DESIGN AND EXPERIMENTAL STUDY OF FLEXIBLE THRESHING DEVICE FOR LONGITUDINAL AXIAL FLOW CORN

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纵轴流玉米柔性脱粒装置设计与试验研究

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ABSTRACT

In order to reduce the problems of high grain breakage rate and uncleaned material rate in the threshing and separating device,a threshing device of "front flexible nail tooth + rear elastic grain bar threshing element" was designed and the threshing elements were arranged spirally on the conical threshing drum. Discrete element method and field test were used to verify the feasibility of threshing drum design, and EDEM simulation software was used to obtain the appropriate guide plate angle parameter range. Single factor test was carried out on each experimental factor under high and low water content conditions, and four factors suitable working range was obtained. On this basis, four factors and three levels orthogonal test was carried out on grain breakage rate and undepurated rate, having rotational speed of roller, feeding rate, cylinder-concave clearance and deflector angle as experimental factors. Range and variance analysis were used to analyze the rotational speed of roller, feeding rate, cylinder-concave clearance and deflector angle. The results showed that: under the conditions of low water content, the threshing effect is the best under the conditions of feeding rate of 8 kg/s, rotational speed of roller of 450 r/min, cylinder-concave clearance of 45 mm, and deflector angle of 70°; under the conditions of high water content, the best threshing effect was achieved under the conditions of feeding rate of 7kg/s, rotational speed of roller of 450 r/min, cylinder-concave clearance of 40 mm and deflector angle of 75°. Compared with the conventional threshing separation device, the grain breakage rate of low moisture content decreased by 39.4% and the uncleaned material rate decreased by 63.9%. The grain breakage rate of high moisture content was reduced by 45.5%, and the uncleaned material rate was reduced by 66.7%, which was better than the conventional longitudinal axial flow threshing separation device. The research results can provide reference for the design and optimization of longitudinal axial flow corn harvester.

摘要

为了减少纵轴流玉米脱粒分离装置的破碎率高、未脱净率高的问题，设计了一种"前柔性钉齿+后压簧弹性短纹杆"的脱粒装置和脱粒元件在锥形脱粒滚筒上的排列方式。采用离散元法和现场试验对脱粒滚筒设计的可行性进行了验证，采用EDEM 仿真软件得到了合适的导板角参数范围。在高、低含水率条件下对各试验因素进行单因素试验，得到四因素合适工作范围，在此基础上，以滚筒转速、喂入量、脱粒间隙和导流板角度为试验因素，对籽粒破碎率和未脱净率进行四因素三水平正交试验。采用极差与方差分析方法对滚筒转速、喂入量、脱粒间隙和导流板角度进行分析，结果表明：在低含水率时，参数组合为喂入量 8kg/s、滚筒转速 450 r/min、脱粒间隙 45 mm、导流板角度 70°的情况下脱粒效果最好，在高含水率时，参数组合为喂入量 7kg/s、滚筒转速 450 r/min、脱粒间隙 40 mm、导流板角度75°的情况下脱粒效果最好，与常规的脱粒分离装置相比，低含水率籽粒破碎率降低了39.4%，未脱净率降低了63.9%，高含水率籽粒破碎率降低了45.5%，未脱净率降低了66.7%，优于常规的纵轴流脱粒分离装置。研究结果可为纵向轴流玉米收获机的设计与优化提供参考。

INTRODUCTION

Corn is one of the three major food crops in China, and the total output of corn is on the rise from 2012 to 2021.Corn is not only the main food crop but also the main cash crop in China, so it is of great significance to do a good job in the development of corn industry.

Mechanization of corn harvesting is the important link to realize full mechanization of corn production, corn harvesting is changing from ear harvesting to grain harvesting in China *(Chen et al., 2012; Paulsen et al., 2014; Cui et al., 2019; Wang et al., 2021*). In the process of corn grain harvesting, grain breakage mainly occurs in the stage of threshing and separation, among the main influencing factors being the form and arrangement of threshing elements and parameter matching of threshing system *(Paulsen et al., 2015; Guan et al., 2020C; Hen et al., 2021; Song et al., 2022*).

The new threshing drum and threshing element are designed and studied, and its rationality is verified. The reasonable range of the steering plate angle of corn threshing device is obtained by simulation software. On the basis of single-factor experiments with three moisture contents, four-factor and three-level orthogonal experiments with high and low moisture contents were carried out, and the best combination of operating parameters of the device with high and low moisture contents was obtained by range and variance analysis, which was superior to the conventional threshing device, it provides a reference for improving the operation performance of the longitudinal axial flow threshing device.

MATERIALS AND METHODS

Overall structure and working principle of longitudinal axial flow threshing and separating device

The overall structure of the longitudinal axial flow corn flexible threshing and separation device is shown in Figure 1, which mainly includes threshing concave plate, tapered threshing drum, upper canopy, threshing concave plate and threshing clearance adjustment device.

