# PARAMETERS OPTIMIZATION AND EXPERIMENT ON CYCLONE SEPARATION AND CLEANING SYSTEM FOR BUCKWHEAT

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# *荞麦旋风分离清选的参数分析与试验研究*

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## ABSTRACT

*Based on the material characteristics of buckwheat, the cyclone separation and cleaning test bench were designed. The cleaning rate and loss rate of the buckwheat separation and cleaning by the influencing factors of the investigation were studied through single factor and orthogonal tests. The single-factor test results show that the cyclone separation and cleaning performance is better when the speed range of the suction fan is 800~1200 r/min, the speed range of the feeding fan is 600~1200 r/min, and the length range of the suction pipe is 100~250 mm. The regression equation model of the cleaning rate and loss rate was constructed, and the response surface analysis of the test influencing factors and their interaction was carried out. The results show that the speed of the suction fan has the most significant influence on the cleaning rate and loss rate, followed by the speed of the feeding fan and the length of the suction pipe in the separation cylinder has the least effect. By optimizing and solving multi-objective parameters of the regression equation model, reasonable experimental parameters are obtained. The appropriate speed of the suction fan is 1055 r/min, the appropriate speed of the feeding fan is 600 r/min, and the proper length of the suction pipe in the separation cylinder is 175 mm. The cleaning rate and the loss rate of the cyclone separation and cleaning system were 94.78% and 1.67%, respectively.*

## 摘要

*本文基于荞麦的物料特性，对荞麦旋风分离清选试验台进行了设计；通过单因素和正交试验研究了试验影响因素对荞麦分离清选的清洁率和损失率的影响规律。单因素试验结果表明：吸杂风机转速范围为800～1200 r/min，喂入风机转速范围为600~1200 r/min，吸杂管长度范围为100 ~250 mm。采用三因素三水平的正交试验，构建了试验影响因素与荞麦分离清选的清洁率和损失率间的回归方程模型，并对试验影响因素及其交互作用进行了响应面分析，结果表明：吸杂风机转速对荞麦分离清选的清洁率和损失率影响最大，喂入风机转速影响次之，分离筒内吸杂管长度影响最小；通过对回归方程模型的多目标参数优化求解，得到了合理的试验影响因素参数：吸杂风机转速为1055 r/min，喂入风机转速为600 r/min，分离筒内吸杂管长度为175 mm；在此工况条件下，荞麦分离清选的损失率为1.67%，分离清选的清洁率为94.78%。*

## INTRODUCTION

Buckwheat is rich in nutrients and has outstanding medicinal and healthcare functions. It is an internationally recognized economic crop for food and medicine *(Shi, et al., 2015; Hu, 2004; Tae-Gyh. N, et al., 2015)*. Due to the influence of growth characteristics and economic factors, buckwheat in China is mainly cultivated in hilly and mountainous areas with poor natural conditions, irregular plots and large field drops *(Li, et al., 2020; Wang, et al., 2021; Yang, et al., 2021)*. At present, conventional grain combine harvesters with air and screen cleaning devices are primarily used for mechanized buckwheat harvesting and have high terrain flatness requirements, resulting in unsatisfactory cleaning quality in hilly and mountainous areas *(Chen, 2002; Lu, et al., 2020)*.

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Cyclone separation and cleaning device has been widely used in small grain combine harvesters because of its small size, low cost, stable performance, and low requirements for terrain flatness *(Liao, Q. X., et al., 2015; Liu, D. W., et al., 2016)*.

In recent studies, scholars at home and abroad have mainly researched on grain cyclone separation and cleaning performance *(Huang, 2015)*. *Fuat et al. (2016)* compared the pressure losses at various exit pipe diameters, cylinder heights, cone bottom diameters, and inlet velocities for the conventional and modified design, and designed a new cyclone separation and cleaning model. *Wan et al. (2020)* designed a cyclone separation and cleaning system with replaceable parts, and analyzed the influence of the baffle on the separation performance of rapeseed; they provided a reference for the structural optimization and improvement of the cleaning device for the rapeseed combine harvester. *Zhao et al. (2014)* studied the effect of bucket diameter and bucket length concerning the cyclone body on the separation efficiency by the Fluent method. The loss rate was reduced to 2.2% when the bucket length was 94 mm and the diameter was 196 mm compared to the cyclone separator without a bucket. *Liu, et al., (2015),* designed an air-flowing cleaning unit, and the simulation of the 3D model of the air-flowing field in the cleaning unit was analyzed. The simulation analysis showed that the cleaning device structure and distribution of airflow speed met the design requirements and the cleaning effect well. It improved the efficiency of the micro combine harvester.

