DESIGN AND TEST OF VARIABLE DIAMETER PNEUMATIC DRUM TYPE BEAN SEED METERING DEVICE
/
变粒径气力滚筒式豆类种子精量排种器的设计与实验

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ABSTRACT

The roller for seeds of different sizes, a variable-size pneumatic cylinder precision seed metering device was designed, which could realize the precision seeding of different diameter seeds without changing the roller. The structure and working principle of seed metering device were explained, and the structural parameters of the main components of the seed meter were determined. The ANSYS was used to analyse the influence of the size of the negative pressure inlet pipe and the shape of the eyelet on the airflow velocity in a negative pressure chamber. Based on the above optimal structure, the orthogonal experiment of seed metering device was carried out. Testing results showed: under the negative pressure of 4 kPa, roller speed of 16.93r/min and the wind speed of 11.48m/s, the seed metering device had the best seeding effect. The qualification rate of the seed metering device was 92.37%, the miss-seeding rate was 3.74% and the over-seeding rate was 3.88%.

摘要

针对豆类种子排种器对不同粒径种子进行排种时需要更换滚筒等问题，设计了一种变粒径气力滚筒式豆类种子精量排种器，无需更换滚筒便可实现不同径粒种子的精量播种。首先，阐释了排种器的结构以及工作原理，确定了排种器主要部件的结构参数。其次，通过 ANSYS 流体仿真分析了负压进气管结构尺寸和窝眼孔形状对负压腔内气流流速的影响。最后，基于上述优选结构对排种器进行正交实验。结果表明：滚筒转速为 16.93r/min，负压为 4.97kPa，清种风速为 11.48m/s 时为最佳参数组合，排种器的合格率为 92.37%，漏播率为 3.74%，重播率为 3.88%。

INTRODUCTION

In China, bean is one of the important food crops. The performance of the seed metering device directly affects the quality and effect of the seeding (*Karayel D, 2009*). The efficient, versatile, and qualified seed metering device provide strong support for the survival and development of beans. Owning to the adaptability of the air-suction metering device and the ability to achieve high speed and precision seeding, the air-suction metering device has gradually developed into the mainstream (*Gaikwad B. B. and Sirohi N. P. S, 2008; Yang et al., 2016*). Negative pressure, seed speed and suction hole shape have a great influence on the performance of the seeding device (*Zeliha Bereket and Aziz, 2004; Singh R.C. et al., 2005; Jack St. Dylan et al., 2013; Dizaji H.Z et al., 2010*). Singh et al. monitored the seed metering process in real time through an electronically controlled metering system, reducing the miss-seeding rate and improving seeding quality (*Singh T. and Mane D., 2011*). Qi Bing et al designed a circumferential cleaning device suitable for the seed metering device, which solved the serious problem of reseeding (*Qi Bing et al., 2015*).

The working parameters have a great influence on the seeding effect (*Rajaiah. P et al, 2016; Yazgi A and Degirmencioglu A, 2014*). Kumar Devesh et al. designed the seed metering device that overcomes the

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uneven distribution of seeds (*Kumar Devesh et al., 2017*). Jia Honglei et al improved the seed filling effect by increasing the type of seed churning device and filling power (*Jia H et al., 2018*).

The above research did not realize the seeding of multi-size seeds. Therefore, this paper designed a seed meter that converts different pore diameters by double drum rotation combination, which can realize seeding of different particle sizes.

MATERIALS AND METHODS

- **Overall scheme design**

Structure and working principle

The seed metering device mainly consists of inner and outer roller, rotating handle, seed box, pressure releasing device and others, as shown in Fig.1

