DESIGN AND EXPERIMENT OF COTTON STALKS PULLING DEVICE WITH NON-FLAT TOOTHED DISCS
/
仰角齿盘式拔棉秆装置设计与试验

Weisong ZHAO[1,2,3], Jianhua XIE[2*], MINGJIANG CHEN[1,3], Chunsong GUAN[1*], Jia ZHANG[2], Zhenwei WANG[1], Yan GONG[1,3]
[1] Nanjing Institute of Agricultural Mechanization, Ministry of Agriculture and Rural Affairs, Nanjing 210014, China
[2] College of Mechanical and Electrical Engineering, Xinjiang Agricultural University, Urumqi，830052, China
[3] Institute of Western Agriculture, the Chinese Academy of Agricultural sciences, Changji, 831100, China
Tel: +8609974680383; E-mail: xjh199032@163.com, cs.guan@163.com
** Correspondent authors: Jianhua Xie, Chunsong Guan*
DOI: https://doi.org/10.35633/inmateh-76-01

Keywords: *cotton, stalk, uprooting, toothed discs, pulling machine*

ABSTRACT
Efficient cotton stalk recycling is crucial for agricultural sustainability. Traditional manual removal methods suffer from low efficiency and high labor intensity. Existing mechanical harvesters face limitations such as low removal rates, high stalk breakage rates, and significant omission rates. To address these challenges, this study focuses on optimizing a self-developed multi-row disc-type stalk puller. The conventional flat disc was redesigned into an obliquely angled disc with a bending angle. This 3D curved design enhances stalk constraint capability, thereby improving gripping stability and lifting height. A kinematic model was developed using the ADAMS dynamics simulation platform, revealing the relationships between motion trajectories and key structural parameters. Parametric analysis quantified the effects of disc diameter and bending angle on lifting height and working width. A three-factor, three-level orthogonal experimental design was implemented to evaluate the influence of speed ratio, disc diameter, and disc inclination on three performance indicators: removal rate (Y_1), breakage rate (Y_2), and omission rate (Y_3). The results showed that for Y_1 and Y_3, the primary influencing factors, in order of importance, were: disc diameter > bending angle > speed ratio; for Y_2, the order was: speed ratio > bending angle > disc diameter. The optimal parameter combination was determined to be: 600 mm disc diameter, 20° bending angle, and 0.7 speed ratio. Field tests achieved a pull-out rate of 95.7%, a breakage rate of 3.2%, and an omission rate of 1.1%. These findings provide both theoretical and technical support for enhancing the efficiency of mechanized cotton stalk harvesting.

摘要
棉秆高效回收对促进农业可持续发展具有重要意义，然而传统人工拔秆存在作业效率低、劳动强度大等问题，现有机械收获装置普遍存在拔净率低、断秆率高等技术瓶颈。针对现有棉花秸秆机械化收获存在的整株拔除率低、作业效率不高等问题，本研究基于自主研发的多行齿盘式拔秆机开展结构优化。通过将传统平面齿盘创新设计为带有折弯角的仰角齿盘结构，利用三维曲面增强茎秆约束能力，从机构学层面提升夹持稳定性和有效提拔高度。基于 ADAMS 动力学仿真平台，建立仰角齿盘运动学模型，揭示了运动轨迹与结构参数间的映射关系，通过参数化分析明确了齿盘直径、折弯角对提升高度和工作幅宽的量化影响规律。通过构建三因素三水平正交试验平台，系统研究速比、齿盘直径、齿盘倾角等关键参数对拔净率、拔断率和漏拔率的影响规律。试验结果表明：影响拔净率的参数从主到次排序为：齿盘直径＞折弯角度＞速比；影响漏拔率的参数从主到次排序为：齿盘直径＞折弯角度＞速比；影响拔断率的参数从主到次排序为：速比＞折弯角度＞齿盘直径。以拔除率为主要评价指标，得到最优参数组合是：齿盘直径=600mm、折弯角=20°、速比=0.7。验证结果表明，该参数组合下棉秆拔净率为95.7%、拔断率为 3.2%、漏拔率为 1.1%。研究成果为进一步提高棉秆拔净率提供了理论依据和技术支撑。

INTRODUCTION
China is one of the world's major cotton producing countries, with the third largest cotton planting area in the world and abundant cotton stalk resources. Cotton stalk is a high-quality biomass resource with a wide range of applications such as building boards, chemical product raw materials (such as ethanol and

[1] *Weisong Zhao, Assistant researcher, Ph.D.; Jianhua Xie, Professor, Ph.D.; Mingjiang Chen, Researcher, Ph.D.; Chunsong Guan, Associate researcher, Ph.D.; Jia Zhang, Associate Professor; Zhenwei Wang, Assistant researcher;Yan Gong, Researcher.*

carboxymethyl cellulose), fuel and papermaking *(Agwa et al., 2020; Keshav et al., 2023; Nguyen et al., 2020; Wang Fangzheng et al., 2022)*. The comprehensive utilization of cotton stalks is an important measure to accelerate the green and low-carbon development of agriculture, and mechanized removal of these is the primary link in achieving numerous important uses *(Fernando Correa Da Costa and Cuiaba, 2010; Jiang et al., 2021; Liu Fei et al., 2019).*

