DESIGN AND EXPERIMENT OF ROTARY PRECISION HILL DIRECT SEED-METERING DEVICE FOR RICE

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转勺式水稻精量穴直播排种器设计与试验

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ABSTRACT

In order to realize the mechanical direct seeding of precision rows and hills in rice field, a rotary precision hill direct seed-metering device for rice was designed. Through designing the key components of seed-metering device and analyzing its working principle, the main factors and critical conditions affecting the seed-metering performance were obtained. Using the secondary rotation combination test, taking the rotation speed of seed-metering disc and seed capacity height as the test factors, and the re-broadcasting rate, seed-metering qualified rate and miss-seeding rate as the indexes, the seed-metering performance was experimentally studied by using the JPS-12 seed-metering device tested. Design-Expert 6 0.10 software was used to analyze the test data to obtain the mathematical model between factors and indexes. The test results show that when the speed of the seed-metering plate was 24.60 r/min and the seed capacity height was the radius of the seed-metering disc, the qualified rate of seed-metering was 94.83%, the re-broadcasting rate was 3.43%, and the miss-seeding rate was 1.74%. The seeding performance meets the agronomic requirements of rice seeding, and provides a reference for the design of the whole machine.

摘要

为实现水稻田间精量成行成穴机械直播，设计了一种转勺式水稻田间精量穴直播排种器。通过设计排种器关键部件，并对其工作原理进行分析，得到影响排种性能主要因素和临界条件。采用二次旋转组合试验以排种盘转速、容种高度为试验因素，重播率、排种合格率和漏播率为性能指标，利用 JPS-12 排种器检测试验台对排种性能进行试验研究，并运用 Design-Expert6.0.10 软件对试验数据进行分析，得到因素与指标之间的数学模型。试验结果表明：排种盘转速为 24.60r/min、容种高度为排种盘半径时，排种合格率为 94.83%，重播率为 3.43%，漏播率为 1.74%，排种性能满足水稻田间播种的农艺要求，并为整机设计提供参考。

INTRODUCTION

Rice direct seeding technology is different from the seedling raising and transplanting technology *(He and Zhao et al, 2019; Arzu and Adnan, 2014).* It saves the work of conventional cultivation, seedling raising, seedling transportation and transplanting, and the seedling field operation *(Andrade et al, 2019; Hevko et al, 2008).* It is also a cost-saving and efficient planting technology suitable for the development of economics *(Blümmel et al, 2020; Yin, 2020).* The mechanical direct seeding of rice has the advantages of high efficiency, low labor intensity and low production cost, and is suitable for large-scale promotion *(Yazgi et al, 2017; Vasylkovska et al, 2019).* Rice direct seeding does not have the recovery stage caused by seedling and transplanting, which is conducive to promoting tillering and increasing the effective panicles of the rice plant *(Dai et al, 2020; Ibrahim et al, 2018).* It is also an important way to improve the level of mechanized planting in the whole process *(Poncet et al, 2018; Yang, 2020).*

Seed-metering device is an important part of the precision seeder *(Huang et al, 2020; Andre et al, 2020).* Rice precision seeding is a little difficult. Currently, Heilongjiang Province mostly adopts the drilling method, and most of the drilling tools are the outer groove wheel or the hill wheel seed-metering device. Due to the limitation of the structure, the seed-metering device has low accuracy, poor uniformity and easily damage of seeds, and a large number of fine rice seeds are wasted. It is difficult to achieve the purpose of reasonable hill spacing required by agronomy *(Zhou et al, 2016).*

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In order to meet the needs of precision mechanical hill direct seeding for rice, realize the uniform seeding of bud seeds in rows and hills, and reduce the damage to bud seeds during the seeding, a rotary precision hill direct seed-metering device for rice is designed in this paper. It adopts the operation modes of rotary seed-picking, gravity seed-cleaning, rotary seed-delivery and secondary seed-feeding to explore the structural parameters of key components and analyze its working principle. The best combination of various factors was obtained through bench test to provide reference for the design of the whole machine.

MATERIAL AND RESEARCH METHODS

MAIN STRUCTURE

The structure of the seed-metering device is shown in Fig. 1. It is mainly composed of seed filling cover, seed-metering shaft, bearing, bearing end cap, separator (track and seed delivery port), seed groove wheel, seed-metering shell and more. The rotary spoon disc is composed of 18 seed-picking rotary spoons, which are connected with the slider through the torsion spring. Each seed-spoon makes a circular motion with the rotary spoon disc and rotates in the assembly hole under the control of the torsion spring and the slider. The separator is fixedly assembled with the pin hole of the seed-metering shell by means of a fixed pin. The separator is made of a 1.5 mm thick steel plate with a triangular groove on the edge, which is provided with a track groove and a seed delivery port. The track is welded in the track groove, and the track, the slider and the torsion spring jointly control the rotation of the seed-spoon in the assembly hole. The seed groove wheel rotates synchronously with the rotary spoon disc, and its circumference is evenly distributed. The seed groove corresponds to the seed-picking rotary spoon one by one, and forms 18 seed guiding chambers with the diaphragm and seed-metering shell.

