DESIGN AND EXPERIMENT OF HIGH MOISTURE CORN THRESHING DEVICE WITH LOW DAMAGE
/
高水分玉米低损伤脱粒装置的设计与试验

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ABSTRACT
To address the requirements of direct corn kernel harvesting in the Huang-Huai-Hai region of China, this study aimed to rectify issues related to kernel damage and low threshing rates observed in the operation of existing corn kernel direct harvesting machines. Initially, a novel threshing device was designed, incorporating staggered rotary motions for the threshing cylinder and concave grate. Subsequently, the experimental factors such as the speed of threshing drum, the speed of concave grate and the threshing gap were considered on the test bench, and the indexes such as corn grain crushing rate and threshing rate were evaluated. Moreover, orthogonal testing indicated that optimal threshing performance was achieved with a threshing cylinder speed of 287 rpm, a concave grate speed of 106 rpm, and a threshing clearance of 49 mm, resulting in a kernel crushing rate of 4.12% and a threshing rate of 94.18%. These experimental findings confirm the feasibility of the Rotating Concave Screen Threshing Device, underscoring its ability to significantly enhance corn threshing rates while minimizing kernel fragmentation and damage.

摘要
为了满足中国黄淮海地区玉米籽粒直接收获的要求，本研究旨在解决现有玉米籽粒直收机操作中观察到的与籽粒损伤和脱粒率低相关的问题。设计了一种新型脱粒装置，其中脱粒滚筒和凹板筛交错反向旋转运动。选取脱粒滚筒转速、凹板筛转速和脱粒间隙为试验因素，玉米籽粒破碎率和脱净率等试验指标开展了台架试验。实验结果揭示了这些因素对玉米粒破碎率和脱净率的影响。正交试验表明，当脱粒滚筒转速为 287 rpm、凹板筛转速为 106 rpm、脱粒间隙为 49 mm 时，脱粒效果最佳，籽粒破碎率为 4.12%，脱净率为 94.18%。这些实验结果证实了旋转凹板筛脱粒装置的可行性，强调了其在最大限度地减少谷粒破碎和损坏的同时显著提高玉米脱净率的能力。

INTRODUCTION
Corn stands as the preeminent cereal crop globally, playing a pivotal role in food production, chemical applications, and livestock feed due to its exceptional yield (*Steponavičius et al., 2023*). In China, corn holds a prominent position as one of the three principal staple foods, boasting the largest planting area and the highest total output (*Chen et al., 2015*). Notably, the Huang-Huai-Hai Wheat-Corn Rotation Region ranks as the second-largest corn-producing region in China. The harvested corn kernels from this region exhibit elevated water content, ranging between 30% and 35%. The corn harvesting process subjects the kernels to compression, impact, and abrasion by threshing components, precipitating issues such as kernel damage, skin breakage, and cracks. These challenges heighten the susceptibility to aflatoxin infection and mildew, posing a significant threat to food security. Addressing these concerns is crucial for ensuring the integrity of the corn supply chain and safeguarding food resources (*Yang et al., 2022*).

Currently, mechanized corn harvesting predominantly takes two forms: ear harvesting and grain harvesting. Beyond a grain moisture content of 28%, the increased softness renders the grains susceptible to compression, leading to amplified losses (*Wacker, 2005; Miu, 2015*). A widely adopted approach involves peeling, threshing, and cleaning the corn cob in a single operation, yielding labor and time savings. This process entails the use of a stripper attached to the header for corn cob removal from the stem, followed by threshing using either a tangential or axial threshing device-essentially the central component of the combine harvester, crucially influencing the quality of the corn harvest (*Yang et al., 2016*).

Notably, as the moisture content surpasses 14%, the grain breakage rate escalates with higher moisture levels. At a water content of 35%, the grain damage can reach up to 40% (*Alonge A.F et al., 2000; Volkovas V. et al., 2006*). The persistent challenge of elevated crushing rates in corn ears with high moisture content during grain harvesting remains a primary constraint on the advancement of corn mechanization (*Li et al., 2014*).

