DESIGN AND EXPERIMENT OF ANNULAR AIR-BLOWING ASSISTED SEED GUIDING DEVICE FOR CORN NO-TILL SEEDER

/

玉米免耕播种机环形气吹辅助导种装置设计与试验

Haojie ZHOU[1)], Chunling ZHANG[*1 2)], Tao LIU[1)], Yazi WANG[1)], Jun FANG[1)], Antai HU[1)]
[1)] College of Engineering, Anhui Agricultural University, Hefei, Anhui, 230036, China
[2)]Engineering Laboratory of Intelligent Agricultural Machinery Equipment, Anhui, Hefei, 230036, China
Tel：+86-18715160995；E-mail：zhangcl@ahau.edu.cn
DOI: https://doi.org/10.35633/inmateh-73-04

Keywords: *air-blowing, auxiliary seed guide, seed guide tube, experiment, seed guide device*

ABSTRACT

In the process of seed introduction, there is a problem of seed falling disorderly due to the collision between the seed and tube wall, which seriously affects the uniformity of seed spacing in the field. To solve this problem, this paper designed a kind of annular air-blowing auxiliary seed guide device. After a series of simulation experiments, theoretical research, and high-speed camera bench experiments, the optimal parameter selected combination of the critical structure of the seed guide device. The experimental results showed that when the annular air-blowing assisted seed guide tube was used, the positive air pressure was 2 KPa, the airway angle was 150°, the airway outlet width was 12 mm, and the distribution pore diameter was 4 mm. When the forward speed was 6 km/h (the rotation speed of the seed metering disc was 25.30 rpm), the seed sowing effect was the best in the seed guide device; the qualified rate was 88.36%, and the coefficient of variation was 12%. This study provides a reference for improving seed spacing uniformity and can be used to optimize seed guide tubes.

摘要

导种过程中存在着因种子与管壁碰撞引起的种子无序下落的问题，此问题严重影响了种子在田间的粒距均匀性。针对此问题，本文设计了一种环形气吹辅助导种装置，经过一系列的仿真实验，理论研究，高速摄像 台架实验，选取导种装置关键结构的最优参数组合。实验结果表明采用环形气吹辅助导种管，正风压为 2 KPa，气道角度 150°、气道出口宽度 12 mm，分配气孔直径 4 mm，在前进速度为 6km/h(排种盘转速 25.30rpm)时种子在导种装置内，种播种效果最好到达最好，合格率达到 88.36%，变异系数 12%。导种效果好，该研究为提高播种粒距均匀性提供了借鉴，能够用于导种管的优化。

INTRODUCTION

Sowing operation is an essential primary link in agricultural production, and the precision seeding device is an integral part of realizing agricultural modernization (*Dayoub et al., 2021; Lei et al., 2021*). Accurate sowing position and grain spacing distribution are the key to proper sowing of corn. The value of precise positioning and seeding lies not only in saving seeds and reducing costs but also in improving the quality of seeding, making seedlings orderly, improving the utilization rate of light energy and soil power, and providing highly consistent operating objects for the midterm management and harvesting, to effectively improve the yield per unit area (*Liu et al., 2017; Huang, 2015; Liu, 2013*). Therefore, improving the uniformity of corn seed sowing has significant effects on the later growth and yield of corn. Scholars at home and abroad have conducted a series of studies on seed guide technology and device. For corn, a large grain crop, in the process of seed introduction, the seed guide device is required to restrict the movement of seeds, control the movement of seeds in three-dimensional space, and prevent the collision between seeds and seed guide tube, to meet the requirements of precision seeding.

After leaving the seed metering device, due to the inertia of the rotary table of the seed metering device, the seeds cannot fall along a straight line only by gravity. The collision between the seeds and the seed guiding device will be caused by the vibration and displacement of the machine. The results of Wang Qing's field experiment showed that as the forward speed increased, the vibration of the seeder became more intense, and the peak vibration acceleration became larger (*Wang et al., 2024*). Resulting in the longer migration time of the seeds in the seed guiding device.

Haojie Zhou, U.G. Stud.; Chunling Zhang, Lecturer; Tao Liu，M.S. Stud.; Yazi Wang, M.S. Stud.; Jun Fang, M.S. Stud.; Antai Hu M.S. Stud.

Wang Jinwu used high-speed photography and took the finger clip corn precision seeder as the research carrier. The test results showed that when the working speed was 15 rpm~45 rpm, and the tilt angle was 0 °, the lateral displacement of the seed front and side tracks increased with the increase of the working speed; When the working speed was more significant than 35 rpm, the seed trajectory and the position distribution of the falling point are gradually dispersed, and the coefficient of variation of plant spacing becomes larger; When the working speed is 30 rpm and the tilt angle is -12°~12°, the trajectory seed throwing angle decreases with the increase of the tilt angle (*Wang et al., 2017*). Sweden Vaderstad company is a high-speed planter that uses pneumatic projection technology to control the planting trajectory to achieve accurate planting. This falling method can reduce the collision between seed and seed metering tube and improve the precision of the seed dropping (*Chen et al., 2022*). Zhang Yunhe designed a pressure-holding precision seed-metering device for corn, which uses a guide plate to control the movement trajectory of corn seeds. The experimental results show that the device can effectively improve the accuracy of seed dropping (*Zhang et al., 2023*). Zhao Shuhong designed a corn seed guiding device that limits the seed pod's movement trajectory by combining the wrist seeder with the V-slot (*Zhao et al., 2018*). Li Yuhuan designed a straight-line seed-pushing device for air-suction corn metering device. The device is equipped with a straight-line seed-feeding device during the seed-feeding process. When the machine is working, the seeds arriving at the seed-pushing area will be pushed by the airflow, move downward straight away from the seed metering disc, and then quickly reach the seed bed along the seed guide tube (*Li et al., 2020*).

