrt{F_f^2 + J^2 + G^2 + 2G(F_f\sin\beta + J\cos\beta)}\tan\alpha \tag{14}$$

The relationship between the negative pressure P of the seeding tray and the adsorption force of the seeds in the suction hole is

$$P = \frac{F}{S} = \frac{F}{\pi L_1^2} \tag{15}$$

In the formula, S represents the cross-sectional area of the hole, mm^2

From equations (13) to (15), we can obtain

$$P = \frac{L}{\pi L_1^3}\sqrt{F_f^2 + J^2 + G^2 + 2G(F_f \sin\beta + J\cos\beta)} \tag{16}$$

In practical operations, peanut seeds are also affected by impact and vibration, so it is necessary to consider the reliability coefficient K_1 of seed suction and the environmental reliability coefficient K_2. After introducing these two coefficients, formula (16) can be obtained

$$P = \frac{K_1 K_2 L}{\pi L_1^3}\sqrt{F_f^2 + J^2 + G^2 + 2G(F_f \sin\beta + J\cos\beta)} \tag{17}$$

According to formula (17), the vacuum setpoint P required in the metering chamber depends on both seed properties and the kinematics/geometry of the metering system, including peanut characteristics (e.g., mass, projected area and surface condition), disc rotational speed, disc diameter, and the design of the suction orifices (diameter and number). Under otherwise identical conditions, a lower disc speed or fewer orifices reduces the holding demand per unit time, and therefore allows a lower chamber vacuum to maintain stable single-seed pickup. To achieve high-speed sowing of peanuts, a larger negative pressure chamber is needed to provide strong adsorption force, thereby achieving good seed filling effect and reducing the occurrence of missed sowing. However, excessive air pressure in the chamber can cause the phenomenon of replay. Therefore, when designing the parameters of the seeding disk, multiple factors should be considered to design a reasonable seeding device.

3.2 Parameter design of the metering disc

The metering disc is the core element responsible for stable high-speed pickup and controlled delivery; its dimensions therefore have a direct impact on singulation performance and overall sowing quality. The disc design is primarily governed by geometric features, including the disc outer diameter, the radial position of the suction orifices (i.e., the distance from each orifice centre to the disc centre), the orifice configuration (diameter and shape), and the total number of orifices distributed along the pitch circle.

3.2.1 Seeding disc diameter

The disc diameter is coupled with disc rotational speed and determines the circumferential (linear) velocity at the suction-orifice locations. The relationship between these variables can be expressed as follows.

$$D = \frac{v}{\pi \cdot n} \tag{18}$$

where: D - Diameter of seed discharge disc, mm

v - Linear velocity at the seed suction hole, m/s

n - Rotational speed of seed discharge disc, r/s

where the relationship between the forward speed of the planter and the rotational speed of the seed discharge disc is:

$$v_f = z_1 L_Z n \tag{19}$$

where: v_f - forward speed of the planter, m/s

z_1 - number of seed suction holes

L_Z - spacing of sowing plants, take 180 mm

Combining formula (18) and formula (19) to get the diameter of the seed discharging disc is calculated as follows

$$D = \frac{z_1 L_Z v}{\pi v_f} \tag{20}$$

To support high-speed peanut sowing, the target operating range of the planter forward speed is 8–12 km·h^{-1}, with a nominal in-row spacing of 180 mm per seed. For the air-suction metering disc, the circumferential velocity at the suction orifices should be limited; the maximum allowable linear speed at the orifice pitch circle is taken as 0.35 m·s^{-1}. Using Eq. (20), the feasible diameter of the suction-orifice pitch circle is calculated to fall within 150–225 mm. Increasing disc size generally lowers the required rotational speed for a given forward speed, which helps mitigate excessive centrifugal effects during pickup, improves seed retention, and reduces misses. Nevertheless, an overly large disc increases the load on the suction source and can raise fan power demand [17-20]. Considering these trade-offs, the pitch-circle diameter of the suction orifices was set to 182 mm. In addition, based on the overall layout of the metering unit and agronomic requirements, the disc outer diameter-typically selected in the 140–260 mm range-was finally specified as 210 mm.