Initially, investigations into low-loss threshing technology were conducted abroad, revealing that the threshing process was contingent upon the corn variety and the design and adjustment of the threshing device (*Wacker, 2005*). A key strategy involved the redesign of the threshing device, encompassing the drum and concave plate, to mitigate grain damage, allowing the hulled grain to promptly exit the threshing drum after hulling (*Chowdhury et al., 1978*). Numerous scholars have delved into the impact of structural parameters of the threshing device on threshing damage and loss. *Petkevichius et al. (2008a and 2008b), Spokas, et al. (2008)* analyzed the influence of drum speed and concave gap on grain separation, revealing that a judicious increase in gap significantly reduced grain loss and crushing. Moreover, the movement of the ear in the threshing chamber was scrutinized, exposing varied movement speeds based on the ear's posture. Specifically, the ear parallel to the drum axis exhibited a faster movement speed than the ear perpendicular to the drum axis. *Pužauskas et al., (2017),* investigated the impact of the grid concave gap on grain damage, revealing that a concave gap of 62.5 mm could reduce the grain damage rate to less than 3%. *Miodragovic et al., (2006),* explored the influence of threshing gap on grain quality, establishing that an increased threshing gap was conducive to reducing grain crushing rates and improving grain threshing quality. In the domestic domain, scholars have probed the crushing mechanism of corn grain *(Niu et al., 2011; Xu et al., 2009),* exploring the influence of key working parameters such as moisture content and drum circumferential speed on the crushing rate of corn grain through the development of a small threshing test bench *(Xiang et al., 2015; Yang et al., 2018).* To comprehensively evaluate two distinct threshing drums, *Yang et al., (2022),* scrutinized the effects of various threshing parameters, including corn ear feed, drum circumferential speed, and threshing gap, on grain crushing rates under different moisture content conditions.

Currently, research on threshing technology predominantly focuses on traditional longitudinal or transverse axial threshing systems, examining the influence of threshing drum rotation speed, types of threshing elements, and threshing gap on threshing damage to identify optimal parameters. However, there remains a notable gap in the study of threshing damage for corn seeds with water content ranging between 20% and 30%, as well as those exceeding 30%. To address this gap, this paper introduces a low-damage threshing device designed to alleviate the issue of high moisture content corn grain threshing damage, thereby minimizing grain damage while ensuring an efficient corn grain threshing rate.

MATERIALS AND METHODS

High moisture corn

The focus of this study was Zhengdan 958, the predominant maize variety cultivated in the Huang-huai-hai region of China (see Figure 1).

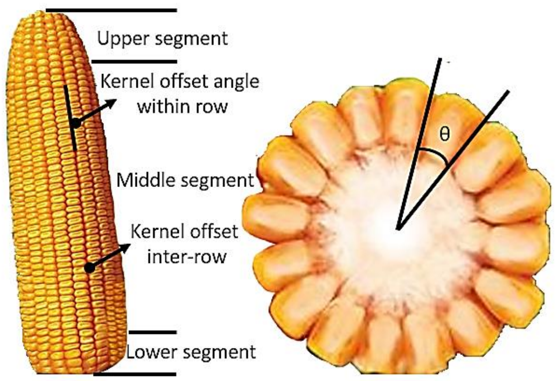


Fig. 1 - Zhengdan 958 corn

This variety exhibits a plant height ranging from 240 to 250 cm and an ear height of 100 to 110 cm. Characterized by a cylindrical ear, white axis, 18-20 cm ear length, approximately 5 cm ear thickness, 14-16 rows per ear, about 36 grains per row, yellow-colored grains, and a 1000-grain weight ranging from 300 to 350g.

To capture representative data, 50 ears were randomly selected for measurement using a vernier caliper, which included the diameter of the large end, the diameter of the small end, and the length of the ear. The resulting average values are presented in Table 1.

Table 1

Corn ear physical parameters

parameter	Unit	Maximum value	Minimum	Average value
Big-endian diameter	mm	56.64	48.28	52.31
Little-endian diameter	mm	49.17	43.55	46.82
Ear length	mm	198.16	117.04	154.46

Preceding the experiment, ten ears were randomly chosen, and the moisture content of the grains was gauged using a grain moisture meter, with the average value determined through three measurements. The measuring tool employed was the Kate PM-8188 grain moisture measuring instrument, boasting a measurement range of 6-40% and an accuracy of 0.5%. The recorded grain moisture content registered at 30.12%, categorizing it as high-moisture corn grain.

