DESIGN AND TESTING OF A SINGLE-ROW FRESH CORN PICKING MECHANISM
/
单行鲜食玉米摘穗机构的设计与试验

Bang JI [1,3,4], Yusong XIE [1], Long PAN [1], Zhukun WANG [1], Pu LI [*2], Xiushan WANG [*1,3]
[1] Hunan Agricultural University, College of Mechanical and Electrical Engineering, Changsha/China;
[2] Hunan Mechanical and Electrical Polytechnic, Changsha/China;
[3] State Key Laboratory of Agricultural Equipment Technology, Guangzhou /China
[4] Hunan Key Laboratory of Intelligent Agricultural Machinery and Equipment, Changsha/China.
Tel: +86 18711148341; Email: 494519721@qq.com
Corresponding author: 619741039@qq.com (Pu Li); 494519721@qq.com (Xiushan Wang)
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ABSTRACT
To address the challenges of low mechanization in harvesting and the high damage rate of fresh corn, this paper proposes a cutter-stalk pulling roller type tassel picking mechanism designed to achieve low-damage tassel picking and fresh corn harvesting. Using high-speed camera technology and pressure testing, a kinematic analysis of the tassel picking process was conducted. A three-factor, three-level orthogonal experimental design was employed to systematically investigate the effects of forward speed, stalk-pulling roller rotational speed, and cutter clearance on operational quality. The results showed that the picker maintained the force at the bottom of the corn cob below 35 N, effectively reducing mechanical damage. Under the conditions of a forward speed of 0.40 m/s, stalk-pulling roller speed of 420 r/min, and cutter clearance of 34 mm, the cob damage rate was 0.05%, and the impurity rate was 0.62%. These findings provide a valuable basis for the optimization and further improvement of single-row fresh corn cob picking cutters.

摘要
针对鲜食玉米机械化采收程度不高且损伤率高的问题，本文设计了一款切刀－拉茎辊式摘穗机构，旨在实现对鲜食玉米低损伤摘穗收获。基于高速摄像技术和压力测试试验对摘穗过程进行运动学解析，采用三因素三水平正交试验设计，系统探究前进速度、拉茎辊转速和切刀间隙对作业质量的影响。试验结果表明：该摘穗机能够使玉米果穗底端受力控制在 35N 以下，能够有效减少机械损伤。当前进速度 0.4m/s、拉茎辊转速 420 r/min、切刀间隙 34mm，此时果穗损伤率为 0.05%，含杂率为 0.62%，研究结果可为单行鲜食玉米摘穗割台的优化改进提供依据与参考。

INTRODUCTION
Fresh corn was harvested during the milk-ripe stage for direct consumption. They can be divided into four categories: waxy corn, sweet corn, sweet waxy corn, and bamboo shoot corn *(Shi et al., 2022)*. However, fresh corn has high moisture content and brittle stalks during harvest. This leads to problems in mechanical harvesting, such as a high ear damage rate and a high impurity rate *(Zhou et al., 2024; Zhang et al., 2021)*.

In 2014, Zhang Zhilong et al. introduced a novel approach to corn ear picking with comb teeth and further explored the impact effect of the comb corn ear picking plate on corn ears, as well as the mechanical characteristics and movement of the ears when the mechanism acts on the ears *(Zhang et al., 2014; Zhang et al., 2020; Zhang et al., 2020)*. In 2015, Zhang Qiang et al. introduced a novel approach to bionic ear picking of corn and used ADAMS to simulate the ear-picking process of a new corn ear picking a plate and conducted experiments *(Zhang., 2015; Zhang et al., 2023)*. In 2020, Luo Huizhong verified through comparative tests that the flexible coupling structure could change the collision contact force parameters between the ear and the ear-picking part so as to reduce the damage caused by the collision between the corn ear and the ear-picking platform. In 2023, a fresh corn ear-picking plate with reverse bionic ear picking was proposed. This mechanism performs ear picking by applying deflection torque to the cob by pulling the stalk roller *(Luo et al., 2023; Luo et al., 2023)*. In 2023, Fu Qiankun et al. found that the fruit stalk changed from tensile fracture to bending fracture by applying force to the corn fruit stalk from different directions, which reduced the ear-picking force by more than 80% and significantly reduced the ear damage rate *(Fu et al., 2023)*.