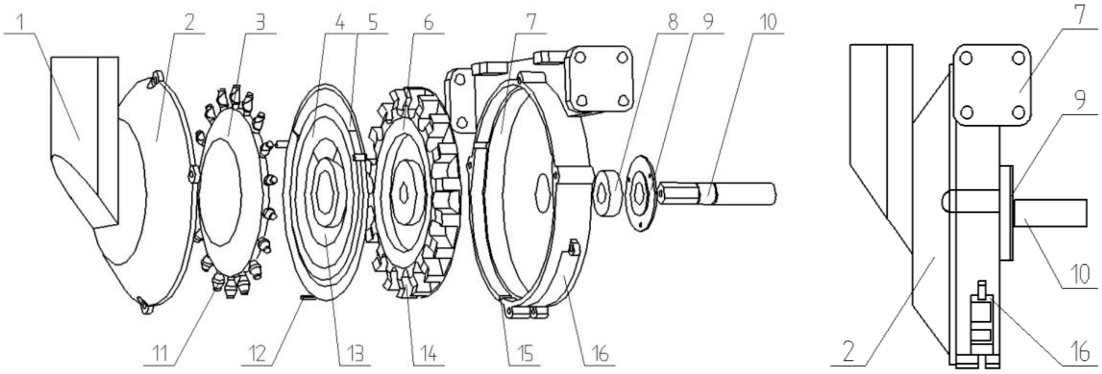


Fig. 1 - Rotary seed-metering device

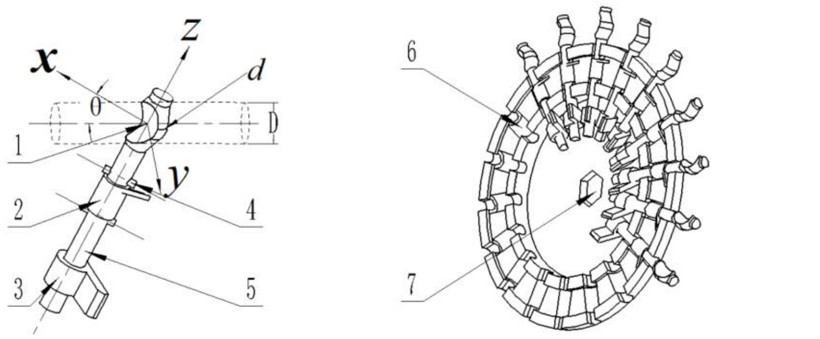
1. Feed opening; 2. Seed filling cover; 3. Rotary spoon disc; 4. Separator; 5. Seed-delivery port; 6. Seed groove wheel; 7. Seed-metering shell; 8. Bearing; 9. Bearing end cap; 10. Seed-metering shaft; 11. Pickup finger; 12. Fixed pin; 13.Track groove; 14. Seed groove; 15. Housing pin hole; 16. Seeding port.

The working process of seed-metering device is mainly divided into five stages: seed-picking, seed-clearing, seed-delivery, seed-guiding and seed-feeding. During operation, the bud seeds are filled into the seed filling cover through the feed opening, and the machines and tools transmit the power to the seed-metering shaft through the chain to drive the rotary spoon disc and seed guiding groove wheel to rotate. The track in the separator and groove is fixed, and the seed-picking spoon is controlled to rotate regularly in the assembly hole with the slider and torsion spring. In the seed-picking area, the bud seeds fill the seed capsule space formed by the seed-picking rotary spoon and the triangular groove of the separator, and leave the seed-picking area driven by the rotary spoon disc to complete the seed-picking process. When the seed-picking rotary spoon pushes the bud seeds to the seed clearing area, the bud seeds in the unstable state of seed capsule space fall back to the seed filling area to complete the seed-clearing process. Driven by the rotary spoon disc, the seed-picking rotary spoon continues to move to the seed-delivery port. Under the joint action of the track, slider and torsion spring, the seed-picking rotary spoon rotates around the axis of the seed-picking rod to push the fixed bud seeds of the seed capsule space into the seed guiding chamber through the seed-delivery port of the separator to complete the seed-delivery process. The seed-guiding groove wheel and the rotary spoon continue to rotate to send the bud seeds in the seed guiding chamber to the seed-feeding port. The bud seeds are separated from the seed-metering device and thrown out under the action of gravity and centrifugal force *(Zhang et al, 2021).*

In order to reduce the height and improve the uniformity of seed-feeding, the seed-metering device has the function of secondary seed-feeding, that is, when the bud seeds in the seed capsule space reaches the seed-delivery port, it is pushed into the corresponding seed guiding chamber to complete one seed feeding. The bud seeds in the seed-guiding room rotate with the seed-guiding groove wheel, turns to the seed-feeding port and are thrown out to complete the secondary seed-feeding.