Kocher took the new and old seed guide tubes produced by John Deere company of the United States as the test object using its precision seeder to conduct a comparative test on the seeding performance. The results showed that the new seed guide tube's seeding performance was better, mainly caused by the smooth inner wall of the new seed guide tube and the rough inner wall of the old seed guide tube (*Kovher M.F. et al., 2011*). Yazgi studied the effect of different seed guide tube shapes on seed metering performance under various operating speeds and theoretical seed spacing test conditions. Regarding the seed metering qualification rate, the performance of a plastic bellows-type seed guide tube is much worse than that of a smooth metal surface (*Yazgi A., 2016*). Yatskul studied that the diameter of the pneumatic seed guide tube commonly used by foreign agricultural machinery enterprises (Horse, Kuhn, and John Deere) is mostly 20~30 mm, which can achieve a better sowing effect (*Yatskul A. et al., 2018)*. Endrerud used the combination of the seed guide tube and ditcher to conduct a numerical simulation to study how the kinetic energy of seed sliding from the seed guide tube is affected by the ditcher's diameter, inclination angle, and bending radius. The test shows that when the seed guide tube is tilted to 45°, the diameter does not affect on the energy loss. When the seed guide tube is divided into a smooth horizontal, inclined plane and smoothly transits to the shape of an arc curve, this time, the collision energy is minimized (*Endrerud H.C., 1999*).

Therefore, in order to improve the uniformity of corn planting spacing, a kind of annular air-blowing assisted seed guide device was designed in this paper. Through theoretical analysis and fluid numerical simulation, the key structural parameters were determined. The rationality and accuracy of the design were verified by bench test, and the optimal combination of operation parameters was obtained. This study can provide a theoretical basis and technical support for the innovative design of a corn precision seeding device.

MATERIALS AND METHODS

The following is a schematic diagram of seeds bouncing inside the seed guide tube. A new type of seed guide tube will be designed to avoid such bounce.

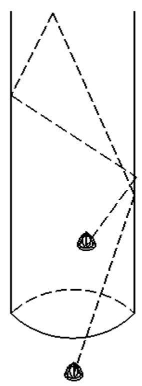


Fig. 1 - Schematic diagram of seed bouncing inside the seed guide tube

Whole structure design

The square cross-section seed guide tube was used as the research carrier, and the annular air-blowing auxiliary seed guide device was installed in the linear seed guide section. The annular air-blowing additional seed guide device mainly comprises an upper annular airway, inclined guide airway, fan airflow interface, distribution hole, and other components. The overall structure is shown in Fig. 2.

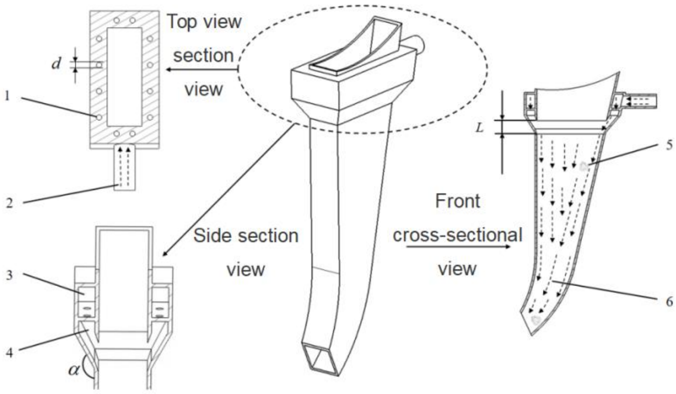


Fig. 2 - Overall and partial structure diagram of annular air-blowing auxiliary seed guide device

1 - distribution hole; 2 - air flow interface of fan; 3 - upper annular airway; 4 - inclined guide airway; 5 - corn grain; 6 - air flow direction
Note: α is the angle between the inclined guide airway and the tube wall of the seed guide tube, d is the diameter of the distribution pore, L is the width of the distribution airway

During the seeding operation, the annular air-blowing auxiliary seed guide device is installed on the precision seed metering device, and the airflow interface of the fan is connected to the supporting fan. After the fan sets a specific air pressure, the seed guide device continuously provides a high-speed stable air flow. After entering the upper annular airway, the airflow will fill the upper airway and then enter the lower inclined plane to guide the airway through the distribution hole. At this time, a uniform airflow will be formed in the seed guide device continuously downward along the inclined plane. The seeds distributed by the seed metering device migrate to the airflow area of the annular air-blowing auxiliary seed guiding device and scurry downward along the seed guiding tube curve under high-speed airflow. This device shortens the running time of seeds in the tube and reduces the number of collisions.

Design of key components

Inclined airway

When the seeds enter the air flow area of the seed guide device, they will be subjected to forces in different directions, and the force diagram is shown in Fig 3:

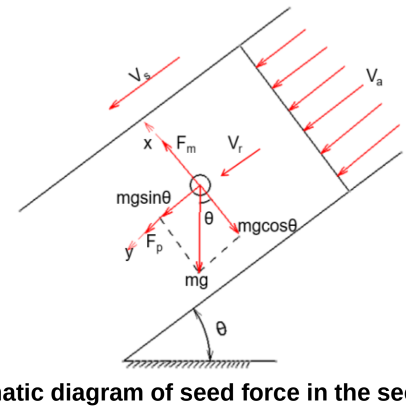


Fig. 3 - Schematic diagram of seed force in the seed guide device

Note: mg – Gravity; F_m - Magnus effect force; θ - air flow angle; v_r - relative velocity of seed and air flow; v_a - air velocity; v_s -seed velocity

According to the theory of gas-solid two-phase flow, the force acting on the corn seed in the air passage with an air flow angle of θ is:

$$F_p = \mu \rho S {v_r}^2 \tag{1}$$

where:

$$v_r = v_a + v_s \tag{2}$$

$$v_a = \frac{Q}{S_T} \tag{3}$$

where μ - resistance coefficient of corn seed, taking 0.22;

ρ - air density at normal temperature(20°C), taking 1.205 kg/m^3;

S - relative contact area between seed and air flow, m^2;

v_r - relative velocity of seed and air flow, m/s;

v_a - air velocity, m/s;

v_s - seed velocity, m/s;

Q - air flow, m^3/s;

S_T— cross-sectional area of seed guide device, m^2;

Force analysis of seed in seed guide device:

$$F_x = F_m - mgcos\theta \tag{4}$$

$$F_y = F_p + mgsin\theta \tag{5}$$

where: F_x – the force of seed in the vertical direction of seed guide device, N;

F_m— Magnus effect force, N; m— corn seed mass, kg;

g — acceleration of gravity, m/s^2;

F_y— the force of seed along the curve of seed guide tube, N.