Rotating concave screen threshing device

The research indicates that a high threshing drum speed is the primary factor contributing to grain damage (*Paulsen et al., 2014; Miodragovic et al., 2006*). Conversely, other parameters such as threshing gap and the type of threshing element exhibit minimal influence on grain damage *(Brandini, 1969).* For corn kernels with elevated water content, diminishing the rotating speed of the threshing drum proves effective in mitigating damage. However, corn kernels with low rotating speed face challenges in separating from the corn cob, resulting in an increased loss rate. To address this issue, this study proposes a threshing system featuring a 360-degree full-wrap concave screen and a counter-rotating separating drum. This design aims to minimize damage and extend the contact time between the corn cob and the threshing drum and concave screen, facilitating easier separation of the corn kernels. Figure 2 illustrates the structure of the proposed threshing device, highlighting key differences from traditional counterparts. Specifically, the concave screen wrap angle exceeds 270 degrees, reaching a full 360 degrees, and the rotary concave screen can rotate in the opposite direction relative to the threshing drum, differing from the fixed orientation of traditional concave screens.

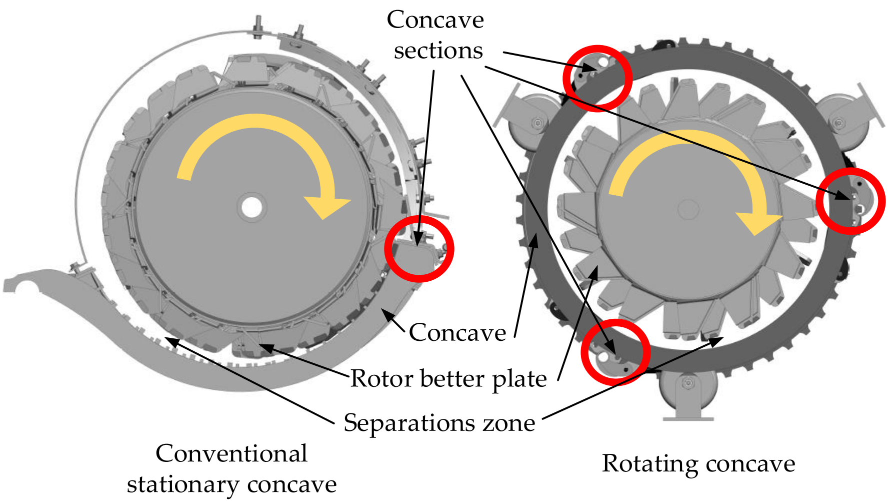


Fig. 2 - Working principles of the conventional stationary concave grate and rotary concave grate

Research findings indicate that the axial threshing device incurs lower grain damage compared to the tangential threshing device (*Wacker, 2005; Poničan et al., 2009*). Consequently, this study opts to enhance the longitudinal axial threshing device utilized in the CASE4099 combine. Figure 3 illustrates the structure of the modified threshing device.

This study aims to investigate the impact of a novel threshing system on reducing threshing damage. Given a fixed corn threshing power, both the method involving a small-diameter cylinder with high threshing speed and the one employing a large-diameter cylinder with low threshing speed can be utilized to achieve grain and ear shaft separation.

However, the adoption of a driven concave screen design in this paper imposes constraints on the layout of the concave screen and raises challenges for the drive system when using a large-diameter threshing cylinder. Additionally, as the cylinder diameter decreases, the inertia force increases, enhancing the cylinder's ability to overcome overload and ensuring a more stable working process. Hence, this paper employs the small-diameter with high threshing speed method. Following the guidelines in the agricultural machinery design manual, the recommended threshing speed for the axial flow cylinder is 10~12 m/s, with a cylinder rotation speed ranging from 300 rpm to 450 rpm. Accordingly, the selected cylinder diameter in this paper is 0.43 m, falling within the suggested range. The threshing area measures 1.30 m, and the separation area has a length of 1.03 m. The total length of the cylinder is 2.86 m, with the threshing area comprising 1.30 m and the separation area extending to 1.03 m. A threshing angle of 10° was chosen based on the reference book. Detailed parameters are presented in Table 2.

