Design and test of a wheel-belt type cotton stalk puller

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Abstract: During the harvesting process, rigid materials are prone to causing damage to the cotton stalks, which will increase the risk of stalk breakage. A cotton stalk pulling component that blends stiff and flexible materials was devised to lower the breaking rate. The cotton stalk pulling component was made up of rollers and flexible belts that pull the stalks using clamping force and the forward speed of the tractor. The influence of various factors in the equipment on the harvesting effect of cotton stalks were analyzed through response surface experiments, and a multiple quadratic regression response surface model with missing pulling rate and breakage rate as response values was established. The significant of influencing factors on the breaking rate of cotton stalks are in a descending order as: the angle of cotton stalk pulling, tractor's forward speed, and the clamping speed of the cotton stalk component. The working parameters of the wheel-belt type cotton stalk pulling machine have been optimized using the response surface combination experimental method, and the optimal parameter combination was obtained as: tractor forward speed of 4.5 km/h, cotton stalk pulling angle of 60°, and clamping speed of the cotton stalk pulling component of 349 r/min. The results of validation experiments showed that the missing pulling rate of cotton stalks was 5.06% and the breakage rate was 13.12%, indicating a good harvesting effect of the cotton stalks. The model was reasonable and the performance parameters could meet the relevant inspection requirements. The results can provide a reference for further research on the technology of flexible cotton stalk pulling.

Keywords: cotton stalk puller, wheeled belt, flexible cotton stalks pulling, verification testing
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1 Introduction

With the precise development of agriculture, there have been many requirements for cotton stalk harvest. First, in the context of shortage of solid waste resources, the paper industry has been impacted by solid waste bans[1]. Therefore, the resource utilization of cotton stalks is increasingly valued, and there is a requirement for whole-stalk harvest. In addition, whole-stalk harvest of cotton stalks is needed to prevent the re-emergence of diseases and pests present in the root system. Diseases and pests spread quickly, and leaving the root system in the field can cause diseases and pests to occur again in the same field[2-4]. Furthermore, in order to promote the further development of the cotton industry towards a precision and intensive production mode, it is necessary to enhance the economic value of cotton stalk by-products (such as activated carbon, feed, and panel materials), and improve the efficient utilization, intensification, and circular use of cotton stalk resources[5-12]. Additionally, in order to prevent pollution and reduce the impact of remaining root residue on film recovery, there is an urgent need to develop whole-stalk cotton stalk pulling equipment[13,14].

Typical cotton stalk picking machines abroad include AMADAS harvesters in the United States and MUTI harvesters in Australia, mainly using roller-type cotton stalk harvesting. The stripping component of the harvester consists of tires or rubber rollers with a roller motion. These two harvesters are suitable for large single-row planting patterns, but not for the planting pattern of machine-harvested cotton in Xinjiang. The planting pattern of machine-harvested cotton in Xinjiang is a wide-narrow row pattern (with a wide row spacing of 660 mm and a narrow row spacing of 100 mm)[15].

As shown in Figure 1, domestic cotton stalk harvesting methods can be specifically divided into four categories: shovel-cutting stalk harvester, clamping stalk harvester, reciprocating shear stalk harvester, and crushing up-throwing stalk harvester[16-18]. The classic domestic models include the 4MC-6 roller gripper harvester, the chain stalk pulling harvester manufactured by Jiangsu Dongtai Snares Agricultural Machinery Factory, and the toothed disk cotton stalk harvester developed by Nanjing Agricultural Mechanization Research Institute of the Ministry of Agriculture and Rural Affairs (MAARI), in which the pulling parts are made of rigid materials[19,20]. However, rigid materials are prone to causing damage to cotton stalks, leading to breakage and high pull-off rates. In order to reduce the pull-off rate, a stalk-pulling component using a combination of flexible and rigid materials was designed in this study. The pulling component consists of a roller and a flexible belt,

