

Harvest Process Analysis and Damage Evaluation of Longitudinal Roller Type Corn Picker

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Aiming at the problem of corn cob damage during the operation of a longitudinal-lying roller corn harvester, based on the method of mechanical modelling, it was determined that the factors leading to cob damage are the diameter of the picking roller, the gap between the two picking rollers, the height of the helical prongs and the rotational speed, and that the main force leading to cob damage is the effect of the camming prongs on the cob. The influence of the main operating parameters on the camber force on the cob was revealed using a one- factor analysis, and the strengths and weaknesses of the influence of the gap and roller speed and camber height on the cob force were analysed using a two-factor orthogonal analysis. This study proposes a method for evaluating losses using the minimum breaking force of corn kernels and the cracking force of corn cobs and stalks as the criteria. The correctness of the loss model was verified by the method of experimental comparison, and the error of the two methods was 0.5%, which verifies the correctness of the evaluation method.

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INTRODUCTION

Corn is one of the most important food crops for human beings and also one of the main staple foods. The nutrients it contains, and its unique flavor have enabled it to be widely applied in the processing of by-products, the production of livestock feed, and biochemical processing fields, thus possessing extensive economic value. Due to the influence of terrain and climate, there are numerous corn varieties and diverse planting patterns, and the row spacing is not uniform. This makes it difficult for harvesters to adapt to the changes in corn traits and agronomy (Kong *et al.* 2021). If advanced models are directly used for corn harvesting, it is easy to cause problems such as high corn harvest loss values, poor stability, and poor adaptability. According to statistics, among the harvesting methods of corn ear harvesters, the header harvesting loss accounts for 75.3% of the total harvesting loss percentage, and among the harvesting methods of corn grain harvesters, the header harvesting loss accounts for 54.5% of the total harvesting loss. From this, it can be known that whether it is the ear harvesting method or the grain harvesting

method. The losses generated in the header section are the main components of the corn harvest losses.

In the early 1920s, countries in Europe, America, and others had already begun to develop equipment for corn planting, mid-term management, and mature harvesting. In 1921, the world's first corn combine harvester was independently designed, developed, and started to be manufactured. After that, in some relatively economically developed Western countries, corn combine harvesters began to be gradually accepted, manufactured, and used. The efficiency of agricultural production has been continuously improving. The United States and France successively designed and developed self-propelled corn harvesting equipment. Since then, some countries led by the United States have begun the research and development stage of the entire process of corn mechanized planting, harvesting, and post-processing. Harvesting technology and innovation have also entered a new stage of development. After years of continuous research and development progress, its technological level and R&D capabilities have gradually become increasingly mature (Saini *et al.* 2015; Ranum *et al.* 2014; Klopfenstein *et al.* 2013; Cook *et al.* 2014).

Horizontal roller structure is one of the main forms of ear picking mechanism of corn harvester cutting table both in China and abroad. The harvesting mechanism is that one or more pairs of ear picking rollers are installed on the cutting table of corn harvester. In the process of harvesting machine, each row of corn plants enters between the two rollers successively, and the rotating ear picking rollers pull the stalk downward, and the stalk of corn fruit is pulled off to achieve ear picking and harvesting. However, due to the direct contact between the high speed picking roller and the ear of corn, compared with the combined picking device of pulling stem roller and picking board, the vertical roller harvesting is more likely to cause ear gnawing, resulting in a higher ear injury rate (Geng *et al.* 2016; Cui *et al.* 2019; Fu *et al.* 2020; Zhang *et al.* 2023; Zhu *et al.* 2023)

Scholars in related fields mainly have conducted research on the mechanism of corn ear or grain loss through methods such as mechanical property tests, bench tests, field tests, and simulation analysis (Zhang *et al.* 2000; Tong *et al.* 2007; Gao *et al.* 2011; Du *et al.* 2012; Yang *et al.* 2016; Zhou *et al.* 2013; Chen *et al.* 2017; Geng *et al.* 2017). In response to the problem of ear picking and harvesting of corn with high moisture content, John Deere, as an established agricultural machinery manufacturer, has absorbed and drawn on the advanced technologies of corn ear harvesters at home and abroad, and developed the John Deere Y210 type corn ear combine harvester. This machine has a novel structural design, can complete multiple tasks at one time, and has a high working efficiency. The corn ear picking header designed by Cressoni Company in the United States adopts a combined longitudinal and radial cutting ear picking roller and ear picking plate for ear picking. The multiple radial tools distributed radially on the ear picking roller interact with the axial tools to cut the stems both axially and radially in a cross and continuous cutting manner, and pull the stems down at the same time, which has a strong crushing force. This design can increase the breaking speed of the stems, optimize the harvesting process, and reduce the vibration of the stems. Babić *et al.* (2013), respectively, measured the physical and mechanical properties of different kinds of corn grains, and confirmed that the compressive strength properties of grains decreased with the increase of water content Keller *et al.* (1972) determined by the Box-Behnken Design (BBD) response surface analysis method that the damage of corn grains under high-speed impact is related to grain water, grain shape and size, impact velocity, impact surface type and impact Angle (Keller *et al.* 1972). Volkovas *et al.* (2006) proposed a method for measuring Young's modulus of corn grains under impact load (Volkovas *et al.* 2006). Mahmoud *et al.* (1975) studied the influence of