The cotton stalk pulling device is a key component of the cotton stalk harvester. Many scholars have carried out work on the design of cotton stalk pulling technology and devices *(Cai Jialin et al., 2020; Chen Mingjiang et al., 2012; He Xiaowei et al., 2020; Tang Zunfeng et al., 2010; Xie Jianhua et al., 2023; Zhao et al., 2023)*. According to the structural form, the pulling devices include toothed discs type *(Ramadan, 2010)*, tire roller type *(Pan, 2014)*, clamping type *(Zhao Weisong et al., 2024)*, flexible belt type *(Cai Jialin et al., 2020)*, toothed roller type *(Zhang Aimin et al., 2016)*, etc. Among them, the toothed discs type stalk puller has a simple structure and affordable price. It is widely welcomed by Chinese farmers and has been applied to a certain extent. However, the operation effect of the toothed discs type stalk puller needs to be further improved, and there are still many cotton stalks that are missed or broken. In order to solve this technical problem, some scholars have carried out mechanism research, structural optimization design and other work. For example, *Wang Xiaoyu et al. (2011)* simulated the motion trajectory of the toothed discs type stalk puller and obtained the trajectory curve under the horizontal working condition of the toothed discs. *Ma Jichun et al., (2010),* further carried out the motion analysis of the toothed discs type stalk puller and explained the influence of different speed ratios on the motion law. *Chen Mingjiang et al. (2019)* used ADAMS to conduct an analysis of the operation process and parameter optimization of a multi-row toothed discs stalk puller. The results showed that the speed ratio was the key factor affecting the removal rate, and the optimal range was 0.55~0.8. *Zhao Weisong et al. (2022),* further conducted a study on the optimization of the toothed discs structure and established the response function of three influencing factors and assessment indicators. However, in the current reported results, the toothed discs are all planar designs, that is, the toothed discs are flat structures. This structure results in unsatisfactory clamping effect and lifting height of cotton stalks. In response to this problem, the goal of this study is to explore the motion law and operation effect of non-planar toothed discs structures, design a non-flat toothed disc, and conduct experimental research on motion trajectory analysis and key influencing factors.

MATERIALS AND METHODS

Overall structure and working principle

The traditional gear-disc type cotton stalk puller is driven by a ground wheel, which relies on the friction between the ground wheel and the ground to achieve power transmission. When operating at high speed, the ground wheel slips and the transmission is unstable, resulting in poor stalk pulling effect and a significantly reduced removal rate. The transmission ratio between the ground wheel and the toothed discs of the traditional toothed discs cotton stalk puller is a constant value, and the working parameters of the mechanism cannot be adjusted according to the changes in the cotton stalk harvesting period, which greatly limits the scope of application of the stalk pulling machinery.

The toothed discs type multi-row cotton stalk pulling device designed in this paper is mainly composed of a parallelogram hanging mechanism, a frame, a hydraulic motor and a speed sensor, a stalk supporter, toothed discs, a folding mechanism and other components, as shown in Figure 1.

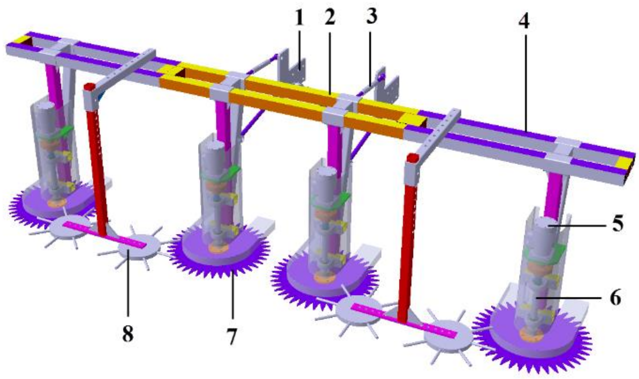

Fig. 1 - Structural diagram of multi-row cotton-stalk uprooting device
1. Hooking mechanism; 2. Fixed frame; 3. Telescopic rod; 4. Foldable frame; 5. Hydraulic motor; 6. Rotating shaft; 7. Non-flat toothed discs; 8. Crop support

The side frames can be folded during transportation, and are easy to assemble and disassemble. They can realize two-row or four-row operations, and the spacing between adjacent toothed discs is adjustable to meet the requirements for harvesting cotton stalks at different row spacings. The electro-hydraulic control technology can realize individual control of each gear disc, and the gear disc rotation direction and speed are adjustable.

Working principle: When working, the stalk pulling tooth plate rotates at a certain speed driven by the hydraulic motor. The tractor moves forward to feed the cotton stalks into the V-shaped tooth grooves on the tooth plate. The stalks are pulled out of the soil.

Key components and hydraulic transmission system design

Overall design of the gear-disc multi-row cotton stalk pulling stand

The overall structure of the gear-disc multi-row cotton stalk pulling stand is shown in Figure 2. It is mainly composed of a load-sensitive pump, an electro-hydraulic proportional valve, a display, a vehicle speed sensor, a cotton stalk pulling device, a tractor, etc. The gear speed and speed ratio are controllable and adjustable, and the gear speed, torque and other key operating parameters are monitored and recorded in real time through sensors, which is convenient for subsequent data mining and analysis.

