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Structure Optimization of Seeding Device of Small Wheat Planter Based on Orthogonal Test

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Author's contribution

The sole author designed, analysed, interpreted and prepared the manuscript.

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Short Communication

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ABSTRACT

In order to further improve the backward status of agricultural infrastructure construction in hilly and mountainous areas, this paper adopted the method of orthogonal experimental design on the basis of existing small wheat planter seeding devices at home and abroad, and selected three factors that had the greatest influence on seeding efficiency and seed damage rate, namely, planting height, rotation speed of seeding wheel and number of single seeding, and obtained the optimized structural parameters. Then the structural design is carried out according to the structural parameters. The above research results show that the orthogonal experimental design combined with numerical calculation and regression analysis can effectively optimize and adjust the structural parameters of the seed arrangement, improve the seeding efficiency and reduce the seed damage rate at the same time, among which the seeding efficiency is increased by 0.23 times /min, and the seed damage rate is reduced by 0.0024%.

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Keywords: Seeding device; orthogonal test; seeding efficiency; seed damage rate.

1. INTRODUCTION

China's grain-producing areas are mainly hilly and mountainous areas, and its output plays an important role in the country's total grain production. Due to the imbalance of economic development, the degree of agricultural mechanization in this region is relatively low [1]. As the main wheat sowing device in this region, the optimization of the seeding device of small wheat seeder can further improve the sowing efficiency and reduce the seed damage rate [2-4].

As an efficient multi-factor test method, orthogonal test can obtain a large amount of information in a limited number of tests, and reveal the influence degree and interaction of various factors on the results [5-8]. In the optimization design of seeding device of small wheat drill, various factors affecting seeding effect, such as seeding height, rotation speed of seeding wheel, size of seeding hole, etc. were systematically analyzed and evaluated by orthogonal test [9], so as to find out the optimal parameter combination.

2. NUMERICAL SIMULATION

As a key component of small wheat planter, the working performance of the seeding device directly affects the working effect of the whole machine.

In this paper, the existing wheat planter is used as a model to analyze its seeding device, and its structure is shown in the following Fig.1 [10].

1. Seed box 2. Seed cleaning brush 3. Seed row 4. Seed protection plate:

The seed box houses the wheat seeds, the seed cleaning brush removes excess seeds above the seeding wheel, the seed row transport wheat seeds, and the seed guard plate prevents seed loss during transportation**.**

2.1 Seed Wheel Diameter

The diameter of the seeding wheel determines the overall structure of the seeding device, the seeding speed and the size of the seeding device. Therefore, according to the references [11], the equation of seeding wheel diameter and seeding speed is established as follows:

$$v_t = \frac{\omega_p d_p}{2} \quad (2\text{-}1)$$

$$\omega_p = \frac{2\pi d_p}{60} \quad (2\text{-}2)$$

In the formula:

v_t--Tangential speed of seeding wheel, m/s;
d_p--Seed wheel diameter, mm;
ω_p--Seed wheel angular velocity, rad/s;
n_p--Seeding wheel speed, r/min.

After sorting out the formulas (2-1) and (2-2), we can get:

