

STUDY ON HULLING CHARACTERISTICS OF BUCKWHEAT HULLER

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荞麦剥壳机剥壳性能影响因素试验研究

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Buckwheat huller is the key equipment of the buckwheat rice processing and its performance is directly related to the quality and yield of buckwheat rice. The key working parts of the sand disc sheller are a pair of parallel sand discs. The structure and the working parameters of the sand discs are the key factors affecting the shelling performance. In this paper, the effect of rotating speed of sand disc, shelling clearance, grain size of sand disc and width of the working face on the shelling performance are experimentally investigated. The results show that the rice yield and relative broken rice rate increase with the increase of the rotating speed of the lower sand disc, and the relative broken rice rate increases sharply when the speed reaches a certain value. With the linear increase of the shelling clearance, the rice yield and the relative broken rice rate are first decreased rapidly, and then decrease slowly. The smaller the particle size of the sand disc is, the higher the rice yield and the relative broken rice rate are, and the influence of the lower sand disc is obviously greater than that of the upper one. Properly widening the width of working face will increase the rice yield but the width tends to have little influence on the rice yield when it increases to a certain extent, and its change has a small impact on the relative broken rice rate. According to the results of single factor test and orthogonal test, the sheller can achieve a better shelling performance and work efficiency when the grain size of the upper sand disc is F24, the grain size of the lower sand disc is F36, the shelling clearance is 5 mm, the rotating speed of the sand disc is 950 r/min, and the width of the working face is 2 cm.

摘要

荞麦剥壳机是荞麦米加工的关键设备,其性能的优劣直接关系着荞麦米的质量和产量。砂盘式剥壳机其关键工作部件为一对平行放置的砂盘,砂盘的结构和工作参数是影响剥壳效果的关键因素。文中以砂盘转速、剥壳间隙、砂盘的粒度及工作面宽度为试验因素对剥壳效果进行了试验研究。试验结果表明:随着下砂盘转速的增加,出米率和相对碎米率随之上升,当速度到达一定数值后相对碎米率急剧上升;随着剥壳间隙的线性增大,出米率和相对碎米率先出现快速下降,随后缓慢下降;砂盘粒度越小出米率和相对碎米率越高,且下砂盘的影响程度明显大于上砂盘;工作面宽度的适当增加会造成出米率的增加,当增大到一定程度后对出米率影响趋于平缓,其对相对碎米率影响较小。综合单因素试验和正交试验结果可知,上砂盘粒度24目、下砂盘粒度36目,剥壳间隙5mm、砂盘转速950r/min、工作面宽度2cm时,剥壳机能够取得较好的剥壳效果和工作效率。

INTRODUCTION

Buckwheat as a traditional nutritious coarse cereal is rich in biological flavonoids and other high active medicinal ingredients and has the function of lowering blood fat, blood sugar and cholesterol. Buckwheat rice is the primary product of buckwheat processing which can be directly used for cooking and eating and as raw materials for processing buckwheat powder or other foods, and its key production equipment is the buckwheat huller.