Fig. 2 - Toothed disc multi-row cotton-stalk uprooting device

1. Hydraulic oil tank; 2. Tractor; 3. Hydraulic proportional valves; 4. Non-flat toothed disc; 5. Hydraulic motor

The cotton stalk pulling device is suspended at the front end of the tractor through a parallelogram mechanism. The pump is driven from the tractor's PTO via a coupling. Each disc is driven by a separate hydraulic motor, for a total of 4 discs, capable of removing 4 rows of cotton stalks per operation. The rack width of the toothed discs type multi-row cotton stalk pulling device is 2400 mm, the toothed discs spacing is adjustable, and it can operate when the cotton stalk row spacing is greater than 500 mm.

Hydraulic transmission system design

In order to achieve adjustable speed ratio during operation, the gear-disc multi-row cotton stalk pulling stand adopts electro-hydraulic control, as shown in Figure 3. The motor drives the stalk pulling gear to rotate, and the tractor moves forward to realize the cotton stalk pulling operation function. The speed sensor can transmit the gear speed signal to the controller. The control system CPU combines the vehicle speed signal and feeds back the control signal to the PVG proportional valve according to the system setting. The PVG proportional valve system controls the motor speed according to the signal.

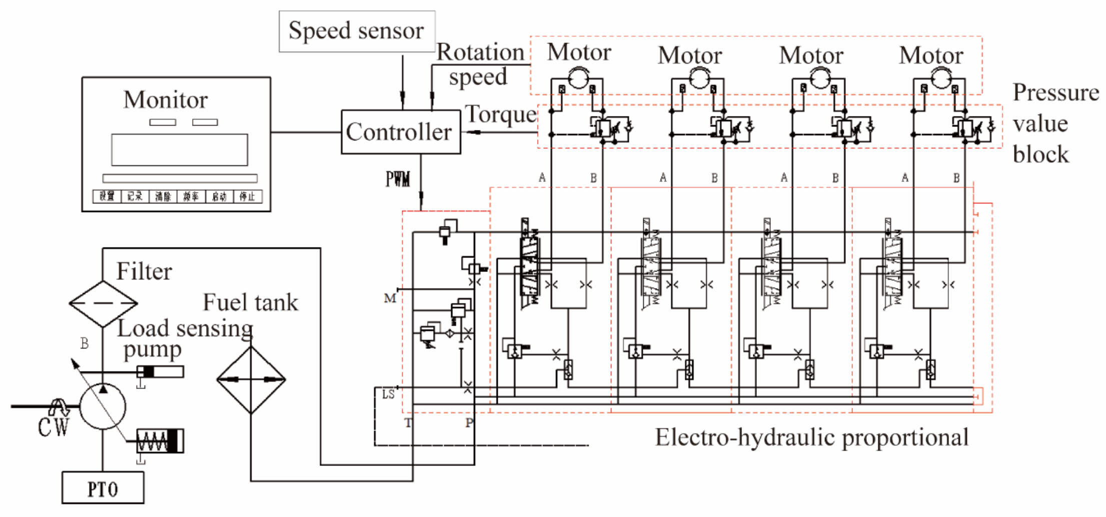

Fig. 3 – Diagram of electro-hydraulic control system

According to the electro-hydraulic control principle in Figure 3, the DANFOSS brand JR-L series load-sensitive pump, PVG16-4 proportional valve, OMP series hydraulic motor and speed sensor, HFBG-NN-0101 pressure measuring valve block, MC024-110 controller, and DP570 display were selected. The numerical range of the hydraulic motor and other modules was determined based on the stalk pulling torque.

According to the cotton stalk uprooting resistance, the stalk pulling torque of a single toothed discs is:

$$M = N \cdot L \tag{1}$$

where:

M is the pulling torque of a single toothed discs, N·m.

N is the pulling resistance of a single cotton stalk, the average value is 500 N, the max. value is 1000N.

L is the pulling arm length, 0.25 m.

The calculation shows that the average stalk pulling torque of a single toothed discs is 125 N·m, and the maximum is 250 N·m. Considering the 20% reserve torque, the maximum torque of a single toothed discs is 300 N·m. When the circumferential speed of the toothed discs ranges from 0 to 6 m/s, the theoretical speed is 0 to 229 r/min. Based on the above calculation results, the OMP 200 hydraulic motor and JR-L-S75C-LS load sensitive pump are selected.

Design and analysis of the elevation gear disc

The gear disc is an important component for clamping and pulling cotton stalks. Its main parameters are the gear disc diameter, tooth shape and tooth angle. The gear disc diameter not only affects its structural strength, but also affects the length of the cotton stalk pulling stroke. The tooth shape is designed as a "V"-shaped tooth groove. The V-shaped tooth groove has strong adaptability to the diameter and thickness of the cotton stalk and good pulling effect. The cotton planting patterns in Shandong Province, China mainly include 760 mm equal row spacing planting and wide and narrow row planting. The narrow row spacing is generally 500-600 mm. Considering the versatility of the test bench, the gear disc radius r is designed to be 250 mm. Too thin gear discs have insufficient strength, and too thick gear discs increase energy consumption and cost. The designed gear disc thickness is 5 mm. The diameter (root) of cotton stalks is mostly between 12 and 15 mm, and some are between 15 and 25 mm. The thinner the root, the easier it is to miss and break, and the thicker the root, the higher the removal rate. According to the geometric relationship in Figure 4, the V-shaped tooth groove must meet the following requirements when it can clamp the cotton stalk:

$$L_{\mathrm{BC}} \geq d_{max} \tag{2}$$

$$L_{\mathrm{AD}} \geq d_{max} \tag{3}$$

$$\angle \mathrm{BAC} = 2\angle \mathrm{BAD} = 2\tan^{-1}\frac{l_{BC}}{l_{AD}} \tag{4}$$

where:

L_{BC} - tooth width, mm; d_{max} - cotton stalk root diameter, taken as 25 mm.