the direction of ear feeding on grain breakage and the type and position of the force along the concave plate during threshing. Quaye *et al.* (1983) designed a corn threshing device and obtained the influence of device parameters on the working performance of the harvester through experimental research. Barać *et al.* (2012) indicated that operation speed, the size of the gap between picking plates, and their interaction significantly affected the loss percentage and the harvest quality of the maize picking device. X. Li *et al.* (2023) designed an automatic control system for corn grain direct harvesting with low loss to reduce the grain crushing rate, aiming at the problem that corn grain direct harvester could not adjust its working parameters independently during the harvesting process, resulting in high post-harvest grain crushing rate under extreme working conditions; this work provides a reference for the automated development of other crop production machinery. According to different water content, varieties, and force forms, X. Li *et al.* (2017, 2018) conducted experimental research on the fracture characteristics of corn seeds and stalks. Through the bionic threshing experiment of corn, the dispersion effect of chicken beak on the grain on the ear was analyzed, which guided the structural design of corn threshing device with low loss. From the perspective of power consumption, Geng *et al.* (2020) explored the influencing factors of broken stem rate, ear loss rate, and ear damage rate through a panel picking bench test (Geng *et al.* 2020). Yu *et al.* (2014) established a three-dimensional model of corn ear particles using discrete element method; they conducted simulation analysis of corn threshing process through self-developed simulation software (Yu *et al.* 2014). Liu *et al.* (2022) simulated and analyzed the interaction between corn stalk, divider and picking roller, and obtained the movement law of corn heading point.

Due to the high yield loss problem in the current roller-type corn harvester, scholars in related fields mainly have focused on improving the structure of the roller-type header and optimize its parameters through mechanical property tests, bench tests, and field tests. However, due to the complexity of corn planting patterns, varieties, and lack of experimental data for theoretical analysis, the research results are difficult to be widely applied. Therefore, it is urgently needed to conduct theoretical research on the interaction between the header and crops to systematically reveal the interaction laws between the header's fruit-picking device and the fruit spike, to providing theoretical reference for improving the design quality of the roller-type corn harvester header.

Mechanical Analysis of Corn Harvesting and Ear Removal Process

To analyze the damage mechanism of mechanical fruit harvesting, the force situation of the fruit during the process of horizontal roller fruit harvesting was analyzed, as shown in Fig. 1. Taking the fruit as the research object, if the fruit harvesting device can complete the fruit harvesting operation, then the resultant force F in the vertical direction on the fruit should be greater than the force of connection between the fruit and the fruit stalk or the connection between the fruit stalk and the stem, *i.e.* $F > F_g$.

Taking spike picking roll 1 as the research object, the diameter of spike picking roll 1 is D , the height of spiral convex edge is h , and the application point of the fruit spike on spiral convex edge can be simplified as the center of spiral convex edge, and its direction is along the tangential direction of the spike picking roll. Then,

$$F'_t \cdot \frac{D+h}{2} + F'_{m1} \cdot \frac{D}{2} = \frac{9549\Delta P_1}{n} \quad (1)$$

where F'_t is the force of the ear on the convex edge of the picking roller (N), F'_{m1} is the friction force of the ear on the picking roller 1 (N), D is the diameter of picking roller (m),

ΔP_1 is the picking roller 1 picking power consumption difference (kW), and n is the picking roller speed (r/min).

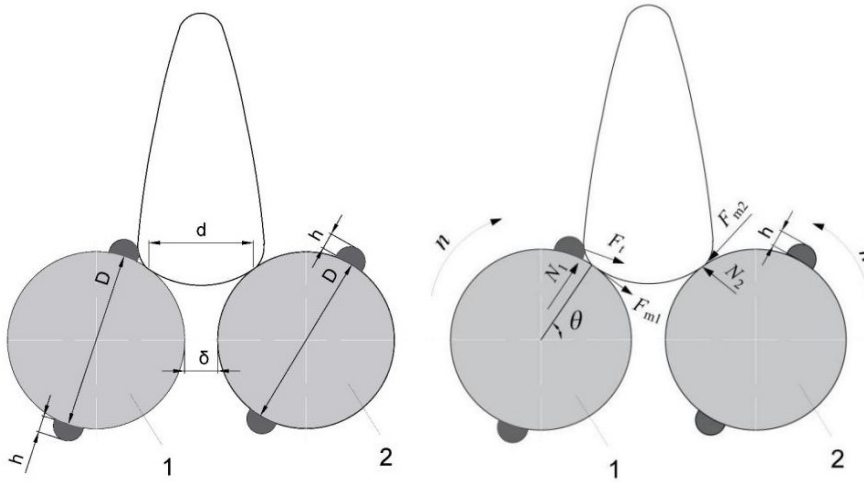


Fig. 1. Stress analysis of ear during ear picking

In the same way,

$$F'_{m2} \cdot \frac{D}{2} = \frac{9549 \times \Delta P_2}{n} \quad (2)$$

where F'_{m2} is the friction force of the ear on the picking roller 2 (N), D is the diameter of picking roller (m), ΔP_2 is the difference of power consumption in picking roller 2 (kW), and n is the picking roller speed (r/min).

Assuming that the sliding friction coefficient between ear picking roller and ear is f , then,

$$\begin{cases} F'_{m1} = N'_1 \cdot f \\ F'_{m2} = N'_2 \cdot f \end{cases} \quad (3)$$

According to the law of action and reaction force between picking roller and ear,

$$\begin{cases} F'_t = F_t \\ F'_{m1} = F_{m1} \\ F'_{m2} = F_{m2} \\ N'_1 = N_1 \\ N'_2 = N_2 \end{cases} \quad (4)$$

where F_t is the force of the convex edge of the picking roller on the ear (N), F_{m1} is the friction force of picker roller 1 on ear (N), F_{m2} is the friction force of picker roller 2 on ear (N), N_1 is the reaction force of ear on impact force of picking roller 1 (N), and N_2 is the reaction force of ear to impact force of picker roller 2 (N).