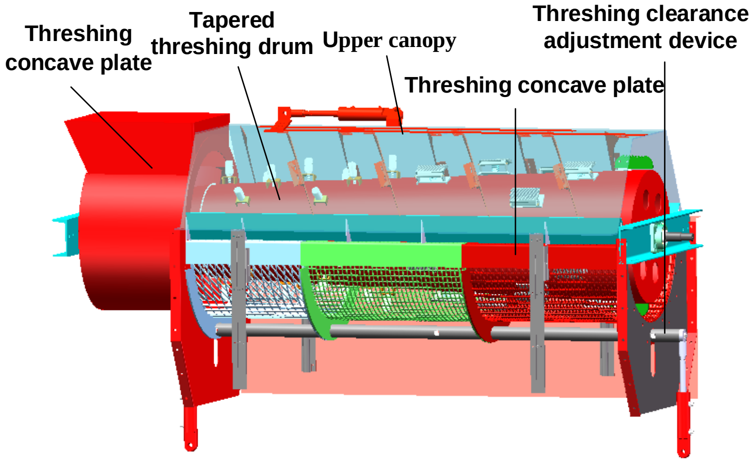


Fig. 1 - Overall view of longitudinal axial flow threshing and separation device

Threshing components

The existing threshing elements of corn grain harvesters are mainly nail-tooth, striated bar block or combination of both. Nail teeth have strong grasp ability, mainly by hitting the corn ear to achieve threshing, threshing is relatively full, but the grain breakage rate is high. Grain bar block has strong rubbing effect, relatively weak threshing effect, resulting in high undepurated rate of grain. Therefore, in order to improve the threshing effect of corn grain, based on the traditional threshing form, the combined threshing element of "front flexible nail teeth + rear elastic grain bar threshing element" was designed, as shown in figure. 2

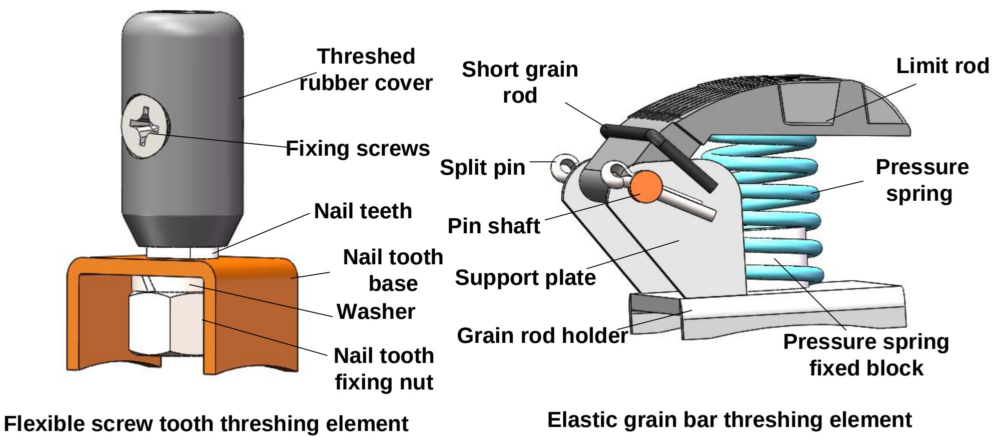


Fig. 2 - Structure diagram of threshing element

The front part of the drum is arranged with screw teeth, having a strong grasping ability for the corn ear, which is conducive to the backward transportation of the corn ear and is not easy to cause blockage. Elastic grain bar threshing element is set in the back section, which mainly plays the role of threshing. In order to realize the turnover and backward movement of the corn ear in the process of cyclic threshing, both the flexible nail teeth and the elastic grain bar threshing element are arranged with spiral lines.

The arrangement of threshing components

In order to ensure full threshing separation of grains, the threshing elements are arranged on the conical threshing drum in a spiral arrangement with 4 heads. In this paper, the tapered drum adopts the way of equal angle conical helix to set threshing elements, so that they can be arranged with varying diameter and spacing, and different pitch can be selected to meet the threshing requirements. The radial diameter of the spiral line between any threshing element and the cone top along the generatrix is ρ_k, and the axial distance between adjacent threshing elements along the same spiral line is Z_k (*Miu et al., 1997; Jin et al., 2021*). The installation position of the combined threshing element and corn ear plate of the conical drum is expanded as shown in figure 3.