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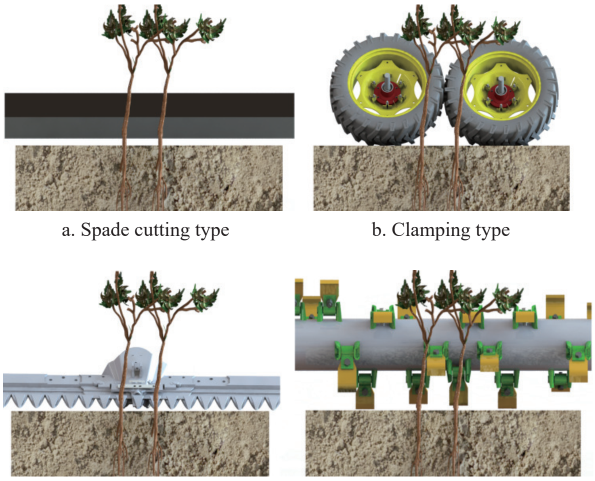
which pulls the cotton stalks by the clamping force and the forward speed of the tractor. The aim of this paper is to investigate the mechanism and mechanism of flexible cotton stalk pulling with a view to adding a new stalk pulling method to the existing cotton stalk harvesting technology. This will provide references and comparisons for the subsequent research and improvement of cotton stalks whole stalk harvesting implements.



a. Spade cutting type b. Clamping type

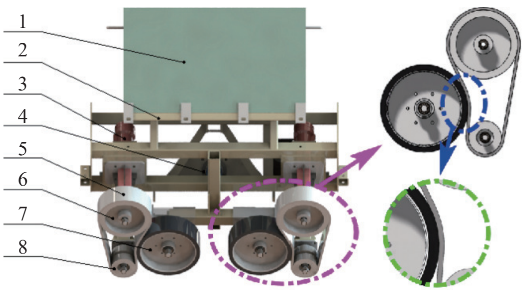
c. Reciprocating shear d. Crushing up throwing type

Figure 1 Domestic cotton stalk harvester classification diagram

2 General structure and work principle

2.1 Overall structure

As shown in Figure 2, the wheel and belt stalk puller mainly consists of a hydraulic drive system, a splitter, and a wheel and belt stalk pulling device. It is connected to the tractor by a rear-mounted three-point suspension. The machine is suitable for wide and narrow row planting mode, and the number of rows of operation is two monopolies and four rows.



1. hydraulic oil tank 2. frame 3. hydraulic motor 4. power input shaft head 5. flexible belt 6. wheel 1 7. roller 8. wheel 2

Figure 2 Structure design schematic

2.2 Working principle

As shown in Figure 3, the cotton planting pattern in Xinjiang is wide and narrow row planting. The wheel and belt stalk puller relies on a three-point suspension device, which is attached to the rear of the tractor. The three-point suspension device can adjust the angle formed by the stalk pulling parts and the ground. The stalk puller is driven by the tractor. The rear power output shaft of the tractor is connected to the head of the power input shaft of the implement through a rotating shaft and universal joint. The power of the tractor is transmitted to the gear pump through V-belt pulley 1, V-belt and V-belt pulley 2. The gear pump drives the hydraulic motor to rotate. The hydraulic motor drives wheel 1 to rotate. Wheel 1 drives the flexible belt to move. The flexible leather drives the roller movement through friction. The throttle valve and relief valve in the hydraulic system regulate the rotation speed of wheel 1. After the cotton stalks are collected by the grain splitter, they are pulled out of the ground and thrown to the back of the machine under the forward power of the wheel and belt stalk pulling parts and the machine. It was observed through the field test that under different combinations of the three factors of tractor forward speed, angle of pulling cotton stalks and speed of clamping movement of cotton stalks pulling parts, the cotton stalks were pulled out obliquely to the back. That is, the cotton stalks were subjected to a backward pulling force.