3.2.2 Suction-orifice design of the metering disc

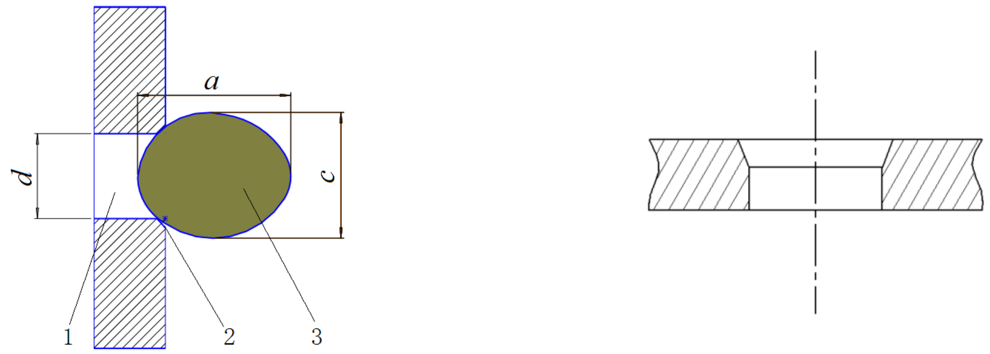
The suction-orifice configuration is characterised by two primary aspects: the orifice diameter and the geometric form of the opening (e.g., profile/edge and internal shape). Orifice diameter plays a decisive role in vacuum pickup because it directly influences the attainable holding force under a given chamber pressure. For peanut seeds, an appropriate diameter can be estimated from seed size to ensure reliable single-seed capture while avoiding excessive multi-seed pickup. The relationship between the orifice diameter and seed dimensions is given below.

$$d = (0.64 \sim 0.66) b \tag{21}$$

where: d - diameter of seed suction hole (mm)

b - width of seed (mm)

As peanut seeds are large in size and require greater adsorption, the larger the diameter of the seed suction hole, the better the adsorption effect of the seeds, but to ensure that the seed particles are not sucked into the seed suction hole and clog the hole, the diameter of the suction hole should be smaller than the minimum of the three axes of peanut seed size (see Fig. 5).



(a) Structure (b) Shape drawing

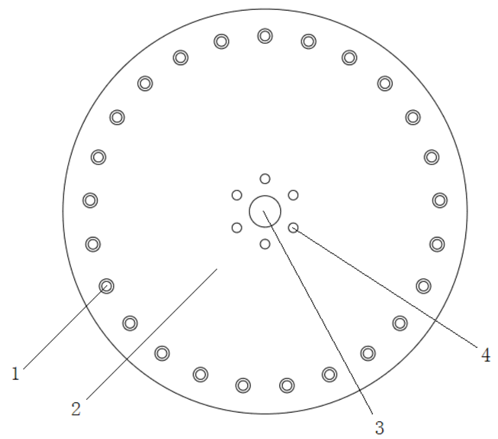
1. Type hole; 2. Seed suction hole; 3. Peanut seed

Figure 5: Shape drawing of the structure of the seed suction hole

Based on the geometric measurements in Fig. 5(a,c), the peanut seed width b was determined to fall within 8–12 mm. Substituting this range into Eq. (22) yields an admissible suction-orifice diameter of 5.2–7.9 mm. Considering that the orifice must provide sufficient holding force while avoiding excessive contact stress and mechanical injury to the seed, a preliminary diameter of 7 mm was selected. To further mitigate surface damage and improve pickup stability, the adsorption-side edge of the suction orifice was designed with a rounded entrance (filleted corner), as illustrated in Fig. 5.

3.2.3 Number of suction orifices

The number of suction orifices on the metering disc is a key design variable because it governs both disc rotational speed (for a given planting speed and target spacing) and metering throughput (Fig. 6). Under identical operating conditions, a smaller orifice count requires a higher disc speed to meet the discharge demand, which increases centrifugal effects during rotation and can promote premature seed detachment, leading to missed seeding. Therefore, the orifice count should be increased within the constraint of normal singulation and smooth discha



1. Seed suction holes 2 Seed discharge disc 3 Shaft holes 4 Mounting holes

Figure 6: Schematic structure of seed discharge disc

The formula for calculating the number of seed suction holes in the seed discharge disc is

$$Z = \frac{\pi D(1+\delta)}{i_p S} \tag{22}$$

where: Z - number of seed suction holes (pcs);

D - drum diameter, mm;

δ - drum slip coefficient;

i_p - transmission ratio;

S - sowing spacing, mm.