Based on the material characteristics of buckwheat, this paper designed the cyclone separation and cleaning test bench for buckwheat. On the self-made test bench, single-factor and orthogonal tests were used to study the influence law of the feeding fan speed, the suction fan speed and the suction pipe length on the cleaning rate and loss rate of the cyclone separation and cleaning of buckwheat.

## MATERIALS AND METHODS

### Overall structure of the test bench

Since the shell of buckwheat grain is easy to break, the buckwheat grain is easily damaged due to collision and hitting when the buckwheat material is fed by a winnower *(Tomchuk, 2020)*. Therefore, this test bench's buckwheat material feeding method adopted pneumatic feeding. It mainly included centrifugal fans, inverters, height adjustment device for suction inlet, cyclone separator, grain tank and anti-backflow nozzle, as shown in Fig. 1.

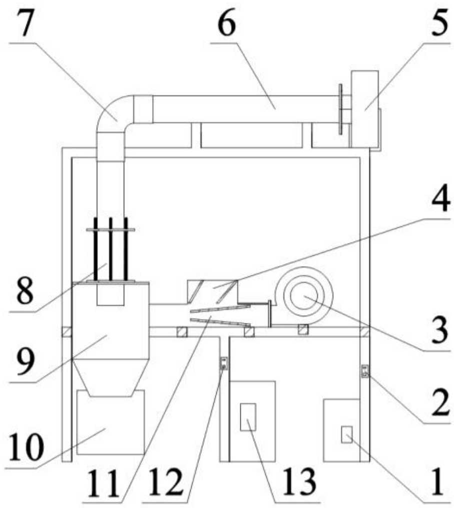



**Fig. 1 - Structural diagram of buckwheat cyclone separation and cleaning test bench**
*1. Feeding frequency converter; 2. Feeding switch; 3. Feeding fan; 4. Feed inlet; 5. Suction fan; 6. Suction pipe; 7. Flexible corner; 8. Height adjustment device of suction inlet; 9. Cyclone separator; 10. Grain box; 11. Anti-backflow nozzle; 12. Suction switch; 13. Suction frequency converter*

The materials of buckwheat after passing through the threshing drum mainly include short straws, grains, chaff, dust, leaves and petals, etc., whose quality, density, shape, and size are different, and their suspension speeds in the cyclone separator are also different. The materials are tangentially fed along the wall of the cyclone separator through a feed inlet by the high-speed airflow, generated by the feeding fan. Under the combined action of inertia force and airflow in the cyclone separator, the movement of different component materials in the cyclone separator is also different.

Dust, chaff, short straws and other light impurities with low density are easy to move toward the center of the cyclone separator when suspended in the cyclone separator and are easily discharged from the suction pipe by the updraft generated by the suction fan in the center of the cyclone separator. Buckwheat grains with high density have a large centrifugal force, and they are easy to move to the wall of the cyclone separator, and the updraft speed here is less than its critical suspension speed. So, the buckwheat grains slide down along the wall of the cyclone separator and finally fall into the grain tank from the grain outlet, which realizes the separation and cleaning of the buckwheat material.

The feeding fan can be selected as a YN5-47 centrifugal fan with a rated speed of 2800 r/min, rated flow rate of 1810 $m^3$/h and total pressure of 790 Pa. Similarly, the suction fan can be selected as the centrifugal fan of YN5-47 which should have an extensive range of airflow velocity adjustment, with a rated speed of 2800 r/min, rated flow of 2250 $m^3$/h, and total pressure of 940 Pa.

According to the design experience *(Harrison, 1992)* of existing cyclone separators, the specific parameters of the cyclone separator of the test bench are shown in Table 1, and a schematic diagram of the structure is shown in Fig. 2.

**Table 1**

**Size of cyclone separator**

| Structure parameters of cyclone separator | Size relation | Numerical value(mm) |
|---|---|---|
| Cyclone separator diameter, D | D | 350 |
| Inlet height, h | (0.3-0.5)D | 120 |
| Inlet width, b | (0.2-0.4)D | 70 |
| Suction pipe diameter, $D_1$ | 0.42D | 150 |
| Outlet diameter, $D_2$ | 0.57D | 200 |
| Separator height, $L_1$ | 0.91D | 320 |
| Cone length, $L_2$ | 0.73D | 255 |
| Gross length | 1.64D | 575 |