Without contacting the tube wall of the seed guide tube, the force on the vertical movement direction of the seed is constrained by the pressure difference force and Magnus effect force generated by the airflow; under the joint action of airflow resistance and gravity component $mg.sin\theta$ along the direction of seed guide curve, the differential equation of seed motion is obtained from cameral principle:

$$\frac{dv_{sx}}{dt} = \frac{F_m}{m} - gcos\theta \tag{6}$$

$$\frac{dv_{sy}}{dt} = \frac{\mu\rho S\ \left(\frac{Q}{S_T}+v_s\right)^2}{m} + g\ sin\theta \tag{7}$$

According to the above formula, when the seed does not collide with the tube wall, its motion acceleration in the tube is affected by the airflow velocity, seed velocity, and air flow angle θ influence. When the corn seed leaves the seed metering device, the seed speed is affected by the angular speed of the rotation of the seed metering plate, which can be regarded as a constant quantity. Since the air velocity is mainly related to the wind speed provided by the fan, it can be kept constant by artificially changing the wind speed. In order to avoid the collision and bounce between the seed and the soil due to the excessive partial velocity in the horizontal direction when the seed leaves the seed guide device, the air flow angle in the tube should be controlled. And it is relevant with an inclined guide airway α. Too large airflow angle will lead to the failure of the design of the pores of the upper distribution channel behind, and too small air flow angle will lead to the loss of the air flow of the annular channel to go down, resulting in eddy currents that disturb the falling of seeds. The angle of the inclined airway in the range of 140°~160° is selected as the later influencing factor.

Airway outlet width L and distribution pore diameter d

In order to ensure the good seeding function of corn seeds under high-speed airflow, the width of the airway outlet should be less than the shortest side length of the nozzle of the seed guide tube. At the same time, if the width of the airway guided by the high-speed airflow is too narrow, the air pressure entering the seed guide tube will be lost, and the aerodynamic resistance will increase (*Sokolov E. and Zingel*, *1977).* Therefore, the outlet width of the intake port is 10~20 mm as the later influencing factor. Both too-large and too-small distribution pores will make the air flow in the airway unevenly distributed into the seed guide tube. According to the size of the design structure and relevant research（*Wang et al., 2020*）, the diameter of the distribution pore is between 3~6 mm as the subsequent influencing factor.

Fan air flow interface and air flow size

The air flow interface of the fan is connected with the pressure-resistant starting hose, and the fan provides a continuous flow of air. The fan model is YASHIBA small drag pump fan, with a working speed of ≤ 3500 rpm and a working pressure between -7 kPa and 7 kPa. The diameter of the large rotating small connector is 16 mm, and the diameter of the air flow interface of the fan should be equal to its outer diameter, taking 16 mm.

Experimental methods
Simulation

The single-factor simulation test was carried out on the critical structural parameters affecting the seed guide effect, the ideal parameter combination was selected for the orthogonal experiment, and the optimal combination of the annular air-blowing auxiliary seed guide device was selected. The test factors and their levels are shown in Table 1:

Table 1

Single factor influencing factor level

Level	Inclined airway angle α/°	Airway outlet width L / mm	Distribution pore diameter d / mm
1	140	10	3
2	145	12	4
3	150	14	5
4	155	16	6
5	160	18	
6		20	

The critical link of the annular air-blowing auxiliary seed guide device is the selection of wind pressure. High or low wind pressure will affect the movement of seeds in the seed guide tube. 2 kPa, 3 kPa, and 4 kPa were used for fluent software simulation experiments, and the ideal wind pressure was selected.

By counting the absolute value of the velocity difference at the midpoint of the length and width of the section（$v = |v_4 - v_2| + |v_3 - v_1|$）, it can be seen whether the seed movement is stable during the process of the seed guide tube. The schematic diagram is shown in Fig 4:

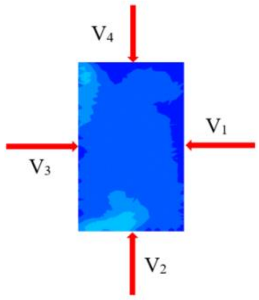


Fig. 4 - Schematic diagram of velocity at the midpoint of section length and width

V_1-V_4 - the velocities in the four directions of the selected cross-section: right, down, left, up.

Bench test

In order to study the seed guiding effect of the auxiliary seed guiding device of the annular device, the JSP-12 seed metering device performance test bench was used in this experiment. The bench test was carried out in the intelligent agricultural machinery equipment laboratory of Anhui Agricultural University； the i-speed 3 high-speed cameras were used to record the movement of seeds in the seed guiding tube. The data processing software of the seed metering device test bed was used to record the corn seed spacing. It mainly counts the plant spacing of corn seeds to obtain the qualified rate and variation coefficient of sowing.

