EXPERIMENT AND PARAMETERS OPTIMIZATION OF SEED DISTRIBUTOR OF MECHANICAL WHEAT SHOOTING SEED-METERING DEVICE

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机械式小麦射播排种器分种装置参数优化与试验

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ABSTRACT

In order to solve problems of lower seed-filling stability and wheat seed damage of mechanical shooting seed-metering device, the filling structure of the shooting device was optimized. The effects of seed movement were obtained through analysing the kinematics and dynamics of wheat seed through seed distributor. The influence factors were the inner diameter of seed distributor, the rotational speed of seed distributor and the inclination angle of distributor window. The discrete element software (DEM) was used to simulate the motion process to explore the different factors on the wheat seeds' movement characteristics in the shooting device. The coefficient of variation of shooting uniformity and shooting speed of wheat seed were selected as test indicators. A verification experiment was conducted, and a high-speed camera was taken to obtain wheat seed's movement and shooting speed. The verification test showed that the constant uniform variation coefficient of seed amount and average shooting depth was 8.6% and 32 mm, respectively.

摘要

针对机械式小麦射播排种器充种效果较差，导致播种均匀度、排种稳定性不佳的问题，对排种器分种结构进行优化，通过对小麦种子经过分种装置时的运动学与动力学分析，得出影响种子运动状态的因素，并对分种轮的结构参数进行优化，采用开口侧壁后倾形式以提升充种效果，并结合 EDEM 软件对排种器的充种、排种过程进行仿真试验。试验结果表明：在内径为 125 mm，开口倾斜角度为 25°，转速为 1100 r/min 时，排种量均匀度变异系数为 8.6%，排种速度为 34.7 m/s，平均播种深度为 32 mm，满足华北地区小麦播种作业要求。

INTRODUCTION

Wheat is one of the important crops in China, which has widely distributed planting area and yield production, and ranks no.2 in the production of crops. As one of the main grain production bases in China, North China plain covers an area of 6 million hectares for winter wheat (*Olaf E. et al, 2008, Bassu S. et al, 2009*). In the growth of wheat, planting quality is an essential process. Thus, the seeding effect of the planter has a crucial influence on the growth and wheat yield (*Cui Qingliang et al., 2001*).

Mechanical and precision vacuum seed-metering device were wildly used in wheat seeders. The seed was pressed on the hole under the action of the internal air pressure and filled in a vertical disc, which was wildly used for precision vacuum seed-metering device (*Ahmet Çelik et al., 2016*). The device was more efficient in plot area sowing operations. However, the seed filling and seeding uniformity were influenced largely during wheat sowing operations in field a*reas (Matin M A et al., 2014).* Some other wheat seeders were using mechanical seed metering devices. For instance, the grooved wheel seed-metering devices were generally used. The structures of seeders were simple, which can be conveniently adjusted. Specifically, the seeding uniformity and stability were worse than that of a pneumatic seed-metering device (*Li Chaosu et al, 2012*). Furthermore, a furrow opener cuts a furrow and allows seed or seedlings to be deposited before being covered with soil. The coverer installed on the rear of the seeder covered seedlings drilled from a seed-metering device (*Wang Chao et al, 2019*). Critical components of the seed-metering device and soil-touching parts such as coverers significantly influenced sowing performance (*Wang Chao et al, 2020*).

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This study aimed to improve the variation coefficient of seeding amount of a non-contact mechanical shooting seed-metering device. Seed could be accelerated by the blade and shot into the soil layer. In this study, the structure and parameter of seed distributor were optimized. A Central-Composite three-factor simulation experiment was also conducted to optimize the independent variables.

MATERIALS AND METHODS

ANALYSIS OF WHEAT SEED MOVEMENT

Structure and working principle

The overall structure of the seed-metering device is shown in Fig.1. It consists of a seeding tube, a device shell, a seed distributor, a seeding control cage, a rotating shaft and eight blades. The seed entered into the seed distributor through the seed tube, fell into the windows of seed distributor, and rotated with the seed distributor. While window of the seed distributor matched on the window of seeding control cage, wheat seeds were rotated into the inner cavity of shooting device, and moved along with blades at a high speed. Eight blades were evenly distributed on the surface of seeding control cage. Meanwhile, seeds were accelerated by blades, which causes seed being continuously and uniformly shot into the field. The rotational speed of blades was equalled to that of the rotating shaft because of the fixed connection among blades, turntable and shaft. The rotary speed of blades was adjusted by sprocket to adapt different operating speeds for wide-row wheat planting.

a) Side view of the shooting device; b) Inner view of the shooting device

Fig. 1 - Structure of shooting seed-metering device

1. Seeding tube; 2. Device shell; 3. Rotating shaft; 4. Seeding control cage; 5. Seed distributor; 6. Blade; 7. Shooting exit

Analysis of seed process

The seed metering device is a critical component in the sowing process, and has a significant impact on the seeding effect. The sowing process of the seed-metering device was divided into four working processes: seed cleaning, seed filling, seed carrying and seed shooting. The operation of filling and cleaning of mechanical shooting metering device was conducted by seed distributor and seeding control cage, which could constantly keep the number of wheat seed in rotation area. Furthermore, the carrying and shooting process was conducted by blade rotating at high speed. The state of seed movement was directly affected by seed movement through the seed distributor. Thereby, subsequent movement process and shooting performance were also affected.