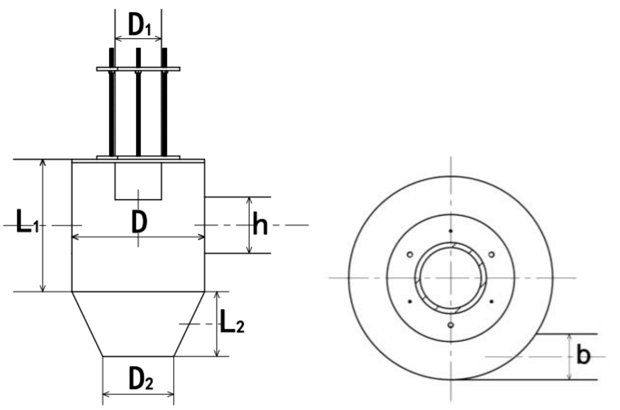



**Fig. 2 - Schematic diagram of cyclone separator structure**

To prevent the material from being blown backward during the pneumatic feeding *(Li, 2009)*, an anti-backward nozzle is designed in the conveying pipe below the feed inlet. The material can be fed into the cyclone separator smoothly, as shown in Figure 1. The feed inlet diameter D is 35 mm.

**Experimental setup**

The breed of buckwheat selected for the experiment was Xinong 9979. The cleaning experiment was conducted on the self-made cyclone separation and cleaning test bench, as shown in Fig. 3. To ensure the excellent data repeatability of the experiment, the materials were mixed according to the mass ratio of grain, chaff and stalk 75%：22%：3%. The average moisture content of grain was12.9%, the average moisture content of chaff was 42.1%, and the moisture content of the stalk was 45.5%.

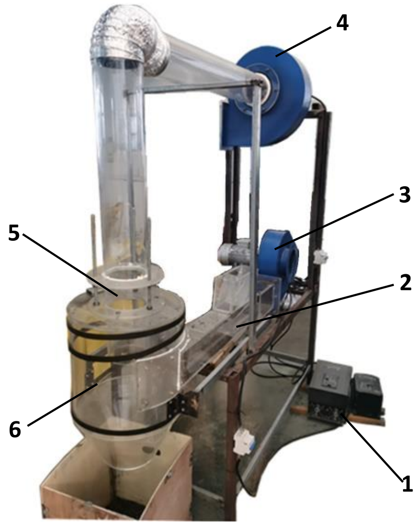



**Fig. 3 - Cyclone separation and cleaning test bench**
*1. Frequency converter; 2. Conveying nozzle; 3. Feeding fan; 4. Suction fan;*
*5. Suction inlet height adjuster; 6. Cyclone separator*

The main performance evaluation indexes of cyclone separation and cleaning test bench are the loss rate and cleaning rate of grain *(Lu, et al., 2016; Liao, et al., 2013; Li, 2006)*. The length of the suction pipe in the cyclone separator, the rotational speed of the suction fan and the rotational speed of the feeding fan were selected as the influencing factors for the loss rate and cleaning rate experiment. The equations of the loss rate and cleaning rate of buckwheat separation and cleaning are as follows:

$$Y_q = \frac{m_2}{m_0} \times 100\% \tag{1}$$

$$Y_s = \frac{m_1 - m_2}{m_1} \times 100\% \tag{2}$$

where, $Y_q$ is the grain cleaning rate, %; $Y_S$ is the grain loss rate, %; $m_0$ is the total mass of the materials after cleaning, kg; $m_1$ is the total mass of grains in the materials after cleaning, kg; $m_2$ is the total mass of the grains after cleaning, kg.

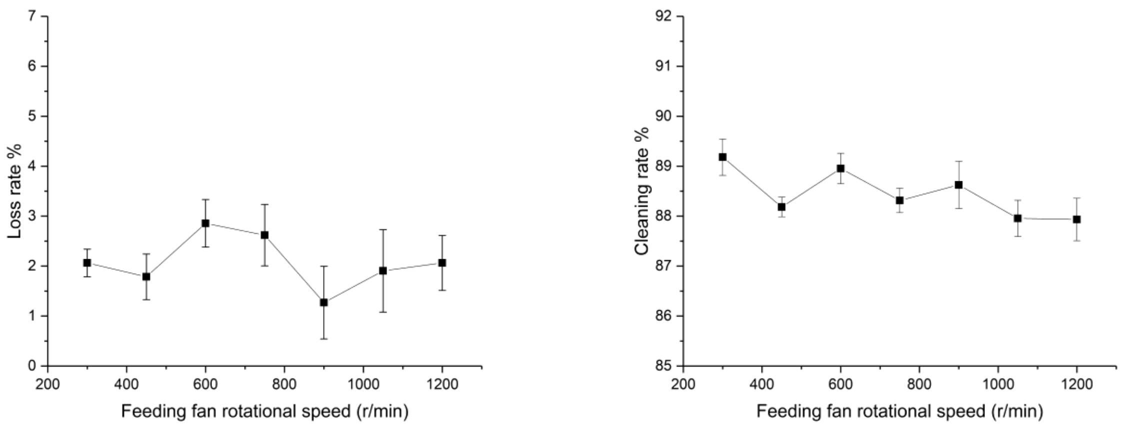
## RESULTS

To ensure the test bench's proper functioning, the range of parameter values of the influencing factors was determined by a trial test. The initial examination has shown that the scope of the rotational speed of the feeding fan is 300~1200 r/min, the rotational speed of the suction fan is 400~1600 r/min, and the length of the suction pipe is 0~250 mm.