$$v_t = \frac{n_p \pi d_p}{60} \quad (2\text{-}3)$$

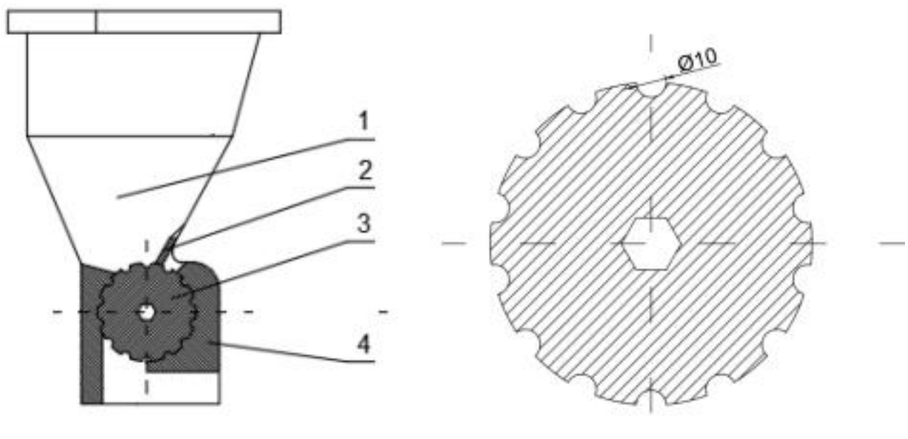

Fig. 1. Structure of seeding device

2.2 Hole Shape and Size

The size of the hole determines how much to plant each time. The shape of wheat seeds is approximately oval, and the average size of wheat seeds commonly used in Henan Province is 5.2×2.5×1.5mm. Combined with the shape of wheat seeds, the shaped hole is set as a hemispherical shape, each hole contains 4 to 6 grains. According to the reference [12], and the size of the shaped hole should meet the following requirements:

$$\frac{(n-2)}{2} l_{\max} < d_k < \frac{(n-1)}{2} l_{\max} \qquad (2\text{-}4)$$

In the formula:

l_{max}--Maximum wheat seed size, mm;
n--Number of seeds per row, grains;
d_k--Mold hole diameter, mm.

2.3 Number of Holes

The speed of the seeding wheel determines the number of holes. According to the reference [12], which meets the relationship:

$$N_k = \frac{\pi d_p v}{t_y v_t} \qquad (2\text{-}5)$$

In the formula:

v--Planter advance speed, m/s;

t_y--Planting spacing, mm.

3. ORTHOGONAL DESIGN SCHEME

The three factors of seeding height h(A), rotation speed of seeding wheel n_p(B), and number of single seeding n(C) have great effects on seeding efficiency and seed damage rate of wheat. In order to improve seeding performance of small wheat seeder, the above three factors were selected for structural optimization design. Meanwhile, orthogonal test Table 1 $L_9(3^4)$ was selected for design experiment in order to facilitate modeling and optimization, the empty columns are error columns, compared to higher-level orthogonal arrays, the L9 OA ensures a more uniform distribution of factor levels while saving time and reducing costs, which is advantageous in minimizing errors during the experiment. According to the requirements of wheat mechanized sowing code, the best distance between wheat seed planting height and seed bed is 30~50mm, not more than 60mm; The rotation speed of the seeding wheel is 26~27r/min; Each hole holds 4 to 6 wheat seeds.

According to the value range of each factor mentioned above, it is divided into three levels, and the results are shown in the Table 1.

The corresponding test scheme is listed according to the selected orthogonal table, and its test scheme is shown in Table 2.

Table 1. Factor level table

Level	Planting height h(A)/mm	The speed of the Seeding Wheel Is n_p(B)r/min	Number of Species in a Row n(C) /mm
1	30	26	4
2	40	26.5	5
3	50	27	6

Table 2. Orthogonal test scheme

Test Number	Planting Height h(A)/mm	The Speed of the Seeding Wheel Is n_p(B)r/min	Number of Species in a Row n(C) /mm	Black Column
1	1	1	1	1
2	1	2	2	2
3	1	3	3	1
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

4. ANALYSIS OF ORTHOGONAL TEST RESULTS

With seeding efficiency and seed damage rate as the result indicators, nine simulated calculations were carried out on the influencing factors, and the calculation results were shown in Table 3.

4.1 Range Analysis

The range analysis was carried out to determine the influence of each factor on the result of orthogonal experiment. The analysis is as follows. The range analysis results of seeding efficiency and seed damage rate are shown in Tables 4 and 5. Based on Table 4 and Table 5, it can be seen that the degree of influence on seeding efficiency from large to small is the speed of seeding wheel > the number of seeding > the height of seeding; the degree of influence on seed damage rate from large to small is the speed of seeding wheel > the height of seeding > the number of seeding.