Considering the overall metering capacity and operating stability, the metering disc was conFig.d with 25 suction orifices (Fig. 6). The final disc has an outer diameter of 210 mm and a thickness of 1.6 mm. The orifice centres lie on a pitch circle with a radius of 91 mm, and the 25 orifices are evenly distributed along the circumference.

3.3 Air-chamber structure design

The vacuum chamber is a critical component of the air-suction metering unit because seed pickup is achieved primarily by the pressure differential across the suction orifices. Accordingly, the chamber should deliver a uniform and stable vacuum field to minimise spatial variation in suction force and to maintain consistent singulation performance. The chamber layout is presented in Fig. 7. In addition, an auxiliary suction port is incorporated to enhance the effective vacuum level in the chamber and facilitate vacuum regulation, thereby improving seed retention at the disc orifices.

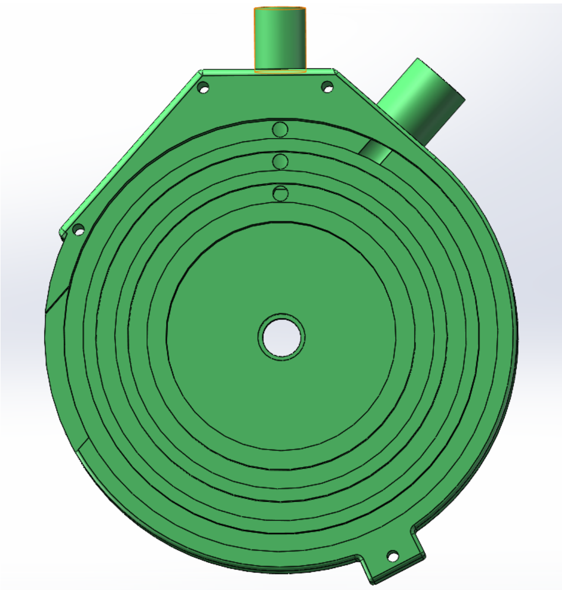


Figure 7: Internal structure of air chamber

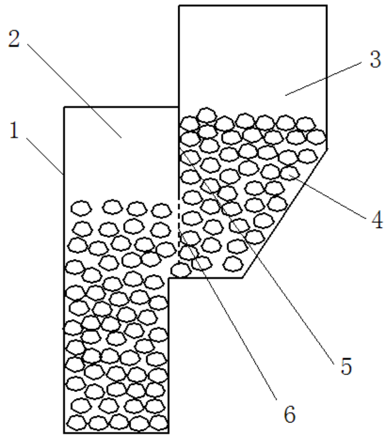
3.4 Air chamber air pressure

Whether the seed discharger can achieve precision seed discharge at high speed has a direct relationship with the air chamber air pressure, the size of the air chamber air pressure is the key factor in deciding whether the seed discharger can achieve precision seed discharge at high speed, so the air chamber air pressure is an important parameter of the seed discharger.

Air chamber critical air pressure can be obtained by formula (18). Where P - air chamber critical air pressure value, kg.cm-2; in the maximum limit conditions, $\cos\beta = 1$; reliability coefficient K_1 value range of 1.8 ~ 2.0, environmental reliability coefficient K_2 value range of 1.6 ~ 2.0; peanut seed specific parameters into the formula (18), can get the critical air pressure value of the air chamber. In order to adsorption force at the seed suction hole can firmly adsorb the seed, the actual value of air pressure in the air chamber must be greater than P. According to the above theoretical analysis, and taking into account the characteristics of the peanut seed itself as well as the influence of the impact and vibration of the seeds, the final determination of the range of air pressure in the air chamber of the seed discharger is 4 kpa ~ 6 kpa.

3.5 Seed chamber structure design

The seed chamber plays a critical role in the performance of the metering unit. In practice, the chamber can be regarded as comprising a seed reservoir and a local seed-feeding region adjacent to the pickup zone. The seed-layer height in this feeding region strongly affects discharge quality. If the layer is too shallow, seeds may not adequately contact the disc, increasing the likelihood of missed pickup and resulting in miss-seeding. Conversely, an excessively deep layer raises the normal load and friction between seeds and between seeds and the disc, which can promote seed damage or breakage. To maintain an appropriate and stable seed-layer height, an adjustable baffle plate was designed. The adjustment mechanism is illustrated in Fig. 8.