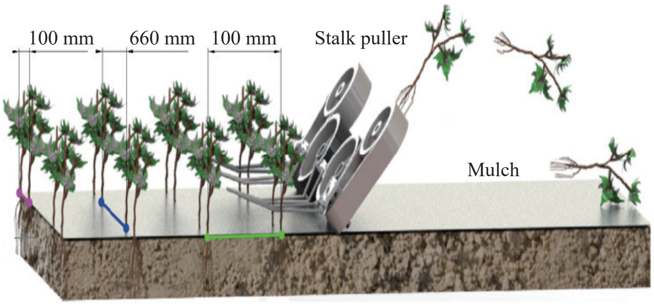


Figure 3 Working principle diagram

2.3 Main technical specifications

As shown in Table 1, the working width of the wheel-belt stalk puller was designed to be 1021 mm according to the wide and narrow row planting pattern of cotton in Xinjiang. The operational productivity of the stalk puller was calculated, and the main technical parameters were obtained. The main working parameters of the wheel-belt stalk puller are listed in Table 1.

Table 1 Working parameters of stalk harvester

Items	Working parameters/model
Machine size/mm×mm×mm	1232 × 992 × 1350
Operating width/mm	1021
Driving form	Rear-mounted power output shaft with hydraulic drive
Hanging and connection form	Rear-mounted three-point suspension
Number of working row	Two monopolies and 4 rows
Cotton stalk breaking rate/%	≤ 10
Cotton stalk leakage rate/%	≤ 10

Theoretical productivity of the stalk puller:

$$W = 0.1Bv, \tag{1}$$

where, W is the theoretical productivity, hm^2/h; B is the construction width of the unit, m; v is the theoretical speed of the unit, km/h.

The working width of the stalk puller is 1021 mm, and the theoretical forward speed of the unit is 2.5-4.5 km/h. The theoretical productivity is calculated according to Equation (1) to be about 0.26-0.46 hm^2/h [16].

3 Key mechanism design

The wheel-belt stalk puller works in cotton fields by collecting and straightening the stalks through a splitter and feeding them into the wheel-belt stalk pulling mechanism. The gripping angle of the stalk puller holds the stalks so that the rollers and flexible belt can hold them steadily. The stalks are pulled out of the ground by the forward pull of the tractor and the gripping force of the stalk puller. The cotton stalks are conveyed by the direct force of the rollers and the indirect force of the flexible belt. In order to obtain better stalk pulling effect and reduce the leakage rate and breakage rate, the key mechanism is designed.

3.1 Hydraulic drive system design

As shown in Figure 4, the main components of the hydraulic transmission system are hydraulic oil tank, gear pump, belt, power input shaft head and hydraulic motor. Hydraulic transmission system through the tractor rear power output shaft drive gear pump, hydraulic oil in the action of the gear pump through the throttle valve to control the two parallel hydraulic motor rotation. The relief valve and throttle valve are used to control the motor speed. In order to make the hydraulic motor can work at the same time, and prevent the hydraulic motor to the return system pressure requirements are too high, the hydraulic motor is located in the circuit using parallel connection.

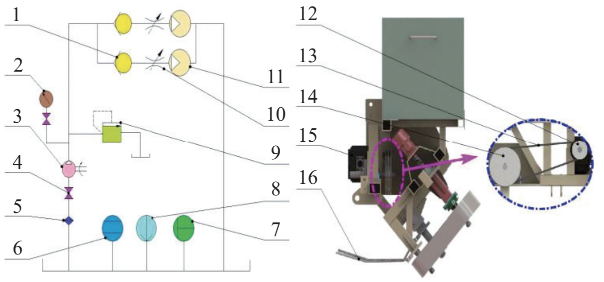


Figure 4 Hydraulic drive system schematic

The maximum speed of the motor is set above 450 r/min, and the motor model is BM2-100, where the motor displacement q = 100 mL/r, input flow Q = 58 mL/min, rotational speed n = 551 r/min, and torque T = 178 N·m.