### Single-factor test and analysis of results

The single-factor test of seven levels for the rotational speed of the feeding fan was conducted by setting the suction fan rotational speed at 1200 r/min and the length of the suction pipe in the cyclone separator at 150 mm. Each level of tests was repeated three times with the same input parameters. Based on the above single-factor test, the effect of the rotational speed of the feeding fan on the cleaning rate and loss rate was obtained, as shown in Fig. 4.

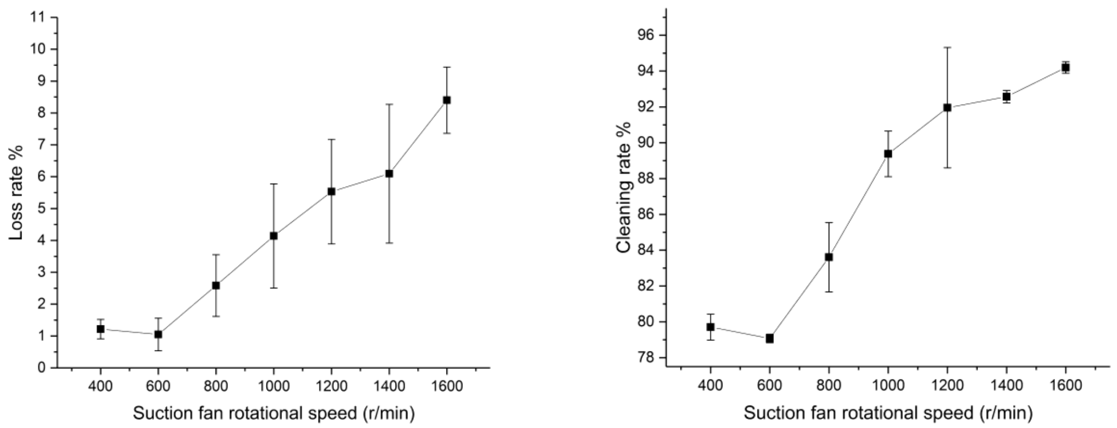
Figure. 4 shows that the rotational speed of the feeding fan has little effect on the loss rate and cleaning rate. As the feeding fan rotational speed increases, the cleaning rate of grains decreases slowly, while the loss rate of grains tends to be raised first and then decreases. The reason is that the feeding fan generates tangential airflow, which provides the initial power to rotate and suspend materials when the materials are fed into the cyclone separator. However, with the increase of the rotational speed of the feeding fan and the rise of feeding airflow velocity, the disturbance of the swirling airflow in the cyclone separator increases. The symmetry of the swirling airflow in the cyclone separator decreases, which increases the loss rate of grain and drops of the cleaning rate of gain. Therefore, the feeding fan rotational speed should be in the range of 600~1200 r/min.




(a) Effect of feeding fan rotational speed on loss rate (b) Effect of feeding fan rotational speed on cleaning rate

**Fig. 4 - Effect of feeding fan rotational speed on cleaning performance**

The single-factor test of seven levels for the rotational speed of the suction fan was conducted by setting the feeding fan rotational speed at 1200 r/min and the length of the suction pipe in the cyclone separator at 150 mm. Each level of tests was repeated three times with the same input parameters. Based on the above single-factor test, the effect of the rotational speed of the suction fan on cleaning rate and loss rate was obtained, as shown in Fig. 5.