1. Seed filling area; 2. Seed discharging disc; 3. Seed layer height adjusting area; 4. Seed layer height adjusting plate; 5. Peanut seed; 6. Seed chamber

Figure 8: Schematic diagram of the seed chamber structure

4 Bench test

4.1 Test method

Previous studies indicate that the performance of an air-suction peanut high-speed metering device is primarily influenced by the chamber vacuum level, planter forward speed, and suction-orifice diameter [21]. Accordingly, these three variables were selected as experimental factors to quantify their effects on metering quality. The factor ranges were set as follows: forward speed 8–12 km·h⁻¹, chamber vacuum 4–6 kPa, and suction-orifice diameter 6–8 mm. The response variables were the qualified single-seed pickup rate, miss-seeding rate, and multiple-seeding rate. A three-factor, three-level orthogonal experimental scheme was adopted, and the coded factor levels are listed in Table 1.

Table 1: Coding of test factors

Code	Test factor		
	Forward speed km/h	Suction hole diameter mm	Negative pressure of seed disc kPa
-1	8	6	4
0	10	7	5
1	12	8	6

All indices were calculated in accordance with GB/T 6973–2005 (Test method for single-grain/precision seeders) [22]. For each run, 251 observations were recorded. Each condition was tested three times, and the average of the three runs was reported. The qualified pickup rate was calculated as the number of single-seed pickups divided by 251. The miss-seeding (leakage) rate was calculated as the number of missed pickups divided by 251. The multiple-seeding (reseeding) rate was calculated as the number of pickups with two or more seeds divided by 251.

4.2 Analysis of test results

Using the qualified rate, miss-seeding rate, and multiple-seeding rate as evaluation criteria, the experimental results were analysed to assess the significance and contribution of each factor to metering performance. The orthogonal test plan and corresponding results are summarised in Table 2.

Table 2: Experimental programme and results

Test number	Experimental factors			Pass rate	Missed sowing rate	Reseeding rate
	x_1	x_2	x_3	%	%	%
1	12	7	4	91.15	7.83	1.02
2	10	7	5	94.39	4.52	1.09
3	8	7	4	89.77	5.12	5.11
4	12	8	5	91.85	6.53	1.62
5	10	7	5	94.43	4.23	1.34
6	10	6	4	91.59	5.09	3.32
7	10	7	5	94.26	4.12	1.62
8	10	8	6	92.07	4.11	3.82
9	10	8	4	91.69	4.86	3.45
10	12	7	6	93.14	5.59	1.27
11	12	6	5	91.31	6.88	1.81
12	10	7	5	94.11	4.18	1.71
13	8	6	5	91.08	4.09	4.83
14	8	8	5	91.11	4.26	4.63
15	8	7	6	91.12	3.75	5.13
16	10	7	5	93.46	4.73	1.81
17	10	6	6	92.24	4.03	3.73

4.3 Regression modelling and significance testing

An analysis of variance (ANOVA) was performed to evaluate factor effects and model adequacy. The experimental dataset was then processed in Design-Expert 12.0 to develop multiple regression relationships between the three input variables-planter forward speed, chamber vacuum (negative pressure), and suction-orifice diameter-and the three performance responses (qualified rate, miss-seeding/leakage rate, and multiple-seeding/replanting rate). The fitted equations quantify how each factor contributes to the responses. Based on the regression results, the model for response Y_1 is expressed as follows:

$$\begin{aligned} &Y_1 = 93.09 - 2.57x_1 + 0.4075x_2 + 0.4275x_3 \\ &+0.1325x_1x_2 - 0.2175x_1x_3 + 0.1025x_2x_3 \\ &+0.3312x_1^2 - 1.19x_2^2 - 1.26x_3^2 \end{aligned}$$

By fitting a multiple regression to the experimental data, the regression model for the effect of each experimental factor on the leakage rate Y_2 was obtained as

$$\begin{aligned} &Y_2 = 4.36 + 1.19x_1 - 0.0425x_2 - 0.6625x_3 \\ &-0.1325x_1x_2 - 0.2475x_1x_3 + 0.0775x_2x_3 \\ &+1.08x_1^2 + 0.0032x_2^2 + 0.1633x_3^2 \end{aligned}$$

