BENCH TESTS AND PARAMETERS OPTIMIZATION OF ONBOARD SEED COTTON CLEANER
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机载籽棉预处理机台架试验及参数优化

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ABSTRACT
The working quality of a cotton stripper harvester is limited by the efficiency of onboard seed cotton cleaners. As a basis for research in the design of a cotton stripper harvester prototype, the bench cleaning tests were designed to study the effect of structural and technological parameters on the loss rate and impurities rate of the cleaner. According to the features of different test factors, a combined orthogonal test was applied to determine the best combination of the sawtooth distance, saw cylinder diameter, and cleaning distance. With these parameters fixed, the optimal parameters for the cleaning distance, saw cylinder rotating speed, and brush thickness were obtained using a quadratic-regression rotatable orthogonal test. The best parameter configuration to ensure the cleaning quality of the onboard seed cotton pre-cleaner included the following structural parameters: sawtooth distance of 38 mm and saw cylinder diameter of 340 mm, and technological parameters: rotating speed of 282–288 rpm, clearance of 12.55–14.84 mm, and brush thickness of 8.37–9.69 mm, which decreased the loss rate to less than 10% and the impurities rate to less than 6%. The reliability of the theoretical analysis results was verified by a comparison with experimental results. The experimental results provide a theoretical basis and technical reference for the research and the structural design of seed cotton pre-cleaners.

摘要
针对统收式采棉机作业质量受限于机采籽棉预处理装置清理效率的问题，设计机采籽棉预处理清理作业试验台架。以含杂籽棉为研究对象，研究籽棉清理过程中锯齿间距、锯齿辊直径、锯齿辊转速、排杂棒间距、毛刷厚度等因子对损失率，含杂率的影响，并进行优化分析，确定清理单元结构及工艺的最优组合参数。根据试验因素特点，采用响应面优化设计试验，得到锯齿间距、锯齿辊直径、锯齿辊转速、排杂棒间距的最优参数组合。结果表明：锯齿间距 38 mm，锯齿辊直径 340 mm 时，最优参数组合为锯齿辊转速 282-288 rpm，排杂棒间距 12.55-14.84 mm，毛刷厚度 8.37-9.69 mm，机载籽棉预处理机清选损失率降至 10%以下，含杂率低于 6%。通过试验验证结果可信，可为机采籽棉预处理装置相关研究和结构设计提供理论依据。

INTRODUCTION
Cotton is one of the important cash crops and raw material for textile industry in China. In recent years, the problem of labor shortage has become increasingly prominent, which has seriously limited the development of Chinese cotton industry. Therefore, promoting mechanized cotton picking is an inevitable trend to realize the sustainable development of cotton industry. The mainstream model used in China is the horizontal spindle type cotton picker produced by John Deere and other foreign companies. This type is too large to adapt to the small and medium-sized cotton fields in the Yangtze River and Yellow River basin. Therefore, it can't be popularized in all cotton regions in China. The stripper harvester, which has the advantages of wide range of adaptation and low price, has shown great potential for development. But its shortcomings of high impurity rate have become the main bottleneck hindering its popularization and development. Therefore, it is of great significance to develop an onboard seed cotton cleaner with high efficiency and excellent performance to reduce the seed cotton impurity rate of the stripper harvester and promote the process of cotton picking mechanization in China.