Due to the parallel connection of hydraulic motor, in order to meet the needs of harvesting operation, the actual displacement of hydraulic pump V is selected as 200 mL/r, so the gear pump model JHP3200 is selected, and the rotational speed n_1 is 540 r/min, and the actual flow rate of gear pump q_1 is calculated as 91.8 L/min.

$$q_1 = \frac{Vn_1\eta}{1000} = \frac{200\times540\times0.85}{1000} = 91.8\ \mathrm{L/min}. \tag{2}$$

The tank volume is taken as 3 times the actual flow rate of the gear pump, i.e., V_1 is 290 L. The working parameters of each component of the pipeline are listed in Table 2.

Table 2 Hydraulic drive system operating parameters

Items	Working parameters/model
Motor displacement/mL·r^{-1}	100/BM2-100
Pump displacement/mL·r^{-1}	200/JHP3200
Fuel tank capacity/L	290
Inlet diameter/mm	12
Return pipe inner diameter/mm	18

3.2 Design of roller diameter

As shown in Figure 5, the cotton stalks are fed by the grain splitter to the gripping angle α of the wheel-belt stalk pulling mechanism[21]. The force analysis is performed by taking the moment when the cotton stalks just enter the gripping angle. Under the action of the grain splitter, the stalks come into contact with the roller and the flexible belt. The roller pulley generates a support force N and a gripping force T on the stalks. The conditions under which the stalks can be gripped by the pulley-belt mechanism are:

$$T_1 > N_1, \tag{3}$$

Therefore

$$T\cos\alpha > N\sin\alpha, \tag{4}$$

Since

$$T = \mu N, \tag{5}$$

where, μ is the gripping coefficient of the wheel and belt stalk pulling mechanism on the cotton stalks.

α is the initial gripping angle of the wheel-belt stalk-pulling mechanism on the cotton stalks.

Substituting Equation (5) into Equation (4) yields:

$$\mu = \tan\alpha. \tag{6}$$

From Equation (6), it can be known that the tangent value of the grasping angle α should be less than the grasping coefficient for the wheel and belt stalk pulling mechanism to grasp the cotton stalks and convey them inward.

To meet the condition that the wheel and belt stalk pulling mechanism can grasp the cotton stalks, there are:

$$\cos\alpha = \frac{\mathrm{OA}}{\mathrm{OB}} \approx \frac{D-d}{D} = \frac{1}{\sqrt{1+\tan^2\alpha}}, \tag{7}$$

where, D is the diameter of the roller, mm. d is the diameter of the cotton stalk, mm.

Equation (7) indicates that the larger the roller diameter D, the lower the initial grasping angle α of the stalks by the wheel and belt stalk pulling mechanism, and the more stable the stalks may be grabbed.

Equations (16) and (17) yield:

$$D = \frac{d}{1-\frac{1}{\sqrt{1+\tan^2\alpha}}}. \tag{8}$$

From the simplification of Equations (4) and (7) can be obtained:

$$D \geq \frac{d}{1-\frac{1}{\sqrt{1+\mu^2}}}. \tag{9}$$

Therefore, the diameter of the roller is designed to be 320 mm in this study.

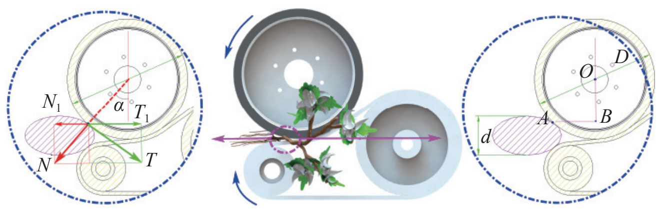


Figure 5 Force analysis of cotton stalks at the gripping angle

3.3 Cotton stalk pulling path length design

The length of the stalk pulling path has an important influence on the harvesting effect of cotton stalks. If the clamping and conveying path is too short, the stalks are not completely pulled out of the ground; if the clamping and conveying path is too long, the mechanism is unstable in clamping the stalks, which affects the smoothness and continuity of stalk pulling.