Taking corn ear as the research object, there are,

$$\begin{cases} N_1 \cos \theta + (F_t + F_{m1}) \sin \theta - N_2 \cos \theta - F_{m2} \sin \theta = 0 \\ N_1 \sin \theta - (F_t + F_{m1}) \cos \theta + N_2 \sin \theta - F_{m2} \cos \theta = F \end{cases} \quad (5)$$

where θ is the angle between the reaction force of the ear to the impact force of the picking roller and the horizontal direction ($^\circ$).

Based on the geometry, from Eqs. 1 through 5,

$$N_1 = \frac{19098 \left[\frac{\Delta P_2}{nfD} (\cos \theta + f \sin \theta) - \frac{\Delta P_1}{n(D+h)} \cdot \sin \theta \right]}{\cos \theta + \frac{fh}{D+h} \cdot \sin \theta}$$

$$N_2 = \frac{19098 \Delta P_2}{nfD}$$

$$F = \frac{19098(D+h) \cdot \left[\frac{\Delta P_2}{nfD} (\cos \theta + f \sin \theta) - \frac{\Delta P_1}{n(D+h)} \sin \theta \right] \cdot [2 \sin \theta + f(D-2) \cos \theta]}{2[(D+h) \cos \theta + fh \sin \theta]}$$

$$F_{m1} = \frac{19098f \left[\frac{\Delta P_2}{nfD} (\cos \theta + f \sin \theta) - \frac{\Delta P_1}{n(D+h)} \sin \theta \right]}{\cos \theta + \frac{fh}{D+h} \sin \theta}$$

$$F_{m2} = \frac{19098 \Delta P_2}{nD}$$

$$F_t = \frac{19098}{n(D+h)} \cdot \left[\Delta P_1 - \frac{\frac{\Delta P_2}{fD} (\cos \theta + f \sin \theta) - \frac{\Delta P_1}{D+h} \sin \theta}{\cos \theta + \frac{fh}{D+h} \sin \theta} \right]$$

Among them,

$$\cos \theta = \frac{\frac{D}{2} - \frac{d-\delta}{2}}{\frac{D}{2}} = \frac{D-d+\delta}{D} \quad (6)$$

Effect of Working Parameters on the Plucking Roller Flange and the Force of Ear

Effect of picking roller speed and picking roller convex edge on the force of ear

According to the design experience, the rotational speed of the picking roller of the current roller-type picking device generally varies within the range of 600 to 1200 r/min. In order to study the influence of the rotational speed of the picking roller on the damage of corn ears, the variation range of the rotational speed of the picking roller is taken as 600 to 1200 r/min, and the parameter variation interval is 100 r/min. The values of other parameters are shown in Table 1.

Table 1. Parameter Values

Parameter	Symbol	Data
Diameter of picking roller (m)	D	0.08
Height of convex edge of picker roll (m)	h	0.008
The sliding friction coefficient between picking roller and ear	f	1
Large end diameter of ear (m)	d	0.05
Gap between two picker rolls (m)	δ	0.015
The power consumption of two picker rolls during picking (kW)	ΔP	0.25

Based on the relationship between the force of the plucking roller edge on the ear and various parameters obtained by analysis, the data in Table 1 were input into Matlab software for calculation, and the changes of the force F_t of the plucking roller edge on the ear, the horizontal force F_{t1} and the vertical force F_{t2} along with the rotation speed n of the plucking roller were output, as shown in Fig. 2.

Under the above working conditions, when the rotation speed of the picking roller ranged from 600 to 1200r/min, the resultant force F_t of the picking roller rims on the ears decreased with the increase of the rotation speed of the picking roller, and the range was from 50 to 95N. The horizontal force F_{t1} of the plucking roller flange on the ears decreased with the increase of the rotation speed of the plucking roller, and its range was 43 to 83 N. The vertical force F_{t2} of the plucking roller on the ear decreased with the increase of the diameter of the main end of the ear, and its range was 23 to 48 N.

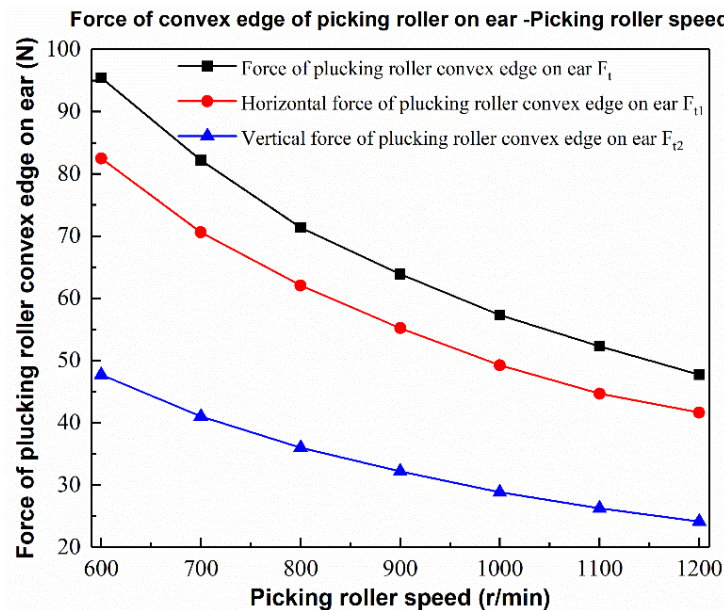


Fig. 2. The change of the force on the ear with the speed of the picking roller

Effect of the gap between two picker rolls on the convex edge of picker rolls and the force of fruit ears

The gap between pickers and rollers is an important adjustment parameter of pickers and an important parameter affecting the quality of pickers. In order to study the effect of gap δ between two plucking rollers on ear damage, δ range between two plucking rollers was taken to be 0.01 to 0.018m with a change interval of 0.001m. The values of other parameters are shown in Table 2.