L_{AD} - tooth depth, mm; ∠BAC - tooth angle, (°).

Increasing both the tooth width (L_{BC}) and tooth depth (L_{AD}) can enhance the adaptability of the non-flat toothed discs to cotton stalks of varying thicknesses. However, an increase in tooth width reduces the number of teeth, which may raise the probability of omission. Similarly, insufficient tooth depth (L_{AD}) can also increase the likelihood of omission. Based on Equations (2)~(4), when L_{BC} and d_{max} are both set to 25 mm and ∠BAC is set to 35°, the calculated tooth depth L_{AD} is 39.64 mm (>d_{max}), satisfying the required conditions. After rounding, L_{AD} is determined to be 40 mm. As shown in Figure 4, the toothed discs can meet the pulling out of cotton stalks with different root diameters. After the cotton stalks are pulled out, they fall down due to the loss of soil force on the root system. In order to enable the pulled cotton stalks to be smoothly separated from the toothed discs, an auxiliary separation component is designed. It is a curved component that can change the movement path of the cotton stalks so that the cotton stalks can be smoothly separated from the toothed discs.

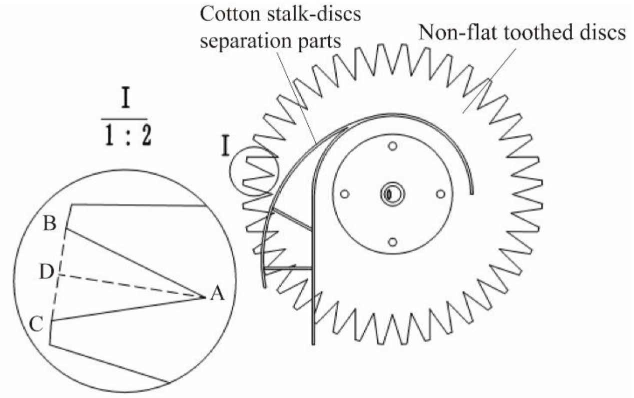

Fig. 4 – Non-flat toothed disc structure diagram

The clamping point (Point *O*, also the contact point) during stalk pulling was analyzed, as shown in Fig. 5. In traditional flat discs, the clamping point follows a trochoidal trajectory *(Chen Mingjiang et al., 2019)*. When discs are horizontally positioned (parallel to the ground), this trajectory becomes two-dimensional (parallel to the ground). Under these conditions, cotton stalks are typically pushed forward by the discs. This occurs because the clamping point lacks upward motion, eliminating vertical pulling forces. In order to optimize the trajectory of the clamping point, non-flat toothed discs were designed in this study. The objective of the design is to make the disc able to hold the cotton stalks firmly and to make the clamping point have an upward motion trajectory. The schematic structure of the non-flat toothed disc and its kinematic sketch are shown in Fig. 5.

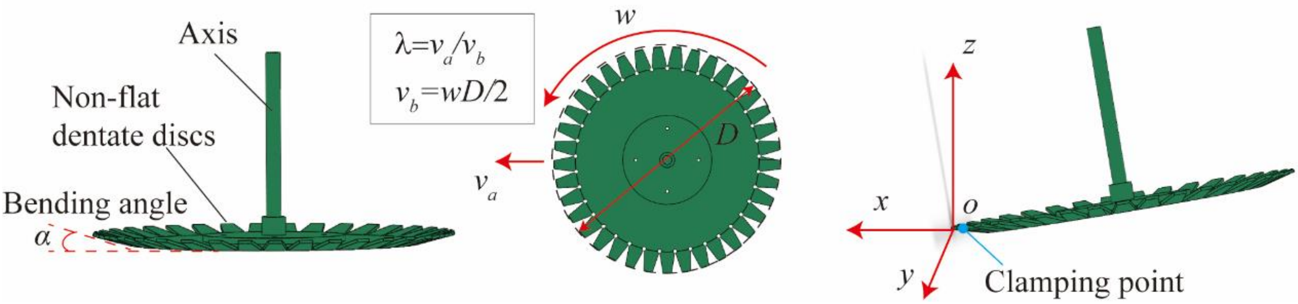

Fig. 5 - Non-flat toothed discs structural diagram and motion diagram

α is bending angle; λ is the ratio of the forward speed of the machine to the speed of the toothed disc, hereinafter referred to as the "speed ratio"; v_D is machine forward speed; w is angular speed of toothed discs; v_b is linear speed at clamping point; D is diameter of toothed discs.

To analyze the motion trajectory of clamping points on non-flat toothed discs and its impact on cotton stalk removal, ADAMS software was used for simulation. Under identical speed ratios, trajectories were simulated with varying disc diameters (D) and bending angles ($α$), as shown in Figure 6. Four parameter combinations were tested: D =500 mm, α=6°; D =500 mm, α=12°; D =600 mm, α=6°; D=600 mm, α=12°. It can be seen from Figure 6 that the overall movement trends of the trajectory curves of the four parameters are consistent, all of which are spiral lines. However, the curves do not overlap, indicating that both the toothed discs diameter D and the bending angle have an effect on the trajectory. On the whole, under the same bending angle conditions, the larger the diameter of the toothed discs, the larger the value of the curve in the z-axis direction, indicating a higher lifting height. Under the same gear disc diameter conditions, the larger the bending angle, the greater the lifting height.