As shown in Figure 6, in order to determine the length of the path S of the stalk clamping movement of the wheel and belt stalk pulling mechanism, the direction of the movement of the stalk needs to be known first. To analyze velocity, it's necessary to consider the cotton stalk's state after being pulled from the ground:

$$\begin{cases} v_1 = \dfrac{2\times60\pi rn_2}{10^6} \\ v_3 = v_1\cos\theta \end{cases}, \tag{10}$$

where, v_1 is the speed of clamping motion of the culm pulling mechanism, km/h. v_3 is the horizontal fractional velocity of clamping motion speed, km/h. r is radius of the clamping and conveying path of the culm-pulling mechanism, mm.

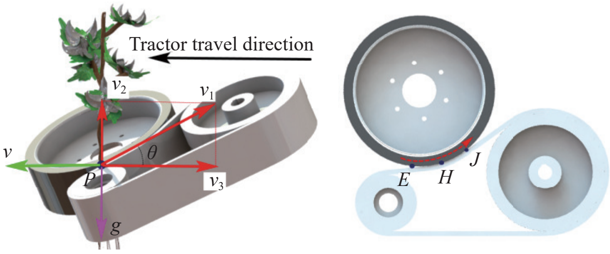


Figure 6 stalk speed analysis diagram

Among them, gravity g has little effect on the motion state of the cotton stalks, so the calculation of gravity g is ignored.

The roller speed n_2 of the wheel-belt stalk puller is 250-350 r/min and the pulling angle θ is 30°-60°. The horizontal partial speed v_3 of the clamping belt is greater than the forward speed v, so the cotton stalks will be pulled backward under the action of forward speed and clamping speed.

The horizontal combined velocity of the cotton stalk is

$$v_4 = v_3 - v \tag{11}$$

As shown in Figure 6, the path EHJ is the path S for the clamping movement of the stalks by the wheeled stalk pulling mechanism. The planting distance U before and after the stalks is 100 mm. The time required for the wheeled stalk pulling mechanism to finish the plant distance U is T_1, and the time required to pull out a stalk is T_2. To avoid congestion, T_1 is required to be less than or equal to T_2. Therefore:

$$T_1 \leq T_2, \tag{12}$$

Since

$$T_1 = \frac{U}{v}, \tag{13}$$

$$T_2 = \frac{S}{v_4}, \tag{14}$$

Then it is possible to obtain

$$S \geq \frac{Uv_4}{v}. \tag{15}$$

Therefore, the design of the culm pulling path S length in this paper is 168 mm.

3.4 Design of stalk pulling angle

As shown in Figure 7, the stalk pulling angle γ refers to the angle between the stalk pulling mechanism of the wheel and the ground. In order to find the optimum stalk pulling angle, the optimum stalk pulling angle was tested by the homemade pulling force test device, and it was concluded that the minimum force was needed to pull out the stalk when the angle β between the stalk and the ground was about 45°. The angle relationship between the forward speed and the clamping motion speed of the stalk pulling mechanism is analyzed to be the stalk pulling angle γ.

Using the cosine theorem, it is possible to determine:

$$\cos\gamma = \frac{v_1^2 + v^2 - v_h^2}{2vv_1}. \tag{16}$$

The sine theorem states that triangle ΔKMW has the following properties:

$$v_1 \sin(\beta - \gamma) = Z. \tag{17}$$

The triangle ΔKMW has the following:

$$v \sin\beta = Z. \tag{18}$$

Equations (16) and (17) yield:

$$\frac{v_1}{v} = \frac{\sin\beta}{\sin(\beta - \gamma)}, \tag{19}$$

where, v_h is clamping belt speed and forward speed of the combined speed, km/h.

From Equation (18), it can be seen that the clamping speed of the culm pulling mechanism is proportional to the angle of the horizontal plane, i.e., the angle of culm pulling γ and the angle of the combined speed β. In this paper, the culm pulling angle is designed as 40°.