Table 2. Parameter Values

Parameter	Symbol	Data
Picking roller speed (r/min)	n	900
Diameter of picking roller (m)	D	0.08
Height of convex edge of picker roll (m)	h	0.008
The sliding friction coefficient between picking roller and ear	f	1
Large end diameter of ear (m)	d	0.05
The power consumption of two picker rolls during picking (kW)	ΔP	0.25

Figure 3 shows that under the above working conditions, when the gap δ between two plucking rolls was 10 to 18mm, the resultant force F_t of plucking rolls' convex edges on the ears decreased with the increase of the rotation speed of the plucking rolls, and its range was 158 to 180N. The horizontal force F_{t1} of the head picking roller on the ears decreased with the increase of the speed of the head picking roller, and the force range was 133 to 162N. The vertical force F_{t2} of the plucking roller on the ear increased with the increase of the diameter of the big end of the ear, and its range was 78 to 83N. A greater the gap between the two pickers resulted in less damage to the ear, but in the process, the gap between the two rollers must be greater than the diameter of the stalk.

In summary, with the change of each parameter, the force of picking roller convex edge on fruit ears varies greatly. Before harvesting specific corn areas, the diameter of the big end of the fruit ear and the diameter of the corn stalk at the ear-setting point should be measured and counted. The loss of the operation can be predicted and evaluated according to the shape and structure parameters and matching parameters of the operation cutting table and the modeling method.

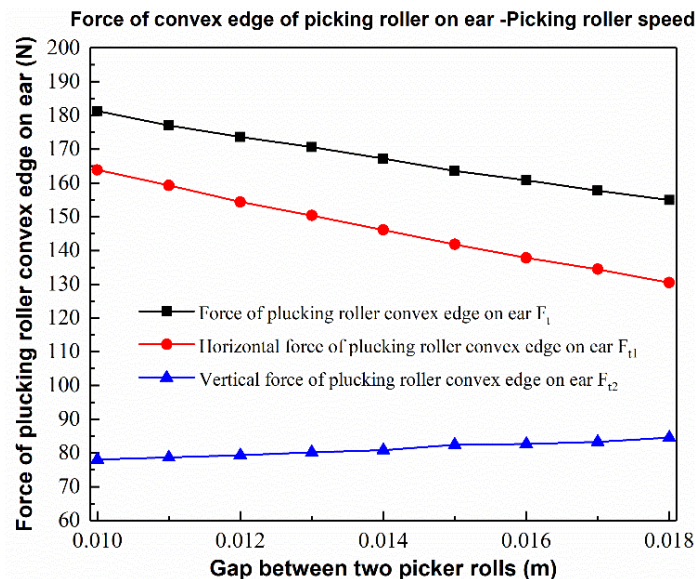


Fig. 3. The change of the force on the ear with the gap between the two picking rolls

Orthogonal Analysis of Interaction Force between Plucking Roller Rims and Ear by Working Parameters

Design-expert software was used to design the test scheme, and the central combination design method in the response surface design was selected. The speed of the picking roller and the gap between the picking rollers were taken as the analysis factors, and A was set as the speed of the picking roller and B was the gap between the two picking rollers. The values of fixed parameters are exhibited in Table 3. The factors of orthogonal analysis and their coding levels are shown in Table 4.

Table 3. Values of Fixed Parameters

Parameter	Symbol	Data
Diameter of picking roller (mm)	D	85
The sliding friction coefficient between picking roller and ear	f	1
Large end diameter of ear (m)	d	0.055
Height of convex edge of picker roll (mm)	h	8
The power consumption of two picker rolls during picking (kW)	ΔP	0.25

Table 4. Factors in Orthogonal Analysis

Analytical Sequence Number	Picking Roller Speed (r/min)	Gap between Two Picker Rolls (mm)
-1	600	8
-0.5	800	10
0	1000	12
0.5	1200	14
1	1400	16

Table 5. Results of Orthogonal Analysis

Analytical Sequence Number	Factor A	Factor B	F_t/N	F_{t1}/N	F_{t2}/N
1	600	8	175.25	156.76	78.35
2	600	10	169.47	149.53	79.75
3	600	12	164.06	142.63	81.07
4	600	14	158.99	136.03	82.3
5	600	16	154.2	129.67	83.45
6	800	8	131.44	117.57	58.76
7	800	10	127.1	112.15	59.81
8	800	12	123.05	106.97	60.80
9	800	14	119.24	102.02	61.72
10	800	16	115.65	97.25	62.59
11	1000	8	105.15	94.06	47.01
12	1000	10	101.68	89.72	47.85
13	1000	12	98.44	85.58	48.64
14	1000	14	95.39	81.62	49.38
15	1000	16	92.52	77.8	50.07
16	1200	8	87.63	78.38	39.17
17	1200	10	84.73	74.76	39.87
18	1200	12	82.03	71.32	40.53
19	1200	14	79.49	68.01	41.15
20	1200	16	77.1	64.84	41.73
21	1400	8	75.11	67.18	33.58
22	1400	10	72.63	64.08	34.18
23	1400	12	70.31	61.13	34.74
24	1400	14	68.14	58.3	35.27
25	1400	16	66.09	55.57	35.76

The orthogonal analysis results are shown in Table 5. The orthogonal analysis and design model combination analysis were carried out for the two factors of picking roll speed and picking roll gap respectively under the five encoding levels shown in the table. The results show that the contact force between the helical flange of picking roll and the ear varied between 34.18 N and 83.45 N.