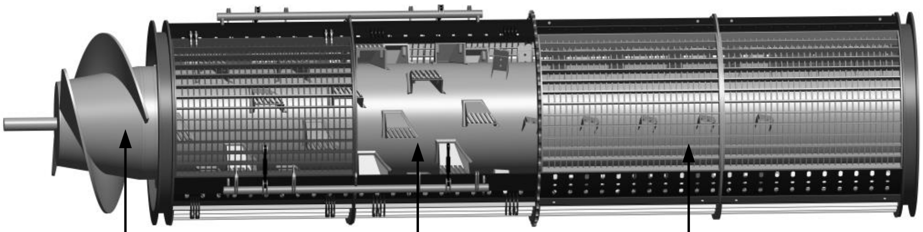


Fig. 3 - Schematic of modified threshing device

Table 2

Main parameters of threshing cylinder

Parameter	Unit	Value
Cylinder diameter	mm	430
Cylinder length	mm	2860
Length of the threshing area	mm	1300
Length of the separation area	mm	1030
Threshing inclination	°	10°

Threshing cylinder

As depicted in Figure 4, the rotating concave screen threshing device comprises a spiral feeding cone, a closed threshing cylinder, and a rotary concave screen.

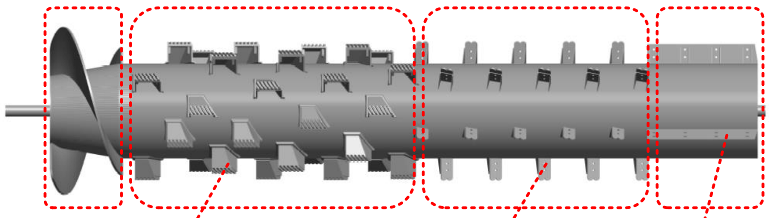


Fig. 4 - Schematic of the threshing cylinder

Notably, the rotary movement direction of the concave screen opposes that of the threshing cylinder. In the feeding process, corn ears undergo tangential and axial forces from the spiral cone, progressing along the cone toward the threshing cylinder. This journey is characterized by even stress on the ears due to the smooth surfaces of the feeding blade and cone, coupled with a uniform increase in the cylinder's diameter, preventing any damage. Upon entering the threshing cylinder, the corn kernel gradually dislodges through the kneading, squeezing, and impacting actions of the threshing element and concave screen, ultimately reaching the cleaning device via the concave screen.

The counter-directional movement of the concave screen compared to the threshing cylinder significantly amplifies the threshing wrapping angle, prolonging the threshing duration for corn ears in the device and enhancing the overall threshing rate. Furthermore, the reduction in the rotation speed of the threshing cylinder diminishes the impact of the corn threshing element on the corn ear, minimizing kernel shattering and associated damage.

Concave screen

The primary purpose of the concave screen is to facilitate the threshing and separation of corn ears in conjunction with the threshing cylinder. The proposed rotary concave screen comprises a frame, threshing concave screen section, and separation concave screen section. The frame encompasses the rotary track, transition plate, sprocket plate, threshing concave screen clearance adjustment plate, and separation concave screen fixed plate. Within the threshing concave screen section, six groups of concave grates are arranged, with three groups evenly distributed between the rotary track and transition plate, and the remaining three groups between the transition plate and the sprocket plate. Similarly, the separation concave screen section features six groups of concave grates, with three groups evenly distributed between the chain wheel plate and the transition plate, and the other three groups evenly distributed between the transition plate and the rotary track. A clearance adjustment device is incorporated into the threshing section concave screen to accommodate variations in corn varieties, ear diameter, feeding amount, and moisture content during harvest (refer to Figure 5).

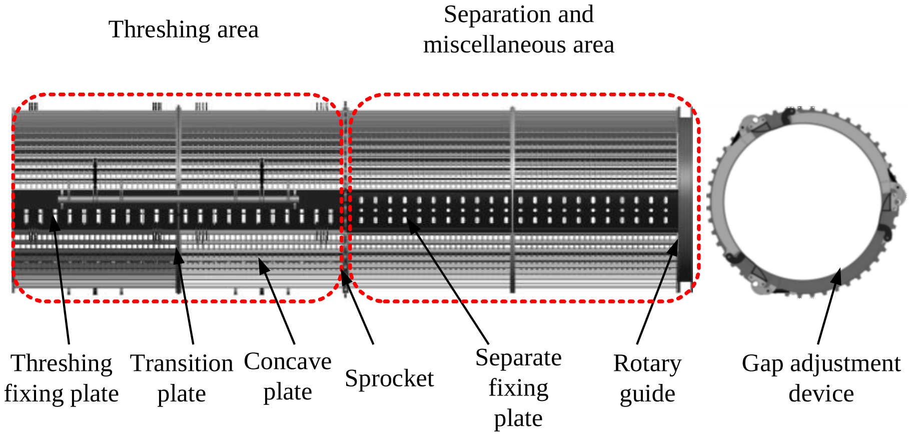


Fig. 5 - Schematic of rotary concave screen

The concave screen employs a grid format, consisting of both flat and round steel components, as illustrated in Figure 6. The structural parameters of the concave grate are established in accordance with guidelines outlined in the agricultural machinery design manual and pertinent literature, detailed in Table 3.