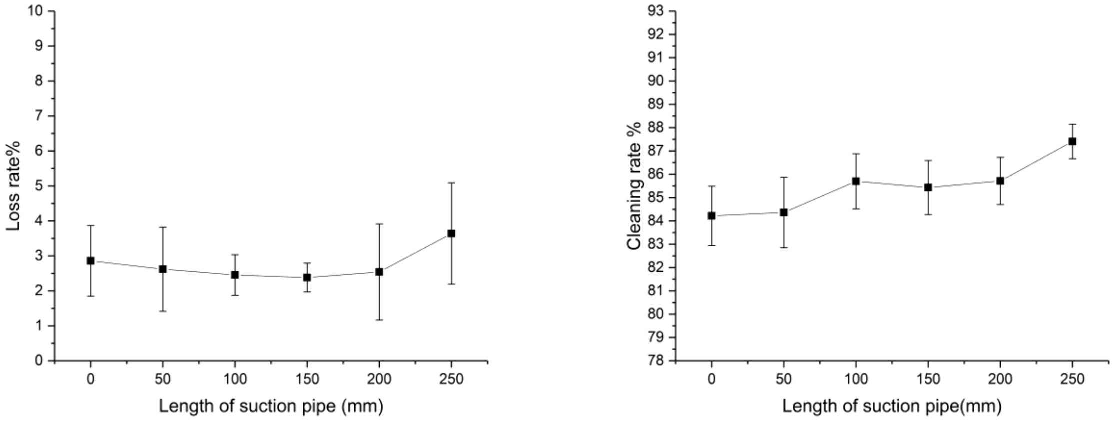



（a）Effect of suction fan rotational speed on loss rate （b）Effect of suction fan rotational speed on cleaning rate

**Fig. 5 - Effect of suction fan rotational speed on cleaning performance**

Fig. 5 shows that the rotational speed of the suction fan has a significant effect on the loss rate and the cleaning rate. As the rotational speed of the suction fan increases, the velocity of updraft generated by the suction fan increases, the buoyancy of the updraft increases, and the probability of impurities and grains being sucked out by the impurity suction fan increases, and the likelihood of impurities entering into the grain box decreases, which results in the loss rate and the cleaning rate of grain continuing to increase. When the rotational speed of the suction fan exceeds 1200 r/min, the cleaning rate of grain increases slowly, while the loss rate of grain increases significantly. Therefore, the suction fan rotational speed should be in the range of 800~1200 r/min.

The single-factor test of six levels for the length of the suction pipe in the cyclone separator was conducted by setting the suction fan rotational speed at 1200 r/min and the feeding fan rotational speed at 1200 r/min. Each level of tests was repeated three times with the same input parameters. Based on the above single-factor test, the effect of the length of the suction pipe in the cyclone separator on the cleaning rate and loss rate was obtained, as shown in Fig. 6.



(a) Effect of length of the suction pipe on loss rate (b) Effect of length of the suction pipe on cleaning rate

**Fig. 6 - Effect of length of the suction pipe on cleaning performance**

Fig. 6 shows that the length of the suction pipe in the cyclone separator has little effect on the loss rate and some influences on the cleaning rate. As the length of the suction pipe in the cyclone separator increases, the grain's cleaning rate increases and the grain's loss rate changes little. When the length of the suction pipe in the cyclone separator exceeds 200 mm, the cleaning rate and the loss rate of grain begin to increase significantly. The reason is that as the length of the suction tube in the cyclone separator continues to grow, the suction inlet is incessantly approaching the feed inlet. More and more airflow generated by the feeding fan are sucked away by suction inlet directly. Therefore, the suction airflow reduces the interference of tangential airflow from the feeding fan on the airflow symmetry in the cyclone separator to increase its cleaning rate. Meanwhile, the grains at the feed inlet are easily sucked away by the suction fan through the suction pipe, increasing the grain loss rate. Therefore, the length of the suction pipe in the cyclone separator should be in the range of 100 mm~250 mm.

### Orthogonal test and result analysis

Based on the results of the single-factor test, feeding fan rotational speed $X_1$, suction fan rotational speed $X_2$ and length of the suction pipe $X_3$ were taken as test factors, and the grain loss rate $Y_s$ and the grain cleaning rate $Y_q$ were taken as the evaluation indexes in the trial. The three-factor and three-level response surface method was adopted in the test, and the level codes of the test factors are shown in Table 3.

**Coding of factors and levels** **Table 3**

| Influencing factors | Coding | Coding level | | |
|---|---|---|---|---|
| | | -1 | 0 | 1 |
| Feeding fan rotational speed（r/min） | $X_1$ | 600 | 900 | 1200 |
| Suction fan rotational speed（r/min） | $X_2$ | 800 | 1200 | 1600 |
| Length of suction pipe（mm） | $X_3$ | 100 | 175 | 250 |

Response surface analysis tests of 17 groups were carried out (Table 4), and each group of tests was repeated three times.