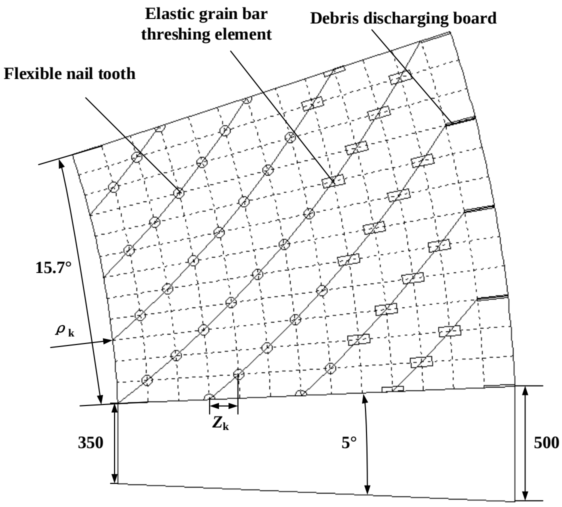


Fig. 3 - Schematic diagram of installation position of combined threshing element

The basic parameters of conical threshing drum are determined, and the parameter equation of isogonal conical helix is as follows:

$$\begin{cases} x = e^{t\sin\gamma\cot\alpha + c}\sin\gamma\cos t \\ y = e^{t\sin\gamma\cot\alpha + c}\sin\gamma\sin t \\ z = e^{t\sin\gamma\cot\alpha + c}\cos\gamma \end{cases} \tag{1}$$

Where：

α is the helix angle;

c is the integral constant;

γ is the cone tip half angle, the drum cone angle 1/2, 2.5º;

t is the angle parameter (kπ, k≥0).

According to Eq.1, it can be known that the projection radius R_d and the vector diameter ρ_k of the helical line in plane X and plane Y are respectively:

For $m = \sin\gamma\,\cot\alpha$

$$R_d = \sqrt{x^2 + y^2} = ne^{mt} \tag{2}$$

$$\rho_k = \sqrt{x^2 + y^2 + z^2} = ae^{mt} \tag{3}$$

Since the conical threshing roller is the latter part of the cone, four helical lines are designed for distribution. At this time, the initial moment t=0 is at the front end of the conical threshing roller. As the design front end diameter is 350 mm, the radius R_a=175 mm. R_a=*a* sin*γ*=175 mm, ρ_0=a=4011.98 mm, can be obtained from Eq.2 and Eq.3.

In order to meet the requirements of threshing, the spiral lines on the conical threshing roller are distributed by twelve equal angles, and four spiral lines are designed on the conical threshing roller. Then the axial distance Z_{sk} of adjacent threshing elements with the same helix is:

$$\begin{cases} Z_{\text{sk}} = Z_k\text{-}Z_{k-1} \\ \quad = \rho_k \cos 2.5^\circ\text{-}\rho_{k\text{-}1} \cos 2.5^\circ \\ \quad = a(e^{\frac{km\pi}{6}} - e^{\frac{(k-1)m\pi}{6}})\cos 2.5^\circ \end{cases} \tag{4}$$

The axial spacing of the cone threshing drum is L_S=1717.78 mm, the length of the designed tail debris discharging board is 150 mm, and the axial spacing from the last row of the hybrid plate to the front end of the threshing roller is Z_{12}=L_S-150=1567.78 mm.

According to Eq.4, it can be obtained:

$$\begin{cases} Z_{S12} = a(e^{\frac{12m\pi}{6}} - e^{\frac{11m\pi}{6}})\cos\gamma \\ Z_{S11} = a(e^{\frac{11m\pi}{6}} - e^{\frac{10m\pi}{6}})\cos\gamma \\ \quad \cdots \\ Z_{S2} = a(e^{\frac{2m\pi}{6}} - e^{\frac{m\pi}{6}})\cos\gamma \\ Z_{S1} = a(e^{\frac{m\pi}{6}} - e^{0})\cos\gamma \end{cases} \tag{5}$$

$$(\rho_k\text{-}\rho_{k\text{-}1})\ \cos\gamma = Z_{sk} \tag{6}$$

By analogy from Eq.5 and Eq.6 above, the axial distance L_{SK} between the radial diameter ρk of conical drum and adjacent threshing elements can be obtained, as shown in table 1:

Table 1

Radial diameter ρ_k and axial distance Z_{sk} of conical drum spiral line

Location of threshing element	ρ_k	Z_{sk}
0	4011.98	0
1	4123.49	111.40
2	4238.11	114.51
3	4355.92	117.70
4	4477.00	120.96
5	4601.46	124.34
6	4729.37	127.79
7	4860.85	131.35
8	4995.98	135.00
9	5134.87	138.76
10	5277.62	142.61
11	5424.35	146.59
12	5581.40	156.90

The three-dimensional model and physical figure of conical corn threshing drum are shown in figure 4 and figure 5.

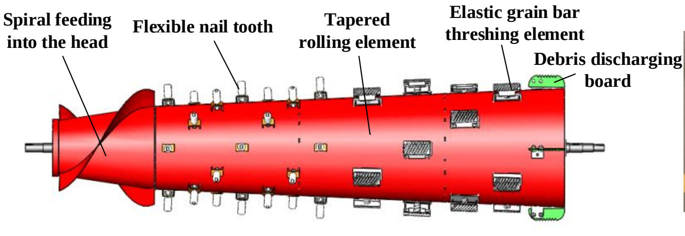


Fig. 4 - Three-dimensional model of threshing drum

Fig. 5 - Picture of cone corn threshing drum

Dynamic balance verification of threshing drum

The threshing drum designed in this paper is conical and it has spirally distributed nail teeth and short grain bar threshing element. These characteristics lead to the uneven movement of the drum, and drum will be left and right vibration and make it subjected to unnecessary external force. Because the unbalanced rotation will produce additional force in the bearing, resulting in accelerated wear and destruction of the bearing on both sides, it is necessary to check the balance of action *(Yang et al., 2017*).