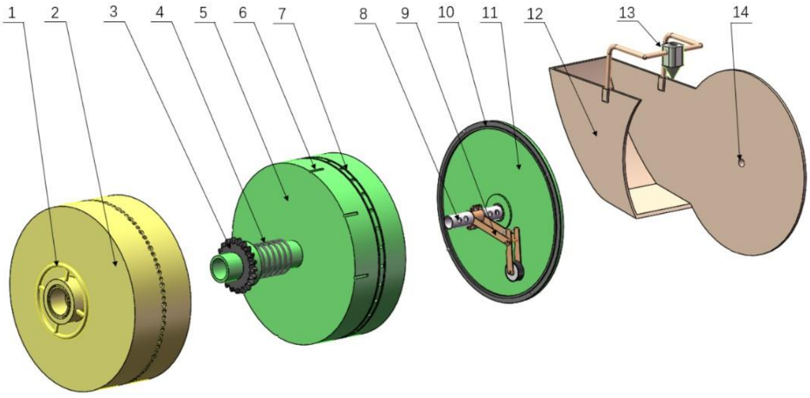


Fig.1 - Schematic diagram of seed metering device

1 -Rotating handle; 2 - Outer roller; 3 – Driving chain wheel; 4 – Spring; 5 - Inner roller; 6 - Groove; 7 - Seal ring;8 – Intake manifold; 9 - Pressure releasing device; 10 - Seal ring; 11 - Rear cover; 12 - Seed box; 13 - Blow nozzle; 14 - Air inlet

With main seed metering disc rotated, the seeds are adsorbed on the holes by gas chamber negative pressure. When the seeds pass through the seed cleaner, the excess seeds are removed by the weight and the airflow produced by the blow nozzle. The seed rotates away from the zone of negative pressure with the disc, and the adsorption force of the seed disappears. The hole loses the adsorption force to the seed. Under the action of gravity and centrifugal force, the seed falls into the seed bed at a certain speed to complete the seeding process.

- **Determination of main parameters**

The diameter of the seeding drum is the basic characteristic parameter of the seed metering device, and its size affects the linear velocity of the seed metering device, the number of holes and other parameters. According to agricultural machinery design manual, the diameter range of the roller is 80~200mm. Therefore, the diameter of the outer roller is 200mm and the diameter of the inner roller is 196mm. Both materials are made of stainless steel with a thickness of 2mm.

$$\begin{cases} Q = \dfrac{V_s}{S} = \dfrac{v_l}{P} \\ 60v_l = \pi D n \\ ZT = \pi D \\ 2d_{max} \le T \end{cases} \tag{1}$$

Where:

Z is the number of holes; Q is the dropping frequency, [s^{-1}]; T is the distance of the holes, [m]; S is the plant spacing, [m]; v_l is the line speed of the metering device, [m/s]. P is the power, [W]; d_{max} is the maximum particle size of seeds, [m].

Each seed of Zhong Wan no.6, Qing Feng no.4 and Lin Fan no.6 was measured several times to obtain their respective triaxial dimensions. The equivalent diameter (*Ds*) was calculated according to the obtained average value.

$$D_S = \sqrt[3]{LWH} \tag{2}$$

Where:

D_S is equivalent diameter, [mm];

L is length, [mm]; W is width, [mm];

H is thickness, [mm].

The results of the number of holes and equivalent particle size are shown in Table 1.

Table 1

Equivalent diameter size of beans and the number of holes

Varieties of beans	plant spacing（m）	Number of holes	equivalent diameter (mm)
Zhong Wan no.6	0.25~0.40	18~27	6.70
Qing Feng no.4	0.40~0.55	20~35	8.80
Lin Fan no. 6	0.12~0.20	15~23	12.52

According to Table 1, the number of holes in the three types of beans is 20, all of which are uniformly placed on the drum. The combination of the holes is shown in Fig 2. From the empirical formula d= (0.64~0.66) Ds, it can be concluded that the diameter of class A hole is 8mm, that of class B hole is 5.8mm, and that of class C hole is 4.4mm.

