Journal of Engineering Science and Technology Review 16 (5) (2023) 132 - 139

Research Article

JOURNAL OF
Engineering Science and Technology Review

www.jestr.org

Design and Experimental Analysis of Drone Rice Direct Seeding Device

Wu Zhijun*, Chen Yu, Shi Shengcai, Deng Hao, Liao Xiaobing and Xu Lijia

College of Mechanical and Electrical Engineering, Sichuan Agricultural University, Ya'an, 625014, China

Received 05 August 2023; Accepted 25 October 2023

Abstract

Given the low degree of mechanization on rice planting in hilly and mountainous areas, as well as the time-consuming and labor-intensive process involved in traditional seedling transplantation, a drone rice direct sowing device compatible with the drone platform was developed in this study. This device combines the advantages of unrestricted terrain and high efficiency of drone seeding. The discrete element simulation method was used. Single-factor experiments and three-factor three-level response surface experiments were conducted on the structural parameters of the device, including the angle of the ring baffle, the arc length of the blade, and the number of blades. A relational model was also established between these three structural parameters and the lateral coefficient of variation of sowing. The optimal parameter combination was determined, namely, rectangular ring baffle angle of 21°, blade arc length of 45 mm, blade quantity of 4, and lowest lateral coefficient of variation of 19.621%. Results demonstrate that the simulation results are consistent with the field experiment results, both of which are much lower than 45%, which is the lateral coefficient of variation of rice seeding specified in the standard NY/T3881-2021. The average yield per mu of rice sowing by drones is equivalent to that of the transplanting mode, verifying the feasibility of drone rice sowing. The proposed method provides evidences for the design of drone-based rice sowing devices.

Keywords: Drone, Rice direct sowing, Discrete element simulation, Spreading unit

1. Introduction

In recent years, drones have been increasingly applied in various fields because of their relatively small size, portability, low environmental requirements, good adaptability, and flexible operation. Drones have become a new type of equipment in agricultural operations, and they are especially suitable for hilly and mountainous areas and areas with inconvenient transportation instead of manual work. Compared with traditional rice cultivation methods, rice direct sowing technology is used to reduce the need for transplantation and shorten the rice growth period. Using drones for rice direct sowing can greatly improve the efficiency of seeding. The term "drone" has become common since 2015, and related studies have increased exponentially since 2019. However, recent studies on drone-specific sowing devices are limited [1], and among all drones, the proportion of drones used in agriculture is less than 20% [2].

The use of drones for rice direct sowing must meet the rice planting requirements, including suitable sowing density and uniformity [3]. Ensuing the uniformity of seeding can effectively increase the rice yield. Most of research of rice direct sowing technology mainly focuses on improving the distribution characteristics of rice seed through experiments, but applications in numerical simulation are still lacking, which can continuously and dynamically repeat the test at any time to improve the understanding of the test results [4]. In the hilly areas of Southwest China, situations such as deep muddy fields, inadequate roads for agricultural equipment, and small and dispersed farmland make the ground operation machinery experience problems such as impaired mobility and tendency to become stuck [5-7]. Therefore, the continuous improvement and promotion of drone rice direct sowing technology are conducive to saving manpower and material resources and enhancing the efficiency of rice cultivation, which is of great significance to the development of the rice cultivation industry. Moreover, such technology has an important impact on the general goal of the development strategy of rural revitalization in China. The use of drone rice direct sowing technology is beneficial to the country and the people.

2. State of the art

At present, scholars all over the world have conducted extensive studies on the efficiency and accuracy of drone-mounted sowing devices. N. Vovchenko et al. [8] concluded that drones at high speed cannot guarantee sowing accuracy, so the sowing process must be simplified to improve accuracy. A. Andrio et al. [9] loaded seeds into a seed box and threw them by using a drone at a speed of 5 m/s; the seeds that impacted the soil were used to determine the location of the rice seeds, but the location of seeds' landing sites was randomly distributed and unsuitable for environments with high sowing accuracy. E. P. Fortes [10] mounted a motor unit on the spreader to accurately regulate the seed release flow rate; given that the motor speed is proportional to the drone flight speed, a basis for the proportionality of the spreading flow rate to the flight speed of the drone was proposed. Mengliang Li [11] designed a centrifugal rice sowing device with a ring baffle, and the mean value of the lateral coefficient of variation reached 19.43%. However, the linear blade in the sowing device damages the rice seed, which will affect the rice yield. M.