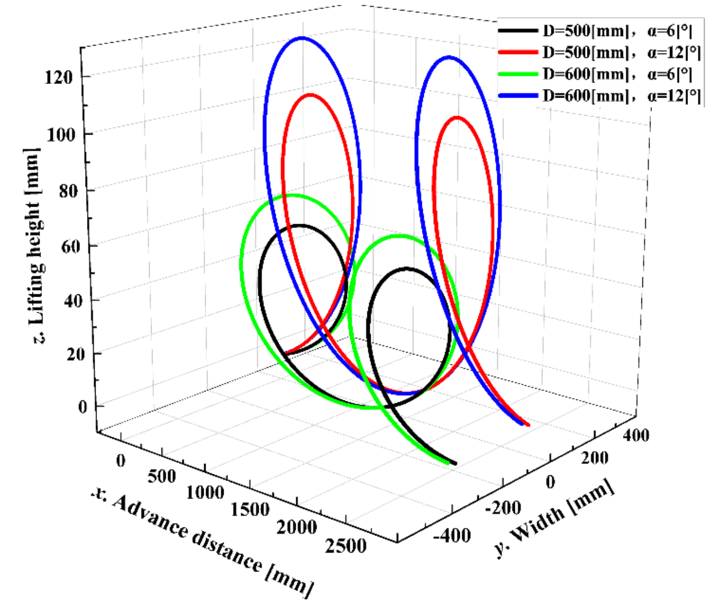

Fig. 6 - Motion trajectory of non-flat toothed discs

In order to further analyze the influence of the gear disc diameter and bending angle on the running trajectory, the x-y curve (Figure 7) and x-z curve (Figure 8) are drawn respectively. The x-y curve is used to analyze the variation of the gear disc working width, and the x-z curve is used to analyze the variation of the lifting height.

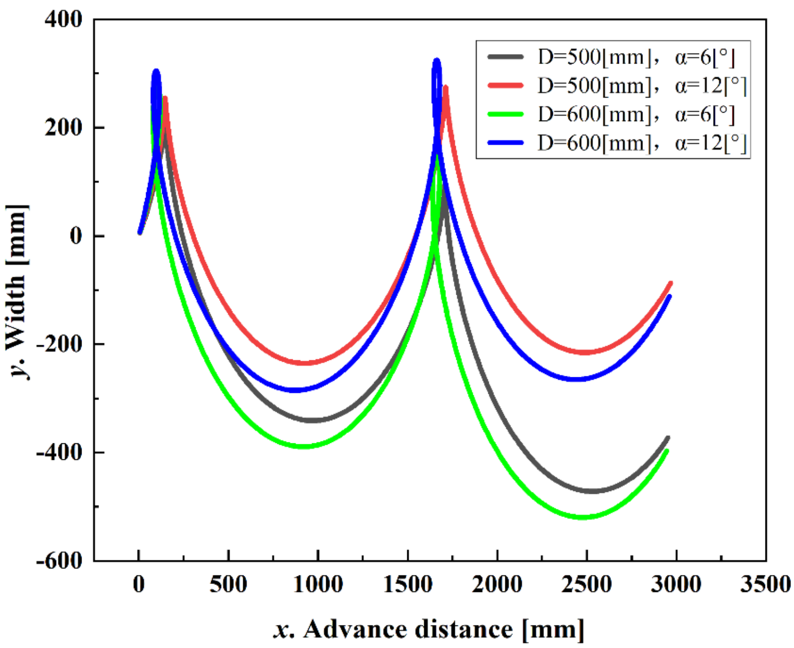

Fig. 7 - x-y curves

As can be seen from Figure 7, when the toothed discs diameters are the same (D=500 mm, D =600 mm), the toothed discs with a large bending angle (α=12°) have a small movement width, while the toothed discs with a small bending angle (α=6°) have a large movement width. The reason is that the large bending angle causes the projection diameter of the toothed discs on the horizontal plane to become smaller, so the movement width is reduced. A small movement width means a small effective working area, which easily increases the probability of missing cotton stalks. When the bending angle is the same, the movement width of the toothed discs with a diameter of 600 mm is greater than that of the toothed discs with a diameter of 500 mm. This shows that increasing the diameter of the toothed discs is an effective way to increase the movement width.

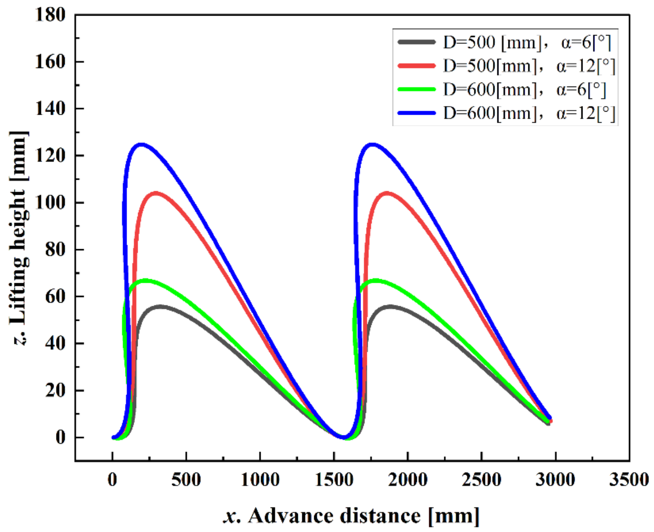

Fig. 8 - x-z curves

As can be seen from Figure 8, when the diameter of the toothed discs is the same, the toothed discs with a large bending angle has a larger lifting distance. This shows that under effective clamping conditions, the cotton stalk can be pulled to a higher height, which is conducive to the successful removal of the cotton stalk. At the same time, it can also be seen that increasing the bending angle (from 6° to 12°) produces a more obvious height increase than increasing the toothed discs diameter (from diameter = 500 mm to diameter = 600 mm).