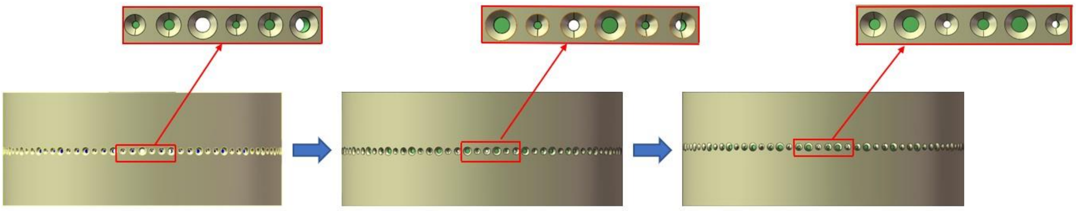


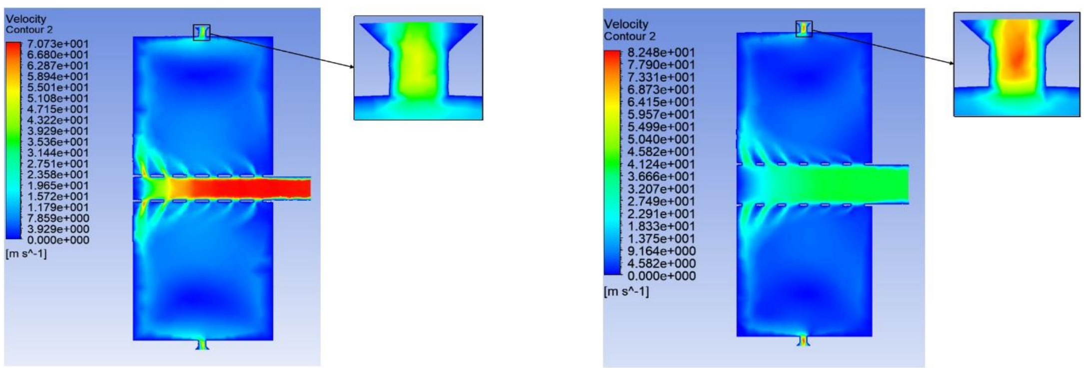
Fig. 2 - Combination diagram of three kinds of eyelet

- **Simulation analysis of planter based on ANSYS**

The model of seed metering device was imported into Geometry, and the seed metering device was meshed and simulated. The inlet pressure was set to 0 kPa, the outlet pressure was set to -5 kPa, the convergence accuracy was set to 0.001, and the number of iteration steps was set to 100 steps.

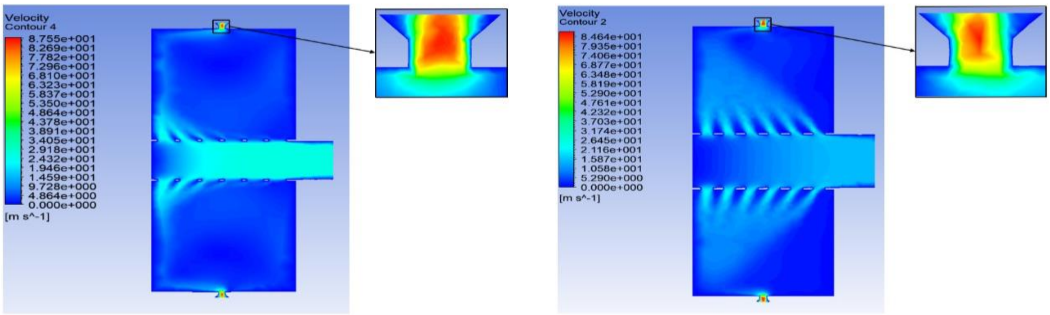
- **Influence of pipe diameter on flow velocity**

The diameter of the air outlet on the intake pipe was set to 6mm, and the arrangement was set to 6×6. The FLUENT was used to simulate the flow field in the negative pressure inlet pipe when the diameter was 15mm, 24mm, 30mm and 40mm, as shown in Fig.3 and Fig.4.



a) *b)*

Fig. 3 - Velocity cloud diagram of negative pressure cavity with different tube diameters
a) Diameter of 15 mm *b) Diameter of 24 mm*



a) b)

Fig. 4 - Velocity cloud diagram of negative pressure cavity with different tube diameters

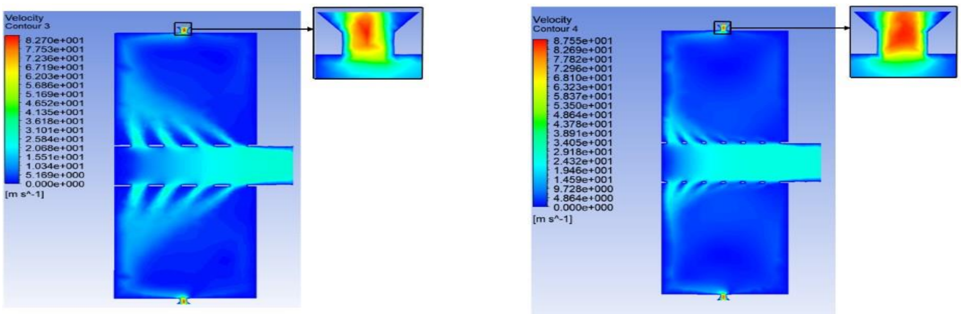
a) Diameter of 30 mm *b) Diameter of 40 mm*