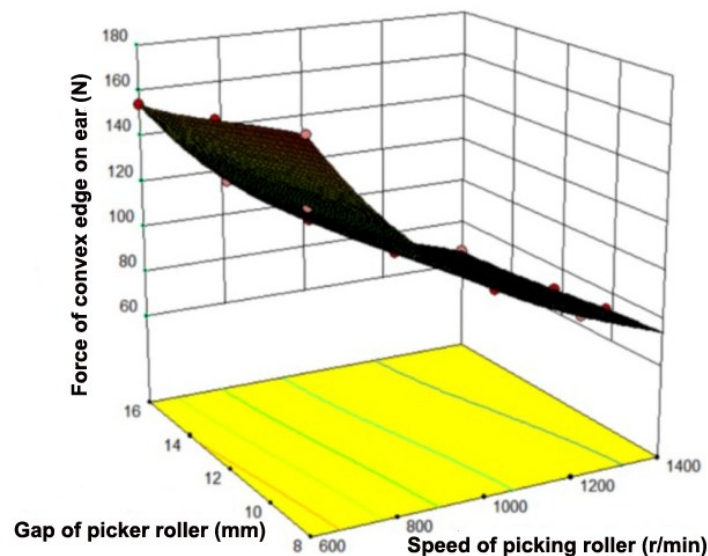
Based on the quadratic polynomial regression analysis of Table 5, the interaction force model between the plucking roller flange and the ear was established. The $p < 0.05$ and the coefficient of determination $R^2 = 0.7793$ of the interaction force model indicate that the regression model of the interaction force between convex edge and ear had good significance and fit, and the experimental error had little influence on the test results. The regression models of the interaction force between kyphotic edge and ear with insignificant items were removed. Figure 8 shows the response surface of the picking roller speed and the gap between two picking rollers to the ear and the convex edge of the picking roller.

$$F_t = -0.0006B^3 + 0.0005A^2 - 0.0782B^2 + 0.0063AB - 0.7754A - 6.9090B + 510.1767$$

$$F_{t1} = -0.0006B^3 + 0.0005A^2 + 0.0719B^2 + 0.0079AB - 0.7027A - 8.2840B + 470.4938$$

$$F_{t2} = 0.0002A^2 - 0.0149B^2 - 0.0015AB - 0.3294A + 1.6333B + 198.3783$$

As shown in Fig. 4a, when the gap between the threshing drum and the reaping head is fixed at a certain value, the force F_t exerted by the convex ridge on the grain head decreases gradually as the threshing drum speed increases from 600 to 1400 r/min. The change is more obvious. When the diameter of the threshing drum is fixed at a certain level, when the gap between the threshing drum and the reaping head is 8 to 16 mm, the force exerted by the convex ridge on the grain head decreases gradually as the gap increases. However, the overall trend is not obvious. By partial regression analysis, it can be concluded that the force F_t exerted by the convex ridge on the grain head decreases with the increase of both factors, but the influence of the threshing drum speed on the force is greater than that of the gap.



(a)

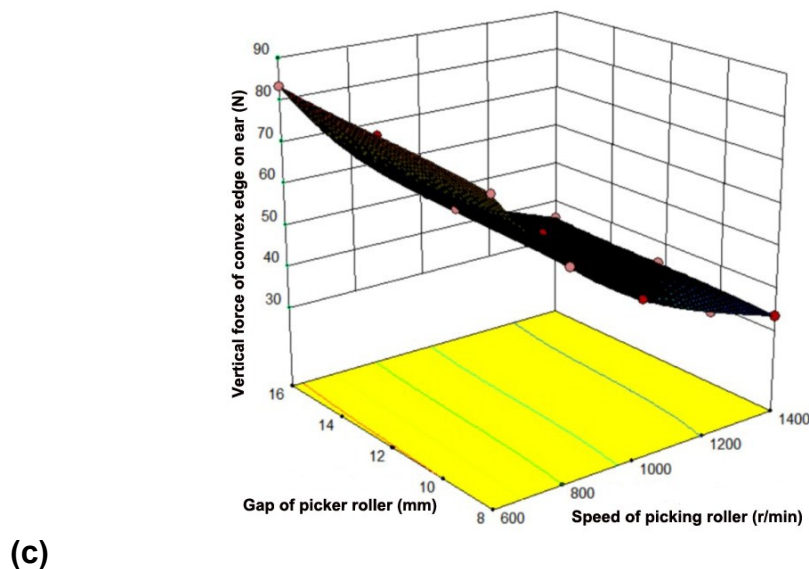
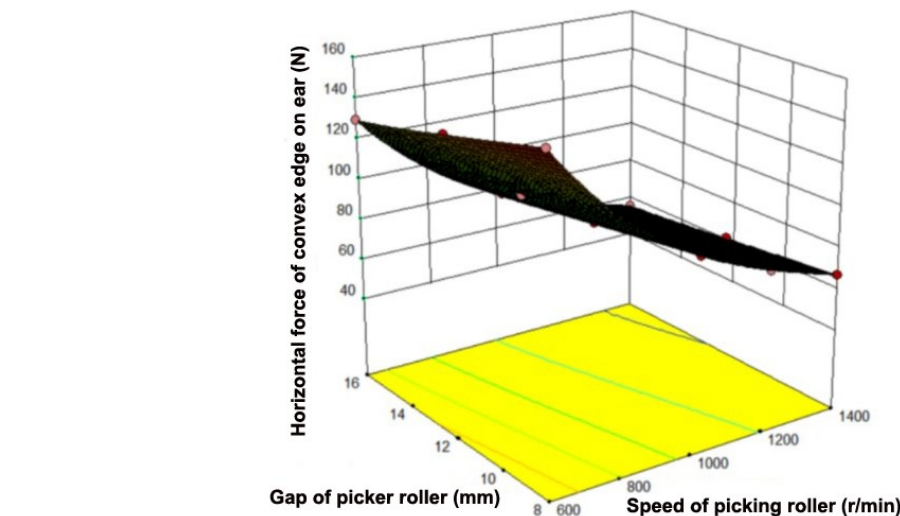