In the same year, Qin Jiahao et al. verified the conclusion that a curved ear-picking plate can reduce mechanical damage to corn ears during ear-picking through simulation analysis and high-speed imaging *(Qin et al., 2020)*. In addition, Li et al, through the study of the corn ear-picking process, designed a shear-type Corn ear-picking plate that can reduce the loss and power consumption of corn ear-picking *(Li et al., 2023)*. Special corn ear harvesters mainly use a combination of a horizontal roller stalk-pulling roller and ear-picking plate and use conical small inclination angles to lengthen the stalk-pulling roller and an adaptive device for the ear-picking gap to achieve low-damage ear detachment *(Cui et al., 2019)*. These types of harvesters usually have the characteristics of a large size, high power, wide cutting width, large feed volume, and adjustable and equal machine chassis. For example, DRAGO in the United States has designed an ear-picking plate with a cushioning effect to effectively reduce collisions between corn ears and ear-picking mechanisms to reduce ear damage. The JOHN DEERE 700c series headers are equipped with hydraulic headers with adjustable working parameters to further reduce damage. The OXBO 3000 series headers feature conical cutter rollers, which reduce grain loss by reducing the impact acceleration of the ears and picking plates.

To solve the problems associated with small plots, a low degree of mechanized harvesting of fresh corn and a high damage rate during harvesting in hilly areas *(Su., 2021)*, a cutter-stalk-pulling roller ear-picking mechanism was designed. A high-speed camera was used to analyze the pressure on the corn plants during the ear-picking operation of the corn ear-picking plate. The feasibility of the cutting knife-stalk-pull roller-picking device was determined through a pressure test of the ear-picking plate. The parameters of the picking mechanism were optimized using three-factor and three-level orthogonal experiments.

MATERIALS AND METHODS

Morphological parameters of fresh corn

The test material was "Jin tian 13" corn, which has a high overall water content and significant brittleness in texture. Experimental protocols strictly followed GB/T 5262-2008 "General Provisions for Determination Methods of Experimental Conditions of Agricultural Machinery" *(Wang et al., 2024)*. The main measuring tools included rulers, tape measures, and vernier callipers.50 mature corn plants were randomly selected in the field using the five-point sampling method. The morphological characteristics of the fresh corn plants are shown in Table 1.

Table 1

Morphological characteristics of fresh corn plants

Parameter	Range [mm]	Mean [mm]
Height of the corn ear	530~890	737.72
Diameter of the bottom end of the corn ear	56.59~67	60.10
Diameter of the corn stalk	26.12~36.4	30.59
Length of the corn shank	32.19~63.33	48.19
Diameter of the corn shank	15.96~25.53	20.95

Structure and working principle of ear-picking machine

The stalk-pulling portion comprised a pair of stalk-pulling rollers arranged below the picking device and driven via the collection tank. The cob-picking device comprises a stalk-pulling part and a corn-picking part, and the overall structure is mounted at the front end of the cob-picking machinery. The stalk-pulling part consists of a pair of stalk-pulling rollers, which are arranged below the tassel-pulling device and driven by the tassel-pulling tank. The picking mechanism mainly consists of a picking plate and cutter, both of which are bolted to the frame on both sides of the stalk-pulling rollers.

The specific structure is shown in Fig. 1, and the main technical parameters of the fresh corn picker are listed in Table 2.