**Experimental methods and results of orthogonal rotational experiment** **Table 4**

| Number | $X_1$ | $X_2$ | $X_3$ | $Y_q$ | $Y_s$ |
|---|---|---|---|---|---|
| 1 | 1 | 1 | 0 | 93.96 | 7.29 |
| 2 | -1 | 1 | 0 | 95.63 | 10 |
| 3 | 1 | -1 | 0 | 90.98 | 0.62 |
| 4 | 1 | 0 | -1 | 91.89 | 2.92 |
| 5 | -1 | 0 | -1 | 93.49 | 2.5 |
| 6 | -1 | 0 | 1 | 95.18 | 5.41 |
| 7 | 1 | 0 | 1 | 93.39 | 1.46 |
| 8 | 0 | 1 | -1 | 93.65 | 6.04 |
| 9 | 0 | -1 | -1 | 90.97 | 0.42 |
| 10 | 0 | -1 | 1 | 92.94 | 0 |
| 11 | 0 | 1 | 1 | 94.4 | 10.42 |
| 12 | -1 | -1 | 0 | 93.53 | 0.83 |
| 13 | 0 | 0 | 0 | 93.39 | 1.25 |
| 14 | 0 | 0 | 0 | 93.36 | 1.67 |
| 15 | 0 | 0 | 0 | 93.75 | 1.25 |
| 16 | 0 | 0 | 0 | 93.75 | 1.25 |
| 17 | 0 | 0 | 0 | 93.68 | 2.5 |

### Establishment and test of the regression model of cleaning rate and loss rate

The quadratic regression equation models of *Yq* and *Ys* were established with $X_1$, $X_2$ and $X_3$ as independent variables. The regression equation models were tested for significance by the variance analysis of regression coefficients and F-test. The results are shown in Table 5 and Table 6.

**Table 5**

**Regression equation variance analysis of cleaning rate response surface**

| Number | Variance source | Quadratic sum | Degrees of freedom | *F* value | *P* value (Prob > *F*) |
|---|---|---|---|---|---|
| 1 | Regression | 23.74 | 9 | 49.08 | < 0.0001 |
| 2 | $X_1$ | 7.24 | 1 | 134.66 | < 0.0001 |
| 3 | $X_2$ | 10.63 | 1 | 197.67 | < 0.0001 |
| 4 | $X_3$ | 4.37 | 1 | 81.22 | < 0.0001 |
| 5 | $X_1X_2$ | 0.19 | 1 | 3.60 | 0.0995 |
| 6 | $X_1X_3$ | 0.009 | 1 | 0.17 | 0.6942 |
| 7 | $X_2X_3$ | 0.37 | 1 | 6.92 | 0.0339 |
| 8 | $X_1^2$ | 0.20 | 1 | 3.73 | 0.0947 |
| 9 | $X_2^2$ | 0.33 | 1 | 6.11 | 0.0427 |
| 10 | $X_3^2$ | 0.42 | 1 | 7.86 | 0.0264 |
| 11 | Residual error | 0.38 | 7 | | |
| 12 | Lack of fit | 0.22 | 3 | 1.96 | 0.2614 |
| 13 | Error | 0.15 | 4 | | |
| 14 | Sum | 24.12 | 16 | | |
| $R^2$=0.9844; *Adj* $R^2$=0.9643; Coefficient of variation *C.V*=0.25% | | | | | |

**Table 6**

**Regression equation variance analysis of loss rate response surface**

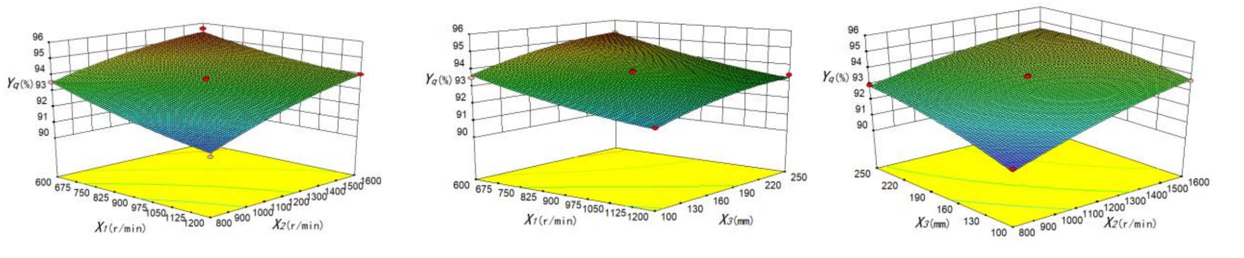
| Number | Variance source | Quadratic sum | Degrees of freedom | *F* value | *P* value (Prob > *F*) |
|---|---|---|---|---|---|
| 1 | Regression | 173.98 | 9 | 66.98 | < 0.0001 |
| 2 | $X_1$ | 5.20 | 1 | 18.02 | 0.0038 |
| 3 | $X_2$ | 127.04 | 1 | 440.21 | < 0.0001 |
| 4 | $X_3$ | 3.66 | 1 | 12.68 | 0.0092 |
| 5 | $X_1X_2$ | 1.56 | 1 | 5.41 | 0.0529 |
| 6 | $X_1X_3$ | 4.77 | 1 | 16.54 | 0.0048 |
| 7 | $X_2X_3$ | 5.76 | 1 | 19.96 | 0.0029 |
| 8 | $X_1^2$ | 4.02 | 1 | 13.92 | 0.0074 |
| 9 | $X_2^2$ | 19.00 | 1 | 65.84 | < 0.0001 |
| 10 | $X_3^2$ | 1.10 | 1 | 3.82 | 0.0915 |
| 11 | Residual error | 2.02 | 7 | | |
| 12 | Lack of fit | 0.84 | 3 | 0.95 | 0.4976 |
| 13 | Error | 1.18 | 4 | | |
| 14 | Sum | 176.00 | 16 | | |
| $R^2$=0.9885; *Adj* $R^2$=0.9738; Coefficient of variation *C.V*=16.36% | | | | | |