Fig. 4. Influence of picking roller diameter and picking roller flange height on the force (a) The effect of picking roll speed and picking roll gap on ear; (b) the effect of picking roll speed and picking roll gap on ear horizontally; (c) the effect of picking roll speed and picking roll gap on ear vertically

Figure 4b shows that when the gap of the snapping roller was fixed at a certain value, within the range of 600 to 1400 r/min of the rotational speed of the snapping roller, the horizontal component force F_{H1} of the convex edge on the ear gradually decreased with the increase of the rotational speed of the snapping roller, and the change range was relatively obvious. When the diameter of the snapping roller was fixed at a certain level, when the gap of the snapping roller was within the range of 8 to 16 mm, the force of the convex edge on the ear gradually decreased with the increase of the gap of the snapping roller, but the overall change trend was not obvious. Through partial regression analysis, it can be concluded that the force F_{H1} of the convex edge of the snapping roller on the ear decreased with the increase of both factors, but the influence of the rotational speed of the snapping roller on the force was greater than that of the gap of the snapping roller.

Figure 4c shows that when the gap of the snapping roller was fixed at a certain value, within the range of 600 to 1400 r/min of the rotational speed of the snapping roller, the vertical component force F_{t2} of the convex edge on the ear gradually decreased with the increase of the rotational speed of the snapping roller, and the change range was relatively obvious. When the diameter of the snapping roller was fixed at a certain level, when the gap of the snapping roller was within the range of 8 to 16 mm, the force of the convex edge on the ear gradually increased with the increase of the gap of the snapping roller, but the overall change trend is not obvious, and the increase amplitude is relatively slow. The partial regression analysis shows that the influence of the rotational speed of the snapping roller on the force was greater than that of the gap of the snapping roller.

Evaluation Method of Picking Injury with Horizontal Roller Cutting Table

The stress condition of the ear of corn is directly related to the structural parameters and operation parameters of the ear picking device of the corn cutting table. The main cause of corn kernel loss is the extrusion of the ear of corn by the spiral edge of the roller ear picking device. Therefore, it is of great significance to propose an evaluation method for evaluating the ear's harvest performance from the perspective of mechanics.

As shown Fig. 5, the force on the spiral convex edge of the corn ear during operation is F_t , the component of F_t in the horizontal direction is F_{t1} , and the component of F_t in the vertical direction is F_{t2} . If the F_{t1} value is greater than the breaking limit of the longitudinal pressure of the corn kernel stalk, or the F_{t2} value is greater than the sum of the tensile force of the bracts and the longitudinal bending pressure limit of the corn kernel stalk, the corn kernel can fall off.

According to the characteristics of corn growth, corn can be divided into five segments along its axis, including the first segment, the upper segment, the middle segment, the lower segment and the last segment. In the process of ear picking, the head of the ear of corn is directly in contact with the picking roller, which is the part of threshing loss, its length is about 12 to 24 mm, and the longitudinal length is about 3 to 5 grains.

If the grain is pressed sideways by the convex edge of the picking roller and threshed, it must meet the requirements.

$$F_{t1} \geq F_{10} + F_{11} + F_{12} + 3F_{23} \quad (7)$$

where F_{t1} is the horizontal component of helical rims on corn ears (N), F_{10} is the minimum threshing force of single grain under longitudinal unsupported compression (N), F_{11} is the minimum threshing force of single grain longitudinal single grain support (N), F_{12} is the minimum threshing force of two longitudinal double grain supports (N), and F_{23} is the minimum threshing force of 3-grain lateral 3-grain support (N).

If the grain is extruded lengthwise by the convex edge of the picking roller and threshed, it is necessary to overcome the buffering effect of the corn bracts first, stretch the corn bracts open, and then bend the corn grains laterally and longitudinally to threshed,

$$F_{t2} \geq F_p + F_{30} + F_{31} + F_{32} \quad (8)$$

where F_{t2} is the vertical component of corn ear subjected to spiral flange (N), F_p is the force required to tear the bracts with spiral rims (N), F_{30} is the minimum threshing force of single grain under longitudinal unsupported bending (N), F_{31} is the minimum threshing force of single grain longitudinal single grain support under bending (N), F_{32} is the minimum threshing force of single grain longitudinal double grain support under bending (N), and

F_{23} is the minimum threshing force of single grain under longitudinal three-grain support bending (N).