Through the above research, it can be found that for non-planar toothed discs, the diameter and bending angle of the toothed discs have a greater impact on the movement width and lifting height. Therefore, this study selects three main influencing factors, namely, toothed discs diameter, bending angle and speed ratio, and studies the influence of each factor on the quality of cotton stalk removal through orthogonal experiments.

Experimental conditions

With the help of a self-made toothed discs type cotton stalk pulling test bench (*Chen Mingjiang et al., 2022*), all the tests were completed by replacing different toothed discs. The test site was the Binzhou Cotton Production Full Mechanization Agricultural Machinery and Agronomy Integration Demonstration Base in the National Agricultural Science and Technology Park of Binzhou City, Shandong Province. The test time was November 15-18, 2018, and the weather was cloudy. The cotton variety in the data collection area was Zhongmian 619, cultivated without film, with a planting row spacing of 760 mm, a plant spacing of about 200 mm, and a plant height of 900~1200 mm.

Experimental methods

The test was carried out with reference to GB/T8097-2008 "Test Methods for Harvesting Machinery Combine Harvesters" and DB37/T1856-2011 "General Technical Conditions for Toothed discs Type Cotton Stalk Pullers". Before the test, the toothed discs spacing was adjusted according to the cotton planting row spacing. The effective test length of each test was 30 m, and each group of tests was repeated 3 times. The experimental factors were toothed discs diameter, bending angle and speed ratio. The removal rate is the main test index for cotton stalk removal, and the non-removal rate mainly includes the breakage rate and the omission rate.

The calculation formula for the assessment index is shown below.

$$y_1 = \frac{N_1}{N} \times 100\% \tag{5}$$

$$y_2 = \frac{N_2}{N} \times 100\% \tag{6}$$

$$y_3 = \frac{N_3}{N} \times 100\% \tag{7}$$

$$y_1 + y_2 + y_3 = 100\% \tag{8}$$

In the formula, y_1, y_2 and y_3 are the removal rate, breakage rate and omission rate respectively; N_1, N_2 and N_3 are the number of cotton stalks successfully pulled, the number of cotton stalks broken and the number of cotton stalks missed respectively; N is the total number of cotton stalks, $N = N_1 + N_2 + N_3$.

RESULTS AND ANALYSIS

Based on the single factor test, the tooth disc diameter D, tooth disc inclination angle α and speed ratio λ were selected as influencing factors. The three different levels of factors were arranged according to the $L_9(3^4)$ orthogonal table for orthogonal test. The evaluation indicators were cotton stalk removal rate (y_1), breakage rate (y_2) and omission rate (y_3). Each group of experiments was repeated 3 times, and the experimental factor levels are shown in Table 2.

Table 1

Factors and levels

Levels	Toothed disc diameter, D [m]	Bending angle, α [°]	Speed ratio λ
1	0.5	0	0.5
2	0.6	10	0.7
3	0.7	20	0.9

The three-factor, three-level orthogonal test design scheme and results are shown in Table 2.

Table 2

Tests design scheme and results

No.	Factors			Response indicators		
	D	α	λ	Removal rate y_1 [%]	Breakage rate y_2 [%]	Omission rate y_3 [%]
1	1	1	1	83.31	4.73	11.96
2	1	2	2	90.89	3.95	5.16
3	1	3	3	92.31	6.05	1.64
4	2	1	2	93.69	1.11	5.20
5	2	2	3	95.06	1.43	3.51
6	2	3	1	93.24	5.41	1.35
7	3	1	3	76.74	13.52	9.74
8	3	2	1	82.82	2.30	14.88
9	3	3	2	89.71	2.94	7.35

The experimental results in Table 2 were subjected to range analysis using SPSS software. The range values characterize the relative influence weight of each factor on the evaluation metrics within the selected level ranges. Specifically, factors with larger ranges demonstrate stronger impact weights on the evaluation indicators under their respective level selections, as summarized in Table 3.

Table 3

Orthogonal test range analysis results

Parameters	y_1 [%]			y_2 [%]			y_3 [%]		
	D	α	λ	D	α	λ	D	α	λ
k_1	88.83	84.58	86.45	4.91	6.45	4.15	6.25	8.97	9.40
k_2	94.0	89.59	91.43	2.65	2.56	2.67	3.35	7.85	5.90
k_3	83.09	91.75	88.04	6.25	4.80	7.00	10.66	3.45	4.96
R	10.91	7.17	4.98	3.60	3.89	4.33	7.31	5.52	4.44
Factors of priority	D>α>λ			λ>α>D			D>α>λ		
Optimal parameter combination	D2α3λ2			λ2α2 D2			D2α3λ3		

Note: k_1~k_3 refer to the mean values of each factor at its respective levels, %; R refers to range, %.