*E-mail address: wzj@sicau.edu.cn
ISSN: 1791-2377
doi:10.25103/jestr.165.16

Lysych et al. [12] investigated a high-precision spreading device, which can accelerate seeds to more than 50 m/s, ensuring that the trajectory of seeds will not be affected by the airflow. However, the device can only launch one seed at a time, which greatly reduces the efficiency of spreading. S. Meivel et al. [13] designed a set of spraying and fertilizing modules embedded in an unmanned aerial vehicle (UAV) to recognize crop and plot edges for precise work. As a result of the slow speed of crop recognition, the spreading efficiency is significantly reduced compared with other sowing devices. A. Mukherjee et al. [14] integrated sensing technology and drone architecture to realize efficient and high-precision sowing by drones. However, with the accumulation of technology and the increase in the number of drones, the sowing cost increases dramatically, so it is not suitable for large-scale agricultural production. According to R. K. Bansal et al. [15], computer simulations revealed that changing the angle of shot of the air supply can change the velocity of particles. Although, changing the trajectory can improve the sowing precision, the high precision puts high demands on the response time of the spreading device as the flight speed of drone increases. R. Felismina et al. [16] elaborated the importance of mutual coupling of drones and sowing machines and proposed the theoretical direction of drone direct seeding, but they did not find a practical solution to realize this goal. Weizhuo He et al. [17] developed a UAV-mounted spot spray rice seeding device, which utilized electromagnetic ejection of rice seeds into a linear arrangement to achieve high precision seeding. However, a UAV can only carry one seeding device, which does not take advantage of the high maneuverability of UAV and lowers the direct seeding efficiency. Conghua Zhu et al. [18] developed a UAV rice seeding device with rollers and brushes, which facilitated seeding through the thrust of the rollers, and adjusted the seeding speed to ensure the same seeding rate at each outlet.

The above studies mainly focused on the sowing speed or sowing accuracy to carry out the design and experiment of the sowing device, and studies on the comprehensive consideration of the sowing speed and efficiency are limited. In particular, work on the combination of simulation calculation using the discrete element method (DEM) for modeling and experimental verification is rarely reported. The influence of spreading structure on uniformity and efficiency was discussed, and the functional equation between the structural parameters and the lateral coefficient of variation was obtained in this study, which also provides a basis for the optimized design of the seeding device.

The layout of the remaining sections of this study is as follows. In section 3, the seedmeter and spreading unit were designed, the simulation model of the rice seed and spreading unit were established, and the parameters of discrete element simulation software were set. In section 4, the three factors affecting the uniformity of spreading were subjected to single-factor test. Response surface tests were also conducted to derive a set of optimal parameters for the angle of rectangular ring baffle, the number of blades, and the arc length of the blade. Finally, prototype fabrication was completed. Compared with the results of field tests, the yields of drone rice direct sowing were basically the same as those of transplanting. The conclusions were given out in the last section.

3. Methodology

DEM is a method for analyzing the discrete particulate materials and is mainly used to analyze the motion of particles under given conditions [19]. This method is another powerful numerical computational method for analyzing the dynamics of material systems after the finite element method (FEM) and computational fluid dynamics (CFD).

The current computational process of the DEM is to establish the geometric model, determine the particle contact model, analyze the direct interaction between the particles and the boundary, solve the force and acceleration, update the parameters such as the particle velocity coordinates, and save the data. The discrete element numerical simulation needs to import the 3D module of sowing device and the particle model of rice seed. Therefore, in this section, the structure of the rice direct sowing device, especially the spreading unit, was designed, and the physical parameters of of the rice seed were determined.

3.1 Structure design of rice direct sowing device

In this study, a rice direct sowing device equipped with a drone platform was designed, which mainly consisted of three parts: seed box, seedmeter unit, and spreading unit. The overall structure is shown in Fig. 1.

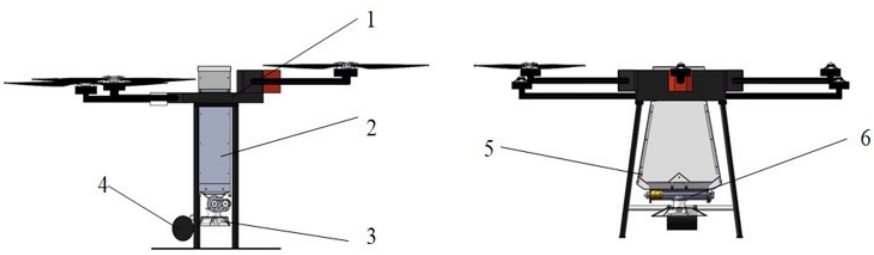

Fig. 1. Structural schematic of rice direct sowing device. ***1*** **-** Drone system; ***2*** **-** Seed box; ***3*** **-** Spreading unit; ***4*** **-** Radar module; ***5-*** Capacitive proximity switch; ***6*** **-** Seedmeter unit.

3.2 Structure design of seedmeter unit

Granular material conveying methods mainly include screw conveying, belt conveying, and pipe chain conveying [20]. Considering the space of the seed box and the continuity of seedmeter, screw conveying type was adopted in this study. According to the structural parameters of the seed box and the relevant agronomic requirements [21,22], seeding capacity was set at 0.148 t/h, the blade spacing of the double-screw convey was 18.0 mm, and the shaft diameter was 7.5 mm. The structural schematic of the seedmeter unit is shown in Fig. 2.