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With the rapid development of the cotton industry, new seed cotton processing technology and equipment have constantly emerged since the Industrial Revolution (*Mao et al., 2017*). The former Soviet Union, the United States, Germany, and other countries are committed to research on related theories, thereby promoting the development of world cotton processing and cleaning technology. Francis et al. proposed a kind of onboard cleaner that primarily uses air flow to separate cotton bolls and seed cotton (*Francis et al., 1969*). Akin et al. designed a cleaning device with adjustable and pre-opening functions. Deutsch introduced onboard seed cotton cleaner with a single-stage cleaning cylinder and a single-stage reclaimed cylinder (Deutsch et al., 1999), whereas Sanderson et al. used an air diverter that is added to the end of the cotton transport pipeline to clean the broken leaves before seed cotton enters the hopper (Sanderson et al., 1990). Patel et al. designed a cotton cleaning device for seed cotton stripper harvesters (*Patel et al., 2002*). Wanjura et al. tested the effect of different intersecting surfaces of the cleaning bar on impurity removal, seed cotton loss, and cotton fiber quality, and optimized the cleaner by establishing a mathematical model and response surface analysis of the impurities rate and loss rate (*Wanjura et al., 2013*). However, most of these research results and equipment have been applied for handpicked seed cotton (*Chen et al., 2015*), and only a few cleaning technology studies have used seed cotton harvested by cotton strippers that contains impurities, like branches and boll shells (*Kazama et al., 2015*). The cleaning of seed cotton harvested by stripper harvesters mainly relies upon the cleaning unit composed of a saw cylinder, brush roller, and cleaning roller. Most of the existing stripper harvesters are equipped with a cleaner consisting of two-stage or multi-stage cleaning units (*Huang et al., 2016*). However, some problems occur with onboard cleaners, such as the incomplete separation of seed cotton and impurities, high loss rate of seed cotton, high power consumption, and poor stability during harvesting.

With the aim of solving these onboard seed cotton cleaner problems, we conducted an experiment on the effects of five factors-sawtooth distance, diameter of the saw cylinder, rotating speed saw cylinder, clearance, and brush thickness-on the loss rate and impurities rate in the seed cotton cleaning process. The structure and operation parameters of the seed cotton cleaning unit were optimized and verified by bench test, which provided a theoretical basis for the design and development of the onboard seed cotton pre-cleaner of the stripper harvester.

MATERIALS AND METHODS
Test Equipment and Material
Test Equipment

A self-designed seed cotton cleaning unit bench was used in the tests. The bench was composed of a feeding bench, power and control system, cleaning bench, and gathering unit, as shown in Figure 1. The cleaning bench was equipped with a replaceable saw cylinder, brush roller, and cleaning bars. The adjustment speed range of the saw cylinder was 0 to 500 rpm and that of the brush roller was 0 to 800 rpm.

Fig. 1 -Seed cotton cleaning bench

1. Gathering unit; 2. Control system; 3. Cleaning bench; 4. Feeding bench

A structural schematic of the seed cotton cleaning bench is shown in Figure 2. We used two kinds of saw cylinder and brush roller combinations. The diameters of the saw cylinder were 420 mm and 340 mm, of the brush roller were 300 mm and 260 mm, respectively. The oval holes were uniformly distributed on the fan area in front of the saw cylinder, which could adjust the clearance between the cleaning bars and saw cylinder. The clearance adjustment was 0-30 mm. The diameter of the cleaning bar was 30 mm. The control system could control the rotating speed of the saw cylinder and brush roller.

The seed cotton and impurities passed through the feed bin and were manually evenly fed into the cleaning bench by the feeding roller. The seed cotton clung to the surface of the saw cylinder under the pressure of the brush. Therefore, the cotton was hooked on the saw cylinder surface and carried into the action range of the brush roller. Then, due to the higher linear speed of the brush roller, it was brushed off the saw cylinder surface and fed into the cotton gathering box. The impurities mixed in the seed cotton were discharged between the clearances of cleaning bars and fell into the impurities gathering box under the action of the centrifugal force of the saw cylinder and counter-acting force of the cleaning bars.

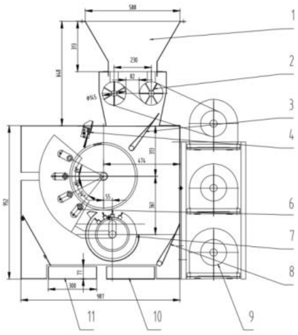

Fig. 2 - Structural schematic of the seed cotton cleaning bench

1. Feed bin; 2. Feeding roller; 3. Overhead baffle; 4. Brush; 5. Saw cylinder; 6. Cleaning bar; 7. Brush roller; 8. Underneath baffle; 9. Motor; 10. Cotton gather box; 11. Impurities gather box.

Test Material

Whole seed cotton, bolls, a few branches and other impurities, which were removed by the stripper harvesters, were manually fed into the onboard seed cotton pre-cleaner for primary cleaning.