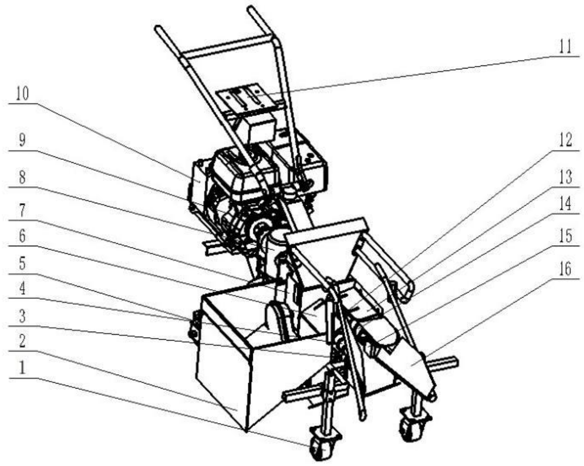

Fig. 1 – Schematic diagram of the single row fresh corn picking machine

1. Universal wheel; 2. Set spike tank; 3. Stalk cutting knife; 4. Lower stalk-pulling roller; 5. Track; 6. Left picking plate; 7. Collection tank 8. Speed tank; 9. Diesel engine; 10. Battery; 11. Operation desk; 12. Cutter; 13. Right picking plate; 14. Upper stalk-pulling roller; 15. Snapping rolls; 16. Grain separator

Table 2

Dimensional parameters of the whole machine

Parameter	Value
Overall dimensions	Length: 2150 mm, Width: 1350 mm
Minimum turning radius	0.8 m
Engine power	3.4 kW
Forward speed	0~2 km/h

The working process is illustrated in Fig. 2. During field operation, the front end of the tassel-picking machine advances along a row of fresh corn plants, guiding the stalks toward the machine's front end, where they are directed into the stalk-pulling roller gap by the snapping rolls. As the plants enter, the protruding structures on the surface of the stalk-pulling rollers drive the stalks backward into the upper picking plate gap, after which the lower portion of each stalk enters the roller gap. Here, the stalk is crushed in a way that avoids damaging the cob while reducing the tensile force required to break the stalk. The stalk rollers then continue pulling the stalk downward, while the cutter blocks the cob, enabling separation of the cob from the stalk. The detached cob subsequently falls through the lower side of the picking plate into the cob tank.

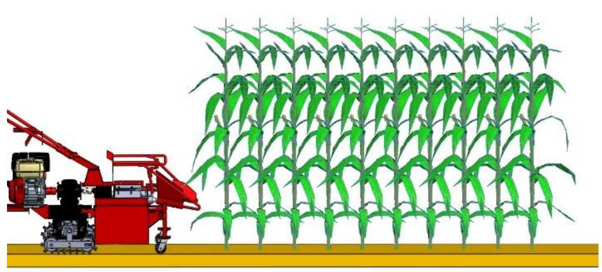

Fig. 2 – Working diagram of single row fresh corn picker

Design of functional components

The corn-ear-picking plate was the core component of the corn-ear-picking machine. Its primary function is to separate corn ears from plants directly. Therefore, its performance directly affects the overall operational performance of the corn ear-picking machine *(Zhu et al., 2023)*.

As shown in Fig. 3, a fresh corn ear-picking plate was designed to ensure ear integrity during mechanized harvesting. The mechanism consists of a cutter, an ear-picking plate, and upper and lower stalk-pulling rollers.

The ear-picking plate is positioned at a specific angle to work in coordination with the rollers, pulling the corn stalks downward. During the ear-picking process, the stalks tilt toward the side of the lower stalk-pulling roller, while the cutter severs the fruit stalk directly. This design prevents direct contact between the ear and the picking plate, thereby effectively achieving low-damage harvesting of fresh corn ears.