SEED-PICKING ROTARY SPOON

The seed-picking rotary spoon is composed of a seed-spoon, a torsion spring, a seed-picking rod, a slider and a positioning pin, as shown in Fig. 2. During operation, the seed capsule space composed of the seed-spoon and triangular groove of the separator to scoop the bud seeds. The positioning pin combines the torsion spring and the seed-picking rod into a whole, and positions the seed-picking rotary spoon in the assembly hole at the same time. The slider contacts and rubs with the track, controls the seed-picking rotary spoon to rotate around the axis of the seed-picking rod in the assembly hole, and then controls the seed-spoon to scoop, hold and push the bud seeds.



(a) Pickup finger (b) Rotary spoon disc (including 9 pickup fingers)

Fig. 2 - Diagram of pickup finger

1. Seed-spoon; 2. Torsion spring; 3.Slider; 4. Positioning pin; 5. Seed-picking rod; 6. Assemble hole; 7. Shaft fastening hole.

The seed-spoon is a curved body formed by the intersection of the drum column at the top of the seed-picking rod and the cylindrical surface, and the curved surface is surrounded by the triangular groove of the separator to form a seed capsule space. The maximum diameter *d* of the drum column and the inclination angle θ of the cylindrical surface relative to the separator, and the diameter D of the cylindrical surface determine the space of the seed capsule space. If the seed space is too small, the bud seeds are difficult to enter the spoon, which is easy to cause miss-seeding. If the seed capsule space is too large, many bud seeds will enter the spoon, and it is easy to cause re-broadcasting. In order to improve the scope of seed selection, three kinds of direct seeding rice, Longjing 26, Kenjiandao 6 and Konyu 131 in Heilongjiang Province were selected. After soaking the seeds to promote germination until the chest was broken and white, 1000 seeds were randomly selected to measure the overall dimensions of bud seeds. The average value of statistical data is shown in Table 1.

Table 1

Statistical Results of Dimensions of Rice bud seeds

Variety	Length L / mm	Width W / mm	Thickness T / mm
Longjing 26	7.08	3.96	2.39
Kenjian rice 6	6.68	3.62	2.54
Konyu 131	7.35	3.88	2.47

According to the statistical results in Table 1, the shape and size of seed-spoon surface should meet $W_{max}<d<D<L_{max}$. The structural parameters of the spoon are 7 mm of the cylindrical diameter D, 30° of the inclination angle θ and 4.5 mm of the maximum diameter *d* of the drum.

SEPARATOR TRACK

According to the needs of seed-metering, the circumferential angle of the separator track is divided into four parts: seed-spoon opening, seed-picking duration, seed-spoon delivery and delivery duration, as shown in Fig.3. In the seed-spoon opening area, the track height gradually decreases, and the slider gradually disengages from the track. Under the action of torsion spring, the pickup finger rotates in the assembly hole, and the seed capsule space is opened to the maximum.

After the pickup finger turns over the seed-picking continuation area, the slider contacts the closed slope of the track and enters the seed-spoon delivery area. The height of the guiding rail increases gradually, and the slider overcomes the action of the torsion spring to control the rotation of the pickup finger in the assembly hole. The seed capsule space gradually decreases, and the bud seeds in the seed–spoon are pushed into the seed-guiding chamber through the seed-delivery port. The slider enters the delivery continuous area. Under the action of track lifting, the pickup finger maintains the pushing state of bud seeds at the seed-delivery port.

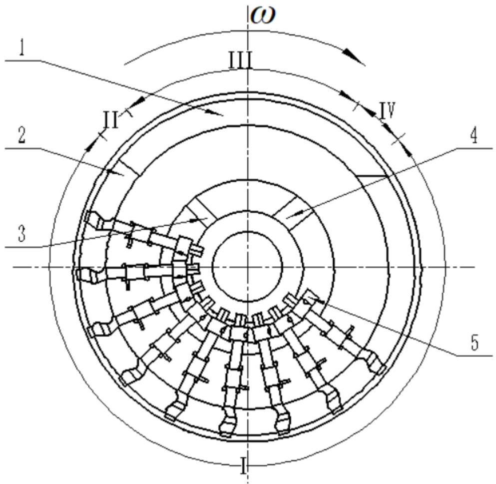


Fig. 3 - Diagram of the separator track

I. Seed-picking duration; II. Seed-spoon delivery; III. Delivery duration; IV. Seed-spoon opening.
1. Seed-delivery port; 2. Triangular groove; 3. Closed slope; 4. Involute slope; 5. Slider

According to the position of seed-delivery port and the position of bud seed population, the opening angle of seed-spoon orbit circumference is designed to be 30°, the seed-picking duration angle is 250°, the seed-spoon delivery angle is 20° and the delivery duration angle is 60°.