Fig. 5 - JSP seeder performance test bench

1 - drive motor; 2 - high-speed camera; 3 - scoop wheel seed metering device; 4 - annular air blowing auxiliary seed guiding device; 5 - positive pressure air pipe; 6 - test bed control cabinet

RESULTS

Results and analysis of simulation

Three different wind pressures were simulated and analyzed, and the experimental results are shown in Fig 6:

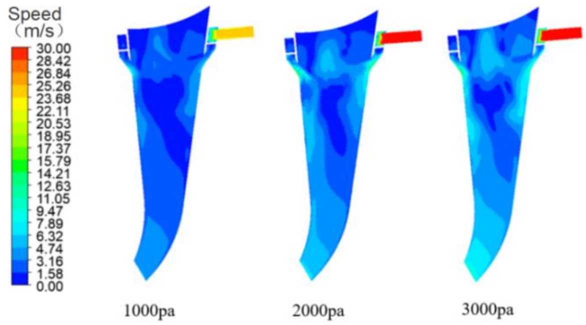


Fig. 6 - Front velocity nephogram under different wind pressures

It can be seen that when the wind pressure is equal to 1 kPa, the airflow inside the pipe is small due to the existence of the distribution airway, which cannot play the role of making the seeds fall rapidly and stably; When the wind pressure is equal to 3 kPa, the turbulence inside the pipe is considerable, which cannot provide stable acceleration for the seeds; At 2 kPa, the air flow in the tube is evenly distributed, which is suitable for the steady falling of sources. 2 kPa air pressure is selected as the inlet air pressure of the seed guide device.

Inclined airway angle

In order to ensure the consistency of test factors, set the airway width as 16 mm and the diameter of the distribution pore as 4 mm, and carry out single-factor numerical simulation for different inclined airway angles. The simulation cloud diagram is shown in Fig. 7 and Fig. 8:

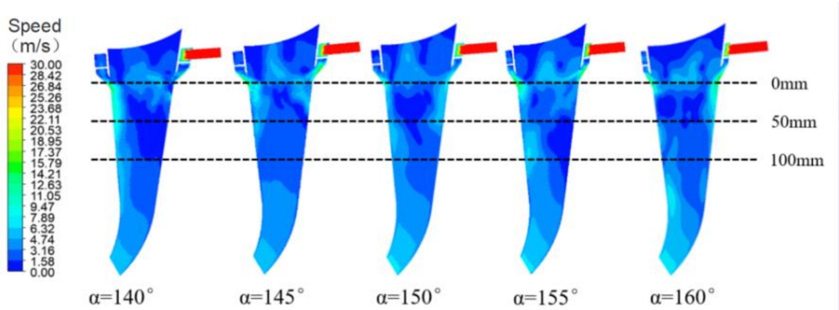


Fig. 7 - Frontal velocity nephogram

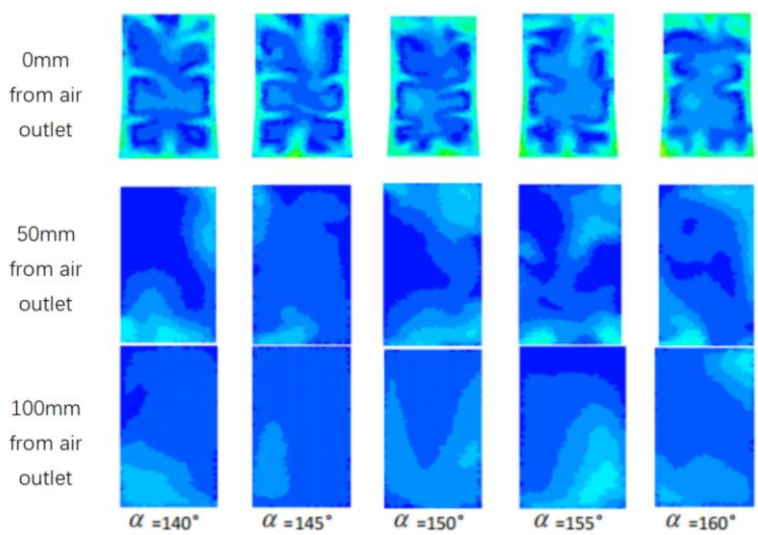


Fig. 8 - Local velocity nephogram of seed guide device

The simulation results are imported into the Origin for drawing, and the influence of different airway angles on the velocity difference in the opposite position is shown in Fig. 9:

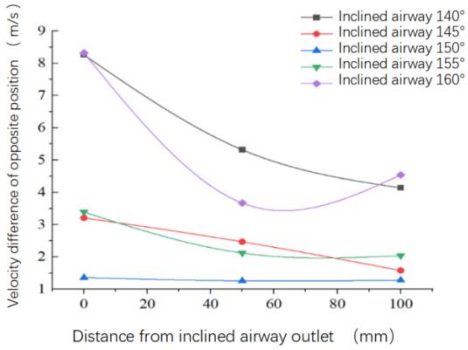


Fig. 9 - Influence of different airway angles on velocity difference in the opposite position

It can be concluded that when the inclined airway angle is between 145° and 155°, the absolute value of the velocity difference at the opposite position of the midpoint of the section is significantly less than 140° and 160°. In order to make the later design of the seed guide tube more in line with the requirements of the experimental design, 145°, 150° and 155° are selected as the factor levels of the later orthogonal test.

Airway width

In order to ensure the accuracy of the single factor simulation, reduce the test error, and ensure the unity of other variables, set the inclined airway angle = 150° and the distribution pore diameter d is 4 mm. Then the single factor experiment was carried out on the airway, and the numerical simulation was carried out on different airway widths.

The results are shown in Fig.10 and Fig.11.