Under different factors, the trend diagram of seeding efficiency and seed damage rate of wheat seed is shown in Figs. 2 and 3 It can be seen from the figure that seeding efficiency always increases with the increase of seeding wheel rotation speed. With the increase of planting height and the increase of the number of planting in a single time, the trend is to increase first and then decrease. The seed damage rate showed an increasing trend with the increase of the rotation speed of the seeding wheel, decreased first and then increased with the increase of the seeding height, and decreased with the increase of the amount of single seeding, but the change was not obvious.

Table 3. Orthogonal test results

Test Number	Seeding Efficiency y_1 Times /min	Seed Damage Rate y_2/%
1	61	0.081
2	65	0.079
3	67	0.091
4	65	0.076
5	64	0.077
6	67	0.083
7	62	0.079
8	60	0.085
9	67	0.093

Table 4. Analysis results of seeding efficiency range

Project	A	B	C
K_1	193	188	188
K_2	196	189	197
K_3	189	201	193
k_1	64.33333333	62.66666667	62.66666667
k_2	65.33333333	63	65.66666667
k_3	63	67	64.33333333
R	2.333333333	4.333333333	3
rank	B>A>C		

Table 5. Results of seed damage rate range analysis

rank	A	B	C
K_1	0.251	0.236	0.249
K_2	0.236	0.241	0.248
K_3	0.257	0.267	0.247
k_1	0.03666667	0.078666667	0.083
k_2	0.078666667	0.080333333	0.082666667
k_3	0.085666667	0.089	0.082333333
R	0.007	0.010333333	0.000666667
rank	B>A>C		