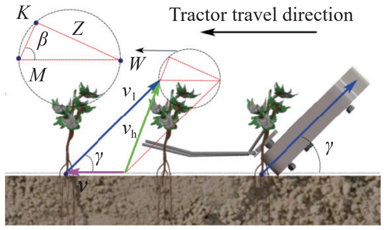


Figure 7 Schematic diagram of velocity angle relationship

4 Field trials and analysis

4.1 Basic test conditions

Experimental variety: Xinlu Early 45. The test site was the third team of Daxi Village, Yuli County, Korla City, Xinjiang Uygur Autonomous Region. Soil compactness of the test field: depth of entry 100 mm, mean value of compactness 3 MPa. Soil moisture content of the test field: depth of entry 50 mm, moisture content of 15%-20%. The average values of stalk height and root length were 750 mm and 200 mm respectively, and the average value of planting density was 30 plants/m^2. The test instruments and equipment were: wheel and belt stalk puller, Changfa CFD604A tractor (standard engine power 44.2 kW, power output shaft speed 540/760 r/min), QS-WT soil moisture temperature tester, TJSD-750-Ⅱ digital display soil compactness tester, and TJSD-750-Ⅱ digital display soil compactness tester. Ⅱ digital display soil compactness measuring instrument, leather ruler and tachometer, etc. The field test site of the wheel-belt cotton stalk puller is shown in Figure 8.


Figure 8 Field trial site of wheeled stalk puller

4.2 Test performance indicators and methods

Field trials were conducted to further determine the optimal combination of tractor forward speed, stalk pulling angle and clamping motion speed on the effect of stalk pulling.

The steps of the field test were: before entering the test area, a distance of 15 m was reserved to stabilize the working condition of the tractor and the culm pulling components to reduce the error; the length of the test area was set at 45 m, and the number of missed and broken culms was registered for 1 group of tests every 15 m, for a total of 3 groups; the working parameters were changed, and the previous steps were repeated and the data were recorded.

4.3 Evaluation index

The stalk leakage rate S_1 and plucking rate S_2 were used as the main indicators to evaluate the harvesting effect of the machine, and the data of each indicator were the average values of multiple trials.

$$\begin{cases} S_1 = \dfrac{Z_1}{Z} \times 100\% \\ S_2 = \dfrac{Z_2}{Z} \times 100\% \end{cases}, \tag{20}$$

where, Z_1 is the number of missed stalks per unit area; Z_2 is the number of broken stalks per unit area; Z is the total number of stalks per unit area.

In this paper, the tractor forward speed v, stalk pulling angle γ and stalk pulling mechanism clamping motion speed V_1 were selected as the test factors, labeled as A, B and C. The cotton stalk leakage rate S_1 and pulling break rate S_2 were used as the response values for the three-factor, three-level quadratic regression orthogonal test, as listed in Table 3.

Table 3 Experimental factor levels

Level	Forward speed/km·h^{-1}	Culm Pulling Angle/(°)	Clamping motion speed/r·min^{-1}
1	2.5	30	250
2	3.5	45	300
3	4.5	60	350

4.4 Results and analysis

4.4.1 Experimental results

The results of the three-factor, three-level test designed according to the Box-Behnken test principle are listed in Table 4.

Table 4 Experimental scheme and results

No.	Factors			Leakage rate S_1/%	Breakage rate S_2/%
	A	B	C		
1	3.5	45	300	6.02	15.56
2	2.5	30	300	5.9	15.01
3	3.5	60	250	5.12	16.9
4	3.5	45	300	12.9	15.95
5	4.5	45	350	6	21.13
6	4.5	30	300	8.59	20.66
7	2.5	45	250	5.92	19.2
8	3.5	60	350	5.81	13.7
9	3.5	45	300	7.49	14.9
10	4.5	45	250	7.3	21.25
11	3.5	30	350	5.9	19.04
12	3.5	30	250	6.3	18.72
13	2.5	60	300	6.31	14.32
14	4.5	60	300	7.25	15.34
15	3.5	45	300	12.7	20.96
16	3.5	45	300	9.31	17.58
17	2.5	45	350	8.42	24.68