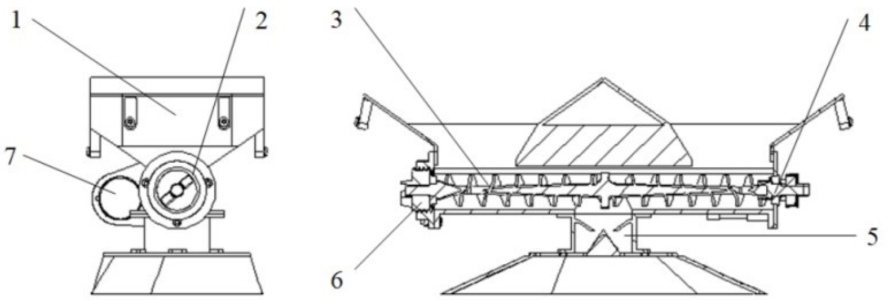

Fig. 2. Structural schematic of seedmeter unit. ***1*** **-** Seedmeter pipe; ***2*** **-** Flange nut; ***3*** **-** Main shaft of double-screw conveyor; ***4*** **-** Small shaft; ***5*** **-** Seed hopper; ***6*** **-** Bolt; ***7*** **-** Geared motor.

3.3 Structure design of spreading unit
As shown in Fig. 3 the rice seeds fall from the seedmeter unit to the spreading unit, collide with the curved blades on the dumping disk, leave the dumping disk and collide with the rectangular ring baffle, and enter the ambient wind field. Finally, they fall to the ground, completing the spreading process.

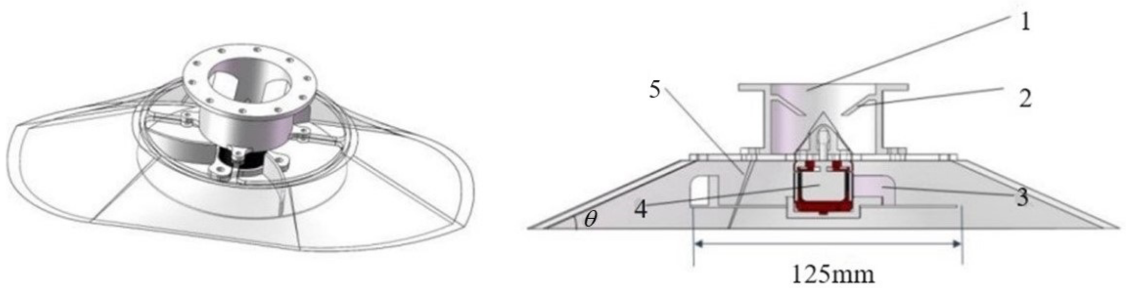

Fig. 3. Structural schematic of spreading unit. ***1*** **-** Funnel channel; ***2*** **-** Seed guide plate; ***3*** **-** Spinning disc; ***4*** **-** Brushless motor; ***5*** **-** Rectangular ring baffle.

Improving the angle of rectangular ring baffle θ to adjust the trajectory of rice seeds helps improve the uniformity of spreading [11]. The shape of the disc blade was designed as a curved shape to increase the movement time of the rice seeds on the disc to improve the spreading width under a certain diameter of the disc. The structural parameters of the disc were 125.0 mm in diameter, 46 mm in arc length, and 15.0 mm in height.

3.4 Modeling of rice seeds
A 3D model of the rice seed was created by measuring the geometrical and physical parameters of the rice seed. The models of the rice seed and the spreading device were imported into DEM software and parameterized for pre-processing.

The rice seeds used in this study were YeXiangYouSi rice seeds (a grain brand). The physical property parameters such as triaxial size, thousand grain weight, stacking density, and static friction were measured, as shown in Tables 1 and 2 below.

Table 1. Triaxial dimensions of rice seeds

Properties	**Average length $\bar{L}$ (mm)**	**Average width $\bar{W}$ (mm)**	**Average thickness $\bar{D}$ (mm)**	**Arithmetic average thickness D_r (mm)**	**Arithmetic mean diameter D_a (mm)**
Values	6.11	2.0	2.0	3.24	4.43

Table 2. Physical properties of rice seeds

Properties	**Thousand grain weight (g)**	**Average density (g/ml)**	**Static friction coefficient between rice seed and photosensitive resin**	**Sliding friction angle (°)**
Values	19.86	0.946	0.592	30.64

According to the measured parameters of the rice seed to establish the particle model in DEM software, the simulation model of rice seed was established by adding spherical particles, adjusting the diameter of the filler particles and the coordinate position, and setting the parameters of the particles and the contact material, as show in Fig. 4.