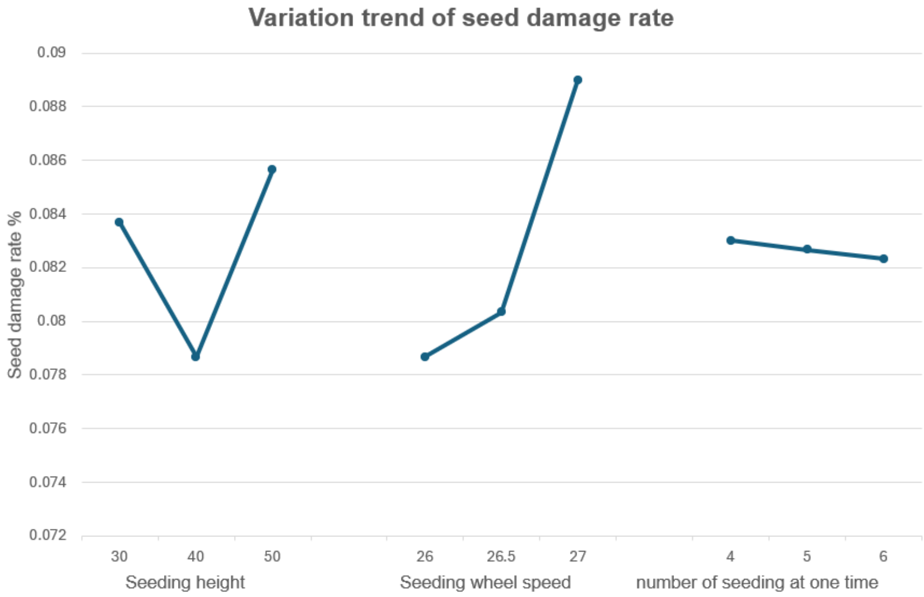

Fig. 2. Variation trend of seeding efficiency

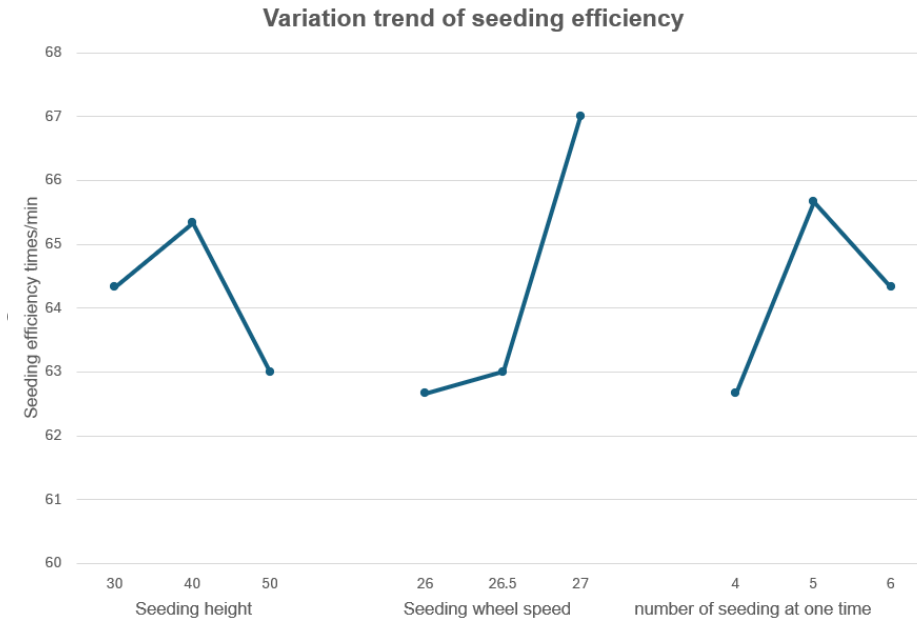

Fig. 3. Trend chart of seed damage rate

4.2 Analysis of Variance

The intuitive method cannot estimate the size of the error and the importance of the influence of the test results, especially for the test with the level number greater than or equal to 3, so the analysis of variance is used to make up for this defect, and the test level confidence is selected as α=0.05.

The range analysis results of seeding efficiency and seed damage rate are shown in Tables 6 and 7. The variance analysis results show that the degree of influence on seeding efficiency from large to small is the speed of seeding wheel > the number of seeding > the height of seeding; the degree of influence on seed damage rate from large to small is the speed of seeding wheel > the height of seeding > the number of seeding. The analysis results are consistent with those of range analysis.

Table 6. Results of variance analysis of seeding efficiency

Difference Source	SS	df	MS	F	P-value	Significance
B	34.88888889	2	17.44444444	39.25	0.02484472	Significant
A	13.55555556	2	6.777777778	15.25	0.061538462	Non-significant
C	8.222222222	2	4.111111111	9.25	0.097560976	Non-significant
e	0.888888889	2	0.444444444			
e^{Δ}	57.55555556	8				

Table 7. Results of variance analysis of seed damage rate

Difference Source	SS	df	MS	F	P-value	Significance
B	0.000184667	2	9.23333E-05	14.57895	0.014552784	Significant
A	7.8E-05	2	3.9E-05	6.157895	0.060104058	Non-significant
C	6.66667E-07	2	3.33333E-07			
e	2.46667E-05	2	1.23333E-05			
e^{Δ}	2.53333E-05	4	6.33333E-06			
Sum	0.000288	8				

4.3 Optimal Scheme Screening

After the influence of various factors on the result is obtained, the optimal plan needs to be determined by comprehensive analysis. The results of seeding efficiency analysis showed that $A_2B_3C_3$ was the best option, but the results of seed damage rate analysis showed that $A_1B_1C_3$ was the best option. It can be seen from the analysis results that the rotation speed of the seeding wheel has the greatest influence on the seeding efficiency and seed damage rate. With the increase of the rotation speed of the seeding wheel, the seeding efficiency also gradually increases, but at the same time, the seed damage rate also increases rapidly, so the rotation speed of the seeding wheel is not the bigger the better. The optimal scheme was $A_2B_2C_3$. The scheme was the planting height of 40mm, the rotation speed of the planting wheel 26.5r/min, and the single planting quantity of 6 grains.