*Note: * significant (P <0.05) and ** extremely significant (P <0.01).*

According to Table 5 and eliminating the insignificant terms in the regression equation, the regression equation of the cleaning rate *Yq* expressed by coding values was obtained:

$$Y_q = 93.59 - 0.95X_1 + 1.15X_2 + 0.74X_3 - 0.30X_2X_3 - 0.28X_2^2 - 0.32X_3^2 \tag{3}$$

The interaction relationship between the other two influencing factors and their influences on *Yq* were analyzed by setting any factor in Equation (3) at zero level to fit the response surface, as shown in Figure 7.




(a) Effect of feeding fan rotational speed and suction fan rotational speed on cleaning rate

(b) Effect of feeding fan rotational speed and length of suction pipe on cleaning rate

(c) Effect of length of suction pipe and suction fan rotational speed on cleaning rate

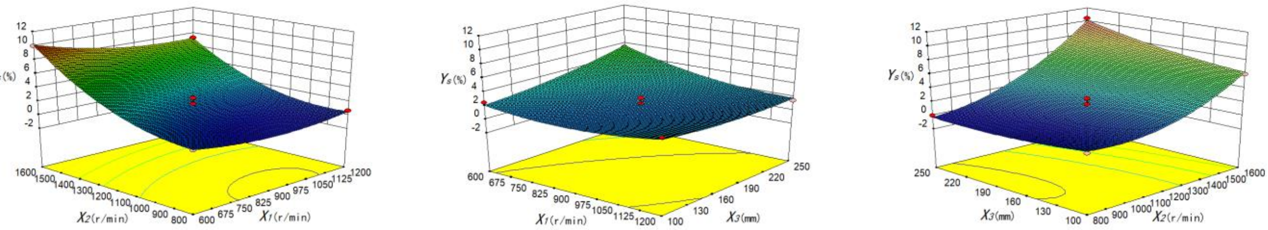
**Fig. 7 - Effects of the interaction of factors on cleaning rate**

As can be seen from Fig. 7 (a), when $X_3$ is 175 mm, *Yq* increases with the decrease of $X_1$ and the rise of $X_2$, but the influence of $X_1$ and $X_2$ on *Yq* is not significant, which is the same as the result of regression equation variance analysis. As can be seen from the response surface shape of Fig. 7 (b), when $X_2$ is 1200 r/min, *Yq* increases with the decrease of $X_1$ and the increase of $X_3$, but the influence of $X_1$ and $X_3$ on *Yq* is also not significant, which is the same as the result of regression equation variance analysis. As can be seen from the response surface shape of Fig. 7 (c), when $X_1$ is 900 r/min, $X_2$ and $X_3$ have a significant influence on $Yq$, $Yq$ increases with the increase of $X_3$ and $X_3$. When $X_2$ increases from 800 r/min to 1600r/min, the effect of $X_3$ on $Yq$ gradually decreases, and when $X_3$ increases from 100~250 mm, the effect of $X_2$ on $Yq$ reduce progressively.

According to the analysis in Table 6 and eliminating the insignificant terms in the regression equation, the regression equation of the loss rate $Ys$ expressed by coding values was obtained:

$$Y_s = 1.58 - 0.81X_1 + 3.98X_2 - 0.68X_3 - 1.09X_1X_3 + 1.20X_2X_3 + 0.98X_1^2 + 2.12X_2^2 \tag{4}$$

The interactional relationship between the other two influencing factors and their influence on $Ys$ were analyzed by setting any one factor in Equation (4) at zero level to fit the response surface, as shown in Figure 8.