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At present, the sand plate buckwheat huller is widely used in the market for its good shelling performance, but it has a low working efficiency. The main working parts of the buckwheat huller are a pair of sand discs which are placed in parallel. The lower sand disc rotates at a high speed and the upper sand disc is stationary. *Campbell et al., (1985)*, carried out the buckwheat hulling experiments and achieved good results by using the self-designed sand disc huller. *Ji et al., (1999)*, carried out experiments on the sea buckthorn shelling and summarized the influence rules of the moisture content, the rotating speed, the clearance and other factors on the shelling performance by utilizing the double disc structure. Then, the application of the sand disc sheller was reported as developed by Inner Mongolia Agriculture University and the relationship between the buckwheat grading and the shelling clearance was discussed (*Chen et al, 1999; Yu et al, 2002*). *Chen et al., (2001)*, made a theoretical analysis of the stress on spherical nuts in the process of shelling and established the relationship between the bending moment on the dangerous section and the distance between grinding plates. *Tian et al., (2002)*, carried out the theoretical analysis and numerical simulation on the movement track of grains in the sand disc shelling equipment by using sea buckthorn as raw material. *Sun et al., (2007)*, introduced the rubber disc and the soaking technology into the buckwheat hulling process which improved the performance of hulling. In order to improve the separation rate of the traditional buckwheat shell, the air-suction separator of the shell was improved. Further experiments showed that the separation rate of the improved air-suction separator reached up to 99.3% (*Wu et al, 2010*). The vibration analysis method was introduced into the buckwheat sheller and the test results showed that it had a promoting effect on the buckwheat shelling (*Denisko et al, 2011*). The research showed that the curing process can effectively improve the mechanical properties of Tartary buckwheat and increase the shelling rate (*Liu, 2012*). Base on the principle of rolling-cut, *Ye et al., (2021)*, designed a new type of lotus seed shelling. They investigated the effects of the rotational speed of hinge pin, the rubbing roller speed and the tool speed on the shelling rate and the damage rate and found the optimal combined working conditions of the lotus seed shelling. *Diao, (2013)*, conducted an experimental analysis of the relationship between the shelling clearance and the whole half kernel rate. *Chen et al., (2018)*, conducted an experimental study on the power consumption per ton-meter of the buckwheat hulling unit. *Lü et al., (2019)*, presented an on-line measuring method based on machine vision to measure the efficiency parameters of buckwheat hulling and the results showed that the rate of unbroken buckwheat rice measured by this method can effectively reflect the hulling efficiency of the buckwheat huller. Combining the experiment with the EDEM simulation calibration, *Xu et al., (2021)*, analysed the contact parameters required for the discrete element simulation of buckwheat rice sieving. The result of the mean error value of discrete element simulation calibration is less than 7.90% which showed that the discrete element method simulation of buckwheat rice screening is feasible. To find out the influence of the flow control on the hulling effect of the buckwheat huller, *Cheng et al., (2020)*, selected rotational speed of sand disc, hulling gap, width of working face and size of sand disc as the influence factors to analyse the limited flow on the hulling effect. Results indicated that the influence of hulling gap and working face width has potential value to optimize the limited flow. *Fan et al., (2021)*, studied on the processing parameters of different buckwheat varieties including particle size distribution ratio, total ratio of skin and rice and triaxial size. They found that these physical parameters have an important influence on the research of buckwheat shelling. *Qing et al., (2021)*, designed a kind of longan flexible counter roll sheller and found that the shelling device had good adaptability to longan with different fruit sizes. According to the physical properties of the coconuts, *Varghese et al., (2021)*, designed a prototype of an auger-assisted semi-automatic coconut husking machine and evaluated husking rate, husking effectiveness, husking efficiency, percent of nut breaking, and capacity of the machine.

Few researches have been reported about the influence of the roughness of sand disc and the width of the working face on the buckwheat hulling. In this paper, through the experimental study of sand disc with different particle size and working face width, we can find out its working rules and lay a foundation for the reasonable use of equipment and the improvement of structural parameters.

MATERIALS AND METHODS

Composition of the buckwheat sheller

Buckwheat huller machine is the main test equipment which is mainly composed of hopper, adjusting wheel, upper cover, upper and lower sand disc, material outlet and locking ring. Its main working parts are a pair of parallel sand disc in which the lower sand disc rotates at a high speed and the upper sand disc is stationary. When the graded materials enter the huller and flow through the gap between the upper and lower sand discs, they are shelled under the friction, collision and extrusion of the sand discs, and finally the mixture

of buckwheat, buckwheat rice, buckwheat skin and dust is obtained. The mixture materials at the outlet are screened to get clean buckwheat rice, broken rice and the buckwheat without hulling. The structure is as follows:

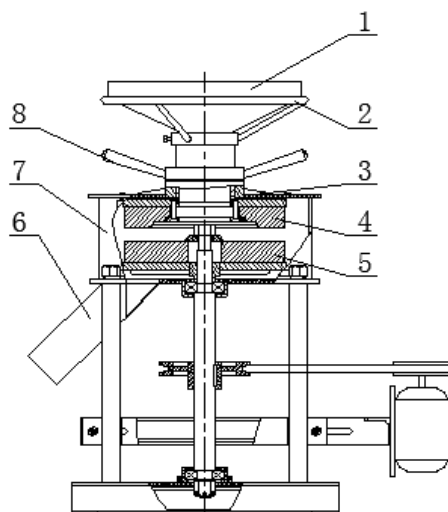


Fig.1 - Structure of buckwheat huller

1. hopper; 2. adjusting wheel; 3. upper cover; 4. upper sand disc; 5. lower sand disc;
6. outlet; 7. outer ring; 8. locking wall

Test materials

In this study, the buckwheat variety selected Windsor which is produced in Wuchuan County of Inner Mongolia Autonomous Region. It was harvested artificially in autumn 2020, and then dried and stored naturally after harvest. The moisture content is 10%-14%.