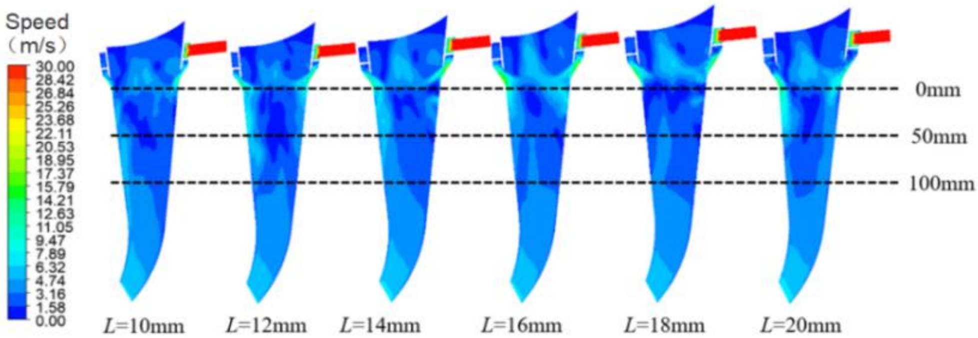


Fig. 10 - Frontal velocity nephogram

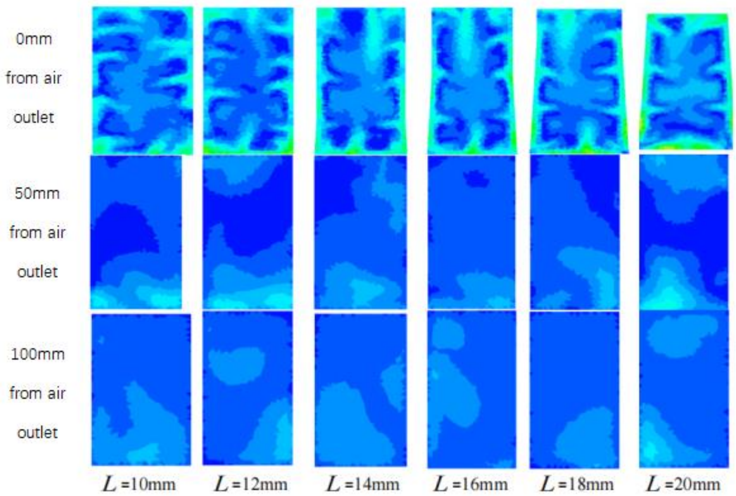


Fig. 11 - Local velocity nephogram of seed guide device

The results were imported into the Origin for drawing, and the influence of different airway widths on the velocity difference in the opposite position was obtained, as shown in Fig.12:

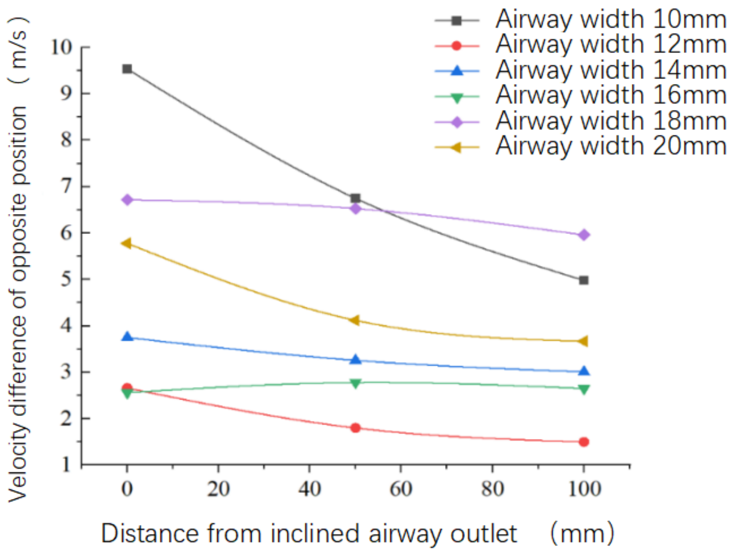


Fig. 12 - Influence of different airway widths on velocity difference in the opposite position

It can be seen from the figure that when the airway width is 12 mm~16 mm, the absolute value of the velocity difference in the opposite position of the experimental index is maintained at a low level relative to the other three factors and are all lower than 4 m/s. In the following orthogonal exploratory analysis, 12 mm, 14 mm and 16 mm were used as the influencing factors.

Distribution pore diameter

In order to ensure the reliability of single factor simulation, the inclined airway angle is set uniformly α=150°, the airway width d=16 mm. The single-factor experiment was carried out on the distribution pores diameter, and the numerical simulation of different pore diameters was carried out. The simulation cloud diagram is shown in Fig.13 and Fig.14:

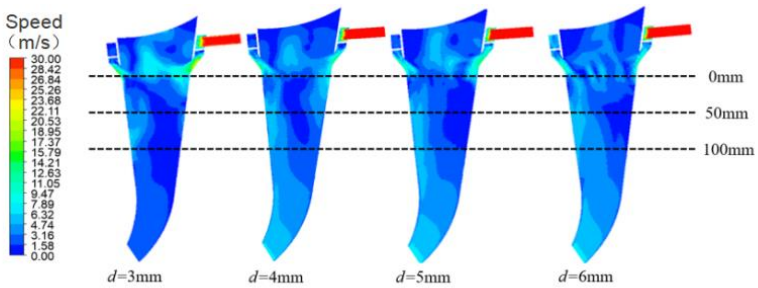


Fig. 13 - Frontal velocity nephogram

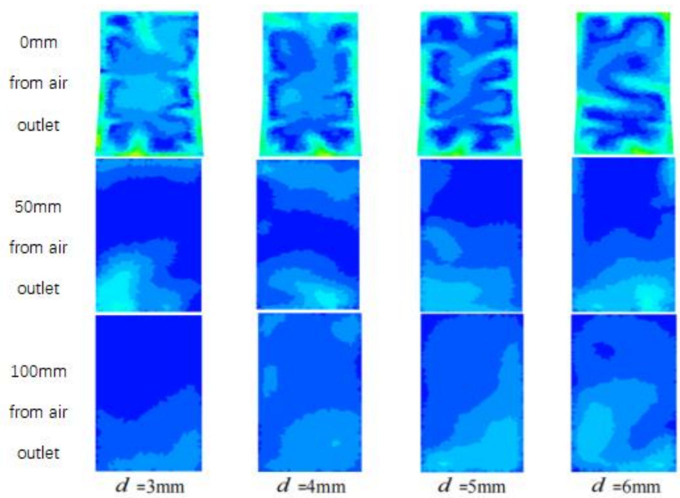


Fig. 14 - Local velocity nephogram of seed guide device

Import the results into the Origin for drawing, and get the influence of different distribution pore diameters on the velocity difference in the opposite position, as shown in Fig. 15:

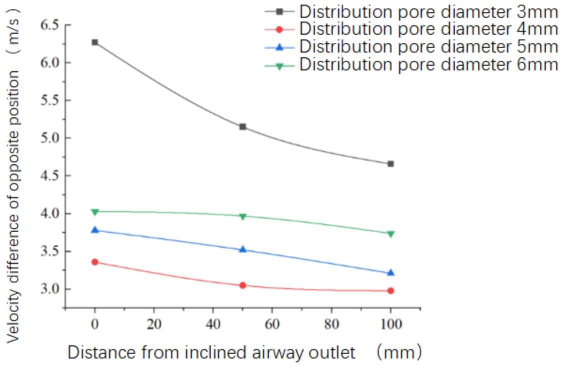


Fig. 15 - Influence of different distribution pore diameter on velocity difference in the opposite position

Therefore, when the distribution pore diameter d≥ 4 mm, the velocity difference in the opposite position in the device section is slight. In order to ensure the accuracy of the orthogonal test, 4 mm, 5 mm, and 6 mm are selected as the influencing factors of the interaction.

Results and analysis of the orthogonal experiment

In order to obtain the interaction effect of three factors on the airflow inside the tube and the optimal parameter combination, the Box-Behnken experimental design principle (*Wang et al., 2021; Araujo et al., 2017*) was adopted. The coding table of the designed experimental factors is shown in Table 2:

Table 2

Test code table

Code	**Factor**		
	Inclined airway angle α/°	**Airway outlet width L/mm**	**Distribution pore diameter d/mm**
1	145	12	4
0	150	14	5
-1	155	16	6

In this experiment, the three-factor three-level quadratic orthogonal rotation combination scheme was used to carry out the multi-factor investigation. The sum of the absolute values of the velocity difference was calculated to judge the airflow stability. The significance of the main factors was analyzed α, the airway outlet width L, distribution pore diameter *D*, and the absolute value of velocity difference (take the average value) is set respectively as x_1, x_2, x_3 and y. The orthogonal test scheme and results are shown in Table 3:

Table 3

Orthogonal test scheme and results

Serial Number	**Factor**			y **/m·s**$^{-1}$
	x_1 **/ °**	x_2 **/ mm**	x_3 **/ mm**	
1	1	1	0	1.86
2	0	0	0	2.78
3	0	0	0	3.44
4	1	0	-1	4.89
5	0	1	-1	2.6
6	1	0	1	4.02
7	-1	0	1	2.79
8	0	0	0	4.21
9	-1	1	0	1.31
10	1	-1	0	3.54
11	0	0	0	1.68
12	0	-1	1	3.65
13	-1	-1	0	2.61
14	0	1	1	2.64
15	-1	0	-1	2.67
16	0	0	0	2.62
17	0	-1	-1	2.5

On the basis of the test, the Design-Expert software was used to carry out multiple regression fitting analysis on the test results, and the regression equation of the sum y of the velocity difference at the opposite position of the midpoint of the section was obtained as:

$$y = 2.61 + 0.65x_1 + 0.99x_2 + 0.11x_3 + 0.13x_1x_2 - 0.065x_2x_3 + 0.75x_1^2 - 0.11x_2^2 + 0.05x_3^2 \quad (8)$$

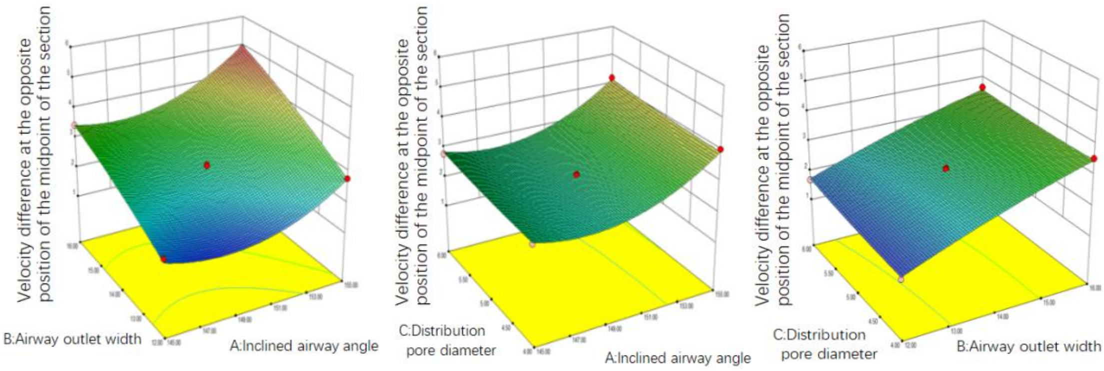
Variance analysis of the Box-Behnken test model was carried out on the experimental results. The results are shown in Table 4. The absolute value y of the velocity difference of the opposite position of the section's midpoint is significant, and the regression equation mismatch is not significant (P>0.05). From the P value of variance analysis, it can be concluded that the inclined airway angle and the airway outlet width have a significant impact on the model, and the distribution pore diameter had a general effect on the model.

Table 4

Variance analysis of the Box-Behnken quadratic regression model

Variance source	Velocity difference y at the opposite position of the midpoint of the section			
	Sum of squares	**Degree of freedom**	**F**	**P**
Model	13.76	9	137.1	<0.0001
x_1	3.39	1	304.29	<0.0001
x_2	7.78	1	697.85	<0.0001
x_3	0.092	1	8.29	0.0237
x_1x_2	0.070	1	6.30	0.0404
x_1x_3	0.000	1	0.000	1.0000
x_2x_3	0.017	1	1.52	0.2580
x_1^2	2.35	1	210.85	<0.0001
x_2^2	0.054	1	4.80	0.0646
x_3^2	0.010	1	0.93	0.3659
Residual	0.078	7		
Lack of fit	0.061	3	4.91	0.0793
Pure error	0.017	4		
Sum	13.84	16		

In order to study the interaction between multiple factors, two factors are selected as variables, and the other variable is fixed at zero level to obtain the response surface curve in Fig. 16.