The experiments were conducted in October 2020 at the workshop of the Baima Scientific Research and Innovation Experimental Demonstration Base, Nanjing Research Institute for Agricultural Mechanization. Ministry of Agriculture and Rural Affairs (Nanjing, China). The cotton variety was China Cotton 50 and the moisture content was 10.8% (Kong et al., 2021). The seed cotton feed rate was 1 kg/s, which was calculated according to the average cotton yield of 6000 kg/ha and the forward velocity of 4MZ-3 type stripper harvester was 2.8 km/h. Testing samples were selected according to the impurities rate of seed cotton harvested by the 4MZ-3 type cotton stripper harvester, which contained 75% seed cotton, 20% boll shell, 4% branches and 1% cotton leaves. The test materials are shown in Figure 3.

Fig. 3 - Cotton test materials

Test Method

In terms of seed cotton, the cleaning quality is affected by various factors (*Jing et al., 2017*), such as the structural parameters of the cleaning bar and saw cylinder, and technological parameters like the rotating speed of the saw cylinder. In this study, it was experimentally researched on the effect of different structural and technological parameters of the onboard cleaner currently used in cotton stripper harvesters on the loss rate and impurities rate.

Selection of Test Factors

In the cleaning test using an indoor bench, it was studied the influence of different cleaning qualities under different structural and technological parameters (*Hardin et al., 2014*). Because studies on cotton stripper harvesters are in the development stage and research on the cleaning part is still in its infancy, the sawtooth distance, diameter of the saw cylinder, rotating speed of the saw cylinder, clearance and brush thickness were chosen as the test factors for the experimental studies.

The sawtooth distance is the minimum axial mounting distance between two adjacent U-shaped sawtooth strips. When the sawtooth distance increases, the hooking efficiency of seed cotton decreases, and the effect of hooking on the cotton stick also reduces, which is beneficial for eliminating large impurities. The mounting distance of U-shaped sawtooth strips was divided into four levels in this study: 32, 38, 44 and 50 mm.

The diameter of the saw cylinder is often limited by the machine space. When the diameter of the saw cylinder increases under a constant rotating speed condition, the linear speed and the centrifugal force on the seed cotton caught by the saw cylinder increase. Impurities are more easily separated from the seed cotton by collision with a cleaning bar. In this study, 420 and 340 mm diameters were chosen for the saw cylinder in the seed cotton cleaning bench, according to the processing conditions.

The rotating speed is the rotating speed of the saw cylinder, which is one of the most important parameters that determines the cotton impurities content, clearing loss rate and production efficiency of the saw cylinder. The higher the rotating speeds of the saw cylinder, the larger the centrifugal force generated and the more impurities cleaned. However, a rotating speed that is too high can cause seed cotton to not be fully hooked by the saw and fly out of the saw cylinder. The cleaning effect of the saw cylinder at different rotating speeds was studied. The adjustable range of the rotating speed was 0 to 500 rpm.

Clearance is the saw-to-bar clearance, which is the distance between cleaning bars and the corresponding external diameter of the saw cylinder, in mm. Note that distances between cleaning bars and the corresponding external diameter of the saw cylinder take the same value. Less clearance leads to better performance in terms of impurities removal, but the cotton fiber is more easily damaged.

Brush thickness is the thickness of the nylon brush that can brush seed cotton adhered to the saw cylinder. The adhesive force between the seed cotton and saw cylinder can be changed by changing the brush thickness.

Establishment of Appraisal Indexes

According to cotton harvester operation quality requirements, the impurities rate and loss rate were used as the indexes.

The impurities rate is the percentage of the weight of impurities in the seed cotton mixed with impurities after cleaning. The impurities rate (*Z*) can be obtained according to:

$$Z = \frac{W_Z}{W_H} \times 100\% \tag{1}$$

where: W_z is the weight of impurities in the seed cotton mixed with impurities after being cleaned

W_h is the total weight of seed cotton mixed with impurities after being cleaned.

The loss rate is the percentage of loss weight of seed cotton entrained in the impurities after being cleaned to the weight of the input seed cotton. The calculation formula of the loss rate (*S*) is as follows:

$$S = \frac{W_S}{W_C} \times 100\% . \tag{2}$$

where: W_s is the loss weight of seed cotton entrained in the impurities after being cleaned

W_c is the weight of feeding seed cotton.

The sampling methods comply with the Chinese national standards GB/T19818-2005 Seed Cotton Cleaner and GB/T 21397-2008 Cotton Harvester.