By fitting a multiple regression to the experimental data, the regression model for the effect of each experimental factor on reseeding rate Y_3 was obtained as

$$\begin{aligned} &Y_3 = 1.51 - 1.57x_1 - 0.02x_2 + 0.1312x_3 \\ &+0.0575x_1x_3 - 0.01x_2x_3 + 0.6318x_1^2 \\ &+1.08x_2^2 + 0.9867x_3^2 \end{aligned}$$

4.4 Optimisation and verification of optimal parameter combination

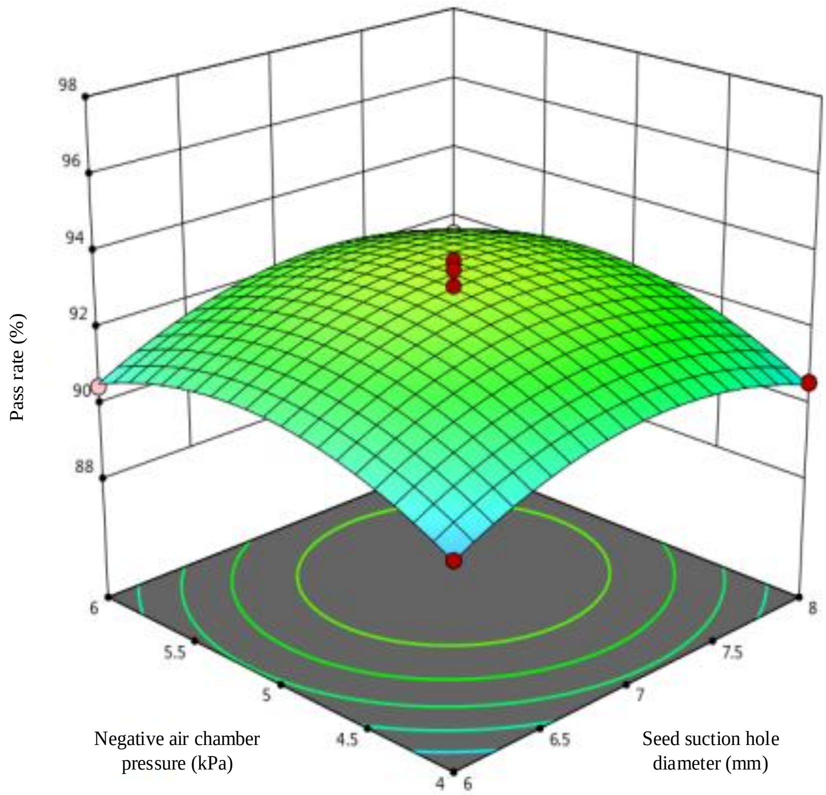
Following the multi-index optimisation strategy reported by Dong et al [23, 24] and Zhao et al [25] for high-speed precision metering devices, this study sets three joint optimisation targets. The qualified rate is expected to be as high as possible, while both the miss-seeding rate and the multiple-seeding rate are expected to be as low as possible. Multiple regression models were established using planter forward speed, the negative pressure in the metering chamber, and suction-orifice diameter as the key influencing factors. The fitted models were then interpreted using response surface methodology to evaluate main effects and interaction effects, and the best parameter set was searched under the predefined operating ranges. The factor ranges were set as follows. Planter forward speed was 8 to 12 kilometres per hour, chamber negative pressure was 4 to 6 kilopascals, and suction-orifice diameter was 6 to 8 millimetres.The corresponding objective function and constraints can be expressed as follows:

$$\begin{cases} \max Y_1(x_1,\ x_2,\ x_3) \\ \max Y_2(x_1,\ x_2,\ x_3) \\ \max Y_3(x_1,\ x_2,\ x_3) \\ s.t. \begin{cases} 8km/h \le x_1 \le 10km/h \\ 6mm \le x_2 \le 8mm \\ 4kpa \le x_3 \le 6kpa \end{cases} \end{cases}$$

An NSGA-II based optimisation procedure was applied to the regression models to obtain the preferred parameter combination. The selected optimum corresponded to a planter forward speed of 8.617 kilometres per hour, a chamber negative pressure of 5.816 kilopascals, and a suction-orifice diameter of 7.02 millimetres. Under this condition, the qualified rate reached 94.86 percent, the miss-seeding rate was 3.49 percent, and the multiple-seeding rate was 1.65 percent, meeting the requirements for high-speed precision peanut sowing.