SEED-PICKING AND SEED-CLEARING PROCESS

When the seed-metering device works, the rotary spoon disc rotates at an angular speed ω to drive the pickup fingers to scoop the bud seeds, and the bud seeds are lifted from the population by the seed spoon to complete the seed-picking operation. When the pickup fingers rise to a certain height, the bud seeds in the unstable state of seed capsule space fall back to the seed-filling area under the action of gravity to complete the seed-clearing operation.

As shown in Fig. 4, when there are too few bud seeds, the seed capacity height H is small and the seed-filling probability is small. When there are too many bud seeds, the seed capacity height H is large and the seed-filling probability is large. However, when the starting angle β of seed-clearing is exceeded, there are still bud seeds filling in the capsule seed space, which would affect the seed-clearing performance. The highest point of *AB* on the population surface should not exceed the seed-clearing starting point. Turning the spoon to dig into the bud seeds until they leave the population surface, and the central angle ζ corresponding to the population surface *AB* is the seed angle, then:

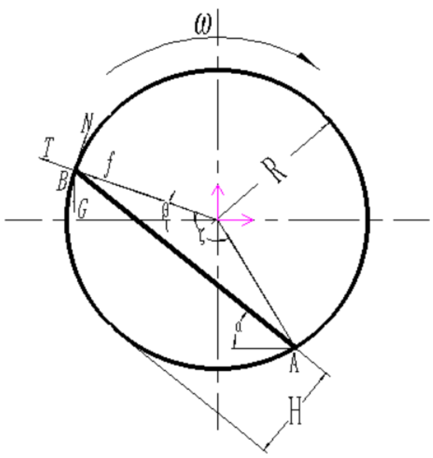


Fig. 4 - Diagram of the force applied to the moving seeds

$$\varsigma = 2\arccos\frac{R-H}{R} \tag{1}$$

where, R - the distance from the bud seeds to the center of the seed-spoon disc, mm

H - seed height in the filling cap of the seed-metering device, mm

ζ - seed-picking angle corresponding to the population surface, (°)

With the rotation of the spoon disc, the seed capsule space gradually decreases. A bud seed B is selected as the research object. There are mainly frictional force f, seed-spoon support force N, gravity G and centrifugal force T acting on the bud seeds to establish the force equation.

$$\begin{cases} G\sin\beta + f = T \\ N = G\cos\beta \\ f = N\tan\varphi \\ T = m\omega^2 R \\ G = mg \end{cases} \tag{2}$$

where: ω - the speed of the rotary spoon disc, r/min,

φ - the sliding friction angle between bud seed and seed-spoon, (°),

β - the starting angle of seed-clearing, (°),

m - the quality of bud seeds, g.

With the rotation of the spoon disc, the seed-picking ends and the seed-clearing process begins.

The clearing start angle β is:

$$\beta = \arcsin\left(\frac{\omega^2 R}{g}\cos\varphi\right) - \varphi \tag{3}$$

The starting and ending positions of the seeds are determined by the angle α between the population plane *AB* and the horizontal direction.

$$\alpha = \frac{\pi}{2} + \arcsin(\frac{\omega^2 R}{g}\cos\varphi) - \varphi - arcco\alpha(\frac{R-H}{R}) \tag{4}$$

where, α - the angle between the population plane and the horizontal direction, (°).

As the angular velocity ω of the rotary spoon disc increases, the distance R from the bud seed to the center of the rotary spoon disc increases, and the included angle α also increases. The highest point of the population surface increases as well, resulting in an excessively large seed filling area and a small clearing area, which is easy to re-broadcast.

ANALYSIS OF SEED-DELIVERY PROCESS

The *xoyz* coordinate system is established, and the center *O* of the seed-spoon surface is the coordinate origin. The xOy coordinate plane is perpendicular to the axis direction of the seed-picking rod, and the z-axis is the axis direction of the seed-picking rod, as shown in Fig. 5. The distance between the bud seed *Q* and the axis of the seed-picking rod is *r*, and the distance from the axis of seed-metering is R'.