Seed falls into the inner cavity of seed distributor for filling stage and moves out of seeding control cage. The structure of seed distributor is shown in Fig.2. The cleaning process was located in the window of seed distributor. The relative position relationship between seeding control cage and seed distributor is shown in Fig.3. Seed could move out of the seeding control cage through the seed distributor under a certain speed and position (*Zhang Boping, 1982*). The critical conditions were analysed to find the limited position of wheat seeds that could move out of the seeding control cage.

Fig. 2 - Structure of seed distributor

Fig. 3 - Relative position of seeding control cage and seed distributor

Initially, the linear motion equation of seed acceleration process inside the window of seed distributor was established. As shown in Fig.4, the radial direction of window was represented by the *X* axis.

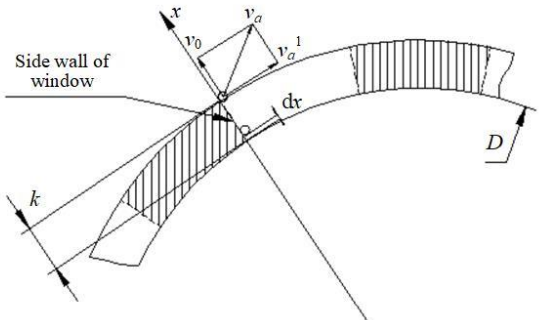


Fig. 4 - Model of seed movement on the window of seed distributor

The acceleration of wheat seed moving radially outward on the inner side of the window:

$$a = \frac{\mathrm{d}v}{\mathrm{d}t} = \frac{\mathrm{d}^2 x}{\mathrm{d}t^2} = \omega^2 (\frac{D}{2} + x) \tag{1}$$

where: ω is the rotational speed of seed distributor, rpm;

D is the diameter of seed distributor, mm;

a is the acceleration velocity of seed, m/s^2.

With initial conditions, the radial velocity when the seed moves to the outmost layer of seed distributor:

$$v_0 = \omega\sqrt{k^2 + kD} \tag{2}$$

where: v_0 is the radial seed velocity, m/s; k is the thickness of seed distributor, mm.

The speed is shown in Equation (3), while seeds move to the outer edge of seed distributor.

$$v_a = \sqrt{v_0^2 + (v_a{}^1)^2} = \omega\sqrt{2Dk + 2k^2 + \frac{D^2}{4}} \tag{3}$$

where: v_0 is the absolute velocity, m/s; $v_a{}^1$ is the tangential speed; m/s.

Analysis of seed cleaning process

Wheat seeds enter the rotation area in sequential order from the seed distributor, because wheat seeds were idealized as spherical particles for theoretical analysis afterward. Other seed particles could enter the window of seed distributor while all seeds in the window need to move out of the seeding control c*age (Jiang Qinghe 2001)*. Wheat seed collides with the end of sidewall of seeding control cage while moved out of seed distributor. The centroid of the seed coincides with intersection point B, a critical state where seeds could move out of the seeding control cage. The first and last seed moved out of seed distributor was seed at point A and point C, respectively. Moreover, point D is the position where seed and blade collided. Specifically, the whole process was the cleaning stage of sowing seed.

The radial velocity of seed while moving out of seed distributor was not affected by position, because the initial radial velocity of the seed was 0. The movement of the seed at extreme position C should be discussed. As shown in Fig.5, the angle β between its absolute velocity and radial velocity was shown in Equation (4).

$$\beta = \arccos\frac{v_0}{v_a} \tag{4}$$

The seed couldn't get into the rotation area and be accelerated since the motion angle of seeds moved to the seeding control cage was less than β. The seed on the left side needed to move a circle between the seeding control cage and seed distributor before moving into the rotation area. Thus, shooting performance was affected.

Therefore, Equation (5) needs to be satisfied:

$$\beta < \beta' \tag{5}$$

where:

β' is the angle between the radial direction and tangential direction of the seeding control cage, (°).

$$\beta' = \arctan[\frac{D}{2r} - \cos(\sqrt{(2r-D)2r} - 30°)] \tag{6}$$

The initial installation angle of the blade and seeding control cage is 30°. According to the geometric relationship, the last seed in the window could move out of directional seeding cage while the outer diameter *r* of the seed distributor was greater than 0.75 times the inner diameter. Therefore, all seeds in the window could move out of the seeding control cage while the seed distributor was rotated once.

The inner diameter *r* of the seed distributor was selected to be 0.75 to 0.85 times outer the diameter because the thickness of the seed distributor couldn't be too small.

The rotation angle of seed distributor (λ) was obtained in Equation (7) by geometric relationship.

$$\tan\lambda = l_{CD} / D \tag{7}$$

where: l_{CD} is the straight distance between two positions of C and D, mm.