The three-dimensional model of threshing drum was imported into ADAMS software. The drum threshing end was defined as E end and the scrapping end as F end, and the dynamic reaction force of the bearings at both ends was 78.08 N and 30.5 N, respectively, according to the simulation at 600 r/min speed. According to relevant regulations of China, the unbalance value U cannot be greater than the allowable unbalance value Uper. According to software calculation, the total unbalance is U_M+U_N=27505.25 g/mm. The allowable unbalance value Uper is 28012.10 g/mm, which meets the national requirements. That is, there will be no bearing failure caused by dynamic balance.

Based on dynamic balance numerical simulation and theoretical calculation, in Shandong Guofeng Machinery Co., LTD., YYW-1 hard support dynamic balancing machine is used to check the axial flow drum into the action balance, dynamic balance detection in accordance with the national standard GB/T 9239.1-2006 "mechanical vibration constant state (rigid) rotor balance quality requirements". The counterweight iron blocks are welded on the non-working surfaces of the inner edges of E end and F end respectively, and the standard requirements are finally met after counterweight re-inspection, as shown in figure 6.

Fig. 6 - YYW-1dynamic balancing machine and drum dynamic balance counter- weight results

Determination of deflector angle parameters

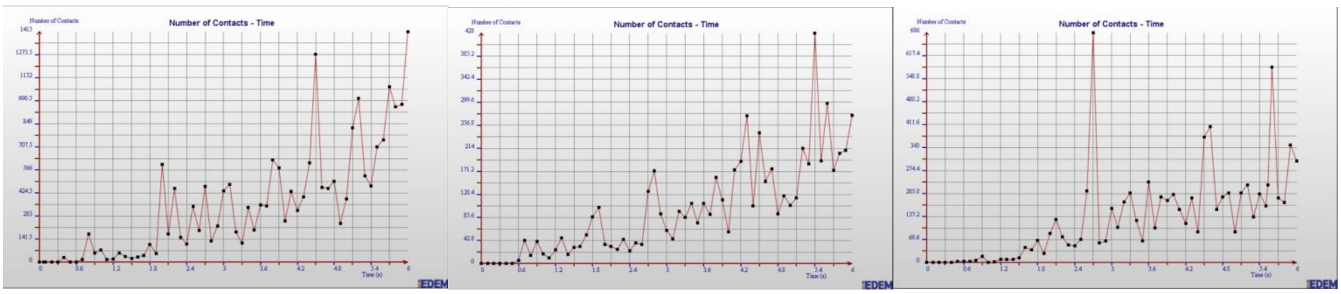
Using SolidWorks draw three cone corn flexible threshing separation device, three types of threshing separation plant in shunt plate angle of 40°, 60° and 80° respectively, in order to guarantee the authenticity and reliability of the simulation model motion process, the attribute parameters of grain and threshing device and the collision parameters of corn ear and corn ear, corn ear and threshing device are constructed respectively, as shown in table 2.

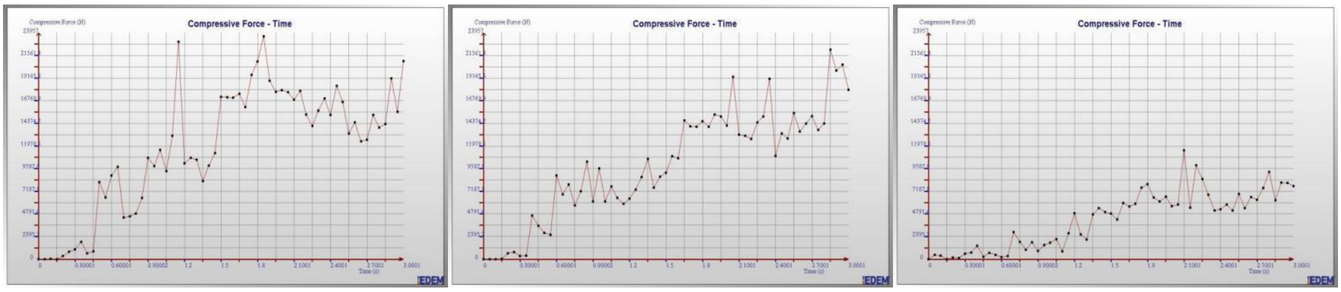
Table 2

Simulation of material parameters and object collision parameters

Materials	Poisson's ratio	Shear modulus (Pa)	Density (kg/m^3)	Collision forms	Resetting modulus	Coefficient of static friction	Coefficient of rolling friction
Corn	0.3	1.0×10^7	1600	**Corn-Corn**	0.3	0.5	0.078
Steel	0.24	7.9×10^{10}	7850	**Corn-Steel**	0.709	0.38	0.051
EPDM	0.331	5.9×10^5	1072	**Corn-EPDM**	0.29	1.05	0.092