The raw grains were cleaned using the combined cleaning screen before the experiment, and the cleaned buckwheat was graded by the plane rotary screen, and the graded buckwheat was stored separately. The buckwheat with particle size of 4.6-4.8 mm was selected as the test sample.

Test index

In the process of the buckwheat rice processing, we should not only pursue the quality of buckwheat rice, but also ensure enough productivity, specifically in the shelling performance and the work efficiency. The shelling performance is mainly reflected in the rice yield and the relative broken rice rate. We can get a better shelling performance when the rice yield is higher and the relative broken rice rate is lower. Work efficiency refers to the rice yield per unit time, which is not only related to the rice yield, but also related to the work flow. Higher rice yield and greater working flow correspond to greater rice yield per unit time (*rice yield per unit time = working flow × rice yield*) and thus indicate higher working efficiency of the huller.

Therefore, we should firstly investigate the effects of the particle size of sand disc, the width of the sand disc working face, the working speed and the hulling clearance on the rice yield and the relative broken rice rate in the process of the experiment.

1) Rice yield *A*

$$A = \frac{M_1}{M} \times 100\% \quad (1)$$

2) Relative broken rice rate *B*

$$B = \frac{M_2}{M} \times 100\% \quad (2)$$

3) Rice yield per unit time *C*

$$C = Q \times A \times 100\% \quad (3)$$

Where:

M is the total mass of test sample before hulling, [g];

*M*₁—Mass of all buckwheat rice obtained after hulling, [g];

*M*₂—Mass of all broken rice obtained after hulling (undersize materials in diameter of 3 mm), [g];

Q—Feeding flow of huller, [g].

Test method

The single factor hulling tests were carried out with different sand disc rotation speed, hulling clearance, sand disc particle sizes and width of working face L (see Fig. 2), and the influence of various factors on the hulling effect and efficiency were obtained. Before the test, the residual materials inside the equipment were cleaned by using a brush and the hulling clearance is preliminarily adjusted. Then the clearance of the sand disc with a needle gauge was measured and the required clearance was repeatedly adjusted, and the periphery was wrapped with cloth. No load operation for about 15 seconds before and after hulling to ensure that the equipment is in normal working condition. The test process of measuring the rice yield rate and the broken rice rate are as follows: *raw materials*→*classification*→*sampling*→*hulling*→*powder removing*→*peeling*→*separation*→*weighing*.

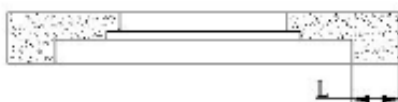


Fig. 2 - Structure of the upper sand disc

The single factor test mainly measured the clearance, the rotating speed of sand disc, the particle size of sand disc and the working face width impacted on the rice yield rate and the relative broken rice rate. All the tests are single factor tests, the selection of factors and levels are shown in table 1. Some test factor levels of the selection are special and one should see the test data for details. The single factor test was repeated three times, and the averaged value was taken as the test result. Material consumption: except for flow measurement, single sample of 500 g is fed into huller at one time.

Table 1

Factor level table				
level	Factors			
	hulling clearance / (mm)	sand disc rotating speed / (r/min)	particle size of sand disc / (mesh)	working face width / (mm)
1	4.6	1050	24	10
2	4.8	1000	36	20
3	5.0	950	46	30
4	5.2	900	-	-
5	5.4	850	-	-

RESULTS

Influence of hulling clearance on hulling effect

In the process of the clearance adjustment, after the initial uniform adjustment the gap is gradually adjusted from large gap to small gap, and the test is carried out in turn. The test results are shown in Fig. 3. The results showed that the rice yield of buckwheat decreases with the increase of the hulling clearance. When the clearance increased to a certain value, the rice yields decrease slowly. The relative broken rice rate decreases rapidly firstly and then increases slightly with the increase of hulling clearance. The inflection point of rice yield and relative broken rice yield is about 5.0 mm, and the optimal hulling clearance should be selected near this point. At this time, the value of hulling clearance is larger than the grain size, which is between the length of buckwheat rice and the length of buckwheat. The larger clearance makes buckwheat grains inclined and vertical keep contact with the upper and the lower part of sand disc at the same time. The extrusion deformation is mainly concentrated on the buckwheat shell, and the buckwheat rice suffered little stress, so it is not easy to cause damage to buckwheat rice and enough rice yield can be ensured. It can be seen from the figure that when the hulling clearance is 5 mm, the broken rice rate is only 3.8%, while the rice yield can reach 38.7%, which is much higher than 10%-25% in production. The reason for this phenomenon is that the buckwheat hulling requires high precision of the clearance adjustment. Because the clearance cannot be directly measured in the working process and the clearance adjustment completely depends on the experience of operators, it is difficult to achieve the optimal state.