Through analysis of Equation 7 and results, it can be concluded that all seeds could move out of the seeding control cage from the opening window of the seed distributor rotated within 30°.

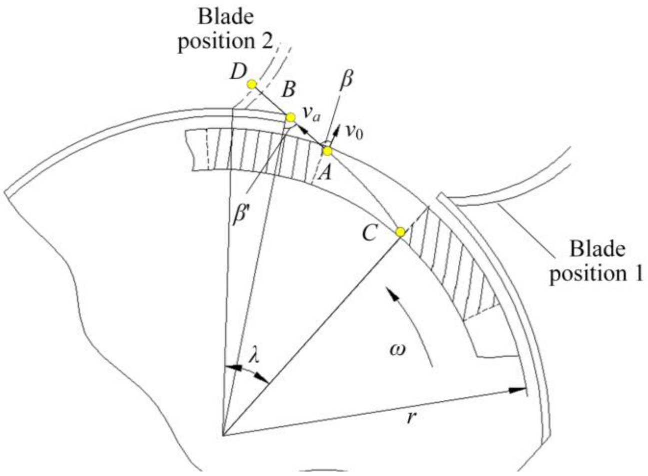


Fig. 5 - Model of seed movement at the limited position

Note: The dotted blade is the position of blade contact with the seed

Principle analysis of seed distributor on seed movement

Determination of the inner diameter of the seed distributor

Some seed particles could not move out of the seed distributor during a rotation process, which could affect the filling process and sowing performance caused by a smaller diameter of the seed distributor (*Zeng Hui, 1990*). The low sowing efficiency was also conducted by the larger diameter of the seed distributor. Therefore, seeds in the seed distributor window were analysed.

The first and last seed particle moved out of seed distributor was a_2 and b_1, respectively, which was two limited position seed (as shown in Fig.6 and Fig.7).

The tangential speed of the seed (a_2) moving out of the seed distributor is shown as Equation (8).

$$v_1 = \omega r \tag{8}$$

where: *r* is the outer diameter of seed distributor, mm.

The rotation angle of blade during the contact between wheat seed and blade was obtained in Equation (9).

$$\omega t = \theta + \delta \tag{9}$$

where: *t* is movement time while the wheat seed is in contact with the blade, s;

δ is the angle between sidewall of window and initial position (blade position 1) of the blade, (°);

θ is the angle between sidewall of window and the contact position of the blade, (°).

The rotation centre angle of seed (φ) from the initial point to contact point is shown in Equation (10).

$$\varphi = \omega t - (\gamma + \delta) \tag{10}$$

where: γ is the angle between two sidewalls of window, (°);

φ is the rotation centre angle of the seed, (°).

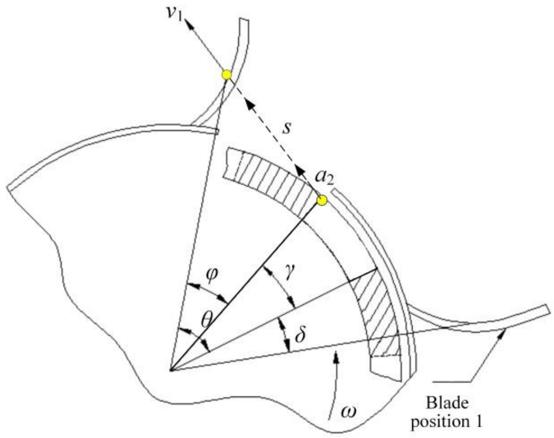


Fig. 6 - Seed movement process of a₂ position

Seed moved out of seed distributor and made a motion in a straight line. The movement distance of seed from the initial point to (a_2) the contact point is shown in Equation (11).

$$s{=}v_1 t = \omega t r \tag{11}$$

where: s is movement distance of the seed from the initial point to (a_2) the contact point, mm;

v_1 is the tangential velocity of the seed particle at a_2 position flying out of seed distributor, m/s.

The rotation angle of seed could be calculated by Equation (12) according to geometric relationship.

$$\tan\varphi{=}\frac{s}{r} = \omega t \tag{12}$$

The line speed at which seeds moved to the outermost side at position a_2 is shown in Equation (13).

$$v_{a1} = \sqrt{v_1^2 + 2\omega(r\omega - 2fv_1)(l - r_0)} \tag{13}$$

where: l is the radial position of wheat seed on the blade, mm;

f the coefficient of friction;

r_0 is position radius of wheat seed on the blade, mm.

The movement of seed inside the metering device was affected by the parameters of seed distributor. Thereby subsequent sowing effect was affected, according to analysis of Equation (11), (12) and (13), respectively.

Determination of outer diameter of seed distributor

In order to enhance the stability of shooting depth, seed velocity at the outer and inner layers of the window should be consistent. Therefore, seed velocity at two limited positions was analysed. The movement of seed of the rest of seed distributor was the same as the limited position.