Set up the corn ear generating surface and build the particle factory, using the plane generating surface model, adjust the position to the feeding inlet, set the appropriate size. Then set the grain yield of corn ear, set the simulation total to 60, and set the unit yield to 20/s. In order to shorten the simulation time and reduce the simulation amount, the simulation time is 6 seconds, and the mesh is divided into 3Rmin. Finally, the simulation operation is started and the post-processing is carried out *(Xu et al., 2008; Wang et al., 2016; Qian et al., 2017; Dai et al., 2019*). The angle of guide plate is an important factor affecting the breaking rate and undepurated rate of corn grain, and it changes the threshing force and threshing motion state of corn ear, thus determining the performance of threshing separation device. The movement and stress of corn ear with different deflector angles were simulated, and the optimal working range of deflector angles was optimized by analyzing the simulation results. Set the deflector angles as 40°, 60° and 80° respectively. Simulation results are shown in Figure 7.





a. Collision times and stress of corn ear with 80° deflector angle

b. Collision times and stress of corn ear with 60° deflector angle

c. Collision times and stress of corn ear with 40° deflector angle

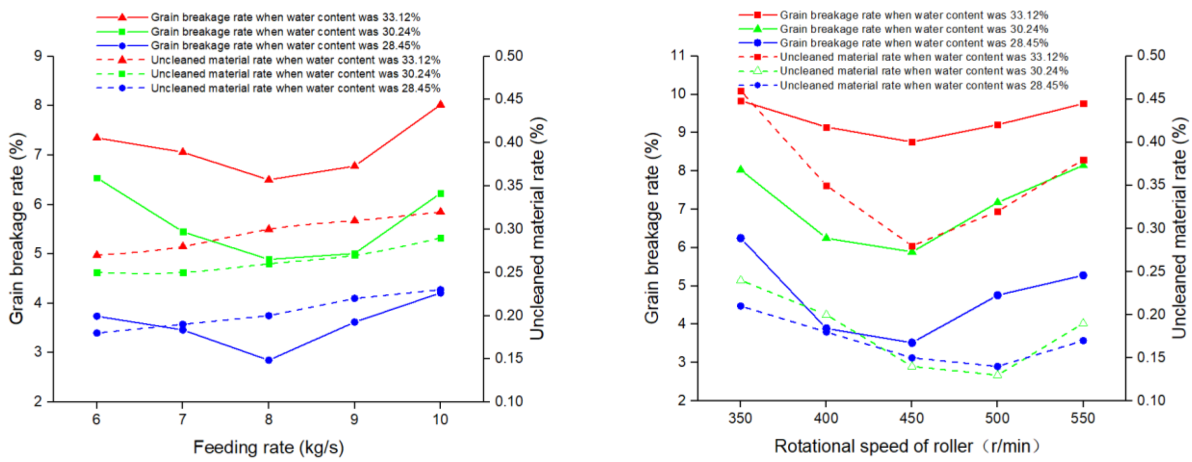
Fig. 7 - Collision times and stress state of corn ear at different deflector angles

As shown in figure 7(a), when the angle of the deflector is too large, the longer the corn ear stays in the threshing and separating device, the more the corn ear itself and the more the collision with the threshing element, and the better the threshing rate of the corn ear. When the angle of the deflector is 80, the stress of the corn ear in the threshing and separating device is obviously higher, and the crushing rate of the corn grain is serious. The angle of guide plate was reduced, and the movement of ear in threshing section was accelerated, which improved threshing efficiency. As shown in figure 7(b), when the deflector angle was 60°, the corn ear moved smoothly without blocking, and the simulation effect of corn ear movement was good. When the angle of the guide plate is too small, the movement of the corn ear at the threshing stage is accelerated, and the axial emergence time of the cob at the threshing stage is short. However, the threshing element has a low threshing effect on the corn ear, which easily leads to poor corn ear depuration effect, as shown in figure 7(c). The reason is that the guide plate angle is too small, when it reaches about 40°, the action contact of the tapered drum threshing parts is reduced, and the axial movement is too fast, and the corn ear is not completely removed from the threshing drum. Therefore, on the premise of meeting the design requirements of corn ear undepurated rate and ensuring a small degree of grain breakage, the optimal working range of the deflector angle is 60-80°.