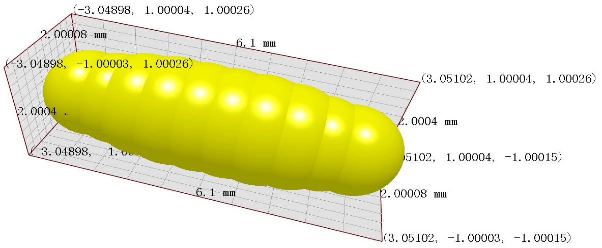

Fig. 4. Simulation model of rice seed in DEM software

3.5 Discrete element simulation pre-processing

This study focused on the effect of structural parameters of the rice direct sowing device on the lateral coefficient of variation. Thus, the model of the sowing device was simplified, and only the spreading unit was retained, which was imported into DEM software (Fig. 5).

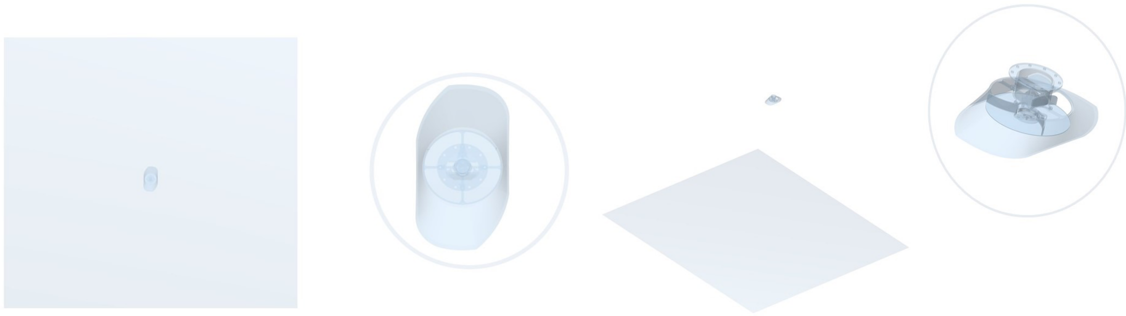

Fig. 5. Simulation model in DEM software

Steps of EDEM Software pre-processing:

(1) Establish the model of rice seed particles and set the gravitational acceleration and the contact model, including the parameters among the rice seed, the spreading unit, and the ground material, as shown in Tables 3 and 4.

Table 3. Material parameters

Parameter	Rice seed	Photosensitive resin	Soil
Density/ ($kg \cdot m^{-3}$)	946	1120	1700
Poisson's ratio	0.30	0.40	0.28
Shear modulus	$1.08{\times}10^8$	$2.61{\times}10^8$	$1.00{\times}10^8$

Table 4. Contact parameters

Contact parameter	Coefficient of static friction	Coefficient of rolling friction	Coefficient of elastic recovery
Rice seed - Rice seed	0.390	0.037	0.086
Rice seed - photosensitive resin	0.592	0.001	0.600
Rice seed - Ground	1.000	1.000	0.001

(2) Set up the rotary axis at the center point position of the dumping disk, and set the rotational speed.

(3) Establish particle factory; set the particle generation speed, start time, and other parameters; and set the seed drop zone. According to the existing research, set the rotational speed of the dumping disk at 600 r/min, the sowing capacity at 0.2 Kg, and the simulation time at 10 s. Establish the ground. The height of the dumping disc from the ground is 2 m, and the ground area in the simulation is 4 m×4 m.

(4) Enter the DEM solver, set the appropriate time step and calculation time, and perform the calculation to obtain the simulation results after completion, as shown in Fig. 6. Calculate the lateral coefficient of variation of rice seeds in a given area to assess the uniformity of sowing, and determine the quality of sowing by the lateral coefficient of variation. The calculation standard is in accordance with NY/T3881-2021 quality evaluation specification for remote controlled flying seeder.