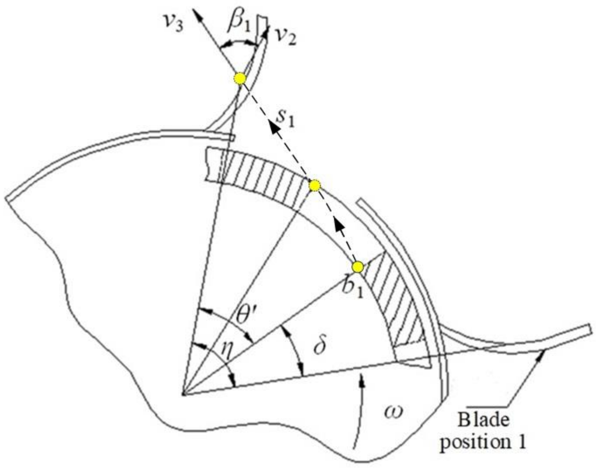


Fig. 7 - Seed movement process of b_1 position

As shown in Fig.7, the movement distance of the seed at inner layer of seed distributor moved to outer edge of seed distributor was the thickness of seed distributor (k). The tangential speed of seed at b_1 position while seed contacted with blade is shown in Equation (14).

$$v_2 = \omega\sqrt{s^2 + r(r - 0.75r)D} \tag{14}$$

The rotation angle of the blade is shown in Equation (15), while wheat seed was in contact with blade.

$$\eta = \sqrt{2(r - r_0)/r_0} \tag{15}$$

where: η is the rotation angle of blade, (°).

The rotation centre angle θ' of seed from the initial point (b_1) to the collision point is shown in Eq. (16).

$$\omega t = \theta' + \delta \tag{16}$$

where: θ' is the rotation centre angle of wheat seed from the initial point (b_1) to the collision point, (°).

The geometric relationship of the seed moved out of seed distributor is shown in Equation (17).

$$\frac{s_1}{\sin\theta'} = \frac{R_0}{\sin(\pi - \beta_1)} \tag{17}$$

where: β_1 is the angle between radial velocity and absolute velocity of wheat seed at position b_1, (°);

s_1 is the movement distance of seed from the initial point (b_1) to contact point, mm.

The absolute speed of seed motion at position b_1 to the outermost of shooting device was obtained by Equation (18).

$$v_{a2} = \sqrt{\omega^2 r^2 + 2\omega(r\omega - 2fv_2) + R^2} \tag{18}$$

where: R is rotation radius of the blade of seed metering device, mm.

Equation (13) and (18) show that two limited positions of seed move out of shooting device at same speed, while outer diameter (r) of seed distributor was 0.3 times the gyration radius (R) of the blade. Therefore, the outer diameter of that was determined to be 150 mm to ensure the shooting speed of seed at each position in seed distributor was consistent.

Optimization of structure parameters of seed distributor

The connection line between the centre point with upper and lower endpoints M and T of the seed distributor sidewall, respectively, was optimized into a non-collinear line. Therefore, a certain angle between MT and OM was conducted, which was shown in Fig.8. The direction of centrifugal force of seed was at a certain angle to sidewall of the seed distributor window.

The acceleration differential equation of motion for seed moves on sidewall with the inclination angle of α and acceleration velocity a_1, respectively, is shown in Equation (19).

$$a_1 = \omega^2[(\sqrt{\frac{D^2}{4} - (\frac{D}{2} + k)^2\sin^2\alpha} + x_0) - f(\frac{D}{2} + k)\sin\alpha] \tag{19}$$

where: α is the inclination angle of seed distributor window, (°);

x_0 is the distance between seed on the sidewall and the bottom line of the window of seed distributor, mm.

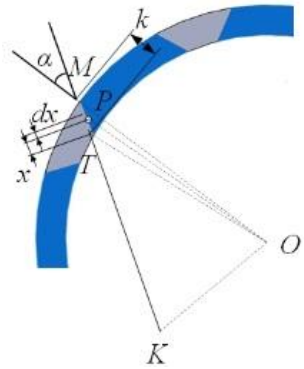


Fig. 8 - Seed movement form at the inclination window

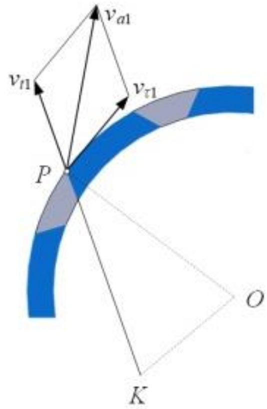


Fig. 9 - Speed diagram at the inclination window

The radial velocity v_{t1} of seed moving to the outer edge of seed distributor was obtained by Equation (20), according to the initial speed.

$$v_{t1}=\omega\sqrt{(2\sqrt{\frac{D^2}{4}-(\frac{D}{2}+k)^2\sin^2\alpha}+{x_0}^2)-2f(\frac{D}{2}+k)x_0\sin\alpha} \tag{20}$$

The sidewall of the opening window with inclined backward could increase the speed of seed under the same rotational speed, according to the analysis of Equation 20 and Fig.9.

Therefore, the shooting performance and shooting velocity were increased with an inclined backward window. The inclination angle (α) shouldn't exceed 45°, while combined with the overall size of window.