RESULTS

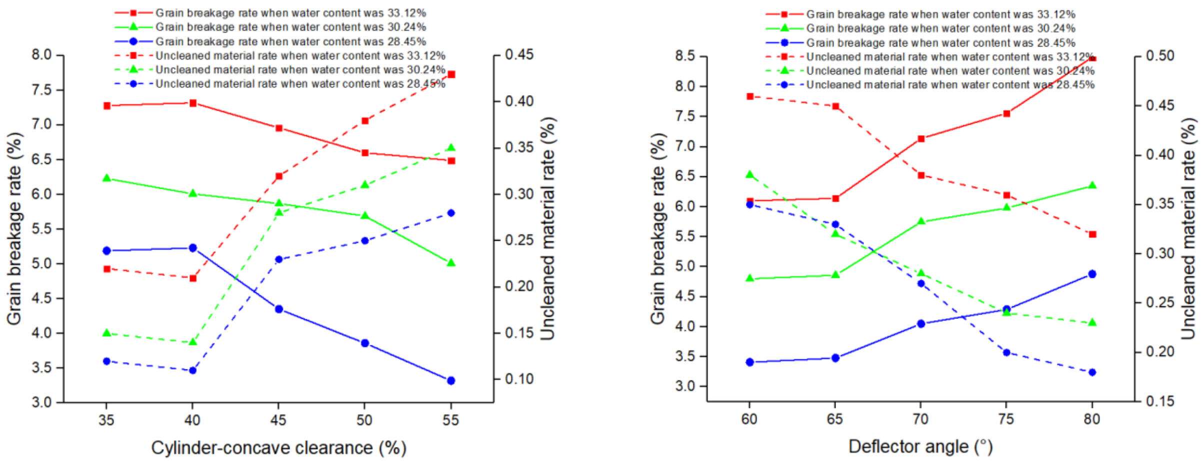
Test purpose and materials

In October 2021, the bench test was carried out outside the agricultural Machinery Equipment Laboratory of Shandong University of Technology, as shown in figure 8. The experimental corn variety "Liyuan 296" ears with bracts were collected by artificial corn ear picking, and 3 ~ 4 layers of outer bracts were retained in corn ears in order to get closer to actual seeds. In order to study the effect of moisture content on corn grain yield, corn ears with different moisture content were used in the bench test. During the 5 days from October 13 to 18, samples were taken from the same corn grain to measure the moisture content, and the bench tests were carried out on October 13, 16 and 18, respectively. At this time, the average moisture content of corn was 33.12%, 30.24% and 28.45%, respectively.



a. Effects of feeding rate on grain breaking rate and uncleaned material rate

b. Effect of rotational speed of roller on grain breakage rate and uncleaned material rate



c. Effect of cylinder-concave clearance on grain breaking rate and uncleaned material rate

d. Effect of deflector angle on grain breakage rate and uncleaned material rate

Fig. 9 - Effect of single factor on grain breakage rate and uncleaned rate

In order to find the optimal threshing separation parameter range, single factor tests were carried out on feeding rate, rotational speed of roller, cylinder-concave clearance and deflector angle, and the test results were averaged.

The results of single factor test showed that with the increase of feeding amount, grain breakage firstly decreased and then increased, and the change of uncleaned rate was not significant. With the increase of rotational speed of roller, grain breakage firstly decreased and then increased, and the uncleaned rate gradually decreased. With the increase of threshing gap, the grain breakage rate decreased and the uncleaned rate increased. With the increase of the deflector angle, the grain breakage rate increased and the undepurated rate decreased.

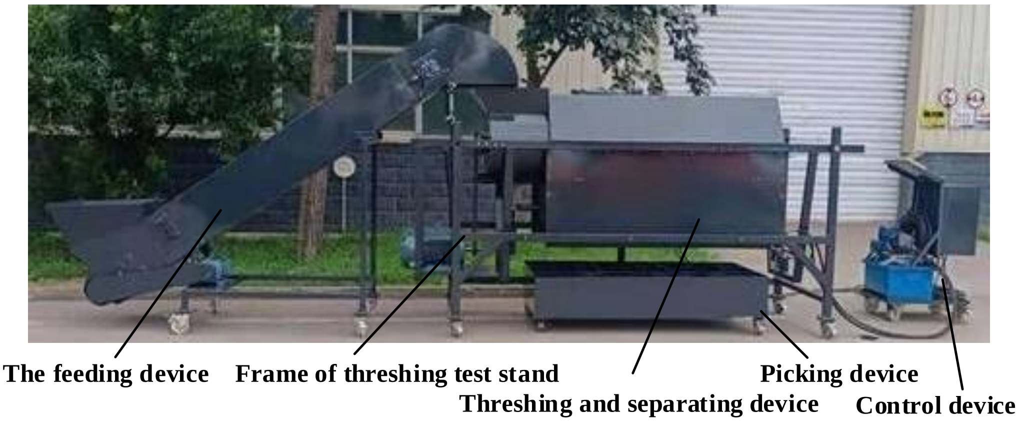


Fig. 8 - Physical picture of longitudinal axial flow threshing and separation test stand

Selected on the basis of single factor experiment, feeding rate and rotational speed of roller,cylinder-concave clearance and deflector angle for orthogonal experiment to investigate factors, grain breakage rate and uncleaned material rate as the evaluation index, the factors level determined by single factor experiment results and theoretical analysis, the design of four factors three levels $L_{27}(3^4)$ orthogonal experiment *(Wu et al., 2010; Wang et al., 2021*), test factors and levels as shown in table 3.