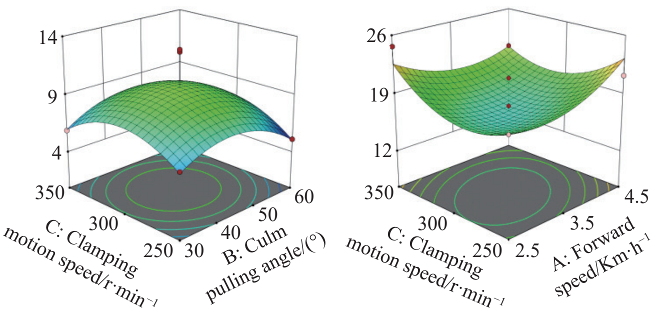
4.4.2 Regression modeling and significance testing

According to the ANOVA, the p values in Table 5 represent the significance levels of the factors. The significant ranking of the impact on the leakage rate of cotton stalks: the clamping speed of the cotton stalk component > the angle of the cotton stalk pulling > the forward speed. The significant ranking of the impact on the breaking rate of cotton stalks: the angle of the cotton stalk pulling > the forward speed > the clamping speed of the cotton stalk component.

Table 5 Analysis of variance of regression equations

Variance	Cotton stalk leakage rate S_1				Cotton stalk breakage rate S_2			
	Square and	Degree of freedom	F	P	Square and	Degree of freedom	F	P
Models	44.38	9	4.93	0.8489	0.6001	9	2.15	0.1622
A	0.8385	1	0.8385	0.1444	0.7153	1	0.5761	0.4726
B	0.605	1	0.605	0.1042	0.7563	1	3.74	0.0944
C	0.2775	1	0.2775	0.0478	0.8332	1	0.1326	0.7265
AB	0.7656	1	0.7656	0.1318	0.7273	1	0.924	0.3684
AC	3.61	1	3.61	0.6215	0.4564	1	1.35	0.2831
BC	0.297	1	0.297	0.0511	0.8276	1	0.5341	0.4886
A^2	2.51	1	2.51	0.432	0.532	1	2.64	0.1479
B^2	15.19	1	15.19	2.62	0.1499	1	4.78	0.065
C^2	16.88	1	16.88	2.91	0.1321	1	5.16	0.0573
Residuals	40.66	7	5.81			7		
Loss of proposed items	2.84	3	0.948	0.1003	0.9557	3	0.9601	0.4929
Error	37.82	4	9.45			4		
Total	85.04	16				16		

The p value of the interaction term BC of the cotton stalk leakage rate equation is about equal to 0.05, which indicates that the interaction term has a significant effect on the cotton stalk leakage rate, and the two factors B and C have an interaction effect; the p values of the interaction terms AB and AC are both greater than 0.05, which indicates that these two interaction terms do not have a significant effect on the cotton stalk leakage rate, as shown in Figure 9.



a. Leakage rate/% (3.5, B, C) b. Breakage rate/% (A, 45, C)

Figure 9 Response surface of the effect of interaction factors on the effect of culm pulling

4.5 Parameter optimization and validation

In order to make the wheel-belt stalk puller play a better harvesting performance, this paper uses the numerical optimization function module of the software Design-Expert to optimize the test factor parameters based on the experiment. The results of the software optimization were 4.5 km/h tractor forward speed, 60° stalk pulling angle, and 349 r/min stalk pulling component clamping motion speed, under which the wheel-belt stalk puller harvested the best results.

The optimization results obtained from the response surface analysis are a prediction and need to be verified by doing experiments. The validation test variety: Xinlu Early 45; location: Team 3, Daxi Village, Yuli County, Kullu City. The test factor parameters were set as forward speed 4.5 km/h, stalk pulling angle 60° and stalk pulling component clamping motion speed 350 r/min.