The factors that affect seed velocity out of seed distributor was the inner diameter of seed distributor (D), rotational speed of seed distributor (ω), and inclination angle of distributor window (α), which resulted from the analysis of Equation (18), (19) and (20), respectively. Thereby, the shooting performance was also influenced.

RESULTS

Simulation model

The model of seed was built with bonding particles, which because of seed shape was similar to an ellipsoid. The bulk density and 1000-seed weight were 780 kg·m^{-3} and 42.3 g, respectively. The average seed size was 5.1×2.3×2.1 mm. The soil model and seed model were established by EDEM *(Philippe Traoré et al, 2015*). The multiple seed-metering devices were conducted by SolidWorks.

The generation rate of seed particles was set as 5000 per second while the sowing rate was selected as 200 kg/ha.

The simulation parameters and characteristics (soil, steel and seed) were set as shown in Table 1 and Table 2 (*Lei Xiaolong et al, 2018*), in which the material of seed-metering device was set as steel.

Table 1

Simulation parameters

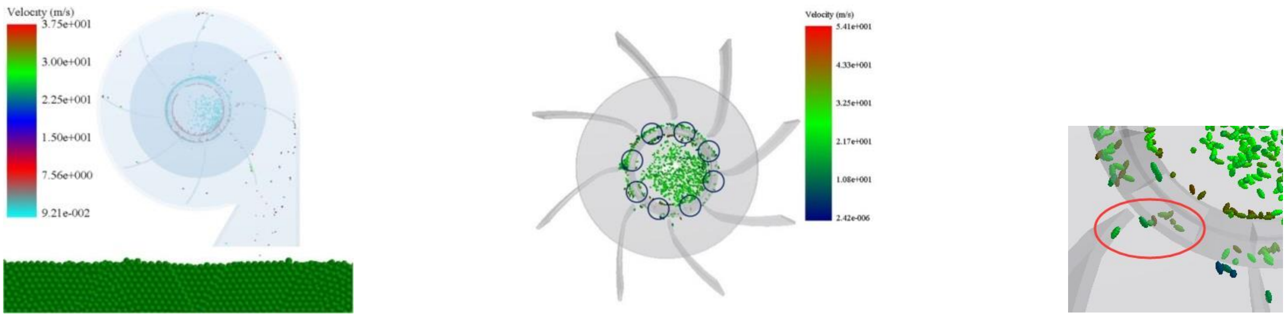
Items	Poisson's ratio	Shear modulus [Pa]	Density [kg·m^{-3}]
Wheat seed	0.4	5.1×10^7	780
Soil	0.4	1×10^6	1,350
Steel	0.3	7.8×10^{10}	7,850

Table 2

Simulation characteristics of soil and wheat seed

Items	Coefficient of static friction	Coefficient of dynamic friction	Coefficient of restitution
Seed-Soil	0.42	0.43	0.07
Seed-Seed	0.61	0.55	0.35
Soil-Soil	0.41	0.35	0.14
Seed-steel	0.40	0.40	0.10

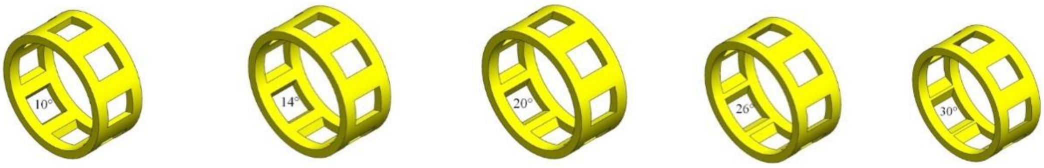
The wheat seed selected in red mark showed the seed moved out of seed distributor as shown in Figure 10c. The shooting process was shown in Fig.10a and Fig.10b.



a. Simulation process *b. Velocity map* *c. Enlarged view of window*

Fig. 10 - Simulation process for seed-metering device

The seed distributor with different inclination angles (10°, 14°, 20°, 26° and 30°) was shown in Fig.11.



a.10° b. 14° c.20° d. 26° e. 30°

Fig. 11 - Structure of seed distributor with different inclination angles

Experiment procedure and results

Experiment plan

A Central-Composite three-factor experiment was carried out to understand the interactions and optimize the independent variables. The factors and levels are shown in Table 3.

Table 3·

Experiment factors and levels

Levels	**Rotational speed of seed distributor x_1 [r·min^{-1}]**	**Inner diameter of seed distributor x_2 [mm]**	**Inclination angle of distributor window x_3 [°]**
+γ	1,200	130	30
+1	1,118	126	26
0	1,000	120	20
-1	882	114	14
-γ	800	110	10

In this study, the performance of the shooting seed-metering device was evaluated in terms of uniform variation coefficient of the seeding amount (*VCSA*), average shooting depth (*ASD*) and shooting velocity (*SV*), according to GB/T 9478-2005 "Test methods of single seed drills (precision drills)" in China.

The soil bin used for sowing in the simulation experiment was divided into ten areas in length (number 1 to 10), as shown in Fig.12. The shooting depth was the vertical distance between soil surface and bottom of shooting hole by high-speed seed. Five seeds were randomly selected in each area (total 50 seed) for the calculation of *ASD*.