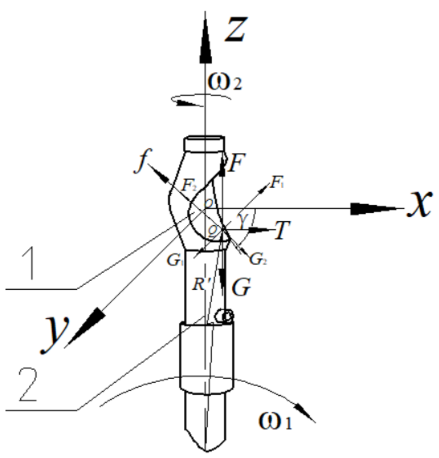


Fig. 5 - Stress analysis of bud seeds in the process of seed-delivery

1. Seed-spoon; 2.Seed-picking rod axis

In the process of seed-delivery, the bud seed Q is subjected to the gravity G, the support force N of the seed-scoop on the bud seed, the centrifugal force F received by the bud seed with the seed-picking spoon rotating around the seeding axis at an angular velocity ω_1, the centrifugal force T received by the bud seeds rotating around the axis of the seed-picking rod with the angular velocity ω_2 and the friction f. The bud seeds subjected to the gravity G can be decomposed into the positive pressure G_1 of the bud seeds on the surface of the seed-spoon and the sliding force G_2 along the surface of the seed-spoon:

$$\begin{cases} G_1 = G\cos\gamma \\ G_2 = G\sin\gamma \end{cases} \tag{5}$$

where, γ - the sliding angle of bud seeds along the surface of the seed-spoon, (°),

The bud seed Q rotates around the seed-picking spoon axis at an angular velocity ω_1 with the rotary spoon, and the received centrifugal force $F=m\,\omega_1^2 R'$ can also be decomposed into two component forces F_1 and F_2 in the opposite direction of gravity,

$$\begin{cases} F_1 = F\cos\gamma \\ F_2 = F\sin\gamma \end{cases} \tag{6}$$

The bud seed Q slides down the surface of the seed-spoon, and the friction force is:

$$f = \mu(G_1 - F_1) \tag{7}$$

where, μ - the friction coefficient between bud seed and seed-spoon surface.

During the seed delivery process, the bud seed Q rotates with the seed spoon around the axis of the seed-picking rod at an angular velocity ω_2, and is also affected by the centrifugal force T. Its direction is the tangential direction of the circle with the z-axis as the center and r as the radius, pointing to the seed-delivery port of the separator, and its value is:

$$T = mr\omega_2^2 \tag{8}$$

where, r - the distance between the seed-spoon and the bud seed from the axis of the seed-picking rod, mm,

ω_2 - the rotational angular velocity of bud seeds around the axis of the seed rod, r/min.

The bud seed Q is pushed into the seed guiding chamber through the seed-delivery port by the resultant force. Its pushing acceleration can be calculated by the following formula:

$$\eta = \frac{\sqrt{(G_2 - F_2 - f)^2 + T^2}}{m} \tag{9}$$

Substituting each known quantity into Equation (9):

$$\eta = \sqrt{(g - \omega_1^2 R')^2(\sin\gamma - \mu\cos\gamma)^2 + (\omega_2^2 r)^2} \tag{10}$$

where: η - bud seed pushing acceleration, m/s^2,

ω_1 - angular velocity of bud seeds around the seed-metering axis, r/min.

Assuming that the length of the bud seed Q is L, the time t required for the bud seed to pass through the seed-delivery port of the partition to reach the seed-guiding chamber can be obtained from the following formula.

$$t = \sqrt{\frac{2L}{\eta}} \tag{11}$$

where: L - the bud seed length, mm,

t - Time of the bud seed passing through the seed-delivery port, s.

From formula (10) and formula (11), the spread angle ρ of the seed-delivery port can be calculated, namely:

$$\rho = \frac{255\omega_1\sqrt{L}}{\pi\sqrt[4]{(g - \omega_1^2 R')^2(\sin\gamma - \mu\cos\gamma)^2 + (\omega_2^2 r)^2}} \tag{12}$$

where: ρ - the spread angle of the seed-delivery port, (°)

Substituting L=0.012 m (length of rice bud seeds), ω_1=24 r/min, R'=0.12 m, γ=55°, r=0.001 m, ω_2=108 r/min and μ=0.47 into formula (12), it is determined that the minimum value of the spread angle ρ of the seed-delivery port is 36°. In order to ensure the smooth passage of the bud seeds through the seed-delivery port, the spread angle of the seed-delivery port is selected to be 90°.

SEED GUIDING GROOVE WHEEL

Under the combined centrifugal force F_e, self-gravity G and frictional force f, the bud seeds move toward the seed-delivery port, where they are finally forced to be thrown out when they reach it, and then the process of seed-guiding and seed-delivery is completed.