The validation effect is shown in Figure 10, and the validation test yielded a missed plucking rate of 5.06% and a plucking break rate of 13.12%. The harvesting effect is good.

a. Before operation b. Post-operation

Figure 10 Validation test effect

5 Discussion

(1) The four commonly used cotton stalk harvesting machine models in China are shovel-cutting type, clamping type, reciprocating cutting type, and shredding and throwing type. These machine models adopt a rigid harvesting method when harvesting cotton stalks. However, the compression of rigid components on cotton stalks can cause fiber separation and fracture, thus reducing the harvesting efficiency. To address this issue, a wheel-belt type cotton stalk harvesting machine has been designed, with key components being the roller and flexible belt. The flexible belt can alleviate the compression of rigid components on cotton stalks, reduce stress concentration, thus lowering the fracture rate and improving the overall harvesting efficiency. This design of wheel-belt type cotton stalk harvesting machine can effectively maintain the integrity of fibers and improve harvesting efficiency in the processing of cotton stalks. This is of great significance for the subsequent processing and utilization of cotton stalks.

(2) Through the wheel-belt design, the tension of the conveyor belt can be easily increased, thereby enhancing the gripping force between the belt and the rollers. This helps to stably pick up cotton stalks and improve harvesting efficiency. Compared to other harvesting machine types, the working principle of a wheel-belt cotton harvester is relatively simple and does not require excessively complex mechanical structures. This reduces the difficulty and cost in the production process, contributing to improved feasibility and economic viability of the equipment. The wheel-belt design enables the conveyor belt to grip the cotton stalks for a longer period of time. This extends the lifting path and duration of cotton stalks during the picking process, reducing incidents of missed picking. Therefore, the wheel-belt cotton harvester can effectively reduce the loss of cotton stalks during the harvesting process and improve the harvest yield. The gripping design of the belt and rollers can effectively alleviate congestion issues in the cotton harvesting process. When the cotton stalks are gripped, they can stay in the gripping area for a longer period, thereby reducing blockage and jamming of the mechanical structure, and improving the continuity and stability of the operation.

(3) The single location and single variety involved in the study may have limitations on the generalizability and applicability of the results. Here is a further explanation of these limitations:

Single Location: Conducting field experiments only at one location may lead to results being influenced by factors such as soil type, climate conditions, and agricultural management specific to that region. Different regions may have variations, making it difficult to directly generalize the experimental results to other areas.

Single Variety: Using only one variety for the study restricts the assessment of broad applicability across different varieties. Different cotton varieties have varying growth characteristics and stalk structures, which may affect the performance of the harvesting machine. Therefore, the feasibility of the research results on other varieties needs further validation.

To enhance the reliability and generalizability of future research, considerations should be given to factors such as experimental locations, varieties, agricultural management practices, and crop growth stages that may influence harvesting outcomes. This comprehensive evaluation will provide more valuable insights for practical applications.

6 Conclusions

(1) It is easy to damage cotton stalks when using rigid materials during harvesting, leading to excessive breakage of cotton stalks. In order to reduce the breakage rate, a cotton stalk pulling component composed of flexible and rigid materials is designed. The component consists of rollers and flexible belts, which use clamping force and the forward speed of the tractor to pull and remove the cotton stalks.

(2) The effects of various factors of the machinery on the harvesting effect of cotton stalks were studied and analyzed through response surface experiment, and a multivariate quadratic regression response surface model with the response values of missed pulling rate and breakage rate was established. When it comes to influencing the breaking rate of cotton stalks, the angle of cotton stalk pulling has the greatest impact, followed by the tractor’ s forward speed and the clamping speed of the cotton stalk component.

(3) The working parameters of the wheel belt type cotton stalk pulling machine were optimized using response surface combination test method, and the optimal parameters were determined to be a forward speed of 4.5 km/h, a pulling angle of 60°, and a clamping speed of the pulling component of 349 r/min. After verification experiments, the missed pulling rate of cotton stalks was 5.06% and the breakage rate was 13.12%, indicating a good harvesting effect of cotton stalks.

(4) The study had some limitations. Firstly, the field trials of the cotton stalk harvester were conducted in limited locations, only in Daxi Village, Yuli County, Korla City, Xinjiang Uygur Autonomous Region. Second, since soil hardness in Xinjiang fields varies in the north-south direction, this may lead to different effects of the same cotton stalk harvester tested on different fields. Obviously, this study has certain limitations, but it is believed that this study can provide a starting point for the development of flexible harvesting of cotton stalks.

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