The calculation equation was given in Equation (21):

$$h_0=\frac{1}{5}\times\frac{\sum_{i=1}^{50}h_i}{10} \tag{21}$$

where: h_0 is *ASD*, mm; h_i is shooting depth of seed number *i* (from number 1 to number 50), mm.

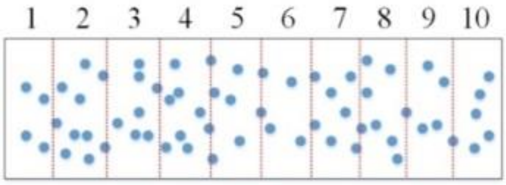


Fig. 12 - Schematic diagram of seed amount

The calculation equation for *VCSA* was given in Equation (22):

$$\lambda=\sqrt{\frac{1}{M}\sum_{i=1}^{M}(n_i-\xi)^2}\times100\% \tag{22}$$

where:

λ is *VCSA*, %;

n_i is seeding amount in seeding area number i (width 50 mm, length 200 mm);

ξ is the average amount in five seeding areas;

M is the total number of all seeding areas, M=5.

The *SV* was captured by a post processor of EDEM. 50 seeds were randomly selected in each experiment for calculation.

The test plan and experiment data are shown in Table 4.

Table 4·

Test plan and experimental data

Test No.	Rotational speed of seed distributor x_1 [rpm]	Inner diameter of seed distributor x_2 [mm]	Inclination angle of distributor window x_3 [°]	VCSA Y_1 [%]	SV Y_2 [m·s^{1}]
1	882	114	14	8.6	27.7
2	1.118	114	14	10.1	38.6
3	882	126	14	6.4	26.5
4	1.118	126	14	7.1	35.3
5	882	114	26	6.2	33.5
6	1.118	114	26	8.1	39.6
7	882	126	26	5.8	30.1
8	1.118	126	26	6.8	38.2
9	800	120	20	5.4	26.3
10	1200	120	20	10.4	37.7
11	1.000	110	20	8.3	35.5
12	1.000	130	20	5.2	30.3
13	1.000	120	10	7.8	32.4
14	1.000	120	30	6.3	36.7
15	1.000	120	20	7.2	33.6
16	1.000	120	20	6.9	32.5
17	1.000	120	20	8.3	33.8
18	1.000	120	20	7.2	31.6
19	1.000	120	20	8.4	33.4
20	1.000	120	20	7.5	33.9
21	1.000	120	20	7.7	32.8
22	1.000	120	20	8.4	33.9
23	1.000	120	20	8.0	34.4

Results analysis

As showed in Table 4 and Table 5, all parameters were significantly ($p < 0.01$) related to *VCSA*. The final regression math model was given in Equation (23):

$$\begin{aligned} Y_1 &= -76.847\,58 + 8.317\,90 \times 10^{-3} x_1 + 1.698\,70 x_2 \\ &\quad -1.581\,26 x_3 + 0.012\,374 x_2 x_3 - 8.730\,47 \times 10^{-3} x_2^2 \end{aligned} \tag{23}$$

Table 5·

Variance analysis for *VCSA*

Variation source		Sum of squares	df	Mean square	*F* value	*P* value
	Model	32.87/31.63	9/5	3.65/6.33	9.02/16.55	0.0003***/<0.0001***
	x_1	13.36/13.36	1/1	13.36/13.36	32.99/34.95	< 0.0001***/ < 0.0001***
	x_2	10.74/10.74	1/1	10.74/10.74	26.53/28.10	0.0002***/<0.0001***
	x_3	4.48/4.48	1/1	4.48/4.48	11.06/11.72	0.0055***/<0.0032***
	x_2x_3	1.53/1.53	1/1	1.53/1.53	3.78/4.01	0.0738*/0.0616*
	x_2^2	1.52/1.51	1/1	1.52/1.51	3.76/3.96	0.0747*/0.0629*
Residual	Lack of fit	2.67/3.90	5/9	0.53/0.43	1.64/1.33	0.2541/0.3479
Total		38.13/38.13	22/22			

SV was an essential indicator for sowing performance and shooting depth of the shooting device.

As showed in Table 4 and Table 6, all parameters were significantly ($p < 0.01$) related to *SV*.

The final regression math model was given in Equation (24):

$$\begin{aligned} Y_2 &= 8.790\,32 + 0.051\,24 x_1 - 0.222\,22 x_2 + 0.602\,43 x_3 \\ &\quad -9.722\,72 \times 10^{-4} x_1 x_3 + 0.015\,567 x_3^2 \end{aligned} \tag{24}$$