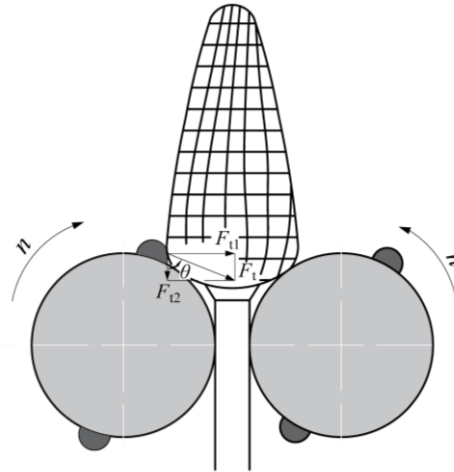


Fig. 5. Analysis of the force of plucking roller on the ear

According to previous studies, as a biological material with strong binding strength, corn bracts have certain particularity, especially in terms of mechanical properties, as shown in Fig. 6 (Hou *et al.* 2018; Xie *et al.* 2018). After field sampling, it was found that most of the outer bracts of corn ears had 7 layers, and the longitudinal tensile strength of corn bracts at harvest stage was about 12.49 MPa, so the breaking force of corn bracts should meet the following requirements,

$$F_b = \sigma \cdot S_t \quad (9)$$

where F_b is the greatest force a bract withstands at breaking (N), S_t is the contact area between bract and spiral rib (m^2), and σ is the longitudinal tensile strength of maize bracts at harvest (Pa).

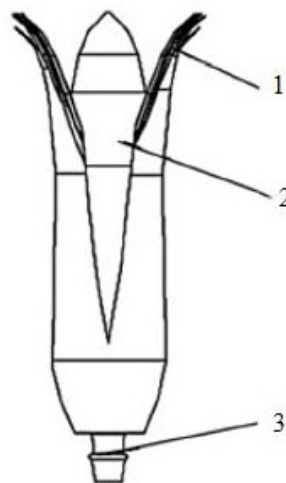


Fig. 6. Structure of an ear of corn: (1) bract, (2), fruit, and (3) stalk

The area at the bottom of the ear is related to the diameter of the ear, and the contact diameter is about 4 to 8 mm, then the contact area with the bracts is about 12.56 to 50.24 mm^2 , and the tensile force on the bracts is about 156.87 to 627.50 N.

Based on the above analyses, the helical flange lateral extrusion pressure F_{t1} and longitudinal bending force F_{t2} were subjected to the corn ear grains during the operation

process. When Eq. 7 is satisfied laterally or Eq. 8 is satisfied longitudinally, it can be considered that there is seed shedding.

Experimental Verification of Picking Damage Evaluation Method

Field trials

(1) Acquisition and statistics of maize physical parameters

To verify the feasibility of the evaluation method of ear harvest performance, a field case experiment was carried out. The field trial was conducted in Decheng District, Shandong Province, China, in October 2023. The corn variety used in the trial was Hongyu 168, and the planting row spacing was 572 mm. The corn plants in the test plot had relatively uniform growth, and there was no lodging. The ear of corn was at the mature stage and did not droop noticeably. The test method for corn harvesting machinery was measured according to GB/T 21961-2008 “Corn Harvesting Machinery Test Method,” and the diameter of the corn ear tip was measured. For each measurement location, 10 consecutive corn plants were selected for measurement. A total of four sets of data were recorded, and the distribution of the data is shown in Fig. 7.

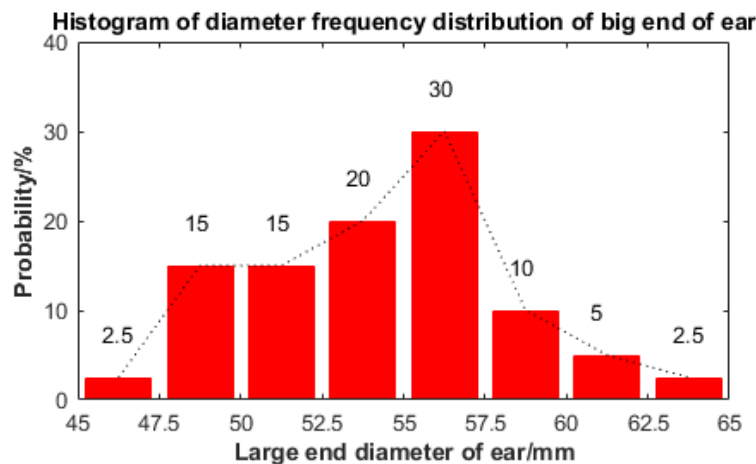


Fig. 7. Probability and statistics of the size distribution of corn plants measured in the field

(2) Field test and analysis of test results

This verification test uses a two-row horizontal roll cutting bench test bed, and its technical parameters and test operation parameters are shown in Table 6.

Table 6. Main Technical Parameters of Cutting Bench Test Bed

Project	Parameters
Supporting power (kW)	19.12
Weight (kg)	1220
Adaptive row spacing (mm)	450 to 700
Working lines	2
Diameter of picking roller (mm)	90
Height of convex edge of picker roll (mm)	10
Gap between two picker rolls (mm)	15
Angle of cutting table and horizontal plane (°)	32
Picking roller speed (r/min)	1050
Test the progress rate of corn plants (m/s)	1.1
Total grain loss rate (%)	≤4
Qualified rate of straw shredding (%)	≥90

Four rows of 50 corn in each row were selected in the test area to be felled, and the corn grain moisture content was 29.07 to 32.13% during the test. Ear picking test was conducted immediately after felling, and the test site and damaged ear are shown in Fig. 8. After statistics, 200 maize plants were tested, 16 ears were damaged by threshing, and the damage rate of ears was 8%.

**Fig. 8.** Test site and damaged ear

Evaluation and Analysis of Case Modeling

To ensure the consistency of control test parameters, the structure parameters and operation parameters of the picking device were set according to the field test conditions, as shown in Table 7 and Fig. 8.