4.5 Effect of factor interaction on performance indices

To clarify how interactions influence performance at higher travelling speed, the experimental data were further processed to visualise the combined effects of suction-orifice diameter and chamber negative pressure on the qualified rate, the miss-seeding rate, and the multiple-seeding rate. The corresponding response surface plots are provided in Fig. 9, which helps identify the regions where parameter coupling becomes prominent and supports practical parameter selection.



(a)

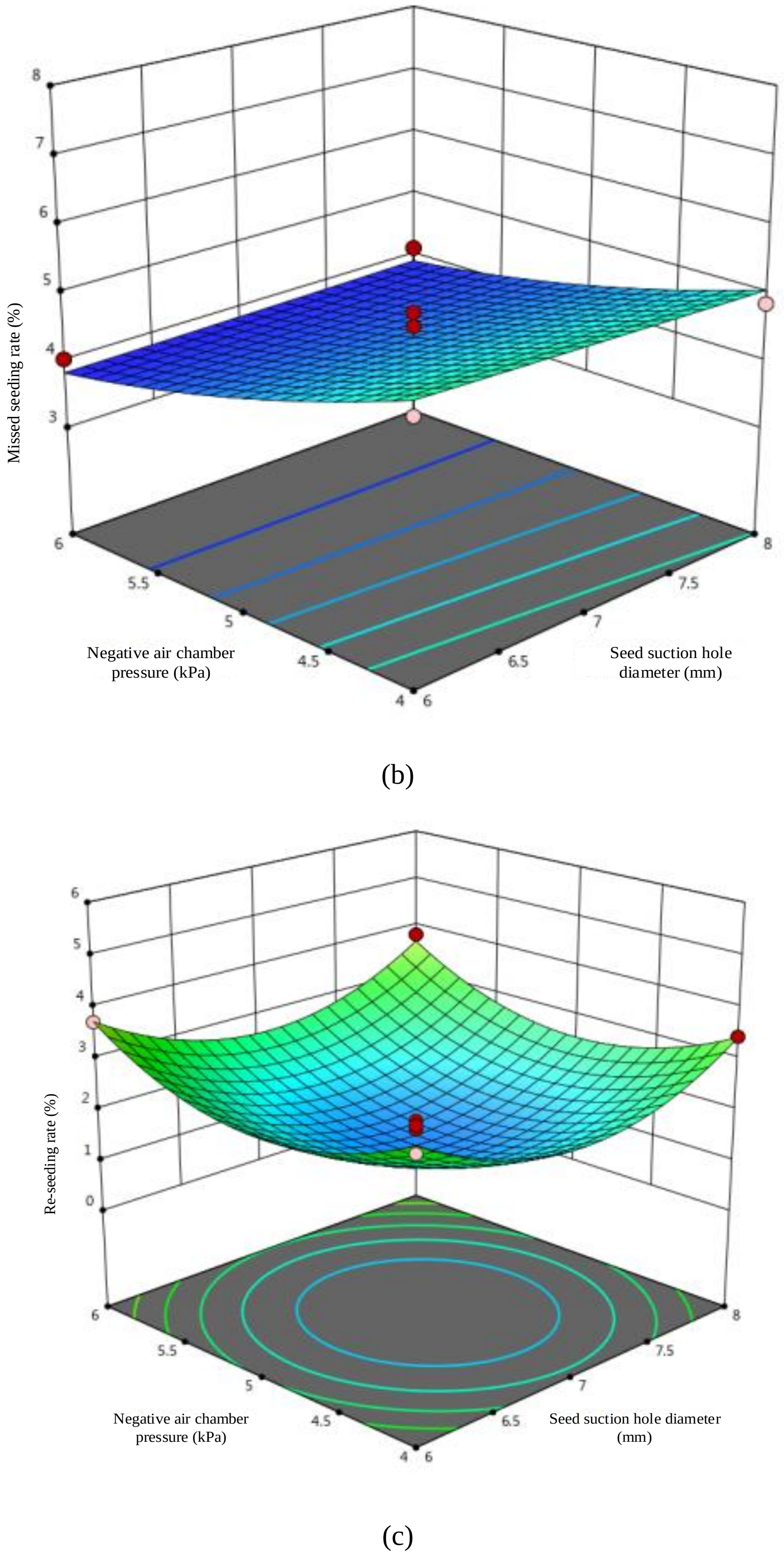


Figure 9: Response surface for the effect of factor interaction on each test indicator