When the diameter of the inlet pipe was 15 mm, the overall flow velocity in the intake pipe was large, and the flow velocity of each discharge port varied greatly, causing large reflux and eddy current. When the diameter of the inlet pipe was 24 mm, the flow velocity of each discharge port varied greatly, resulting in uneven flow field, large backflow and eddy current. When the diameter of the intake pipe was 30 mm, the overall flow velocity in the intake pipe did not change much, there was a gap in the flow velocity of each discharge port, and the phenomenon of reflux and eddy current was light. When the diameter of the intake pipe was 40mm, the overall flow velocity in the intake pipe did not change much, but the airflow had interference intersection.

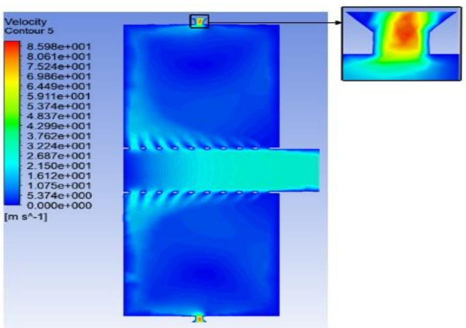
Through the above analysis, it could be concluded that the effect was the best when the diameter of the intake pipe was 30 mm, so the diameter of the intake pipe was selected to be 30 mm.

- **Influence of vent layout on Flow Speed**

The diameter of the negative pressure intake pipe was set to 30mm, and the mode of arrangement was 4 × 4, 6 × 6, and 8 × 9. Flow field in negative pressure cavity were shown in Fig. 5. When the vent layout was 6 × 6, the red part of the velocity cloud at the hole of the seeder was full of the main suction area, and the overall flow field speed was better than the other two cases, so the vent layout was selected to be 6×6.



a) 4 × 4 *(b) 6 × 6*

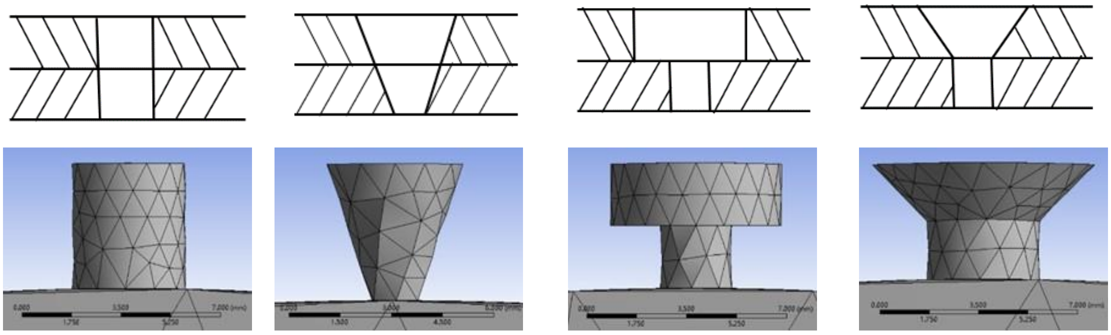


(c) 8 × 9

Fig. 5 - Velocity cloud diagram of negative pressure cavity with different vent layout

- **Influence of hole shape on Flow Speed**

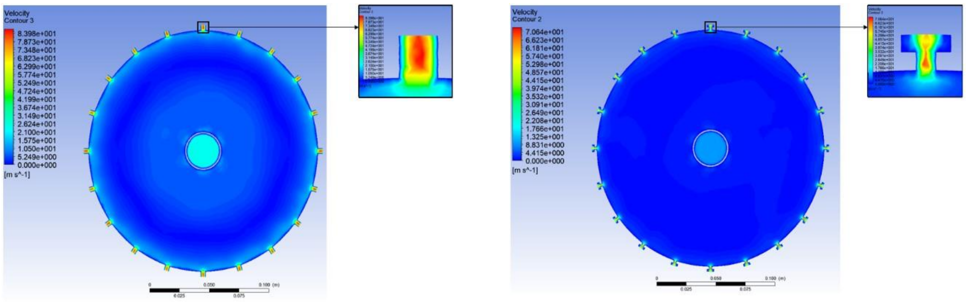
The shape of the socket hole is also the key to affect the suction process and the carrying process. The straight type, the tapered hole type, the countersunk head shape and chamfering type were selected as the variables for simulation analysis, and the meshing result were shown in Fig. 6.