As shown in Table 3, the primary-secondary order of factors influencing cotton stalk removal rate was D > α > λ, while their influence on breakage rate followed the sequence λ > α > D, and the impact order on omission rate was D > α > λ. With removal rate serving as the primary evaluation metric, the optimal parameter combination was determined as D2α3λ2.

In order to more intuitively show the influence of each factor level on the assessment indicators, Origin 9.0 is used to draw a horizontal indicator relationship diagram with the factor level as the horizontal axis and each assessment indicator as the vertical axis, as shown in Figure 9.

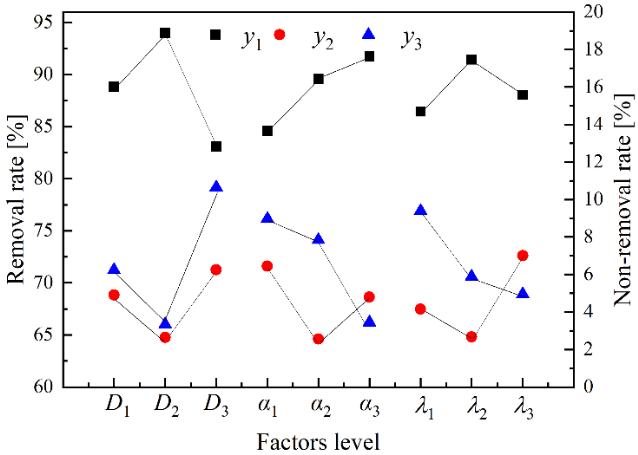

Fig. 9 – Relationship between each factor level and assessment index

An increase in both stalk breakage rate and omission rate directly reduces the removal rate; therefore, the removal rate was selected as the primary evaluation metric. When the removal rate is maximized, the optimal parameter combination is determined as D= 0.6 m, α =20°, and λ= 0.7, as shown in Table 3 and Figure 9. This parameter combination was used for a verification test, and the test was repeated 3 times to calculate the average value of the assessment index. The field environment and the non-flat toothed discs during the test is shown in Fig.10a, and the effect of cotton stalk uprooting is shown in Fig.10b. The test results show that under the $D2\alpha3\lambda2$ parameter combination, the cotton stalk removal rate is 95.7%, the breakage rate is 3.2%, and the omission rate is 1.1%. The test results show that the parameter combination is reasonable and can achieve a good stalk removal effect.

a. Non-flat dentate discs cotton stem uprooting device b. Scene after cotton stalks are removed

Fig. 10 - Cotton stalk removal test

CONCLUSIONS

(1) Based on the requirements and characteristics of cotton stalk uprooting operations, an optimized stalk removal device with non-flat toothed discs was designed. The key advantage of this device is that it imparts a significant upward motion trend to the cotton stalks during the removal process, thereby increasing the lifting height.

(2) ADAMS software was used to simulate and analyze the effects of three factors - disc diameter, bending angle, and speed ratio - on the motion trajectory of the gripping point, lifting height, and working width. The results show that the motion trajectory of the clamping point on the non-flat toothed discs follows a spiral pattern. Increasing the disc diameter helps improve the working width and reduce the omission rate, while increasing the bending angle is more effective than increasing the disc diameter for enhancing the lifting height.

(3) Following the orthogonal experiments carried out, an average cotton stalk removal rate of approx. 96% was obtained, using discs optimized in shape, dimensions and rotation speed. Thus, by using this type of discs, the performance of the cotton stalk removal device can be significantly improved.

ACKNOWLEDGEMENT

This study was supported by the Project category: Autonomous Region Regional Collaborative Innovation Special Project (Science and Technology Aid Xinjiang Program) (2024E02007), and Key R&D Projects in Xinjiang Uygur Autonomous Region (2022293956).

REFERENCES

[1] Agwa, I.S., Omar, O.M., Tayeh, B.A., Abdelsalam, B.A. (2020). Effects of using rice straw and cotton stalk ashes on the properties of lightweight self-compacting concrete. *Constr. Build.* Mater. 235, 117541, https://doi:10.1016/j.conbuildmat.2019.117541.

[2] Chen M., Ping Y., Qu H., Chen Y. (2012). Status and development countermeasures of mechanized cotton-stalk harvesting technologies and equipment (棉秆机械化收获技术与装备现状及发展对策). Chinese *Agricultural Mechanization*, 23–26. Nanjing/China

[3] Chen M., Zhao W., Wang Z., Liu K, Chen Y, Hu Z. (2019). Operation process analysis and parameter optimization of toothed disc cotton-stalk uprooting mechanism (齿盘式多行拔棉秆装置拔秆过程分析与参数优化). *Transactions of the Chinese Society for Agricultural Machinery*, 50, 109–120.Nanjing/China

[4] Chen M. (2022). Research on the key technology of toothed disc cotton-stalk uprooting machine (齿盘式棉秆拔除机具关键技术研究). *Chinese Academy of Agricultural Sciences*, Beijing/China

[5] Cai J., Zhang J., Yeerbolati·T., Gao Z, Rui Z, Liu X. (2020). Design and test of clamping belt cotton straw harvester (夹持带式棉秆收获机设计与试验). *Transactions of the Chinese Society for Agricultural Machinery*, 51, 152–160.Wulumuqi/China

[6] Fernando Correa Da Costa, Av.; Cuiaba, M., (2010) Evaluation of cotton stalks destroyers. J. Soil Sci, Agric, Eng. *Mansoura Univ*, 1, 1061–1073.