Fig. 9 summarises the two-factor response surfaces obtained by holding the remaining factor at its centre level. With planter forward speed fixed at the centre setting, Fig. 9(a) illustrates the combined influence of chamber negative pressure and suction-orifice diameter on the qualified rate. The qualified rate exhibits a non-monotonic pattern with respect to chamber vacuum: it rises and then falls, with a favourable region around 5 kPa. Insufficient vacuum weakens seed retention and increases misses, whereas excessive vacuum promotes multiple pickup, both of which reduce the qualified rate. A similar "increase–decrease" tendency is observed for orifice diameter under a fixed vacuum. Too small a diameter provides inadequate holding force and increases misses; too large a diameter can reduce effective suction due to imperfect sealing at the seed–orifice interface, which may also lead to misses and a lower qualified rate.

Fig. 9(b) shows the interaction of chamber vacuum and orifice diameter on the miss-seeding (leakage) rate at the same centre speed. For a given orifice diameter, the miss-seeding rate decreases as the chamber vacuum increases, consistent with stronger suction improving seed pickup stability. In comparison, variation in orifice diameter produces a relatively smaller change in the miss-seeding rate within the tested range when vacuum is held constant.

Fig. 9(c) presents the corresponding response surface for the multiple-seeding (reseeding) rate. At a fixed vacuum level, the multiple-seeding rate generally decreases first and then increases as orifice diameter increases. The low multiple-seeding region occurs near a chamber vacuum of about 5 kPa and an orifice diameter of approximately 7 mm.

5 Conclusion

(1) To improve the sowing quality of an air-suction peanut high-speed planter, an air-suction high-speed precision metering device was developed. Key design parameters-including metering-disc diameter, suction-orifice diameter, orifice number, and chamber vacuum level-were determined based on theoretical analysis and calculation.

(2) A three-factor quadratic orthogonal experiment was conducted to evaluate performance. Planter forward speed, chamber negative pressure, and suction-orifice diameter were selected as factors, while qualified pickup rate, miss-seeding (leakage) rate, and multiple-seeding (reseeding) rate were used as evaluation indices. The effects of the factors and their combined influences on the indices were then analysed.

(3) The preferred parameter set was identified as a forward speed of 8.617 km per hour, a chamber negative pressure of 5.816 kilopascals, and a suction-orifice diameter of 7.02 millimetres. Under these conditions, the qualified rate reached 94.86 percent, with a miss-seeding rate of 3.49 percent and a multiple-seeding rate of 1.65 percent, indicating satisfactory high-speed precision metering performance for peanuts.

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References

[1] Wang J, Hu M, Xia J, Zheng K, Du J, Liu Z, Zhou M. Design evaluation and performance analysis of the inside-filling air-assisted high-speed precision maize seed-metering device[J]. Sustainability, 2021, 13(10): 5483.

[2] Liu R, Liu Z, Zhao J, Lu Q, Liu L, Li Y. Optimization and experiment of a disturbance-assisted seed-filling high-speed vacuum seed-metering device based on DEM–CFD[J]. Agriculture, 2022, 12(9): 1304.

[3] Guo P, Sun B, Shang S Q, Hou J L, Wang D W, Zhao Z, Elshafie A, Zheng X S, Eltoum F. Effect of auxiliary air-suction seed-filling structure on seed discharge performance of peanut high-speed seed-metering machine[J]. Agriculture, 2025, 15(15): 1678.

[4] Guo P, Shang S Q, Zheng X S, Hou J L, Zhang J, Yan H, Ding Y, Eltom F, Wang D W. Design of a seed-pressing mechanism for precision peanut planters and verification of optimal operating parameters under high-speed seeding conditions[J]. Agriculture, 2025, 15(21): 2246.

[5] Guo P, Liu Y, Salem M, Yan H, Xia C, Xia G, El-Shafie A, Wang D. Design and experiment of a peanut seeding device for synchronous hole fertilization and directly-above seeding[J]. INMATEH – Agricultural Engineering, 2025, 75(1): 1084-1096.

[6] Yu Y, Hu Y R, Shang S Q, Diao L S, Ge R C, Zhang X. Design of motor-driven

precision seed-metering device with improved fuzzy PID controller for small peanut planters[J]. International Journal of Agricultural and Biological Engineering, 2023, 16(1): 136-144.