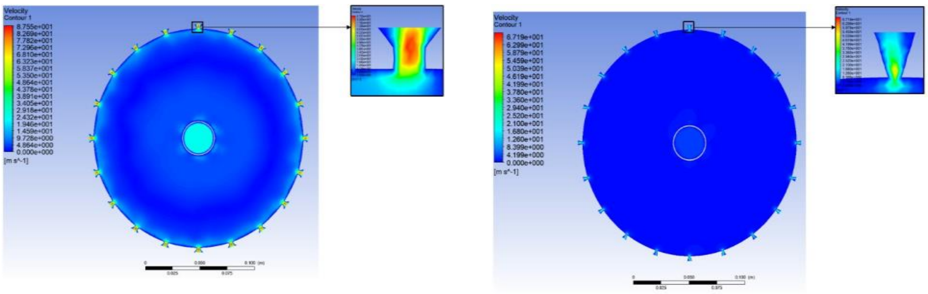
(a) Straight type (b) Tapered hole type (c) Countersunk head type (d) Chamfering type

Fig. 6 - Shape and mesh of socket hole

The airflow velocity of the negative pressure cavity under different socket holes is shown in Fig. 7.



a) Straight type b) Tapered hole type



c) Countersunk head shape d) Chamfering type

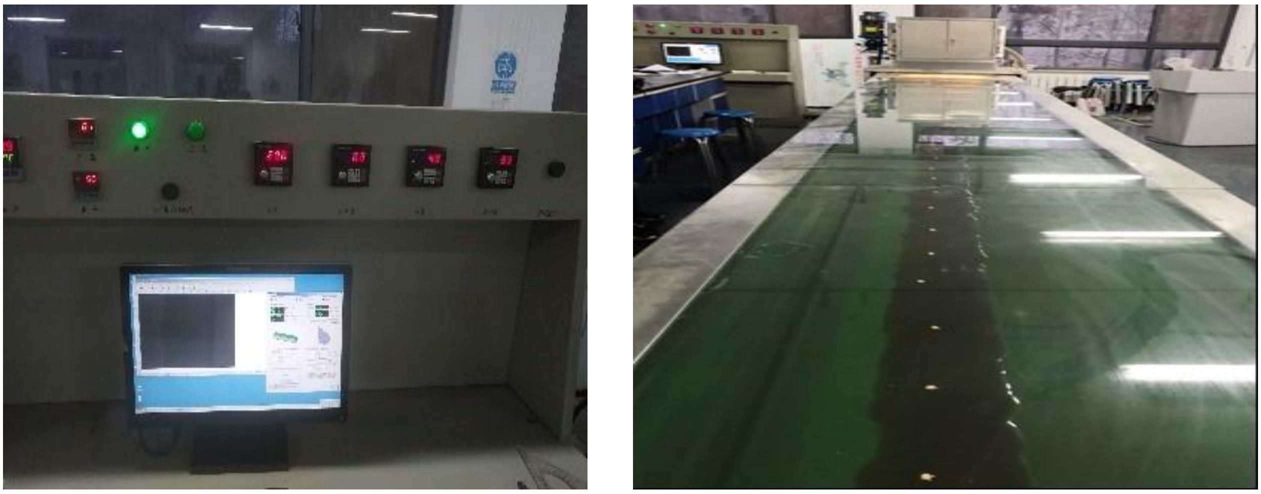
Fig. 7 - Airflow velocity map under different socket hole

Because the gas flow channel did not change, the gas velocity inside the whole straight cylindrical hole was evenly distributed and relatively large. The maximum gas velocity of the cone hole occurred at the minimum diameter of the socket hole. The gas velocity gradually decreased along the bus of the hole to the outer end, and the gas velocity at the outermost edge of the hole was only 5m/s.

Owning to the sudden change of the circular section of the countersunk head, the gas flow velocity in the straight section was disturbed, and the maximum flow velocity of the centre strip was divergent outward, and the lowest velocity of the gas flow appeared on the wall surface. The gas flow velocity at the chamfered hole was gradually increased from the wall toward the centre of the hole, reaching a maximum at the centre.