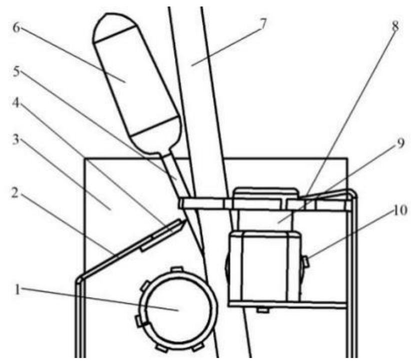

Fig. 3 – Working principle diagram of picking mechanism

1. Lower stalk pulling roller; 2. Left picking plate; 3. Collection Tank; 4. Cutter; 5. Shank; 6. Cob; 7. Corn stalk; 8. Right picking plate; 9. Pivoting wheel; 10. Upper stalk pulling roller

Test bench

In this study, a fresh corn ear-picking test bench was designed, and its structure is illustrated in Fig. 4. The test bench primarily comprises a mobile frame, a motor, an ear collection tank, a corn ear-picking plate, and a control system. The forward speed of the mobile frame was adjustable within the range of 0–5 m/s, with motor output regulated by an inverter. A separate three-phase motor, controlled by a frequency converter, provided a rotational speed of 0~450 rpm for the stalk-pulling roller. In addition, the gap of the corn ear-picking plate was adjustable to accommodate different test requirements.

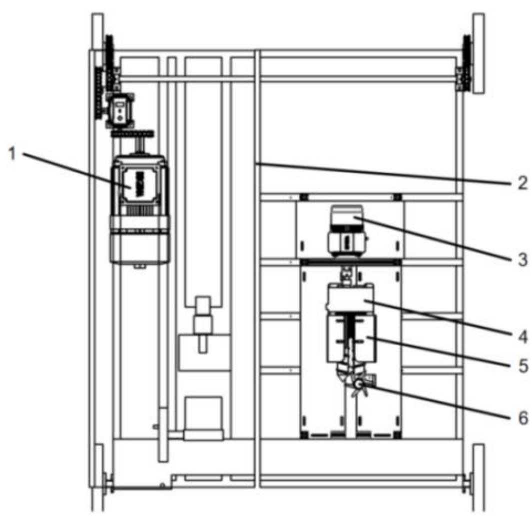

Fig. 4 – Schematic diagram of test stand structure

1. Motor 2. Frame 3. Auxiliary motor 4. Ear collection tank 5. Picking mechanism 6. Snapping rolls

High-speed camera

To explore whether the experimental device can achieve the expected effect, as illustrated in Fig 5, high-speed camera equipment was employed to record and analyze the working process of the corn ear-picking plate *(Li., 2023)*. The rotational speed of the stalk pulling roller (360, 390, 420, and 450 rpm) and cutting knife clearance (26, 28, 30, 32, and 34 mm) were used as variable factors for the single-factor tests. A control test without a cutter but with the same variable settings was also conducted. During the experiment, corn plants were manually fed individually, and each group of experiments was repeated twice.

Pressure test

To explore the impact of the corn ear-picking plate, as shown in Fig. 6, a thin-film pressure sensor was used to measure the force on the ear-picking plate during the ear-picking process with and without the installed cutter. A computer collected and recorded the pressure data in real-time. In the experiment, the rotational speed (390, 420, and 450 rpm), cutter installation gap, and ear-picking plate gap (28, 30, 32, and 34 mm) were used as factor variables. Each group of experiments involved feeding on a single corn plant, and the experiment was repeated twice. Finally, based on the recorded data, the pressure on the ear-picking plate was analyzed under different parameters.

Fig. 5 – Schematic layout of high-speed camera equipment

Fig. 6 – Schematic diagram of pressure test bench
1. Data display 2.FSR pressure sensor 3. Computer

Orthogonal experiment

The test was conducted in accordance with the national standard for corn harvesting machinery, GB/T 21962–2020 *(Li et al., 2024)*. During each trial on the test stand, five plants were fed into the mechanism. After operation, the harvested material was collected from the cob tank and the masses of corn stalks, leaves, other impurities, and damaged cob kernels, as well as the total mass of the harvested sample, were measured. The impurity content rate was calculated using formula (1), and the damage rate was calculated using formula (2).

$$H = \frac{m_2}{m_1} \times 100\% \tag{1}$$

$$Z = \frac{m_3}{m_1} \times 100\% \tag{2}$$

where:

H is the impurity content (%); Z is the damage rate (%); m_1 is the total mass of harvested material (g); m_2 is the total mass of impurities (g); m_3 is the damaged seed weight (g);

An orthogonal test method with three factors and three levels was used. The forward speed, cutter clearance, and stalk pulling roller speed were selected as the experimental factors, and the impurity content H and crushing rate Z were used as evaluation indices to conduct a three-factor, three-level, and two-index bench test. A, B, and C represent coded values for each factor in Table 3.