The orthogonal test results are shown in table 4.

Table 3

Orthogonal factor level table

Level	Feeding rate (kg/s)	Rotational speed of roller (r/min)	Cylinder-concave clearance (mm)	Deflector angle (°)
1	7	400	45	65
2	8	450	50	70
3	9	500	55	75

Table 4

Orthogonal experimental design and results

NO.	A[a]	B[b]	C[c]	D[d]	Vacant column	Y_{s1}	Y_{w1}	Y_{s2}[e]	Y_{w2}[f]
1	1	1	1	1	1	2.91	0.52	9.03	0.43
2	1	1	1	1	2	3.91	0.49	8.89	0.45
3	1	1	1	1	3	3.09	0.53	8.92	0.46
4	1	2	2	2	1	2.73	0.32	5.41	0.37
5	1	2	2	2	2	2.08	0.36	4.34	0.36
6	1	2	2	2	3	1.84	0.38	4.88	0.38
7	1	3	3	3	1	3.04	0.27	5.35	0.42
8	1	3	3	3	2	2.73	0.31	7.01	0.40
9	1	3	3	3	3	2.95	0.28	6.12	0.43
10	2	1	2	3	1	1.32	0.45	5.59	0.37
11	2	1	2	3	2	1.14	0.42	5.83	0.38
12	2	1	2	3	3	2.47	0.43	4.71	0.36
13	2	2	3	1	1	1.15	0.60	3.77	0.73
14	2	2	3	1	2	0.81	0.55	3.42	0.61
15	2	2	3	1	3	0.89	0.58	3.03	0.59
16	2	3	1	2	1	4.61	0.15	7.34	0.21
17	2	3	1	2	2	4.22	0.16	5.71	0.20
18	2	3	1	2	3	3.42	0.14	5.87	0.19
19	3	1	3	2	1	2.96	0.50	7.29	0.60
20	3	1	3	2	2	2.08	0.53	7.35	0.61
21	3	1	3	2	3	3.23	0.52	5.87	0.69
22	3	2	1	3	1	2.64	0.29	3.75	0.30
23	3	2	1	3	2	2.01	0.27	3.47	0.32
24	3	2	1	3	3	3.38	0.25	3.92	0.33
25	3	3	2	1	1	5.26	0.26	9.01	0.40
26	3	3	2	1	2	5.18	0.24	7.57	0.41
27	3	3	2	1	3	5.67	0.22	7.09	0.38

[a]Feeding rate / kg/s; ;[b] Rotational speed of roller / r/min; [c]Cylinder-concave clearance / mm; [d]Deflector angle / °
[e]The grain breakage rate / %; [f] The uncleaned material rate / %.

Range and variance analysis were conducted for the orthogonal test results, and the results were shown in table 5 and 6.

Table 5

Significant test results of the difference analysis of grain breaking rate and uncleaned rate

Evaluation index		A	B	C	D
Y_{s1}	k_1	2.809	2.568	3.544	3.208
	k_2	2.226	1.948	3.077	3.019
	k_3	3.601	4.120	2.204	2.409
	R	1.375	2.172	1.340	0.799
Y_{w1}	k_1	0.384	0.488	0.311	0.443
	k_2	0.387	0.400	0.342	0.340
	k_3	0.342	0.226	0.460	0.330
	R	0.045	0.262	0.149	0.103
Y_{s2}	k_1	6.661	7.053	6.322	6.748
	k_2	5.030	3.999	6.048	6.007
	k_3	6.147	6.786	5.468	5.083
	R	1.631	3.054	0.854	1.665
Y_{w2}	k_1	0.411	0.482	0.321	0.500
	k_2	0.404	0.443	0.379	0.401
	k_3	0.449	0.338	0.564	0.368
	R	0.045	0.144	0.243	0.132

Note: K_1-K_3 represents the sum of values of each factor at each level; R is extreme.

Table 6

Results of variance analysis for significance test of grain breakage rate and uncleaned rate

Source	Sources of variation	D_f	Sum of squares	Mean square	*F-value*	*P-value*
Y_{s1}	A	2	8.580	4.290	16.48	< 0.01
	B	2	22.537	11.269	43.29	< 0.01
	C	2	6.481	3.241	12.45	< 0.01
	D	2	3.138	1.569	6.03	< 0.01
	Error	18	4.686	0.260		
	Sum	26	45.422			
Y_{s2}	A	2	12.516	6.258	13.99	< 0.01
	B	2	51.501	25.75	57.57	< 0.01

	C	2	3.425	1.713	3.829	< 0.05
	D	2	12.516	6.258	13.99	< 0.01
	Error	18	8.051	0.447		
	Sum	26	88.010			
Y_{w1}	***A***	2	0.011	0.006	13.37	< 0.01
	B	2	0.321	0.160	379.76	< 0.01
	C	2	0.111	0.056	131.47	< 0.01
	D	2	0.071	0.035	83.92	< 0.01
	Error	18	0.008	0.000		
	Sum	26	0.521			
Y_{w2}	***A***	2	0.010	0.005	4.95	< 0.05
	B	2	0.102	0.051	48.73	< 0.01
	C	2	0.291	0.145	139.28	< 0.01
	D	2	0.079	0.040	37.86	< 0.01
	Error	18	0.019	0.001		
	Sum	26	0.501			

Note: P<0.01 (very significant); 0.01≤P<0.05 (significant); P≥0.05 (not significant).