Combined Orthogonal Test Arrangement

A number of factors influence the impurities rate and loss rate, such as conditions like the structural and technological parameters. Therefore, after determining the optimum structural parameters of the saw tooth roller with a combined orthogonal test, the technological parameters of the seed cotton cleaning unit bench were optimized using the response surface methodology test method (*Wang et al., 2021; Yang et al., 2021*).

The sawtooth distance (*A*), diameter of the saw cylinder (*B*), and cleaning distance (*C*) were taken as the test factors. The factors and levels are listed in Table 1. According to cotton harvester operation quality requirements, the impurities rate and loss rate were used as the indexes. The aim of the test was to examine the interaction between *A* and *B.* The sawtooth distance (*A*) was tested at four levels and the other two factors were tested at two levels, so a combined orthogonal table was selected in the test. The sum of the degree of freedom (d_f) of the three factors and interaction was:

$$f_A + f_B + f_B + f_{A\times B} = 1+1+1+1=4 \tag{3}$$

The lines of the selected orthogonal table should meet n ≥ 4 + 1 = 5, so $L_8(4^1 \times 2^4)$ was chosen.

Table 1

Factors and levels of orthogonal tests

Factors	Sawtooth Distance (*A*) mm	Diameter of Saw Cylinder (*B*) mm	Clearance (*C*) mm
1	32	340	10
2	38	420	20
3	44	-	-
4	50	-	-

Response Surface Methodology Test Arrangement

The orthogonal test results showed that the diameter of the saw cylinder and other factors have nonlinear effects on the loss and impurities rates. The combined orthogonal test can only reflect the optimal combination of test selection levels. The Box-Behnken response surface test was used to optimize the test to determine the optimized parameters of various factors of the cleaning unit bench (*Omorogie et al., 2017*). The diameter of the saw cylinder is a continuous variable that was obtained by regulation. Other factors that were not involved in the quadratic regression of the orthogonal rotating combinatorial test were fixed as the best level combination of score values in the orthogonal test.

Quadratic regression of the orthogonal rotating combinatorial test of three factors and three levels was conducted according to the Box-Behnken combination principle using Design-Expert software (Stat-Ease, Minneapolis, MN, USA). A total of 17 experiments were conducted on factors influencing the rotating speed *D*: clearance *E* and brush thickness *F*. The experimental factors and level codes are shown in Table 2. The evaluation indexes are as above.

Table 2

Factors and levels of experiments.

Level	Rotating Speed (*D*. rpm)	Clearance (*E*. mm)	Brush Thickness (*F*. mm)
−1	280	10	4
0	340	15	8
1	400	20	12

RESULTS

Combined Orthogonal Test

The loss rate and impurities rate were taken as the appraisal indexes of cleaning quality. The results of the combined orthogonal test and variance calculation for the test of the cleaning quality for each group are shown in Table 3. The analysis of variance (ANOVA) of the loss rate and impurities rate is shown in Table 4.

Table 3

Variance calculation for the loss rate and impurities rate.

No.	*A*	*B*	*A* × *B*	*C*		Loss Rate (%)	Impurities Rate (%)
	1	2	3	4	5	S	Z
1	1	1	1	1	1	25.3	13.1
2	1	2	2	2	2	16.3	11.2
3	2	1	1	2	2	18.4	11.2
4	2	2	2	1	1	19.2	7.4

5		3	1	2	1	2	26.5	15.2
6		3	2	1	2	1	18.3	8.6
7		4	1	2	2	1	26.9	10.5
8		4	2	1	1	2	34.3	9.1
Loss rate	T_1	41.6	97.1	96.3	105.3	89.7		
	T_2	37.6	88.1	88.9	79.9	95.5		
	T_3	44.8	-	-	-	-		
	T_4	61.2	-	-	-	-		
	k_1	20.8	24.275	24.075	26.325	22.425		
	k_2	18.8	22.025	22.225	19.975	23.875		
	k_3	22.4	-	-	-	-		
	k_4	30.6	-	-	-	-		
	S	161.02					x_i = 185.2 $\sum x_i$ = 4287.38 S_T = 4550.22	y_i =86.3 $\sum y_i$ = 975.31 S_T = 930.96
Impurities rate	T_1	24.3	50	42	44.8	39.6		
	T_2	18.6	36.3	44.3	41.5	46.7		
	T_3	23.8	-	-	-	-		
	T_4	19.6	-	-	-	-		
	k_1	12.15	12.5	10.5	11.2	9.9		
	k_2	9.3	9.075	11.075	10.375	11.675		
	k_3	11.9	-	-	-	-		
	k_4	9.8	-	-	-	-		
	Z	12.56	23.46	0.66	1.36	6.3		