Table 6·

Variance analysis for the coefficient of shooing velocity

Variation source	Sum of squares	df	Mean square	F value	P value
Model	271.57/269.55	9/5	30.17/53.91	31.44/63.22	<0.0001***/<0.0001***
x_1	206.25/206.25	1/1	206.25/206.25	214.89/241.87	<0.0001***/<0.0001***
x_2	23.84/23.84	1/1	23.84/23.84	24.84/27.96	0.0002/<0.0001***
x_3	30.8730.87	1/1	30.8730.87	32.16/36.20	<0.0001***/<0.0001***
x_1x_3	3.78/3.78	1/1	3.78/3.78	3.94/4.43	0.0687*/0.0504*
x_3^2	4.77/4.81	1/1	4.77/4.81	4.97/5.64	0.0441**/0.0295**
Residual Lack of fit	6.42/8.44	5/9	1.28/0.94	1.70/1.24	0.2410/0.3866
Total	284.05/284.05	22/22			

Figure 13 shows the effect of x_2 and x_3 on *VCSA*. The value was decreased with increasing x_2 and x_3. A larger inner diameter of the seed distributor led to a greater *VCSA*. In summary, a lower indicator value occurred within the range of 16° > x_3 < 25° of x_3, and 116 > x_2 < 125 mm of x_2, respectively.

Fig.14 shows the effect of x_1 and x_3 on the shooting velocity. The value was increased with increasing x_3 and increasing x_1, respectively. A greater indicator value occurred within the range of 18° > x_3 < 25° of x_3, and 976 > x_2 < 1120 rpm of x_1, respectively.

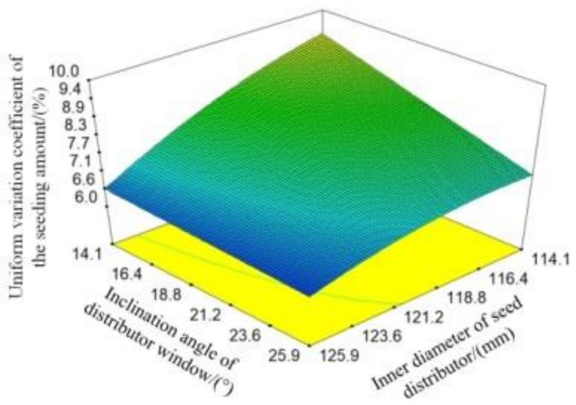


Fig. 13 - Response surface of *VCSA*

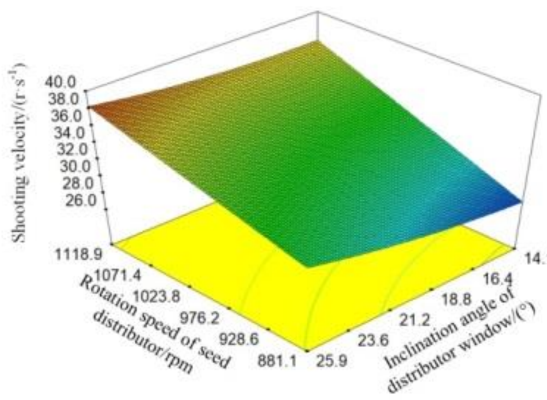


Fig. 14 - Response surface of *SV*

Design-Expert V8.0.6 was used for optimization analysis (*Păun A et al, 2018*). The optimization solution indicated that *VCSA* and shooting velocity was 7.9% and 36.8 m/s, respectively, while inner diameter, inclination angle of distributor window and rotational speed was 125 mm, 25° and 1,100 rpm, respectively.

Verified experiment

A validation experiment was conducted, in which a high-speed camera was used for calculation of *SV*. The shooting device was assembled by parts with resin material. The experiment process and photos captured by high-speed camera was shown in Figure 15 and 16.