The optimal hulling clearance in this test is larger than that in the previous studies. The reason may lie in the way of the clearance measurement. Because the working cavity structure of hulling machine is closed, people often use indirect measurement method to measure the clearance previously. It is difficult to observe

and control the adjustment and the measurement error. The direct measurement method in this experiment can effectively reduce the measurement error and the measured data is more accurate.

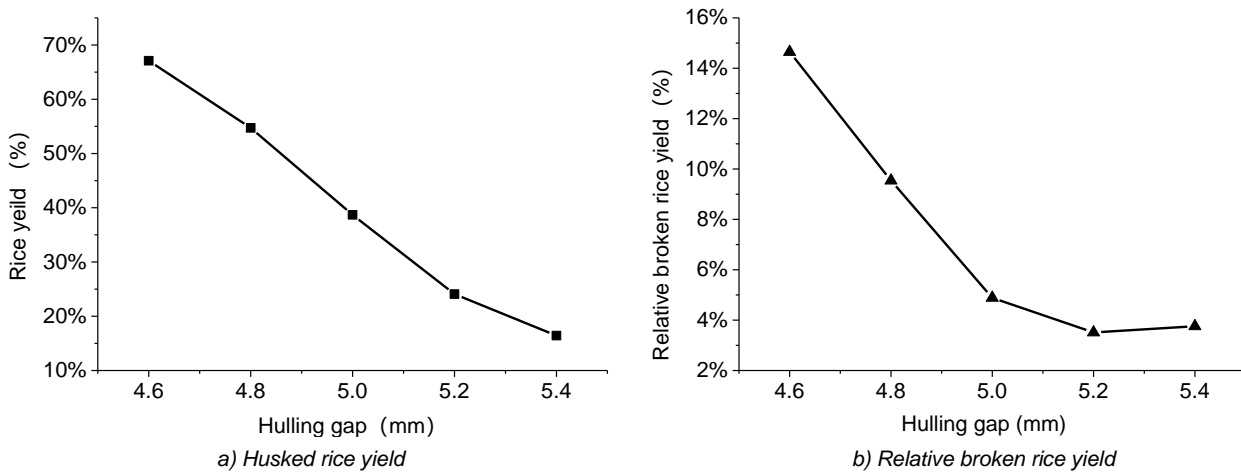


Fig. 3 - Curve of hulling gap

Influence of working face width on hulling performance

During the test, the working speed is 950 r/min, the hulling clearance is 5.0 mm and the relationship between the working face width and the rice yield and the relative broken rice rate is shown in Fig. 4. The test results show that the narrow working face width can reduce the rice yield, but the increase of width cannot significantly improve the rice yield. It can be seen that the width of the working face has a certain decline space. Considering that the decrease of the width of the working face will lead to the increase of the flow, and then increase the yield of buckwheat rice, the width of the working face can be further reduced from 3 cm to 2 cm.

The reason why the linear increase of working face width does not cause the linear increase of rice yield may be that the shelled grains can be shelled within a certain moving distance, while the remaining grains are not shelled because of the close combination of the shell and the rice. The specific hulling process and mechanism need to be further studied.