A - sawtooth distance; *B* - diameter of the saw cylinder; *C* - cleaning distance; *A* × *B*. interaction between the sawtooth distance and diameter of the saw cylinder; *xi* - sum value of the loss rate; *yi* - sum value of the impurities rate; *T* - sum of test values; S_T - total sum of deviation squares; T_1-T_4 - sums of levels 1-4, respectively; k_1-k_4. averages of levels 1-4, respectively; and *S* - sum of deviation squaresy *A*, *B* and *C* respectively.

Table 4

Analysis of variance (ANOVA) of the loss rate and impurities rate

Source	**Loss Rate**				**Impurities Rate**			
	Sum of Squares	***df***	**Mean Square**	***F* Ratio**	**Sum of Squares**	***df***	**Mean Square**	***F* Ratio**
A	161.02	3	53.67	9.71 **	12.56	3	4.19	1.51
B	10.13	1	10.13	1.83	23.46	1	23.46	8.46 *
A × *B*	6.85	1	6.85	1.24	0.66	1	0.66	0.24
C	80.65	1	80.65	14.60 **	1.36	1	1.36	0.49
e	4.21	1	4.21	$F_{0.95}$(3.3)=9.28 $F_{0.90}$(3.3)=5.39	6.30	1	6.30	$F_{0.95}$(3.3)=9.28 $F_{0.90}$(3.3)=5.39
Crt.e	11.1	2	5.53		8.32	3	2.77	
T	262.84	7	37.55		44.35	7	6.34	

e. error of the empty column; *Crt.e*. corrected error; *T*. sum of the value; d_f. degrees of freedom; * and ** indicate significant differences at $p < 0.1$ and $p < 0.05$, respectively.

Through ANOVA of the loss rate, factors *A* and *C* were significant at the significance level of 0.05. Through ANOVA of the impurities rate, factor *B* was significant at the 0.1 significance level. Interaction item

AB was not significant for either the loss rate or for the impurities rate. The results showed that the sawtooth distance and cleaning distance were the main factors affecting the loss rate and the diameter of the saw cylinder was the main factor affecting the impurities rate. Because the degree of freedom of error in the empty column was only one, interaction between the sawtooth distance and diameter of the saw cylinder was not significantly classified as error when calculating the variance of corrected error.

The best combination of cleaning quality was $A_2B_2C_2$, meaning a sawtooth distance of 38 mm, diameter of saw cylinder of 420 mm, and cleaning distance of 20 mm should be used.

Response Surface Methodology Test

All tests were repeated three times and the average of the three values is reported. The test results of the loss rate and impurities rate are listed in Table 5.

Table 5

Test scheme and results

No.	Rotating Speed *D* (rpm)	Clearance *E* (mm)	Brush Thickness *F* (mm)	Loss Rate *S* (%)	Impurities Rate *Z* (%)
1	340	20	12	22.49	8.92
2	340	15	8	7.71	6.79
3	400	10	8	14.21	7.11
4	340	20	4	18.29	7.97
5	340	15	8	10.11	5.94
6	400	20	8	13.9	7.42
7	340	15	8	9.17	6.42
8	280	15	12	11.27	6.71
9	280	20	8	15.49	6.77
10	280	10	8	7.15	6.19
11	400	15	12	13.15	8.21
12	400	15	4	11.52	8.94
13	340	15	8	12.08	5.69
14	340	15	8	9.03	6.24
15	280	15	4	9.34	7.51
16	340	10	4	13.36	8.79
17	340	10	12	16.59	6.25

Data were analyzed using the statistical software and the results are shown in Table 6, based on different levels of factors.