Comprehensive analysis of the orthogonal test results showed that the grain harvest quality was better when the threshing drum with low water content had a feeding rate of 8 kg/s, the rotational speed of roller was 450 r/min, the cylinder-concave clearance was 45 mm, and the deflector angle was 70°. Under the condition of high water content, the harvest quality is better when the feeding rate is 7 kg/s, the rotational speed of roller is 450 r/min, the cylinder-concave clearance is 40 mm, and the deflection angle is 75°.

Validation and comparison tests

In order to verify the optimal parameters of threshing quality under different moisture content, the flexible threshing device (flexible nail tooth + elastic grain bar threshing element) and the conventional threshing separation device (fixed nail teeth + lattice concave plate) were compared at the moisture content of 28.56% and 34.13%, the feeding rate, the rotational speed of roller, the cylinder-concave clearance and the deflector angle as test factors, the grain breakage rate and uncleaned material rate as the evaluation index. When the water cut rate was 28.56%, the optimal operation parameters were 8 kg/s feeding rate, 450 r/min rotational speed of roller, 45 mm cylinder-concave clearance and 70° deflector angle. When the water content was 34.13%, the combination of parameters was 7 kg/s feeding rate, 450 r/min rotational speed of roller, 40mm cylinder-concave clearance and 75° deflector angle. The test results are shown in table 7. It can be seen that the designed flexible corn threshing separation device is obviously superior to the conventional threshing separation device in terms of corn grain breakage rate and uncleaned material rate. When the water cut rate was 33.14%, the average grain breakage rate decreases by 45.5% and the average uncleaned material rate decreased by 66.7%. When the water content was 28.56%, the average grain breakage rate was reduced by 39.4% and the average uncleaned material rate was reduced by 63.9%, which verified the superiority of the flexible threshing device designed.

Table 7

Validation and contrast test of optimal parameter

Moisture content	Order	Test index	Flexible threshing and separation device	Conventional threshing and separation device
34.13%	1	the grain breakage rate/%	3.89	7.42
		the uncleaned material rate/%	0.18	0.56
	2	the grain breakage rate/%	4.31	7.01
		the uncleaned material rate/%	0.12	0.41
	3	the grain breakage rate/%	3.83	7.65
		the uncleaned material rate/%	0.15	0.38
	Average	the grain breakage rate/%	4.01	7.36
		the uncleaned material rate/%	0.15	0.45
28.56%	1	the grain breakage rate/%	1.32	1.48
		the uncleaned material rate/%	0.15	0.40
	2	the grain breakage rate/%	0.56	1.02
		the uncleaned material rate/%	0.13	0.32
	3	the grain breakage rate/%	0.52	1.46
		the uncleaned material rate/%	0.11	0.36
	Average	the grain breakage rate/%	0.8	1.32
		the uncleaned material rate/%	0.13	0.36

Test results and analysis

(1) Designing a corn threshing device, the "front flexible nail tooth + rear elastic grain bar threshing element" of threshing device and threshing device on the conical cylinder with the method of four conical helix arrangement, choosing the right threshing device wheelbase, to achieve high moisture content of corn grain of flexible threshing and separating, was carried out. Discrete element method and field test were used to verify the feasibility of threshing drum design, and EDEM simulation software was used to obtain the appropriate deflector angle parameter range.

(2) The orthogonal test of four factors and three levels was carried out under the harvesting condition of corn water content of 28.45% and 33.12% to obtain the optimized parameter combination, and the comparison test was carried out with the conventional threshing separation device. Through the verification test, it was obtained that when the water content was 28.56%, the best threshing effect was obtained under the conditions of 8kg/s feeding rate, 450 r/min rotational speed of roller, 45 mm cylinder-concave clearance and 70° deflector angle. Compared with conventional threshing separation device, the average grain breakage rate was reduced by 39.4% and the average uncleaned material rate was reduced by 63.9%. When the moisture content was 33.23%, the threshing effect was the best under the conditions of 7kg/s feeding rate, 450 r/min rotational speed of roller, 40 mm cylinder-concave clearance and 75° deflector angle. Compared with the conventional threshing separation device, the average grain breakage rate was reduced by 45.5% and the average uncleaned material rate was reduced by 66.7%. The advantages of the flexible threshing device for longitudinal axial flow corn were verified.

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