(a) Effect of feeding fan rotational speed and suction fan rotational speed on loss rate

(b) Effect of feeding fan rotational speed and length of suction pipe on loss rate

(c) Effect of length of suction pipe and suction fan rotational speed on loss rate

**Fig. 8 - Effects of the interaction of factors on loss rate**

As can be seen from Fig. 8 (a), when $X_3$ is 175 mm, $Ys$ increases with the increase of $X_2$, and the influence of $X_1$ on $Ys$ is not significant, which is the same as the result of regression equation variance analysis that the overall effect of $X_1$ and $X_2$ on $Ys$ is not significant. As can be seen from the response surface shape of Fig. 8 (b), when $X_2$ is 1200 r/min, $X_1$ and $X_3$ have a significant effect on $Ys$. When $X_1$ is lower than about 900 r/min, $Ys$ increases with the increase of $X_3$. When the rotational speed exceeds about 900 r/min, the influence of $X_3$ on $Ys$ is not significant. When $X_3$ is longer than 160 mm, $Ys$ increases with the increase of $X_1$. When the length is shorter than 160 mm, the influence of $X_1$ on $Ys$ is not significant. As can be seen from the response surface shape of Fig. 8 (c), when $X_1$ is 900 r/min, $X_2$ and $X_3$ have an immensely effect on $Ys$, and $Ys$ increases with the increase of $X_2$. When $X_2$ is higher than about 1000 r/min, $Ys$ increases with the rise of $X_3$. When the rotational speed is lower than about 1000 r/min, the influence of $X_3$ on $Ys$ is not significant. In Figure 14, $Ys \le 0$ indicates that the loss rate is 0 at that time.

**Parameter optimization and experiment of cyclone separation and cleaning test bench**

The influence sorting of three test factors on the test bench is as follows: the rotational speed of the suction fan($X_2$), the rotational speed of the feeding fan($X_1$) and the length of the suction pipe($X_3$). To further determine the suitable parameter combination of influencing factors for test bench, multi-objective parameter optimization was carried out by the regression equation model. Taking the range of values of the test influencing factors as the boundary conditions and taking the minimum loss rate and maximum cleaning rate as the optimization objectives, the mathematical model was as follows:

$$\begin{cases} \max Y_q\left(X_1, X_2, X_3\right) \\ max\, Y_s\left(X_1, X_2, X_3\right) \end{cases} \tag{5}$$

Constraint condition: $\begin{cases} -1 \le X_1 \le 1 \\ -1 \le X_2 \le 1 \\ -1 \le X_3 \le 1 \end{cases}$

The Design-Expert 8.0.5 was used to solve the regression equation model by multi-objective optimization, and the optimal test influencing factor parameters were obtained: $X_2$ was 1055.86 r/min, $X_1$ was 600 r/min, and $X_3$ was 175 mm. Under the optimal parameter combination, the loss rate $Ys$ was 1.52%, and the cleaning rate $Yq$ was 94.40%.

According to the results of the multi-objective optimal solution and combined with the actual operation requirements of buckwheat cyclone separation and cleaning test bench, the practical test influencing factor parameters were as follows: the rotational speed of the suction fan was 1055 r/min, the rotational speed of the feeding fan was 600 r/min, and the length of the suction pipe in the cyclone separator was 175 mm. Three tests were carried out under the conditions of the test influencing factor parameters through the self-made cyclone separation and cleaning test bench shown in Figure 3. The test results are shown in Table 7. The average cleaning rate was 94.78%, the average loss rate was 1.67%.

**Table 7**

**Experiment results of optimal parameters test**

| Experimental number | 1 | 2 | 3 | mean |
|---|---|---|---|---|
| Cleaning rate $Y_q$（%） | 95.43 | 94.80 | 94.12 | 94.78 |
| Loss rate $Y_s$（%） | 1.42 | 1.68 | 1.92 | 1.67 |

## CONCLUSIONS

(1) Based on the material characteristics of buckwheat, the buckwheat cyclone separation and cleaning test bench was built.

(2) The parameter value range of the primary test influencing factors was determined by trial and single-factor tests of the buckwheat cyclone separation and cleaning test bench. The rotational speed range of the suction fan was 800～1200 r/min, the rotational speed range of the feeding fan was 600~1200 r/min, the length range of the suction pipe was 100 mm~250 mm. The quadratic regression equation model was established through an orthogonal test, taking the cleaning rate and the loss rate as performance indicators. The model analysis showed that the rotational speed of the suction fan had the most significant influence on the cleaning rate and the loss rate, followed by the rotational speed of the feeding fan and the length of the suction pipe in the cyclone separator.

(3) The orthogonal experimental results were analyzed by response surface method, and the regression equation model was solved by multi-objective optimization. The rational experimental parameters for the buckwheat cyclone separation and cleaning test bench were determined: the rotational speed of the suction fan was 1055 r/min, the rotational speed of the feeding fan was 600 r/min, and the length of the suction pipe in the cyclone separator was 175 mm. Under this condition, the average cleaning rate was 94.78%, the average loss rate was 1.67%.

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