Table 6

Variance analysis of the loss rate and impurities rate

Evaluation Indexes	Source	Sum of Squares	Mean Square	*F*-Value	*p*-Value
Loss rate (%)	Model	244.16	27.13	13.97	0.0011
	D	11.35	11.35	5.85	0.0462
	E	44.46	44.46	22.90	0.0020
	F	15.10	15.10	7.78	0.0270
	DE	18.71	18.71	9.63	0.0172
	DF	0.02	0.02	0.01	0.9173
	EF	0.24	0.24	0.12	0.7380
	D^2	11.43	11.43	5.89	0.0457

Evaluation Indexes	Source	Sum of Squares	Mean Square	*F*-Value	*p*-Value
	E^2	93.61	93.61	48.21	0.0002
	F^2	47.18	47.18	24.30	0.0017
	Lack of fit	3.10	1.03	0.39	0.7649
	Error	10.49	2.62		
	Total	257.75			
Impurities rate (%)	Model	17.11	1.90	12.42	0.0016
	D	2.53	2.53	16.54	0.0048
	E	0.94	0.94	6.13	0.0424
	F	1.22	1.22	7.95	0.0258
	DE	0.02	0.02	0.12	0.7402
	DF	< 0.0001	< 0.0001	0.01	0.9312
	EF	3.05	3.05	19.90	0.0029
	D^2	0.28	0.28	1.83	0.2177
	E^2	0.67	0.67	4.36	0.0751
	F^2	7.88	7.88	51.50	0.0002
	Lack of fit	0.35	0.12	0.64	0.6289
	Error	0.72	0.18		
	Total	18.18			

The *p*-values of the two models were less than 0.05. All regression equations were significant and error stems were non-significant. The significant determination coefficient (R^2) of the loss rate regression models is 0.9473 and the significant determination coefficient (R^2) of impurities rate is 0.9411, respectively. This means that the regression model accurately reflected the actual situations.

Based on the data in Table 6, two secondary multiple regression equations for the loss rate (*S*) and impurities rate (*Z*) were fitted as follows, respectively:

$$S=9.62+1.19\cdot D+2.36\cdot E+1.37\cdot F-2.16\cdot DE-0.075\cdot DF+0.24\cdot EF-1.65\cdot D^2+4.71\cdot E^2+3.35\cdot F^2 \quad (4)$$

$$Z=6.22+0.56\cdot D+0.34\cdot E-0.39\cdot F-0.068\cdot DE+0.018\cdot DF+0.87\cdot EF+0.26\cdot D^2+0.40\cdot E^2+1.37\cdot F^2. \quad (5)$$

According to the data from Equation (4) and the results in Table 6, it was observed that monomial *E* and quadratic term E^2.F^2 had a significant effect on the loss rate, whereas monomial *D*.*F* interaction *D*.*E* and quadratic term D^2 had a significant effect on the loss rate.

The analysis of variance showed that monomial *D*. interaction *EF*. and quadratic term E^2 had a very significant effect on the impurities rate. The impurities rate was significantly affected by monomial *E*. *F*.

The response surface method (RSM) was used to analyze the effects of the three factors on the loss rate and impurities rate by fixing one factor at a zero level.

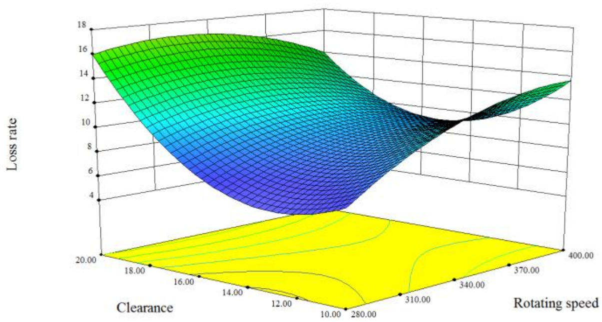

Fig. 4 - Response surface showing the effects of rotation velocity and clearance on the loss rate

To analyze the effect of the interaction between the rotation velocity and clearance on the loss rate, a dual-factor response surface was created, as shown in Figure 4. When the brush thickness was fixed to level zero and the clearance was lower, the loss rate first increased and then tended to remain flat as the rotation increased. These results demonstrated that cotton fiber more easily breaks due to the centrifugal force caused by faster rotation velocities of the saw cylinder (*Tian et al., 2018*). When the centrifugal force continued to increase but was still lower than the break force of intertwining fiber, the loss rate ceased its rapidly increase.