Table 3

Factor coding for orthogonal experiments

Level	Factor		
	A[m/s]	B[mm]	C[rpm]
1	0.2	30	390
2	0.3	32	420
3	0.4	34	450

Verification test

To verify the accuracy of the above-mentioned theory and experimental results, the optimal combination of structural parameters for the ear-picking mechanism was determined, and a verification test was conducted. The forward speed was set to 0.4m/s, the cutter clearance was 34 mm, and the rotational speed of the stalk-pulling roller was 420 rpm for the field test.

RESULTS

High-speed camera test

Tests were conducted under varying rotational speeds and cutter clearances. When the cutter clearance was set to 26 mm, the corn stalks were difficult to feed and frequently became clogged. As shown in Fig. 7, at a clearance of 28 mm, ears could be picked; however, they often became stuck between the ear-picking plates due to the narrow gap (Fig. 8). With a clearance of 34 mm, the contact position between the cutter and the fruit stalk shifted upward because of the increased gap, nearly reaching the base of the ear. Nevertheless, the larger end of the corn ear was not completely cut. In contrast, as illustrated in Fig. 9, most ear-picking devices without cutters directly contact the ear-picking plate, applying pressure. At a stalk-pulling roller speed of 360 rpm, direct ear-picking proved infeasible.

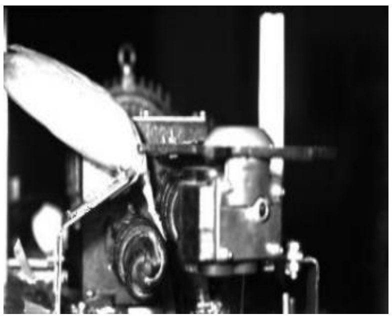

Fig. 7 – Fruit clogging diagram

Fig. 8 – Cutting position of the cutter

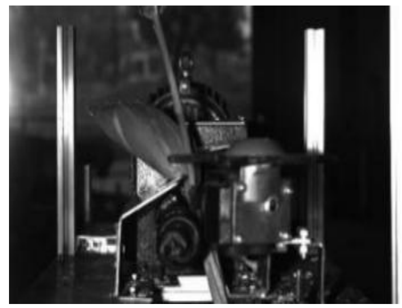

Fig. 9 – Force distribution on the cob in the absence of a cutter

The experiment indicated that, during the harvesting process, the fruit stalk was twisted off by the stalk-pulling roller, and the cutter under the ear-picking plate cut into the upper end of the fruit stalk, effectively preventing the fruit ear from being pulled down. The pressure points of the fruit ear were concentrated at the contact between the fruit stalk and the stalk pulling roller and the contact between the fruit stalk and the cutter, as shown in Fig.10.

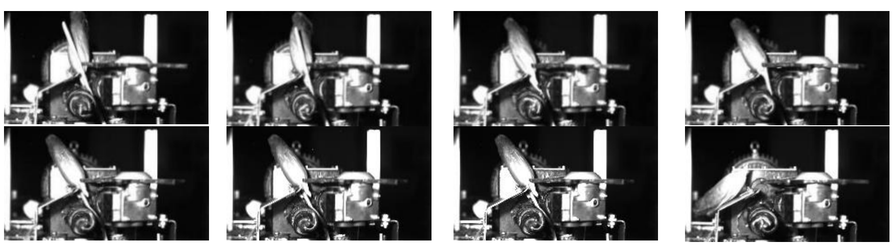

Fig. 10 – Corn picking flow chart

According to the high-speed camera analysis, when the installation gap of the cutting knife of the corn ear-picking plate was 30~34 mm, the ear-picking operation could be performed as expected. After the corn bracts were peeled off, no damage to the corn grains was observed. Moreover, the cutter could effectively prevent damage caused by direct contact between the large end of the corn ear and the ear-picking plate.