Considering the rationality of the structure of the socket hole and the flow velocity, the socket hole was selected as chamfering type.

- **Test materials and methods**



a) Control console *b)Test bench*

Fig. 8 - JSP-12 type seed meter performance test bench

This experiment was carried out on the JSP-12 type seed meter performance test bench. Qing Feng no.4 was selected as the test object. According to the theoretical analysis and pre-test, the cylinder speed range was 15~20 r/min, the negative pressure range was 4~6 kPa, and the air blowing speed range was 10~12m/s. Cylinder speed X_1, negative pressure X_2 and air blowing speed X_3 were selected as test factors, and the qualification rate A, miss-seeding rate D and over-seeding rate M were selected as seed metering performance indicators.

- **Test plan design**

According to the design principle of Central Composite Design, the paper made response surface test analysis on the Cylinder speedX_1, negative pressure X_2 and air blowing speed X_3 in three factors and five levels. These factors were marked as X_1 - X_3. The test factor codes and level are shown in Table 2.

Table 2

Encoding of test factors

Coding	Cylinder speed X_1/(r·min^{-1})	Negative pressure X_2/kPa	air blowing speed X_3/(m·s^{-1})
1.682	21.70	6.68	12.68
1	20.00	6.00	12.00
0	17.50	5.00	11.00
-1	15.00	4.00	10.00
-1.682	13.29	3.32	9.32

RESULTS

- **Results of experimental schemes**

Each group of experiments was repeated three times, and the design and results of experimental schemes were shown in Table 3.

Table 3

Design and results of experimental schemes

Test groups	X_1	X_2	X_3	Response values		
				A	D	W
1	-1	1	1	90.35	5.78	3.87
2	0	0	-1.682	85.13	9.93	4.94
3	0	0	0	91.61	4.78	3.61

Test groups	X_1	X_2	X_3	Response values		
				A	D	W
4	0	0	0	91.91	4.33	3.75
5	0	0	1	90.77	3.84	5.39
6	0	0	0	91.47	4.31	4.22
7	-1	-1	-1	88.85	6.57	4.58
8	-1	0	0	89.54	5.82	4.64
9	0	1.682	0	89.63	5.74	4.64
10	0	0	0	92.35	3.72	3.93
11	1	1	1	89.71	3.15	7.14
12	1.682	0	0	87.92	4.13	7.95
13	-1	1	-1	86.38	8.99	4.62
14	0	0	0	91.87	4.35	3.78
15	-1	-1	1	90.12	4.95	4.93
16	0	0	0	92.34	3.44	4.22
17	0	-1.682	0	90.72	3.83	6.35
18	1	1	-1	85.58	8.35	6.07
19	1	-1	1	91.4	2.19	6.41
20	1	-1	-1	87.92	6.07	6.01

- **Picking performance test analysis and the establishment of regression equations**

Design-Expert was used to obtain the response surface model of comprehensive index Y through multiple regressions fitting for the test results, and made variance analysis on the quadratic equation of the response surface model. It also made significant testing to the terms of regression equations. The significance test results are shown in Table 4.

Table 4

Regression coefficient Y and its significant test

Source of variation	Qualification rate				Miss-seeding rate				Over-seeding rate			
	Square sum	Degree of freedom	Value of F	Value of P	Square sum	Degree of freedom	Value of F	Value of P	Square sum	Degree of freedom	Value of F	Value of P
X1	1.07	1	4.63	0.0469	6.43	1	36.11	0.0001	12.75	1	71.84	<0.0001
X2	4.81	1	20.90	0.0010	6.89	1	38.70	<0.0001	0.71	1	3.98	0.0440
X3	36.53	1	158.78	<0.0001	42.71	1	239.79	<0.0001	0.24	1	1.38	0.0279
X1X2	0.40	1	1.74	0.2164	1.25	1	0.70	0.9935	0.41	1	2.31	0.1597
X1X3	0.70	1	3.05	0.1112	2.26	1	12.68	0.0052	0.44	1	2.46	0.1477
X2X3	1.40	1	6.10	0.0331	1.06	1	5.94	0.0350	0.02	1	0.13	0.7257
X12	18.27	1	79.41	<0.0001	1.44	1	8.08	0.0175	8.69	1	48.93	<0.0001
X22	5.45	1	23.69	0.0007	0.89	1	5.01	0.0492	3.51	1	19.77	0.0012
X32	28.31	1	123.07	<0.0001	14.16	1	79.50	<0.0001	2.05	1	11.53	0.0048
Model	89.59	9	43.27	<0.0001	74.45	9	46.44	<0.0001	26.79	9	16.77	<0.0001
Residual	2.30	10			1.78	10			1.77	10		
Lack of fit	1.64	5	2.47	0.1714	0.60	5	0.50	0.7645	1.45	5	4.47	0.0631
Error	0.66	5			1.18	5			0.32	5		
Sum	91.89	19			76.23	19			28.56	19		