The trend line decreased to a minimum and then increased with an increase in clearance. This occurred mainly because the larger the clearance, the higher the rate of single seed cotton caused by the large hit force and cotton loss, as the saw cannot sufficiently hook seed cotton. When the clearance reaches a certain value, cotton loss and single seed cotton no longer increase accordingly.

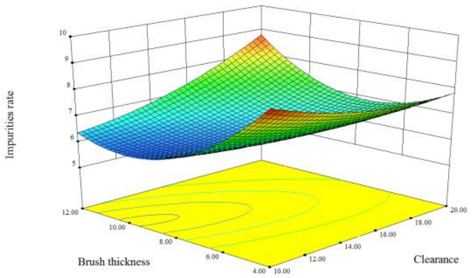

Fig. 5 - Response surface of brush thickness on the clearance impurities rate

When the rotation velocity was fixed to level zero, the impurities rate decreased to a minimum and then increased as the brush thickness increased. It decreased first and then increased with an increase in the cleaning distance. As shown in Figure 5, the impact force of seed cotton generated by the cleaning bar decreased with increasing clearance, and seed cotton was no longer impacted by the cleaning bar to some extent as the clearance increased. Therefore, the impact force of the bar on seed cotton that can separate impurities from cotton increases to maximum and then reduces as the clearance increases. Theoretically, the thicker the brush, the greater the force of seed cotton adhering to the saw cylinder, the more uniform the seed cotton laying. As a result, impurities are easily separated from seed cotton. However, if the brush is too thick, a mixing of impurities and seed cotton may occur, preventing them from being separated effectively.

Based on the test results analysis and model fitting, the experimental parameters were further optimized to guarantee that the loss rate was less than 10% and impurities rate was less than 6%. The scale optimizations were a rotating speed of 282-288 rpm, clearance of 12.55-14.84 mm and brush thickness of 8.37-9.69 mm.

Verification Test

To verify the reliability of the optimized results, a field test was conducted at Baima Scientific Research and Innovation Experimental Demonstration Base, Nanjing Research Institute for Agricultural Mechanization. Ministry of Agriculture and Rural Affairs (Nanjing. China). The optimal structural parameters, which were a sawtooth distance of 38 mm and saw cylinder diameter of 340 mm, were selected as the experimental conditions.

Fig. 6 - Verification test

The results are shown in Table 7. The authentication and predicted values are similar. The test results show that the regression model is reliable and can be used to predict and analyze the technological parameter effect on cotton fiber quality.

Table 7

Experimental scheme and results for prediction verification

No.	Test Scheme			Results	
	Rotating Speed (rpm)	Clearance (mm)	Brush Thickness (mm)	Impurities Rate (%)	Loss Rate (%)
1	285	12	8.5	1.52	9.07
2	285	13	9	0.55	9.37
3	285	13	8.5	0.53	8.91

CONCLUSIONS

In this study, the optimal structural and technological parameters of the cotton stripper pre-cleaner were obtained. The optimal structural parameters of the saw tooth roller were determined using a combined orthogonal test. Then, the technological parameters of the seed cotton cleaning unit bench were optimized using the response surface methodology.

The combined orthogonal test was applied in the bench test using the self-designed test bench. According to the test object, the influences of sawtooth distance, saw cylinder diameter and cleaning distance were investigated. According to the results and analyses of the combined orthogonal test, the best combination of cleaning qualities was a sawtooth distance of 38 mm, saw cylinder diameter of 420 mm, and cleaning distance of 20 mm. The best parameter configuration to maximize the cleaning quality of the onboard seed cotton pre-cleaner included the following structural parameters: sawtooth distance of 38 mm and diameter of the saw cylinder of 340 mm, and the following technological parameters: rotating speed of 282–288 rpm, clearance of 12.55–14.84 mm. and brush thickness of 8.37–9.69 mm, which reduced the loss rate to less than 10% and the impurities rate to less than 6%. The reliability of the theoretical analysis results was verified by comparison with the experimental results, so the findings can provide a theoretical basis and technical reference for research on and the structural design of seed cotton pre-cleaners.

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