The state of bud seeds in the seed-guiding chamber is analyzed, and a Cartesian coordinate system is established. The coordinate origin *O* is set to coincide with the rotation center of the seed-guiding groove wheel, as shown in Fig. 6. The critical conditions for bud seeds in the seed-guiding chamber are:

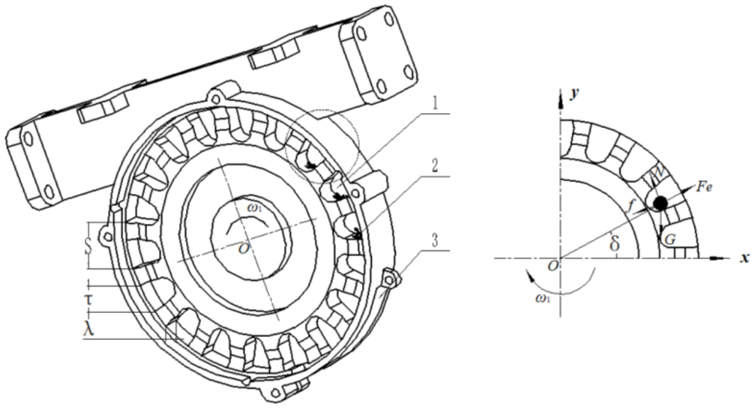


Fig. 6 - Analysis diagram of seed-guiding movement

1. Seed guiding chamber; 2. Rice bud seeds; 3. Seed-delivery port

$$\begin{cases} F_e = \dfrac{mV_1}{K} \\ V_1 = 2\pi nK \\ f = \lambda G\cos\delta \\ f + G\sin\delta \le F_e \end{cases} \tag{13}$$

Where, δ - the angle of circumference of the seed guiding groove wheel, (°),

K - distance from the bud seeds to the metering axis in the seed-guiding chamber, mm,

λ - friction coefficient between the bud seeds and the side wall of seed-guiding chamber,

V_1 - the linear speed of the seed-guiding groove wheel, m/s.

Through the analysis of the seeding process, the seed guiding grooves passing through the seed-guiding chamber is Z in time t. In this design, Z=1, that is:

$$Z\frac{V_0 t}{P} = \frac{V_1 t}{S} \tag{14}$$

Combining formula (13) and formula (14), it is obtained:

$$S = \frac{2\pi nKP}{ZV_0} \tag{15}$$

where, V_0 - forward speed of sowing tool, m/s,

P - spacing of rice planting hill, mm,

S - distance of seed-guiding groove, mm.

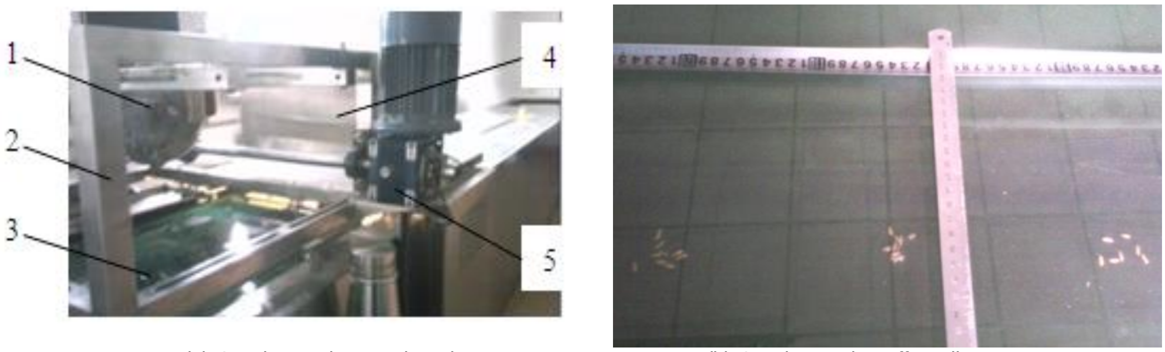
In this design, the radius K of the seed-guiding groove wheel is 120 mm, the distance P between the rice seeding hills is 110 mm-130 mm, and the forward speed V_0 of the seed-metering device is 0.86 m/s. Substituting the above parameters into the formula (15), the distance *S* between the seeding chambers can be obtained as 42 mm. The parameters of the seed-guiding chamber need to consider the external dimensions of the bud seeds, and take the minimum value under the condition that the seeds are not stuck. Therefore, the width τ of the seed guiding groove is 14 mm, and the depth λ of the guiding groove is 12 mm.

EXPERIMENTAL DESIGN AND ANALYSIS

In order to check the working quality of the seed-metering device, referring to the "Testing methods of single seed drills (precision drills)" (GB/T6973-2005), 2 to 6 bud seeds in the hill are selected and the hill diameter is not more than 50 mm as the qualified standard for seed-metering. Design-Expert software was used for data processing.