Note: p<0.5(significant)

In the qualification rate model of the metering device, the *P* was less than 0.0001, and the effect was significant. The *P* in the missed term was equal to 0.1714, and the effect was not significant. It was shown that within a certain range of parameters, the regression model of the qualification rate had a high degree of fit. The *P* of X_1, X_2, X_3, X_2X_3, X_{12}, X_{22} and X_{32} was less than 0.05, and the effect was significant. The *P* of X_1X_2 and X_1X_3 was greater than 0.1, and the effect was not significant. In the miss-seeding rate model of the seed metering device, the *P* was less than 0.0001, and the effect was significant. The *P* in the missed term was equal to 0.7645, and the effect was not significant.

It was shown that within a certain range of parameters, the regression model of the miss-seeding rate had a high degree of fit. The *P* of X_1, X_2, X_3, X_1X_3, X_2X_3, X_{12}, X_{22} and X_{32} was less than 0.05, and the effect was significant. The *P* of X_1X_2 was greater than 0.05, and the effect was not significant. In the over-seeding rate model of the metering device, the *P* was less than 0.0001, and the effect was significant.

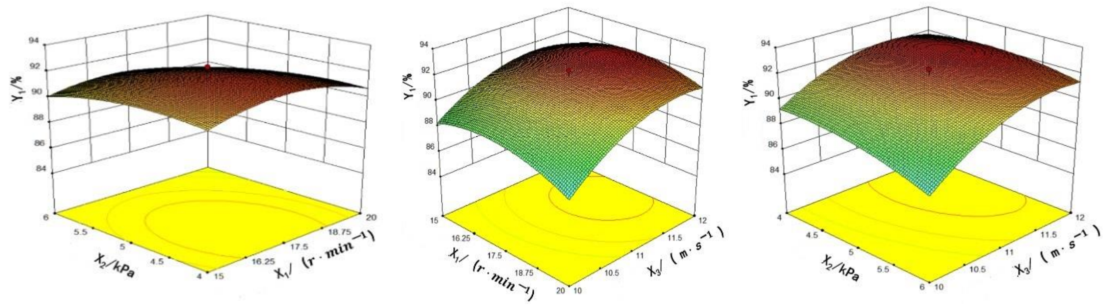
The *P* in the missed term was equal to 0.0631, and the effect was not significant. It was shown that within a certain range of parameters, the regression model of the over-seeding rate had a high degree of fit. The *P* of X_1, X_2, X_3, X_{12}, X_{22} and X_{32} was less than 0.05, and the effect was significant. The *P* of X_1X_2, X_1X_3 and X_2X_3 was greater than 0.05, and the effect was not significant.

The models excluding the insignificant regression term are specific to:

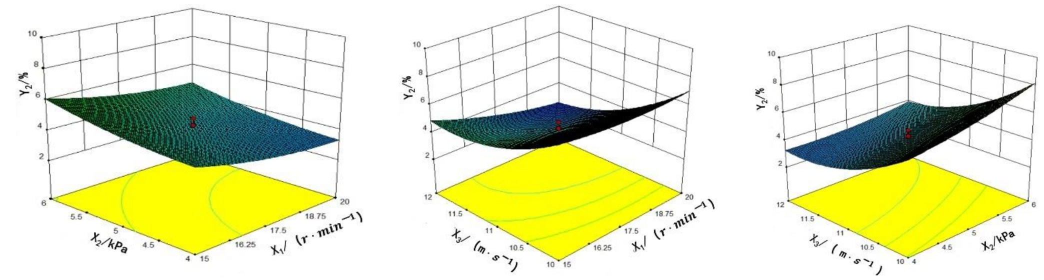
$$\begin{cases} Y_1 = 91.92 - 0.28\,X_1 - 0.59\,X_2 + 1.64\,X_3 - 0.22\,X_1X_2 + 0.30\,X_1X_3 + 0.42\,X_2X_3 - 1.13\,X_1^{\,2} - 0.62\,X_2^{\,2} - 1.40\,X_3^{\,2} \\ Y_2 = 4.15 - 0.69\,X_1 + 0.71\,X_2 - 1.77\,X_3 - 0.00125\,X_1X_2 - 0.53\,X_1X_3 - 0.36\,X_2X_3 + 0.32\,X_1^{\,2} + 0.25\,X_2^{\,2} + 0.99\,X_3^{\,2} \\ Y_3 = 3.93 + 0.97\,X_1 - 0.23\,X_2 + 0.13\,X_3 + 0.23\,X_1X_2 + 0.23\,X_1X_3 - 0.054\,X_2X_3 + 0.78\,X_1^{\,2} + 0.49\,X_2^{\,2} + 0.38\,X_3^{\,2} \end{cases} \tag{3}$$

- **Analysis on the impact of test factors**

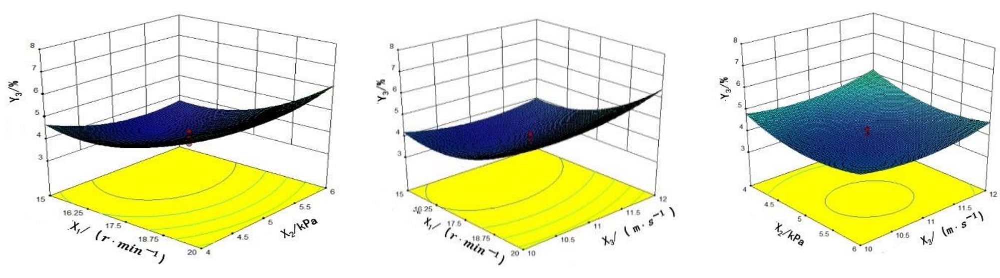
In order to more intuitively analyse the relationship between various influencing factors and the performance of seed metering device, the response surface graph was obtained by processing the data of orthogonal test, as shown in Fig. 9.



a) the influence of various factors on the qualification rate



b) the influence of various factors on the miss-seeding rate



c) the influence of various factors on the over-seeding rate

Fig. 9 - Influences of various factors on evaluation indexes

With the increase of cylinder speed, qualification rate increased first and then decreased, and the miss-seeding rate and over-seeding rate decreased first and then increased. With the increase of negative pressure, the qualification rate increased first and then decreased, and the miss-seeding rate and over-seeding rate decreased first and then increased. With the increase of the air blowing speed, the qualification rate increased first and then decreased, and the miss-seeding rate and over-seeding rate decreased first and then increased.

- **Optimization of the picking condition and test of the regression model**

From the above experiments and analysis, the optimal parameter combination is that the cylinder speed is 16.93 r/min, the negative pressure is 4.97 kPa and the air blowing speed is 11.48 m/s. At this moment, the qualification rate of seed metering device is 92.37%, the miss-seeding rate is 3.74%, and the over-seeding rate is 3.88%.

The optimized theoretical results were tested and verified on the test bench. The cylinder speed of the drum was set at 16.9 r/min, the negative pressure was set at 5.0 kPa, vent layout was selected to be 6×6, and the air blowing speed was set at 11.5m/s. Three repeated tests were carried out.

The average qualification rate was 92.15%, the average miss-seeding rate was 3.82%, and the average over-seeding rate was 4.03%. The experimental results were basically consistent with the theoretical results.

CONCLUSIONS

(1) To solve the problem of changing the drum for seeds with different grain sizes, a double-drum structure with different grain sizes combined by rotating the drum was designed. The precision sowing of seeds with different sizes could be realized without changing the drum, which improved the generality of the seed metering device and saved the cost.

(2) Under the negative pressure of 4 kPa, roller speed of 16.93 r/min and the wind speed of 11.48 m/s, the seed metering device has the best seeding effect; The qualification rate of the seed metering device was 92.37%, the miss-seeding rate was 3.74%. The over-seeding rate was 3.88%.

(3) The seed meter meets the sowing requirements, and the performance of the seed metering device is significantly improved compared with the traditional seed metering device, providing good conditions for seed growth.

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