Pressure test

According to the final results, as shown in Fig.11, when no cutter was installed, the forces on the ear-picking plates were all greater than 30 N. The force change law was as follows: it increased with the increase in the stalk-pulling roller speed and first increased and then decreased with the increase in the ear-picking plate gap. However, the overall range of change was small, with the overall fluctuation range controlled within 5 N. At this time, the force on the ear-picking plate was generally higher than that when the cutter was installed. After installing the cutter, the force of the corn ear-picking plate was lower than 35 N, and the force first increased and then decreased slightly with an increase in the stalk-pulling roller speed. No ear damage was observed during this process.

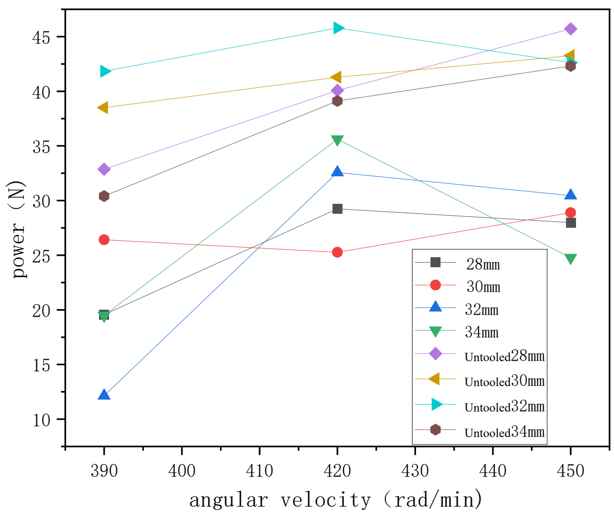

Fig. 11 - Force-speed line diagram

Thus, the reasonable value range for the cutter installation gap was 30~34 mm, and that for the stalk pulling roller speed was 390~450 rpm.

Analysis of Orthogonal Experiment Results

The designed orthogonal test is presented in Table 4. The impurity content and breakage rate of corn were used as evaluation indices and nine groups of tests were carried out. The impurity content ranged from 0.2% to 1.48%, and the breakage rate ranged from 0.02% to 0.2%. The test results were analyzed using SPSS. The primary and secondary factors affecting the impurity content were the cutter clearance, forward speed, and stalk-pulling roller speed, and the optimal combination was determined to be $A_1B_3C_3$. However, if this value is applied to actual work, the mechanical work efficiency will be too low. Therefore, after careful consideration, the best combination is $A_3B_3C_2$.

Table 4

Orthogonal experiments and results

Serial number		Test factors				H [%]	Z [%]
		A	B	C	D（Blank）		
1		1	1	1	1	1.2	0.13
2		1	2	2	2	0.67	0.05
3		1	3	3	3	0.2	0.02
4		2	1	2	3	1.34	0.14
5		2	2	3	1	0.88	0.1
6		2	3	1	2	0.65	0.06
7		3	1	3	2	1.48	0.2
8		3	2	1	3	1.21	0.14
9		3	3	2	1	0.6	0.05
Impurity content	Level 1	2.07	4.02	3.06	2.68		
	Level 2	2.87	2.76	2.61	2.8		
	Level 3	3.29	1.45	2.56	2.75		
	range	0.406	0.856	0.166	0.406		
	optimal combination	$A_1B_3C_3$					
	prioritize factors	B>A>C					

Serial number		Test factors				H [%]	Z [%]
		A	B	C	D（Blank）		
Kernel breakage rate	Level 1	0.2	0.47	0.33	0.28		
	Level 2	0.3	0.29	0.24	0.31		
	Level 3	0.39	0.13	0.32	0.3		
	range	0.0633	0.1133	0.0033	0.01		
	optimal combination	$A_1B_3C_3$					
	prioritize factors	B>A>C					