TEST CONDITIONS AND MATERIALS

The experimental material was Longjing 26, and the rice seeds were soaked and germinated. The test instrument was the JPS-12 seed-metering device test bench, which is adjusted to make the seed-metering shaft run smoothly at 10-150 r/min, as shown in Fig. 7(a):



(a) *Seed-metering test bench* (b) *Seed-metering effect diagram*

Fig. 7 -Test bench of seed-metering performance

1. Seed-metering device; 2. Mounting frame; 3. Seed bed belt; 4. Camera box; 5. Electrical machinery

The seed-metering device is fixed on the mounting frame, and the seed bed belt rotates in the opposite direction relative to the seed-spoon disc to simulate the forward motion state of the seed-metering device. The oil injection pump sprays the sticky seed oil on the surface of the seed bed belt with a fixed width, and the bud seeds are dropped from the seed-metering device to the sticky seed oil layer of the seed bed belt, as shown in Fig. 7(b).

TEST CONTENT AND METHOD

A single factor pre-test was carried out to determine the variation range of each factor on the effects of the speed of the seed-spoon and the seed capacity height on the performance were determined. On this basis, a two-factor five-level quadratic rotation combination design test was used to determine the optimal combination parameters of the seed-metering device. The test factor level coding is shown in Table 2.

Table 2

Coding table of test factor level

Code No.	Speed of rotary spoon disc	Seed capacity height
	x_1 (r/min)	x_2 (mm)
1.414	45	134.40
1	40	120.00
0	28	84.00
-1	16	48.00
-1.414	11	33.60

TEST RESULTS AND ANALYSIS

The experimental plan and results are shown in Table 3. The regression analysis of the experimental data was carried out by Design-Expert software. x_1 is the speed of the rotary spoon, x_2 is the seed capacity height, y_1 is the qualified rate of seed-metering, y_2 is the re-broadcasting rate, and y_3 is the miss-seeding rate.

Table 3

Results and design of tests

No.	Test factors		Performance indexes		
	x_1	x_2	y_1	y_2	y_3
	(r/min)	(mm)	(%)	(%)	(%)
0	1	2	3	4	5
1	16	48.00	76.13	12.28	11.59
2	40	48.00	84.09	8.21	7.70
3	16	120.00	86.24	6.40	7.36
4	40	120.00	73.56	8.17	18.27
5	11	84.00	75.74	17.51	6.75

Table 3
(continuation)

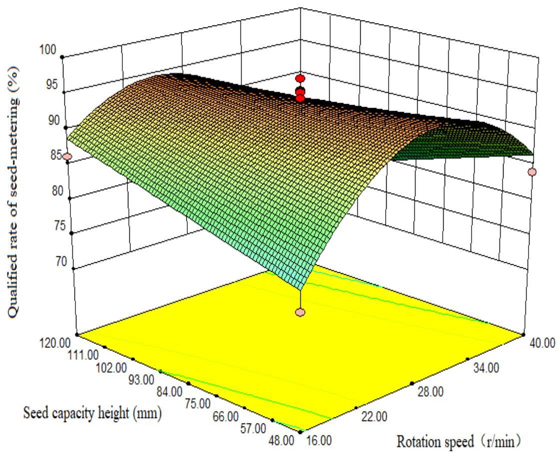
0	1	2	3	4	5
6	45	84.00	71.41	19.66	8.93
7	28	33.60	95.10	2.40	2.50
8	28	134.40	94.07	4.60	1.33
9	28	84.00	92.32	6.15	1.53
10	28	84.00	95.41	3.01	1.58
11	28	84.00	97.13	1.90	0.97
12	28	84.00	95.31	2.55	2.14
13	28	84.00	95.20	3.37	1.43
14	28	84.00	93.04	4.20	2.76
15	28	84.00	94.38	4.84	0.78
16	28	84.00	92.63	7.05	0.32

$$y_1 = 7.26 + 5.34x_1 + 39.35x_2 - 1.43x_1x_2 - 0.08x_1^2 \tag{16}$$

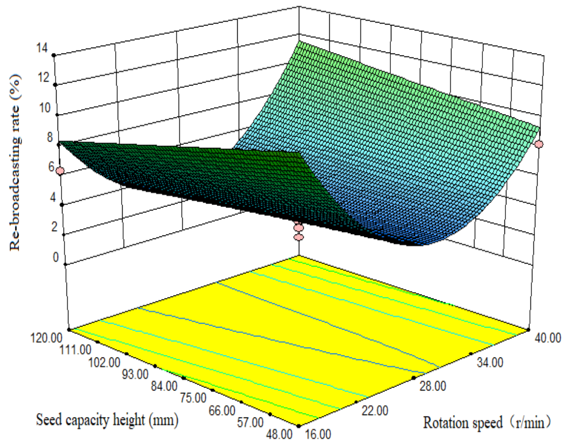
$$y_2 = 48.48 - 2.86x_1 - 12.53x_2 + 0.41x_1x_2 + 0.05x_1^2 \tag{17}$$