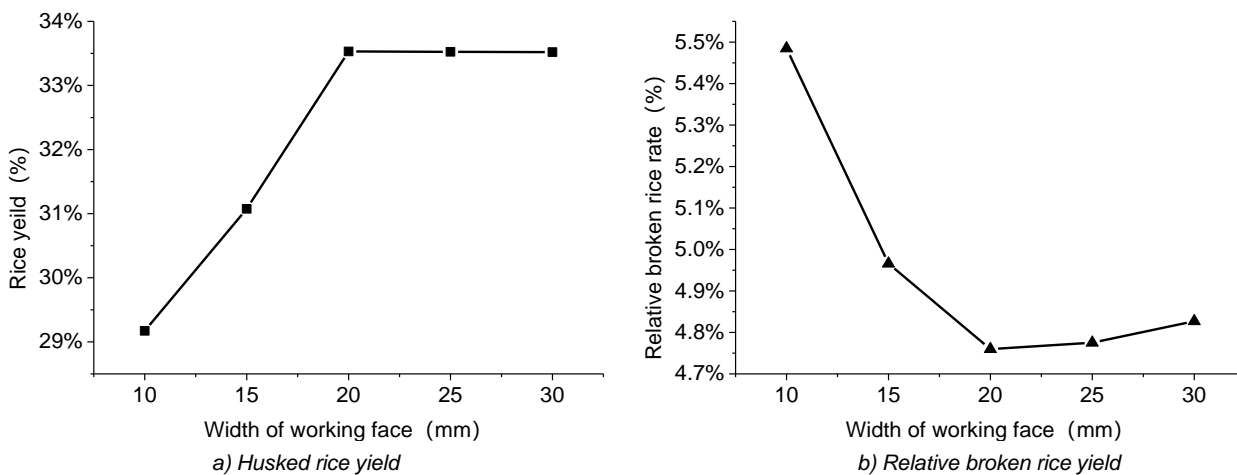


Fig. 4 - Curve of working width

Effect of sand disc mesh size on hulling performance

The surface roughness of the sand disc will directly affect the grinding degree of buckwheat and the friction force, which is mainly determined by the mesh size of the sand disc. The rougher the surface is, the easier it is to produce the dust and the broken rice. The smoother the surface is, the more disadvantageous it is for the grains to stay in the sand disc, resulting in the decrease of the rice yield. In the production, the 24 mesh sand disc is commonly used on the market as the lower sand disc. Due to the special shape of the upper sand disc, it is a special sand disc with the same particle size of 24 mesh. According to the mesh size series table of the sand disc, the upper and lower sand disc of 24, 36 and 46 mesh were selected to test and observe the influence of mesh size on the hulling performance. When the upper sand disc is tested, the lower sand disc is 24 mesh size; otherwise, when the lower sand disc is tested, the upper sand disc is 24 mesh size.

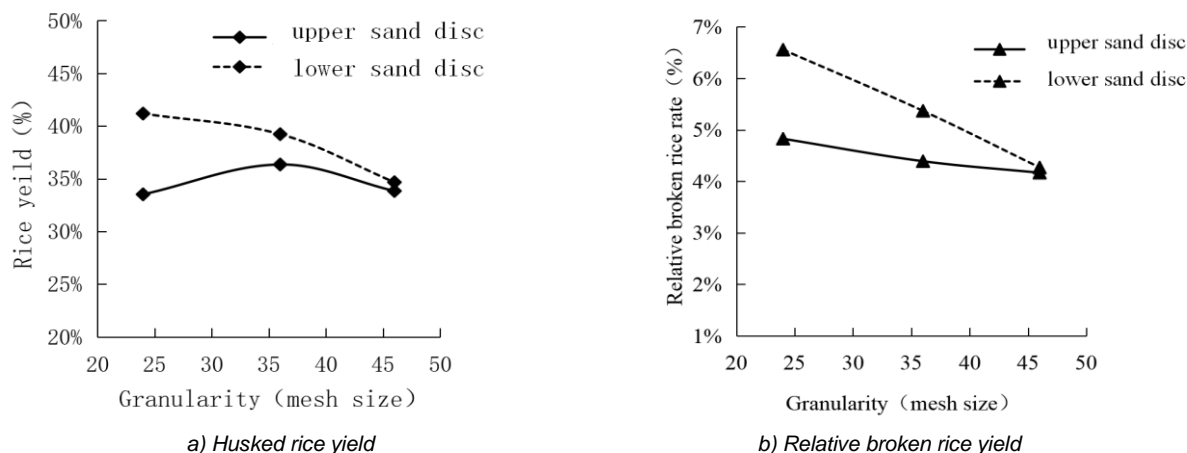


Fig. 5 - Curve of granularity

It can be seen from Fig. 5 that the mesh size of the upper sand disc has little effect on the rice yield and the relative broken rice rate, while the effect of the lower sand disc on the rice yield and the relative broken rice rate is higher than that of the upper one, especially on the relative broken rice rate. The reason is that the impact and grinding effect on buckwheat is more intense in the process of high-speed movement of the lower sand disc, while the upper sand disc is static, so the impact and grinding effect is relatively small. When selecting the mesh size of sand disc, the upper sand disc can be selected with 24 mesh, while the lower sand disc can be selected according to the requirements of the broken rice rate. If the requirement of the relative broken rice rate is not high, 16 mesh or 24 mesh can be selected to increase the rice yield; If the requirement of relative broken rice is high, 36 mesh or 46 mesh can be selected.