Note: H, Impurity content Z, Kernel breakage rate

From the analysis, it can be seen that the forward speed determines the feeding amount of the corn ear-picking plate. The larger the feeding amount, the greater the working pressure of the corn ear-picking plate, which is likely to cause multiple corn stalks to enter the gap of the stalk-pulling roller simultaneously, making it difficult to pick the corn ears smoothly and resulting in blockage. This blockage causes the corn ears to remain above the corn ear-picking plate for a long time, ultimately increasing the impurity and breakage rates.

The cutter clearance has a highly significant effect on both impurity and crushing rates. For the impurity rate, the larger the cutter installation clearance, the more favorable it is for the corn plant to be smoothly fed into the tassel picking mechanism for the corn stalk to pass through the stalk pulling roller gap, and ultimately to be crushed and returned to the field at the rear to reduce the impurity rate. For the crushing rate, within the range of the cutter installation gap, the larger the cutter installation gap, the smaller the possibility of clogging occurring when the cob-picking mechanism is working, and the more favorable it is for the corncobs to be smoothly stripped, thereby reducing the residence time of the cobs above the cob picking mechanism and lowering the probability of the cobs being damaged.

As can be seen from Table 5, the rotational speed of the stalk-pulling roller has a great influence on the impurity content. For a single-row fresh corn ear-picking plate, when the gap between the ear-picking plates and the forward speed is constant, the faster the rotation speed of the stalk-pulling roller, the lower the likelihood of blockage, and thus the lower the impurity content. However, the effect of the stalk-pulling roller speed on the ear breakage rate was insignificant. This is because the main causes of ear damage are excessive feed or a knife gap that is too small, which causes blockage, and contact between the large end of the ear and the cutter due to an unreasonable knife installation gap. The main function of the stalk-pulling roller is to provide force for picking the ears and pulling the corn stalks downward. As long as this basic requirement is met, its rotation speed has little impact on the change in the ear damage rate; therefore, it is not significant.

Table 5

Analysis of Variance results

Test indicators	Source of variation	Sum of Squares	Degrees of freedom	Mean square	F	P	Significance
Impurity content	A	0.256088	2	0.128044	105.7247	0.009369	**
	B	1.100955	2	0.550477	454.5229	0.002195	**
	C	0.050555	2	0.025277	20.87155	0.045721	*
	D(Blank)	0.002422	2	0.001211	1	0.5	
Kernel breakage rate	A	0.006022	2	0.003011	38.71428	0.025179	*
	B	0.019288	2	0.009644	124	0.008	**
	C	0.001622	2	0.000811	10.42857	0.0875	
	D(Blank)	0.000155	2	7.777E-05	1	0.5	

*Note: *indicates significant, **indicates highly significant.*

Verification test

The field results indicated that when the forward speed was 0.4 m/s, the cutter clearance was 34 mm, and the stalk-pulling roller speed was 420 rpm, the impurity content was 0.62%, and the ear damage rate was 0.05%, which were consistent with the expected values.

CONCLUSIONS

A corn tasseling test bench was developed, and a kinematic analysis of the tasseling process was conducted using high-speed camera technology and pressure testing to establish a reasonable range of operational parameters. The pressure test results indicated that the maximum contact force of the corn cob on the picking plate was 35 N, effectively reducing the impact force during cob picking.

An orthogonal test identified the optimal parameter combination as a forward speed of 0.40 m/s, a cutter clearance of 34 mm, and a stalk-pulling roller speed of 420 rpm. Under these conditions, the impurity content was 0.62% and the ear damage rate was 0.05%, both of which are below the thresholds specified by the national standard.

Overall, the single-row fresh corn ear-picking machine demonstrated the capability to complete harvesting in a single pass, achieving low-damage ear picking while enabling effective stalk return.

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