$$y_3 = 44.26 - 2.48x_1 - 26.83x_2 + 1.03x_1x_2 + 0.03x_1^2 \tag{18}$$

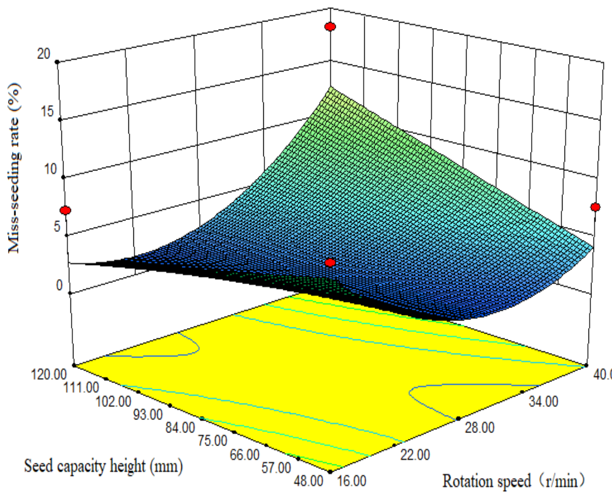
In order to intuitively analyze the relationship between the test indicators and factors, the response surface is obtained by using the Design-Expert software, as shown in Fig.8:



(a) The qualified rate of seed-metering



(b) Re-broadcasting rate



(c) Miss-seeding rate

Fig. 8 - Response surfaces of all factors to the test index

According to the above formulas (16), (17) and (18), and Fig. 8, it can be seen that there is an interaction between the speed of the rotary spoon and the seed capacity height. It can be seen from Fig. 8(a) that when the seed capacity height is constant, the qualified rate first increases and then decreases with the increase of the speed of the rotary spoon. When the speed of the rotary spoon disc is constant, the qualified rate increases with the increase of the seed capacity height. The variation range of the qualified rate is large when the speed of rotary spoon disc changes. Thereby, the speed of the rotary spoon is the main factor affecting the qualified rate of seed-metering. It can be seen from Fig. 8(b) that when the seed capacity height is constant, the re-broadcasting rate first decreases and then increases with the increase of the rotation speed. When the rotation speed is low, the re-broadcasting rate gradually decreases with the increase of the seed capacity height. However, when the rotation speed is larger, the re-broadcasting rate gradually increases. When the rotating speed changes, the variation range of the re-broadcasting rate is large, so the rotation speed is an important factor affecting the re-broadcasting rate. It can be seen from Fig. 8(c) that when the rotation speed is constant, the miss-seeding rate increases with the seed capacity height and the miss-seeding rate gradually decreases.

SEED-METERING ADAPTABILITY TEST

In order to study the adaptability of the seed-metering device to different rice bud seeds, the test seed-metering was carried out. Three kinds of rice bud seeds were selected as the research objects, and the sizes are shown in Table 1. Five repeated tests were carried out when the rotation speed of the seed-spoon disc was 24.6 r/min and the forward speed was 0.86 m/s. The data was processed to obtain the average value, as shown in Table 4.

Table 4

Adaptation test results

Variety	Performance index		
	Qualified rate %	Re-broadcasting rate %	Miss-seeding rate %
Longgeng 26	94.83	3.43	1.74
Kenjiand 6	94.26	3.18	2.56
Kongyu 131	93.32	4.40	2.28

It can be seen from Table 4 that the adaptability of the seed-metering device to the three kinds of rice bud seeds meets the agronomic requirements of precision seeding. Among them, Longjing 26 has better fluidity, is stable in the seed capsule space, and is easy to clear seeds, thus its performance index is the best. In the process of seed filling, Kongyu 131 is prone to the phenomenon that many seeds are in the capsule seed space. The bud seed has poor fluidity, the seed clearing is not thorough, and re-broadcasting is easy to occur. The seeding indexes of Kenjian 6 were better.

CONCLUSIONS

(1) In this paper, a rotary precision mechanical hill direct seed-metering device for rice is designed, and its working principle is analyzed. The structural parameters of key components are optimized to meet the requirements of precision hill direct seeding.

(2) Taking the rotation speed of the rotary spoon disc and the seed capacity height as independent variables, and the seed-metering qualified rate, re-broadcasting rate and miss-seeding rate as objective functions, the influence relationship between the working and structural parameters of the rotary spoon precision hill direct seed-metering device and the performance index of seed-metering was determined.

(3) Through the analysis and optimization of the test results using Design-Expert software, it is concluded that when the speed of the rotary spoon disc was 24.6 r/min, and the seed capacity height was the seed filling cover radius R, the qualified rate of seed-metering was 94.83%, the re-broadcasting rate was 3.43%, and the miss–seeding rate was 1.74%.

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