(a) *(b)* *(c)*

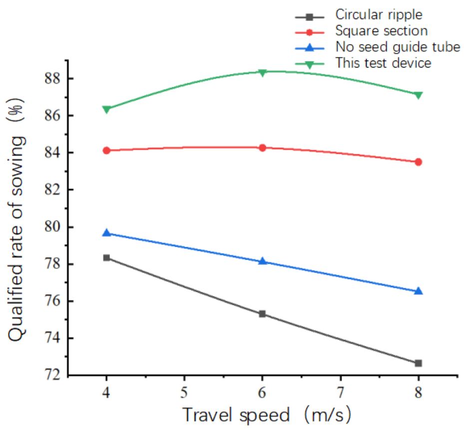
Fig. 16 - Influence of various factors on the velocity difference of the opposite position of the midpoint of the section

As shown in Fig. 16 (a), the inclined airway angle and the airway's outlet width significantly impact the cross-section airflow velocity difference. When the distribution pore diameter is fixed, the velocity difference increases with the increase of the inclined airway angle and the outlet width of the airway; Fig.16 (b) shows that when the outlet width of the airway is fixed, the distribution pore diameter and the inclined airway angle have interactive effects on the velocity difference. With the decrease of the angle and diameter, the sum of the velocity difference becomes smaller; Fig.16 (c) shows that the interaction between the distribution pore diameter and the airway outlet width is not apparent.

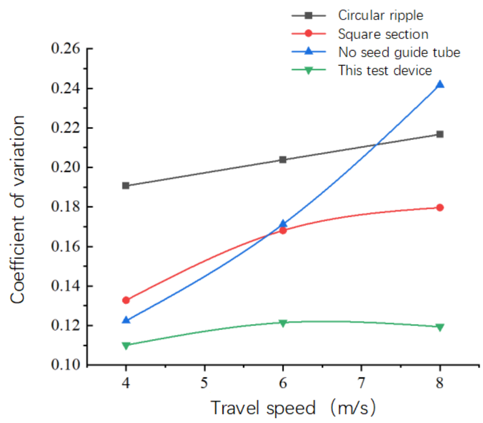
From the single-factor experiment results, it can be concluded that the inclined airway angle of 150° is the better single factor air blowing structure, and the outlet width of 12 mm is the better air-blowing structure; In the orthogonal experiment, the simulation effect of No. 9 is the best, and the velocity difference on the opposite position of the midpoint of the section is the smallest, so the selected factors are the inclined airway angle of 150 °, the airway outlet width of 12 mm, and the distribution pore diameter of 4 mm.

Results and analysis of bench test

Repeat each group of tests three times, calculate the qualified rate and coefficient of variation of the obtained results, take the average value record, import the results into Origin, and draw a dotted line diagram for comparison. The results are shown in Fig.17:



(a）Comparison chart of qualification rate of different seed guide tubes



(b）Comparison chart of variation coefficient of different seed guide tubes

Fig. 17 - Comparison results of seed guide performance

Compared with the seed guide device without a seed guide tube and two kinds of spoon wheel seed metering device, the seed guide performance of the annular air-blowing auxiliary seed guide device designed in this paper has been greatly improved. Compared with the square cross-section seed guide tube, the qualified rate of sowing increased by about 3%, and the coefficient of variation decreased by more than 4%; compared with the mode without seed guide tube, the pass rate can be increased by up to 10% under the condition of high-speed seeding, the coefficient of variation is reduced by about 10%, and the seeding accuracy is significantly improved. The seed metering effect is shown in Fig.18.

Fig. 18 - Seed metering effect

The bench test was carried out. The experimental results showed that the seed metering effect of the seed guide device with air blowing was statistically analyzed. Compared with the seed guide tube without air blowing, the qualified seeding rate increased by 3.2%, with a slight increase, and the coefficient of variation decreased by 7.3%, significantly reducing the coefficient of variation.

CONCLUSIONS

In order to solve the problem of uneven seed spacing caused by the collision between corn seeds and the tube wall of the seed guide tube when sowing, a kind of auxiliary seed guide device with an annular device was designed.

Single-factor simulation analysis and orthogonal experiment were carried out with wind pressure, inclined airway angle, airway outlet width, and distribution pore diameter as experimental indexes. The test results showed that when the wind pressure was 2 kPa, the inclined airway angle was 150°, the outlet width of the airway was 12 mm, and the distribution pore diameter was 4 mm, it was suitable to be used as the key component parameters of the seed guide device.

When the forward speed was 6 km/h (the rotation speed of the seed metering plate was 25.30 rpm), the air pressure was 2 kPa, the inclined airway angle was 150°, the outlet width of the airway was 12 mm, and the diameter of the distribution pore was 4 mm, the qualified rate of sowing reached 88.36%, and the coefficient of variation was 12%, which had high sowing uniformity. The effect is better than that of a round cross-section seed guide tube, square cross-section seed guide tube, and no seed guide tube.

ACKNOWLEDGEMENT

This work was supported by Anhui colleges and universities project under Grand NO.2022AH050897.

REFERENCES

[1] Araujo, M., Santos, M., de Oliveira, M., Matos, R., Matos, M. (2017). Box–Behnken design applied to optimize the ultrasound-assisted extraction of petroleum biomarkers in river sediment samples using green analytical chemistry. *Analytical Methods*, 9(40), 1039. https://doi.org/10.1039/C7AY01470H.