Table 7. Modeling Parameter Values

Parameter	Symbol	Data
Picking roller speed(r/min)	n	1100
Diameter of picking roller (m)	D	0.09
Height of convex edge of picker roll (m)	h	0.01
The sliding friction coefficient between picking roller and ear	f	1
Gap between two picker rolls (m)	δ	0.015
The power consumption of two picker rolls during picking (kW)	ΔP	2.5

From the modeling analysis of pick process, it can be seen that the diameter of the big end of the ear is a change parameter that directly affects the harvest performance of the cutting table, and it is the main demand parameter in the cutting table design process. In order to study the effect of large end diameter of ear picking roller on ear damage during ear picking, the diameter d of large end of ear picking roller varied from 0.04 to 0.07 m according to the size distribution of large end diameter of ear in the experimental area. The relationship between the force of the plucking roller edge on the ear and each parameter was calculated by inputting the data in the table into Matlab software respectively, and then the output was the change of the force F_t of the plucking roller edge on the ear, the horizontal force F_{t1} , and the vertical force F_{t2} with the diameter d of the big end of the ear, as shown in Fig. 9.

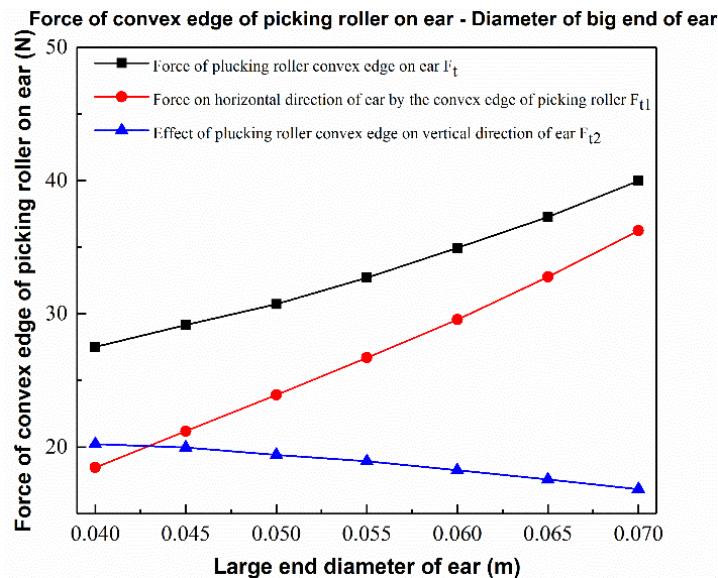


Fig. 9. Effect of the convex edge on the ear varies with the diameter of the big end of the ear

As can be seen from Fig. 9, when the diameter d of the ear was 0.04 to 0.07 m, the resultant force F_t of the plucking roller edge on the ear increased with the increase of the diameter of the big end of the ear, and its range was between 27.5 and 40 N. The horizontal force F_{t1} of the convex edge of the picking roller on the ear increased with the increase of the diameter of the main end of the ear, and its range was between 18 and 36 N. The vertical force F_{t2} of the plucking roller on the ear decreased with the increase of the diameter of the main end of the ear, and its range was between 16.5 and 21 N.

When the water content was 27.07%, the lateral value $F_{10}+F_{12}+F_{11}+3F_{23}=28.51$ N can be calculated from the stress characteristics of the grain. In the vertical, $F_p+F_{30}+F_{31}+F_{32}=357.567$ N.

On the side, when $d > 59.93$ mm,

$$F_{t1} > F_{10} + F_{11} + 3F_{23}$$

In the longitudinal direction, when $45 \text{ mm} \leq d \leq 65 \text{ mm}$ constant,

$$F_{t2} < F_p + F_{30} + F_{31} + F_{32}$$

Summarizing the above two-direction force situation, when the diameter of the big end of the ear is greater than 59.93 mm, the ear will suffer threshing loss. According to the diameter and size distribution of the big end of the ear in this test area, the damage

percentage of the ear damaged by the ear is 7.5%, and the error of the test bench is 0.5%, which indicates the correctness of the modeling method. The reasons for the damage percentage error are related to the following three points: First, during the actual operation process, the rotational speed of the ear picking roller will fluctuate to a certain extent, which leads to changes in the force on the corn ears. Second, the moisture content of corn ears is controlled within a certain range. However, the difference in moisture content within this range will lead to certain differences in their physical properties, resulting in changes in the damage rate. Thirdly, the difference in the inclination angle between the corn ear and the stem will cause different postures when they enter the ear picking roller, thereby resulting in different forces being applied.

CONCLUSIONS

This paper analyzed the interaction relationship between the longitudinal and horizontal roller ear picking device and the corn ears during the operation process. An evaluation method was proposed for the damage of corn ears during the operation of the longitudinal and horizontal roller ear picking device from a mechanical perspective. The correctness of the evaluation method was demonstrated by using the method verified on the test bench. This method can provide theoretical guidance for the design optimization of the header of the longitudinal and horizontal roller corn harvester. The specific conclusions are as follows:

1. Based on the analysis of the operation process of the horizontal corn picker, the interaction model between the corn plant and the vertical roller picker was established. The single factor and two-factor orthogonal analysis method were used to reveal the law of the influence of operation parameters such as the rotation speed of the picker roll and the clearance of the picker roll on the convex force of the ear.
2. A loss evaluation method based on the minimum breaking strength of the corn kernel pedicel and the minimum rupture strength was proposed. Based on the force of the spiral convex rib acting on the ear in the lateral compression and longitudinal bending directions of the ear, combined with the fracture mechanical characteristics of the kernel pedicle, a prediction model of the ear-picking damage rate was established, and a loss evaluation method based on the minimum rupture strength of the kernel and the breaking strength of the pedicle as the discrimination criteria was proposed.
3. Based on the comparison between the test bench and the modeling method, the kernel damage evaluation method was verified by example. The example test showed that the error between the test bench method and the modeling evaluation method was 0.5%, and the accuracy of the evaluation method was verified within the allowable error range.

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