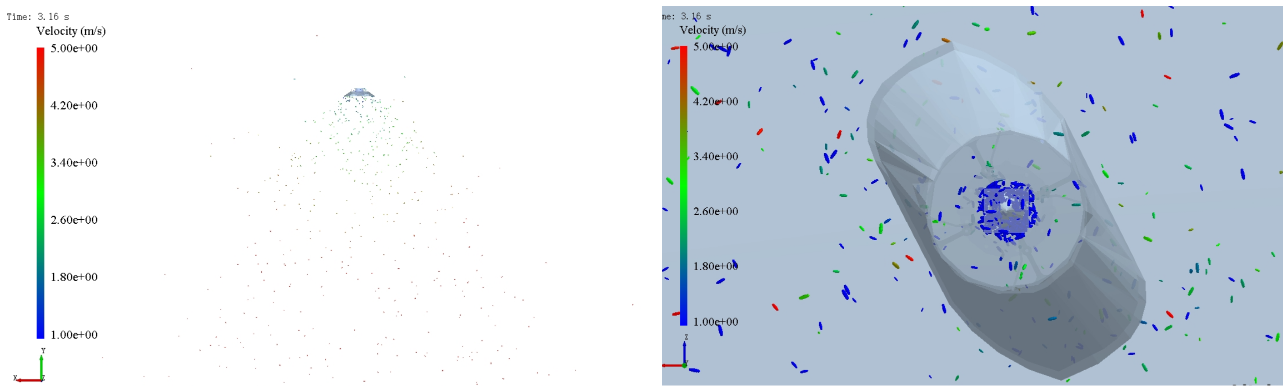

Fig. 6. Simulation effect in DEM software

4. Result Analysis and Discussion

4.1 Effect of rectangular ring baffle angle on the lateral coefficient of variation

The spreading device was equipped with a rectangular ring baffle above the dumping disk to reduce the situation of no seed in the center of the centrifugal spreading unit. The rectangular ring baffle plays the role of blocking the ejection of the rice seed, and the angle of the retaining ring has a remarkable influence on the uniformity of the spreading of the rice seeds. Currently, the angle of the rectangular ring baffle was 22.5°. To study the effect of angle on the quality of seed distribution, we set the angles of the rectangular ring baffle to 19.5°, 21°, 22.5°, 24°, and 25.5°. For the two other factors, the blade arc length was 45 mm and the number of blades was 3. The simulation results are shown in Fig. 7. As the angle of the rectangular ring baffle increases, the lateral coefficient of variation initially decreases and then increases. When the angle of the rectangular ring baffle is 22.5°, the uniformity of rice seed spreading is the optimal among the tested angles.

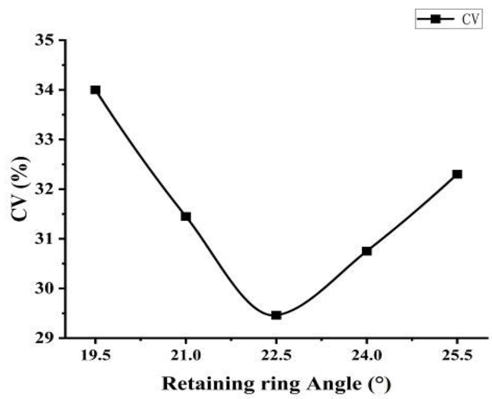

Fig. 7. Varying trend of CV at different ring baffle angles

4.2 Effect of arc length of blades on the lateral coefficient of variation

Changing the straight blade to a curved blade can reduce the impact of the blade on the rice seed, protect the seed, and improve the germination rate. Therefore, the arc length of the blade is an important factor that affects the quality of rice seed sowing. According to the related studies, the five horizontal values of the arc length were 45, 46, 47, 48, and 49 mm. The remaining two factors were as follows: the angle of the retaining ring was 22.5°, and the number of blades was 3. The simulation results are shown in Fig. 8. As blade arc length increases, the lateral coefficient of variation of rice seed spreading shows a general trend of decreasing and then increasing. The uniformity of spreading is optimal when the arc length is 47 mm.

4.3 Effect of the number of blades on the lateral coefficient of variation

The action of the disc on the rice seed is mainly accomplished through the blades, and the number of blades of the disc can directly affect the uniformity of spreading. Under the same rotational speed of the disc, when the number of blades is too low, sowing will produce obvious pulse phenomenon. When the number of blades is too large, the contact time between the rice seed and the blades is shortened, and the effect of pushing the seed is insufficient.

Therefore, the impact of the number of disc blades on the quality of sowing was simulated in this study. Keeping the angle of the rectangular ring baffle at 22.5° and the arc length of the blades at 45 mm unchanged, the number of blades was selected at 2, 3, 4, 5, and 6 for simulation. The simulation results are shown in Fig. 9. As the number of blades increases, the lateral coefficient of variation of rice seed spreading is gradually reduced, and the uniformity of spreading is steadily improved. However, when the number of blades is too high, it will affect the effective area of the dumping disk, resulting in a certain amount of rice seed clogging.