The grain passage rate through the concave screen is computed using Formula (1) (*Miu et al., 2008*).

$$P = \frac{(a_1-a_2-d)(b_1-b_2-d)}{a_1 b_1} \tag{1}$$

where: P = the grain passing rate of concave screen [%]; a_1 = center distance between round bars [mm]; a_2= round steel diameter [mm]; b_1= center distance between flat steels [mm]; b_2= width of flat steel [mm]; d = average diameter of grain [mm].

Table 3

Structural parameters of concave screen

parameter	Unit	Value
Flat bar width	mm	5
Diameter of round steel diameter	mm	5
Flat bar spacing	mm	48
Round bar spacing	mm	22
Deflector helix angle	°	6
Concave radian	°	90
A minimum gap of concave grate and cylinder	mm	45
Maximum gap of concave grate and cylinder	mm	55

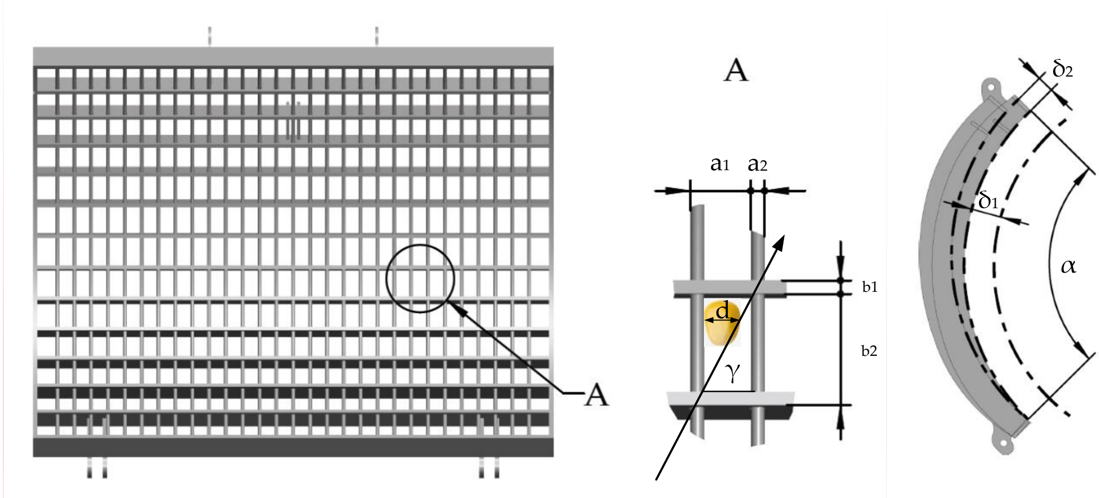


Fig. 6 - Structural parameters of concave grate

RESULTS AND DISCUSSION

Experimental scheme

Test indicators

During the corn ear harvesting process, essential qualitative evaluation indices for combine harvester performance encompass grain loss, grain breakage, work efficiency, and fuel consumption (*Petkevichius et al., 2008; Kutzbach et al.,1999; Li et al., 2020*). This study specifically focuses on the threshing quality of the threshing device in conditions of high grain water content, with no emphasis on work efficiency and fuel consumption. Grain loss is characterized by the proportion of grains threshed from the corncob to the total grain count, termed the grain threshing rate, and is computed using formula (2).

$$T = \frac{m_t}{m_t + m_w} \times 100\% \tag{2}$$

where T- seed cleaning rate, [%]; m_t - take off the grain weight, [g]; m_w - weight of non-threshed grain [g].

Grains damaged during harvesting can be classified into distinct categories based on the extent of damage, as illustrated in Figure 9 (*Chowdhury et al., 1978; Ma et al., 2020*).

The categories include: (1) Broken grains: comprising fragmented and crushed grains, none of which remain intact in this category, with at least one-third of the grains missing. (2) Defective seeds: exhibiting damage to the embryo, radicle, damage around the edge of the embryo, and pericarp loss in this section of the sample. (3) Cracked grains: featuring minute cracks but remaining intact in this portion of the sample.