Orthogonal test and results

The above single factor test shows the influence of each factor on the test index, without considering the interaction between factors. The following is to analyse the primary and secondary order and significance of each factor through orthogonal test, and select a better parameter combination according to the actual production needs. During the working process, the rotating speed of sand disc is generally a fixed value, which is not taken as a test factor, and its value is 950 r/min. L9 (34) table was used for orthogonal test, and the factors were the hulling clearance, the working face width and the sand disc size.

Table 2

Factor level table for orthogonal test			
Level	Experimental factors		
	Hulling gap A (mm)	Width of working face B (mm)	Granularity of sand disc C (mesh size)
1	4.8	10	24
2	5.0	20	36
3	5.2	30	46

Table 3

Result of orthogonal test						
Number	Factors				Experimental index	
	A	B	C		Rice yield rate / (%)	Relative broken rice yield rate / (%)
1	1	1	1	1	29.9	9.5
2	1	2	2	2	35.5	8.1
3	1	3	3	3	35.3	7.3
4	2	1	2	3	17.3	3.9
5	2	2	3	1	23.5	4.8
6	2	3	1	2	22.2	4.2
7	3	1	1	2	10.9	2.9
8	3	2	2	3	15.1	2.2
9	3	3	2	1	17.8	3.6

According to the result analysis in Table 3, when the rotation speed of sand disc is fixed, the shelling clearance has the greatest influence on the rice yield and the relative broken rice rate, followed by the working face width and the sand disc particle size. The width of the working face has a significant effect on the rice yield, but it has no significant effect on the relative broken rice yield. Grain size has no significant effect on the rice yield, but it has significant effect on the relative broken rice rate. When selecting the optimal parameters, the comprehensive balance method should be adopted. Taking the relative broken rice rate less than 6% as the main reference and combining the rice yield and the limit working flow, the optimal combination of A2B2C2 is adopted.

Table 4

Analysis item	Result analysis of orthogonal test					
	Rice yield rate			Relative broken rice yield rate		
	A	B	C	A	B	C
K1	100.7	58.1	71.2	24.9	16.3	17.9
K2	63	74.1	68.6	12.9	15.1	15.2
K3	43.8	75.3	67.7	8.7	15.1	13.4
R	56.9	17.2	3.5	16.2	1.2	4.5
Primary and secondary factors	A>B>C			A>C>B		
Optimal combination	A1>B3>C1			A3>B3>C3		
SS	558.6	61.5	2.2	47.1	0.3	3.4
df	2	2	2	2	2	2
MS	279.3	30.7	1.1	23.6	0.2	1.7
F	270.0	29.7	1.1	336.6	2.3	24.4
Significance	**	*		**		*

CONCLUSIONS

From the above test results, the following conclusions can be drawn:

1) It is helpful to reduce the broken rice rate by appropriately reducing the working speed, but at the same time, it will reduce the rice yield and thus affect the working efficiency. Therefore, 950 r/min is a reasonable choice. The hulling clearance has a great influence on the rice yield and the relative broken rice rate. The optimal hulling clearance is located at the inflection point of the curve of the rice yield and the relative broken rice rate, which is about 5 mm.

2) The width of the working face of sand disc has little influence on the rice yield within a certain range. If it is too small, the rice yield will be reduced. But it can increase the limit flow and thus to improve the output per unit time. So it should be selected slightly larger than 2cm.

3) In the structure of the sand disc huller, only the width of working face has potential value to improve the limit working flow, and other factors can be ignored.

4) The optimal combination of parameters in the working process are the working speed (950 r/min), the hulling clearance (5 mm), the working face width of the sand disc (2 cm), the mesh size of upper sand disc (24 mesh), mesh size of the lower sand disc (36 mesh).

In conclusion, It is difficult to increase the rice yield by greatly increasing the limit flow under the existing structure. The most important factor affecting the shelling performance and the work efficiency is the hulling clearance. According to different varieties and grain sizes of buckwheat, how to adjust the clearance timely and accurately is the key factor to improve the equipment.

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