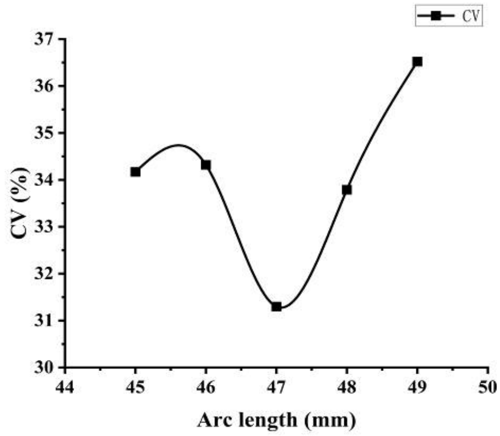

Fig. 8. Varying trend of CV at different blade arc lengths

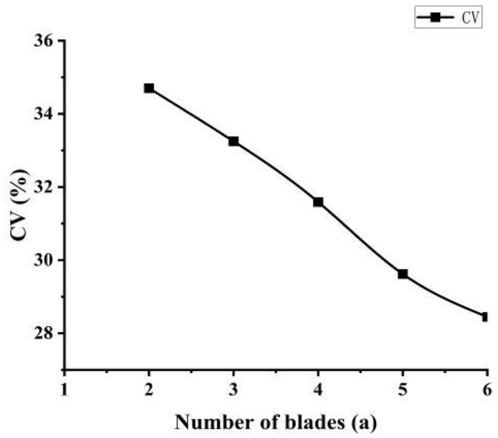

Fig. 9. Varying trends of CV under different blade numbers

4.4 Response surface simulation test analysis

To determine the best sowing effect and optimal parameter combination, the angle of the retaining ring, the arc length of the blade, and the number of blades were selected as the three factors of the response surface test. Three levels were used for each factor to perform the three-factor, three-level response surface test, and the levels of each factor are shown in Table 5. The results of the response surface simulation test are shown in Table 6. The simulation test results reveal that the lateral coefficient of variation of rice seed dispersal is less than 34%, which is smaller than the standard of aerial seeding in China. When the angle of the retaining ring is 21°, the arc length of the blade is 45 mm, and the number of blades is 4, the lateral coefficient of variation of rice seed dispersal is the lowest at 19.621%. At this time, the uniformity of dispersal peaks. When the angle of the retaining ring is 24°, the arc length of the blade is 45 mm, and the number of blades is 4, the lateral coefficient of variation of rice seed dispersal is the highest at 34.762%. At this time, the uniformity of dispersal is the worst.

Table 5. Coding of factors and levels

Code	Ring baffle angle θ (°)	Arc length L (mm)	Number of blades N (single)
-1	21	45	3
0	22.5	46	4
1	24	47	5

Table 6. Analysis of variance of test results

Code	Ring baffle angle θ (°)	Arc length L (mm)	Number of blades N (single)	Coefficient of variation CV (%)
1	24.0	47	4	28.841
2	22.5	47	5	30.587
3	21	47	4	27.733
4	21	45	4	19.621
5	24	46	3	24.314
6	24	45	4	34.752
7	22.5	46	4	24.328
8	22.5	46	4	28.824
9	22.5	45	5	31.713
10	22.5	45	3	26.583
11	21	46	3	21.362
12	22.5	47	3	27.627
13	22.5	46	4	28.136
14	22.5	46	4	24.623
15	22.5	46	4	20.612
16	21	46	5	23.572
17	24	46	5	27.643

ANOVA was carried out for the response surface test, an the results are shown in the Table 7. The regression model is highly significant (P < 0.0001), so the model is reasonable. The P-value shows that the angle of the retaining ring and the number of blades have a remarkable effect on the lateral coefficient of variation of spreading, followed by the length of the blades. The regression response surface equation for baffle ring angle, blade length, number of blades, and lateral coefficient of variation is shown in Equation (1), and the results of ANOVA are shown in Table 7.

$$CV = 24.38 + 2.91\theta + 1.7N + 0.2649L - 3.51\theta L + 0.2797\theta N - 0.5425LN - 0.7734\theta^2 + 4.13L^2 + 0.6173N^2 \quad (1)$$

Table 7. Analysis of variance of test results

Source	Sum of squares	Degree of freedom	F-number	P-value
Model	244.53	9	31.23	＜0.0001**
Ring baffle angle θ	9.20	1	10.58	0.014*
Arc length L	25.80	1	29.66	0.001**
Number of blades N	17.93	1	20.61	0.0027**
θL	7.10	1	8.16	0.0244**
θN	0.0027	1	0.0031	0.9571
LN	7.31	1	8.40	0.0230*
θ^2	69.27	1	79.63	0.0230
L^2	46.25	1	53.17	＜0.0001
N^2	43.28	1	49.75	0.002
Residual	6.09	7		
Lack of fit	2.69	3	1.05	0.461
Error	3.40	4		
Sum total	250.62	16		

Note :** means the difference is extremely significant (p < 0.01), * means the difference is significant (p < 0.05).

4.5 Field experiments

To further verify the rationality of the optimized design of the rice seed spreading device, we used an UAV as the flight platform to carry the rice direct sowing device. In accordance with the NY/T3881-2021 remote-controlled flying planter spreading operation test standard, the UAV flight altitude was set at 2.0 m, flight speed was set at 3.5 m/s, seeding capacity was set at 41 g/s, rotational speed of dumping disk was set at 600 r/min, course spacing was set at 3.0 m, the angle of the rectangular ring baffle was set at 21°, the arc length of the blades was 45 mm, and the number of the blades was 4 to conduct the field test.