[2] Chen, K., Yuan, Y., Zhao, B., Zhou, L., Zhou, L., Niu, K., Dong, X., Jin, X., Zheng, Y. (2022). Design of dynamic compensation system for corn seeding position based on fuzzy PID control and analysis of bench test (玉米播种位置动态补偿系统设计与台架试验分析). *INMATEH - Agricultural Engineering*, 67(2), 394-405. https://doi.org/10.35633/inmateh-67-40.

[3] Dayoub, E., Lamichhane, J., Céline S., Philippe D., Pierre M. (2021). Early-Stage Phenotyping of Root Traits Provides Insights into the Drought Tolerance Level of Soybean Cultivars. *Agronomy,* 11(1), 188. https://doi.org/10.3390/agronomy11010188.

[4] Endrerud, H. (1999). Influence of tube configuration on seed delivery to a coulter. *Journal of Agricultural Engineering Research*, 74(2), 177-184. https://doi.org/10.1006/jaer.1999.0449.

[5] Huang, J. (2015). Effect of Precision Sowing and Traditional Sowing on the Growth and Income of Corn (精量播种与传统播种对玉米生长发育及收益的影响). *Journal of Anhui Agricultural Sciences*, 0(5), 29-31. https://doi.org/10.13989/j.cnki.0517-6611.2015.05.010.

[6] Kovher, M., Coleman, J., Smith, J., Kachman, S. (2011). Corn seed spacing uniformity as affected by seed tube condition. *Applied Engineering in Agriculture*, 27(2), 177-183.

[7] Lei, X., Hu, H., Yang, W., Liu, L., Liao, Q., Ren, W. (2021). Seeding performance of air assisted centralized seed-metering device for rapeseed (油菜小麦兼用气送式直播机集排器参数优化与试验). *International Journal of Agricultural and Biological Engineering*, 14(5), 79-87. https://doi.org/10.25165/j.ijabe.20211405.5349.

[8] Li, Y., Yang, L.， Zhang, D., Cui, T., Zhang, K., Xie, C., Yang, R. (2020). Analysis and test of linear seeding process of maize high-speed precision metering device with air suction (气吸式玉米高速精量排种器直线投种过程分析与试验). *Transactions of the Chinese Society for Agricultural Engineering*, 36(9), 26-35. https://doi.org/10.11975/j.issn.1002-6819.2020.09.003.

[9] Liu, Y., Xu, Y., Wang, Y., Yang, H., Gao, P., Wang, J. (2017). Effect of Precision Sowing on Growth and Economic Benefit of Maize (精量穴播对玉米生长发育及经济效益的影响). *Heilongjiang Agricultural Science*, (04), 12-15. https://doi.org/10.11942/j.issn10022767.2017.04.0012.

[10] Liu, X. (2013). Research on Mechanized Maize Precision Sowing (玉米精量播种机械化技术研究). *Agricultural Science & Technology and Equipment*, 223(1), 66-67. https://doi.org/10.3969/j.issn.1674-1161.2013.01.027.

[11] Sokolov, E.R., Zingel, H. (1977). *Ejector*, Beijing: Science Press.

[12] Wang, J., Tang, H., Wang, J., Shen, H., Feng, X., Huang, H. (2017). Analysis and Experiment of Guiding and Dropping Migratory Mechanism on Pickup Finger Precision Seed Metering Device for Corn (指夹式

玉米精量排种器导种投送运移机理分析与试验). *Transactions of the Chinese Society for Agricultural Machinery*, 48(1), 29-37+46. https://doi.org/10.6041/j.issn.1000-1298.2017.01.005.

[13] Wang, C., Li, H., He, J., Wang, Q., Lu, C., Wang, J. (2020). Design and Experiment of Pneumatic Wheat Precision Seed Casting Device in Rice-wheat Rotation Areas (稻麦轮作区气动式小麦精准投种装置设计与试验). *Transactions of the Chinese Society for Agricultural Machinery*, 51(5), 43-53. https://doi.org/10.6041/j.issn.1000-1298.2020.05.005.

[14] Wang, W., Cai, D., Xie, J., Zhang, C., Liu, L., Chen, L. (2021). Parameter Calibration of Discrete Element Model for Dense Forming of Corn Straw Powder (玉米秸秆粉料致密成型离散元模型参数标定). *Transactions of the Chinese Society for Agricultural Machinery*, 52(7), 127-134. https://doi.org/10.6041/j.issn.1000-1298.2021.03.013.

[15] Wang, Q., Han, D., Xu, Y., Huang, Y., Tang, C., Li, W. (2024). Experimental study on the seeding performance of the spoon-wheel maize seed-metering device under vibration conditions (勺轮式排种器在振动条件下的排种性能试验研究). *INMATEH - Agricultural Engineering,* 72(1), 324-338. https://doi.org/10.35633/inmateh-72-30.

[16] Yazgi, A. (2016). Effect of seed tubes on corn planter performance. *Applied Engineering in Agriculture*, 32(6), 783-790. https://doi.org/10.13031/aea.11274.

[17] Yatskul, A, Lemiere, J. (2018). Establishing the conveying parameters required for the air-seeders. *Biosystems Engineering*, 166, 1-12. https://doi.org/10.1016/j.biosystemseng.2017.11.001.

[18] Zhao, S., Chen, J., Wang, J., Chen, J., Yang, C., Yang, Y. (2018). Design and Experiment on V-groove Dialing Round Type Guiding-seed Device (精量播种机 V 型凹槽拨轮式导种部件设计与试验), *Transactions of the Chinese Society of Agricultural Machinery*, 49(6). 146-158. https://doi.org/10.6041/j.issn.1000-1298.2018.06.017.

[19] Zhang, Y., Cheng, J., Zhang, X., Shi, Z., Wang, M., Wu, H., Fu, H. (2023). Design and experiment of pressure-holding precision seed-metering device for maize (压持式玉米精量排种器的设计与试验). *INMATEH – Agricultural Engineering*, 69(1), 159-169. https://doi.org/10.35633/inmateh-69-14.