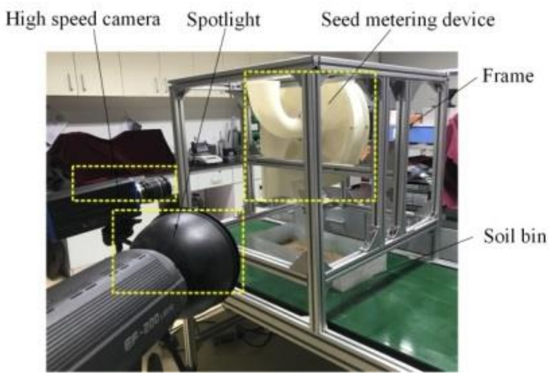


Fig. 15 - Bench experiment

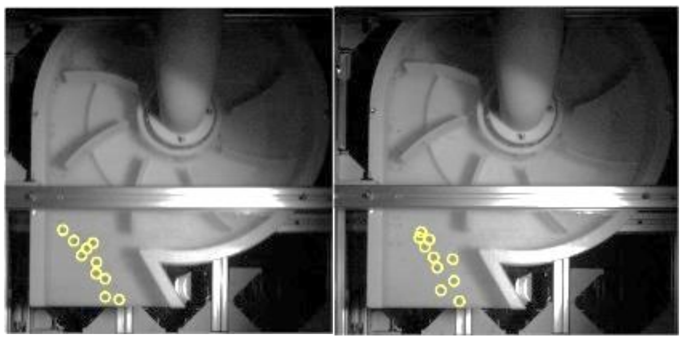
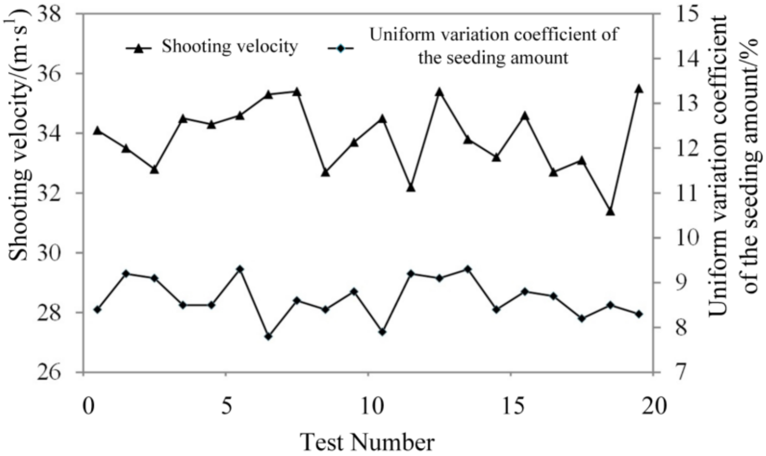


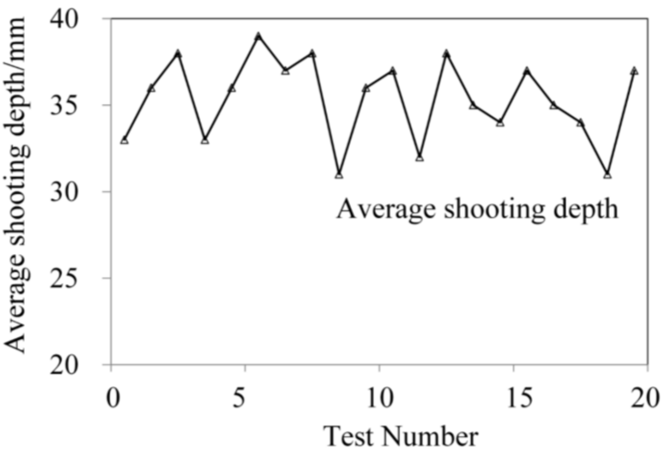
Fig. 16 - Analysis of high-speed camera picture

The experiment data under optimized parameters are shown in Fig.17.

The results show *SV*, *ASD* and *VCSA* were in the range of 32 to 36 m/s, 31 to 39 mm and 7% to 10%, respectively. Therefore, *ASD* was over 30 mm while shooting depth was over 30 m/s, which could achieve requirements for winter wheat sowing.



a. Shooting velocity and uniform variation of seed amount



b. Average shooting depth

Fig. 17 - Results of verification experiment

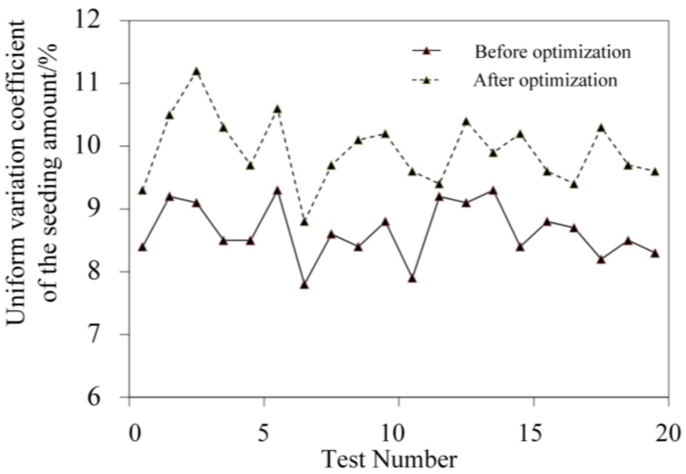


Fig. 18 - Results of the coefficient of uniform variation of seed amount before and after optimization

The results of seed metering device with two different seed distributors (before and after parameter optimized) was obtained in Fig.18. The results show *SV* and *VCSA* for the seed distributor with inclination angle was improved. Therefore, the *VCSA*, *SV* and *ASD* were 8.6%, 34.7 m/s and 32 mm, respectively. These results fully meet the sowing requirement in North China Plain.

CONCLUSIONS

1. In this study, the seed distributor of mechanical shooting seed-metering device was optimized. Theoretical analysis and two experiments were conducted to obtain the connections between factors and shooting performance. Furthermore, the operation parameters of the shooting device were optimized. The main conclusions were obtained. The speed of seed out of seed distributor and shooting performance were affected by the inner diameter of seed distributor (*D*), rotational speed of seed distributor (*ω*), and inclination angle of distributor window (*α*).

2. The shooting performance was primarily influenced by variations in the rotational speed of seed distributor x_1, inclination angle of distributor window x_2 and inclination angle of distributor window x_3.

3. The validation experiment was conducted as the inner diameter of the seed distributor, inclination angle of the distributor window, and rotational speed was 125 mm, 25° and 1,100 rpm, respectively. The results show that *VCSA*, *SV* and *ASD* were 8.6%, 34.7 m/s and 32 mm, respectively, which could meet the winter wheat planting requirements in North China Plain.

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