Substituting n=6 into the formula (2-4) yields:

$$10.4\text{mm} < d_k < 13\text{mm}$$

Take d_k=11mm. Substituting into the formula (2-3) yields:

$$v_t = \frac{n_p \pi d_p}{60} \rightarrow d_p = \frac{60 \times v_t}{n_p \times \pi} = 108.11mm$$

In the formula, According to the requirements of wheat mechanized sowing code, the limit linear speed of the seed plate is v_t =0.15m/s, and d_p=108.11mm is substituted into the formula (2-5) to obtain:

$$N_k = \frac{\pi d_p v}{t_y v_t} = \frac{\pi \times 108.11 \times 0.54}{100 \times 0.15} = 12.22$$

In the formula, According to the requirements of wheat mechanized sowing code,the forward speed of the planter is 0.54~0.72m/s, the planting hole distance t_y=100mm. The calculated N_k>12.0002, According to the reference [12],the number of pattern holes is usually even, so the design of the number of pattern holes is N_k=14.

4.4 Comparative Analysis of Optimized Structure and Initial Structure

The structural parameters before and after the seeding device are as follows:

The comparison results showed that the optimized seed arrangement device not only improved the seeding efficiency, but also reduced the seed damage rate, among which the seeding efficiency was increased by 0.23 times /min, and the seed damage rate was reduced by 0.0024%, which met the expected requirements.

The structure diagram before and after optimization is as follows:

Table 8. Comparison of structural parameters

p Planting Mechanism	Planting Height h(A)/mm	The Speed of the Seeding Wheel Is n_p(B)r/min	Number of Species in a Row n (C) /mm	Seeding Efficiency y_1 Times /min	Seed Damage Rate y_2/%
initial	38	13.7	5	64.44	0.0828
optimize	40	13.5	6	64.67	0.0804

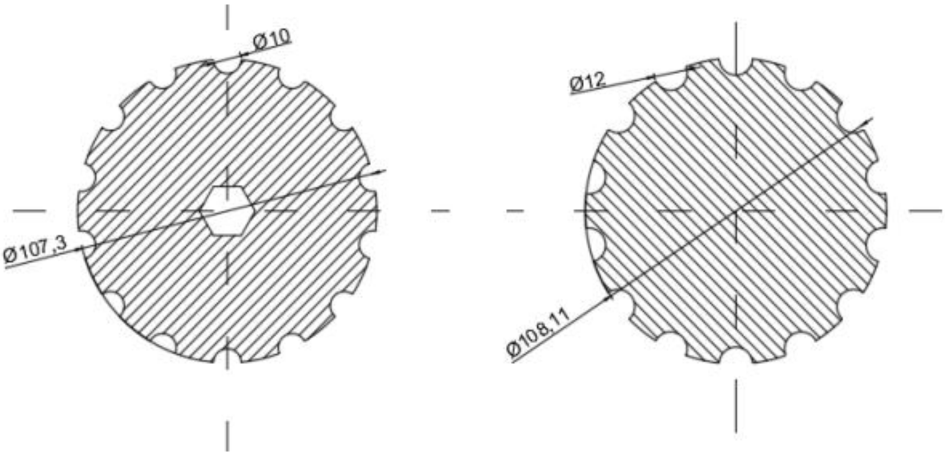

Fig. 4. Structure comparison before and after optimization
Before optimization *After optimization*

Optimize the diameter of the front seed wheel to 107.3mm, the diameter of the mold hole to 10mm, optimize the diameter of the back seed wheel to 108.11mm, the diameter of the mold hole to 12mm.

5. CONCLUSION

(1) Through the orthogonal analysis of the main structural parameters of the seeding device, it was concluded that the main factor that significantly affected the seeding efficiency and seed damage rate was the rotation speed of the seeding wheel.

(2) The structural parameters obtained from range analysis and variance analysis were analyzed, and the analysis results were compared with the results under the initial conditions. It was found that the seeding efficiency was increased by 0.23 times /min and the seed damage rate was reduced by 0.0024% after optimizing the seeding wheel structure, meeting the expected requirements.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

COMPETING INTERESTS

Author has declared that no competing interests exist.

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