[7] Zhao X, Sun B, Shang S Q, Diao L S, Zhao H, Tang J. Design and experiment of the double-seed hole seeding peanut seed-metering device[J]. International Journal of Agricultural and Biological Engineering, 2022, 15(3): 107-114.

[8] Yu Y, Tan X, Li G, et al. Design and experiment of an online monitoring system for peanut seeding parameters based on the Internet of Things[J]. International Journal of Agricultural and Biological Engineering, 2025, 18(3): 186-194.

[9] Yu Y, Tan X, Li G, et al. Development of the peanut precision fertilization control system based on threshold velocity algorithm[J]. International Journal of Agricultural and Biological Engineering, 2022, 15(5): 116-122.

[10] Da Costa E, Yazgi A. Mathematical modeling and optimization of seed metering unit performance in precision peanut seeding[J]. Applied Sciences, 2024, 14(17): 7525.

[11] Karayel D, Güngör O, Šarauskis E. Estimation of optimum vacuum pressure of air-suction seed-metering device of precision seeders using artificial neural network models[J]. Agronomy, 2022, 12(7): 1600.

[12] Li M, Chang X, Gu Y, Wang P, Shang S. Design of dynamic deep sowing system for peanut planter with double-loop feedback fuzzy PID control[J]. Agriculture, 2025, 15(8): 808.

[13] Tang H, Xu F, Guan T, Xu C, Wang J. Design and test of a pneumatic type of high-speed maize precision seed-metering device[J]. Computers and Electronics in Agriculture, 2023, 211: 107997.

[14] Ding L, Yuan Y, Dou Y, Li C, He Z, Guo G, Zhang Y, Chen B, Li H. Design and experiment of air-suction maize seed-metering device with auxiliary guide[J]. Agriculture, 2024, 14(2): 169.

[15] Li J, Huang Z, Jiang Y, Cui Z, Zhang M, Zang Y, Qin W. Design and test of a precision air-suction maize seed-metering device for plot planting based on CFD–DEM coupling[J]. Computers and Electronics in Agriculture, 2025, 238: 110888.

[16] Han D, Liu H, Guo L, Fu L, Tang S. CFD–DEM coupling analysis of the negative pressure inlet structure of an air-suction seed-metering device for maize[J]. Frontiers in Plant Science, 2025, 16: 1485710.

[17] Chen J, Deng S, Feng Y, Cheng X, Wang X, Zhang X, Wei Z. Development of high-speed precision maize metering device for dense planting pattern with standard ridge[J]. Frontiers in Plant Science, 2024, 15: 1452699.

[18] Sun Y, Guo J, Shi L, et al. Design and parameter optimization of air-suction wheel type seed-metering device with elastic pad for maize[J]. International Journal of Agricultural and Biological Engineering, 2024, 17(4): 116-127.

[19] Deng S, Feng Y, Cheng X, Wang X, Zhang X, Wei Z. Disturbance analysis and seeding performance evaluation of a pneumatic-seed spoon interactive precision maize seed-metering device for plot planting[J]. Biosystems Engineering, 2024, 247: 221-240.

[20] Hussain S, Chen Y, Yu X. Design optimization and aerodynamic investigations of air suction seed metering systems through CFD–DEM approach[J]. Smart Agricultural Technology, 2025, 12: 101082.

[21] Gao X, Xie G, Li J, Shi G. Design and validation of a centrifugal variable-diameter pneumatic high-speed precision seed-metering device for maize[J]. Biosystems Engineering, 2023, 227: 161-181.

[22] Gao X, Xie G, Xu Y, Yu Y, Lai Q. Design and experiment of quantitative seed-feeding wheel of air-assisted high-speed precision seed-metering device[J]. Agriculture, 2022, 12: 1951.

[23] Dong J, Zhou B, Yang J, Zhang S, et al. Design and testing of a posture-adjusting precision metering device for high-speed maize planting[J]. Frontiers in Plant Science, 2025, 16: 1458597.

[24] Dong J, Zhao H, Zhou J, Liu H, Wei G, Zhang F, Yao Z. Development of a novel perforated type precision metering device for efficient and cleaner production of maize[J]. Journal of Cleaner Production, 2024, 443: 140928.

[25] Zhao P, Gao X, Su Y, Xu Y, Huang Y. Investigation of seeding performance of a novel high-speed precision seed metering device based on numerical simulation and high-speed camera[J]. Computers and Electronics in Agriculture, 2024, 217: 108563.