4.6 Measurement of coefficient of variation

The fields were all divided into three random sampling plots. Samples were randomly obtained from five sampling points in each plot. The sampling points had a 1.0 m × 1.0 m square area. Each piece was divided into 25 squares. We recorded the number of rice species in each grid. The lateral coefficient of variation was calculated for each row and averaged, and the result was 23.72% (Table 8).

Table 8. Results of field tests

Frequency	1	2	3	4	5	Average
Coefficient of variation CV(%)	23.80	24.12	23.41	25.13	22.16	23.72

4.7 Measurement of grain yield

The yield of UAV direct seeding was measured by the random sampling method. The fields were all divided into three regions, and five sampling points were obtained in each region, totaling 15 sampling points, each with an area of 1.0 m × 1.0 m. The average number of plants per square meter $\bar{a}$, the average number of spikes per plant $\bar{b}$, and the average number of grains per spike $\bar{c}$ were counted. The average number of effective spikes per acre $\bar{n}$ was calculated by Equation (2), and the yield per hectare $\bar{Q}$ was calculated by Equation (3):

$$\bar{n} = 667 \times \bar{a} \times \bar{b} \tag{2}$$

$$\bar{Q} = \frac{\bar{n} \times \bar{c} \times d \times 10^{-6}}{6.67 \times 10^{-2}} \tag{3}$$

In the two equations:
$\bar{Q}$ —Average yield per hectare, kg;
$\bar{n}$ —Average effective panicles per mu;
$\bar{a}$ —Average plant number per square meter;
$\bar{b}$ —Average panicle number per plant;
$\bar{c}$ —Average grain number per panicle;
d —Thousand grain weight, g.

By substituting the measured data into the above two formulas, the yield was obtained, as shown in Table 9. The yield is 8615.81 kg/hm^2, which is not much different from the average yield of 8706.45 kg/hm^2 of the variety, so the feasibility of the direct seeding of rice by unmanned aircraft was further verified.

Table 9. Yield results

Properties	Average plant per square $\bar{a}$	Average panicle per plant $\bar{b}$	Effective panicle number per acre $\bar{n}$	Average grain per panicle $\bar{c}$	Thousand grain weight d	Yield per acre (Kg)
Stats	29	10.6	205035.8	143	19.6	580.43

5. Conclusions

To comprehensively consider the sowing efficiency and uniformity, we designed a rice disordered spreading device that can be mounted on a multi-rotor UAV in this study. The discrete element simulation method was used to analyze the response surface analysis of the angle of the rectangular ring baffle, the arc length of the dumping disk blades, and the number of the blades, which affected the uniformity of the rice seeds. We constructed the response surface equations of the three factors and the lateral coefficient of variation, determined the optimal parameter combinations with the lowest lateral coefficient of variation, and completed field trials to verify the results. The optimal parameter combination was obtained when the lateral coefficient of variation was the lowest, and the field experiment was completed for verification. The following conclusions could be drawn:

(1) With the increase in the angle of the rectangular ring baffle, the lateral coefficient of variation of rice seed spreading decreases first and then increases, and the uniformity of spreading is optimal in the range of 21°–24°.

(2) With the increase in the arc length of the disc blade, the lateral coefficient of variation of seed distribution decreases and then increases, and the uniformity of seed distribution is improved in the range of 45–48 mm.

(3) With the increase in the number of disc blades, the lateral coefficient of variation of seed distribution gradually decreases.

(4) The significance of the effects of the angle of the rectangular ring baffle, the arc length of the disc blades, and the number of blades on the lateral coefficient of variation (uniformity) of seed distribution is in descending order of significance as follows: the angle of rectangular ring baffle (θ) > the number of disc blades (N) > the arc length of the disc blades (L).

In this study, the optimal parameter combination of the UAV rice seed spreading device is determined through numerical simulation tests. Comparison between the simulation results and the UAV fly sowing field test results show that the spreading uniformity of the two is similar to each other. The field test results verify the reliability of the simulation results, which also provide an important basis for the feasibility of drone rice disordered direct sowing. When using DEM to simulate the rice seed sowing process, the particle model of the rice seed is relatively simple. In the future, high-performance computers can be used to establish a realistic particle model, so that the simulation of the rice seed sowing process will be close to reality.

Acknowledgements
The authors are grateful for the support provided by the National Natural Science Foundation of China (No. 32101818) and the Project Foundation of Sichuan Provincial Science and Technology Department (No. 2021YJ0279).