[7] He X., Liu J., Xu Y., Wang L, Gao Y, Wang X. (2020). Improvement design of 4mb-6 row-controlled shoveling and drawing placement machine for cotton-stalks in close planting (4MB-6 型密植棉秆对行铲拔铺放机改进设计). *Transactions of the Chinese Society for Agricultural Machinery*, 51, 21–30. Beijing/China

[8] Jiang, P., Li, Y., Li, J., Meng, H., Peng, X., Zhang, B., He, J., Kan, Z. (2021). Experimental Research on the Bending and Fracture Characteristics of Cotton Stalk. *Trans. ASABE*. 64, 1771–1779, https://doi:10.13031/trans.14589.

[9] Keshav, P.K., Banoth, C., Kethavath, S.N., Bhukya, B. (2023). Lignocellulosic ethanol production from cotton stalk: an overview on pretreatment, saccharification and fermentation methods for improved bioconversion process. *Biomass Convers*. Biorefin. 13, 4477–4493, https://doi:10.1007/s13399-021-01468-z.

[10] Liu F., Tian C., Lu X., Han W., Zhang Y., Ye S. (2019). Effect of cotton straw returning planting model on the growth and pest and disease occurrence at the cotton seedling stage along the Yangtze River in Anhui province (安徽省沿江地区棉秆还田种植模式对棉花苗期生长及病虫害发生的影响). *China cotton*. 46, 20–22. Anhui/China.

[11] Ma J., Jian S., Zhou H., (2010). Design of zigzag disk harvester of cotton stem (齿盘式棉花秸秆整株拔取收获机的研究设计). *Agricultural Equipment & Vehicle Engineering*, 3–5, 12. Shandong/China

[12] Nguyen, T.T.; Bailleres, H.; Redman, A.; Leggate, W.; Vandi, L.; Heiztmann, M. (2020). Homogenous particleboard made from whole cotton (*gossypium hirsutum l*.) stalk agricultural waste: optimisation of particle size and influence of cotton residue on performance. *BioResources*, 15, 7730–7748, https://doi:10.15376/biores.15.4.7730-7748.

[13] Pan, Z.G. (2014). Research on cotton stalk harvester based on double roller type. *Adv. Mater. Res.,* 945–949, 286–289, https://doi:10.4028/www.scientific.net/AMR.945-949.286.

[14] Ramadan, Y.Y.R. (2010). Development and evaluation of a cotton stalks puller. *J. Soil Sci. Agric. Eng*., 1, 1061–1073, https://doi:10.21608/jssae.2010.75470.

[15] Tang Z., Han Z., Gan B., Bao C. Hao F. (2010). Design and experiment on cotton stalk pulling head with regardless of row (不对行棉秆拔取收获台设计与试验). *Transactions of the Chinese Society for Agricultural Machinery*, 41, 80–85. Beijing/China

[16] Wang X., Jian S., Ma J., Yu X. (2011). The simulation design and movement analysis of toothed disc cotton stalk pulling machine (齿盘式拔棉秆机的仿真设计与运动分析). *Agricultural Equipment & Vehicle Engineering*, 5–7. Shandong/China

[17] Wang F., Shi Y., Wang W., Ma X., Zhang J., Guo Z., Song R., Li X., Dong D., Wang Y., Ma X. (2022). Analysis of the utilization prospect and technology of cotton straw in feed (棉花秸秆饲料化前景与技术分析). *China cotton*, 49, 37–41, https://doi:org10.11963/cc20220164 Zhengzhou/China

[18] Xie J., Wu S., Cao S., Zhang Y., Zhao W., Zhou J. (2023). Design and test of clamping-roller cotton stalk pulling device (夹持辊式棉秆拔取装置设计与试验). *Transactions of the Chinese Society for Agricultural Machinery*, 54, 101–111. Urumqi /China

[19] Zhao, W., Chen, M., Xie, J., Cao S., Wu A., Wang Z. (2023). Discrete element modeling and physical experiment research on the biomechanical properties of cotton stalk. *Computers and Electronics in Agriculture*, 204, 107502, https://doi:10.1016/j.compag.2022.107502.

[20] Zhao W., Xie J., Chen M., Gao Q., Cao S., Wang Z., Chen Y. (2024). Design and experiments of the clamping and uprooting device with adjustable stiffness for cotton stalk (变刚度夹拔式棉秆整株拔取装置设计与试验). *Transactions of the Chinese Society of Agricultural Engineering,* 40, 35–45. Urumqi/China

[21] Zhang A., Liu K., Wang Z., Liu Y., Wang H. (2016). Design and trial on cotton stalk pulling head with multi- roller (多辊式棉秆收获台的研究与试验). *journal of agricultural mechanization research*, 38, 91–95, https://doi:10.13427/j.cnki.njyi.2016.03.019. Shandong /China

[22] Zhao, W., Xie, J., Wang, Z., Gao Q., Chen M. (2022). Investigation of mechanical properties of cotton stalk based on multi-component analyses. *Int. Agrophys*., 36, 257–267, https://doi:10.31545/intagr/152488.