References

[1] J. D. Cerro, C. C. Ulloa, A. Barrientos, and J. L. Rivas, “Unmanned aerial vehicles in agriculture: A survey,” *Agron.,* vol. 11, pp. 203-222, Jan. 2021.
[2] M. F. Aslan, A. Durdu, K. Sabanci, E. Ropelewska, and S. S. Gültekin, “A Comprehensive survey of the recent studies with UAV for precision agriculture in open fields and greenhouses,” *Appl. Sci.*, vol. 12, pp. 1047-1076, Jan. 2022.
[3] L. Chin, “Influence of plant density and cultivation season on rice yield and quality,” *M.S. thesis*, Dept. Agron., NTU., Taiwan, China, 1999.
[4] A. Kesner, R. Choteborsky´, M. Linda, M. Hromasova, E. Katinas, and H. Sutanto, “Stress distribution on a soil tillage machine frame segment with a chisel shank simulated using discrete element and finite element methods and validate by experiment,” *Biosyst. Eng*., vol. 209, pp. 125-138, Jun. 2021.
[5] G. X. Xia, “The growth path of "China UAV" -- taking DJI UAV as an example,” (in Chinese), *Mod. Radar.*, vol. 43, pp. 101-102, Aug. 2021.

[6] Y. Diao *et al.*, “Key points and prospects of rice UAV direct seeding technology,” (in Chinese), *Chin. Rice.*, vol. 26, pp. 22-25, Sep. 2020.

[7] L. P. Xiao, X. W. He, M. H. Liu, J. P. Cai, Q. H. Shi, and X. H. Pan, “Analysis of current situation of rice production mechanization in double-cropping rice region in southern China,” (in Chinese), *Acta. Agric. Univ. Jiangxiensis*., vol. 35, pp. 682-686, Jan. 2013.

[8] N. Vovchenko1, A. Novikov, S. Sokolov, and E. Tishchenko, “A proposed technology to ensure high-precision aerial seeding of certified seeds,” in *IOP. Conf. Ser. Earth Environ. Sci*., Voronezh, Russian Federation, Oct. 2020, pp. 66-72.

[9] A. Andrio, “Development of UAV technology in seed dropping for aerial revegetation practices in Indonesia,”in *IOP. Conf. Ser. Earth Environ. Sci.*, Bogor, West Java, Indonesia, Sep. 2018, pp. 51-58.

[10] E. P. Fortes, “Seed plant drone for reforestation,” *J. Grad. Res. Creat. Scholarsh.*, vol. 2, pp. 13-26, Jan. 2013.

[11] M. L. Li, “Design and experiment of UAV hanging centrifugal rice planter,” *M.S. thesis*, Dept. Mech. Electr. Eng., SAU Univ., SC, China, 2019.

[12] M. Lysych, L. Bukhtoyarov, and D. Druchinin, “Design and research sowing devices for aerial sowing of forest seeds with UAVs,” *Inventions.*, vol. 6, pp. 82-108, Nov. 2021.

[13] S. Meivel, R. Maguteeswaran, N. Gandhiraj, and G. Srinivasan, “Quadcopter UAV based fertilizer and Pesticide Spraying System,” *J. Eng. Sci*., vol. 1, pp. 8-12, Feb. 2016.

[14] A. Mukherjee, S. Misra, and N. S. Raghuwanshi, “A survey of unmanned aerial sensing solutions in precision agriculture,” *J. Netw. Comput. Appl*., vol. 148, 102461, Oct. 2019.

[15] R. K. Bansal, J. T. Walker, and D. R. Gardisser, “Computer simulation of urea particle acceleration in an aerial spreader,” *Trans. ASAE.*, vol. 41, pp. 951-957, May. 1998.

[16] R. Felismina, M. Silva, A. Mateus, and C. Malca, “Development of a universal seeder system to be applied in drones,” *J. Adv. Agric. Tech*., vol. 4, pp. 123-127, Jun. 2017.

[17] W. Z. He *et al*., “Design and experiment of the control system of unmanned aerial vehicle point-based rice seeding device,” *Trans. Chin. Soc. Agric. Eng*., vol. 38, pp. 51-61, Jun. 2022.

[18] C. H. Zhu *et al*., “A kind of unmanned aerial vehicle for direct seeding rice,” CHN. Patent 202010139893.3, Mar. 03, 2020

[19] W. H. Wang and X. B. Li, “Discrete element method and its application in geotechnical engineering,” (in Chinese), *Geotech. Eng. Tech*., vol. 19, pp. 177-181, Aug. 2005.

[20] Y. X. Ye, P. P. Yuan, and J. H. Xie, “Research status of conveying device for agricultural harvesting machinery,” (in Chinese), *Agric. Netw. Inf.*, vol. 04, pp.151-154, Apr. 2016.

[21] D. F. Zhu, Y. P. Zhang, H. Z. Chen, and Y. K. Zhang, “Innovation and practice of rice high-yield cultivation technology in China,” (in Chinese), *Sci. Agric. Sin*., vol. 48, pp. 3404-3414, Sep. 2015.

[22] H. C. Zhang and J. L. Gong, “Research status and development of mechanized high-yield rice farming in China,” (in Chinese), *Sci. Agric. Sin*., vol. 47, pp. 1273-1289, Apr. 2014.