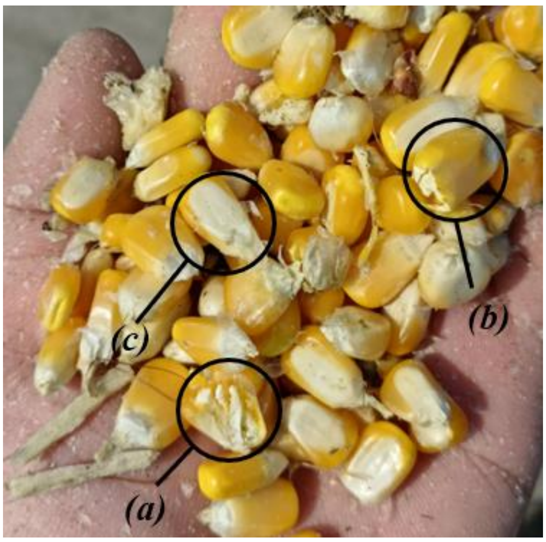


Fig. 9 - Categories of grain damage

(a)broken grains (b) defective grains (c) cracked grains

The proportion of impaired grain quality to the overall grain quality is termed the grain damage rate, and it is determined using formula (3).

$$P = \frac{m_s}{m_i} \times 100\% \tag{3}$$

where P- grain damage rate, [%]; m_s - damaged grain quality, [g]; m_i - total grain mass, [g].

Selection of test factors

Numerous researchers have indicated that the damage to corn kernels is influenced by the rotational speed of the threshing drum (*Petkevichius et al., 2008; Pastukhov et al., 2021; Pachanawan et al., 2021*). *Bumbar et al., (2018),* discovered that optimizing threshing quality to minimize grain damage involves setting the peripheral speed within the range of 17–21 m/s. Given that the threshing mechanism in this study involves the opposite rotation of the threshing drum and the concave screen, the threshing drum's speed is lower than that of conventional designs, operating at 250–500 rpm, while the concave screen rotates at 50–150 rpm.

Another critical technological parameter affecting grain damage is the clearance between the threshing drum and the concave plate, which is contingent upon the size of the ear to be threshed (*Miu P.I. 2015; Steponavicius et al., 2018*). With corn ear diameter averaging around 5 cm in this investigation, the threshing gap is set at 45–55 mm.

Testing program

This study utilized the crushing rate and threshing rate as key indicators in the orthogonal test, with cylinder speed, concave grate speed, and threshing clearance serving as the test factors. The investigation aimed to elucidate the impact of optimized parameter combinations on the threshing system and assess the varying levels of these factors on threshing performance. To achieve this, an orthogonal test was meticulously designed based on the Box-Behnken Design using Design-Expert software. The specified ranges for the test factors were as follows: threshing cylinder speed ranging from 250 to 500 rpm, concave grate speed within the range of 50 to 150 rpm, and threshing clearance set between 45 and 55 mm. The respective levels of the different factors are detailed in Table 6.

Table 6

Parameter levels

Level	cylinder speed v_r, (rpm)	concave grate speed v_c, (rpm)	threshing clearance c, (mm)
-1	250	50	45
0	375	100	50
1	500	150	55

According to Design-Expert, there were 17 experiments, and the experimental results are shown in Table 7.

Table 7

Trial Protocol and Results

Test number	Cylinder speed v_r, (rpm)	Concave speed v_c, (rpm)	Threshing clearance c, (mm)	Crushing rate X, (%)	Threshing rate Y, (%)
1	1	1	0	4.77	92.68
2	-1	-1	0	4.31	92.60
3	-1	0	-1	4.38	93.67
4	0	-1	1	4.39	89.54
5	0	0	0	4.35	94.24
6	1	0	-1	5.84	91.95
7	-1	0	1	4.19	90.84
8	1	-1	0	5.29	90.03
9	1	0	1	4.77	90.29
10	-1	1	0	3.95	91.83
11	0	0	0	4.35	94.04
12	0	1	1	4.25	90.55
13	0	0	0	4.31	94.22
14	0	0	0	4.47	93.85

Test number	Cylinder speed v_r, (rpm)	Concave speed v_c, (rpm)	Threshing clearance c, (mm)	Crushing rate X, (%)	Threshing rate Y, (%)
15	0	1	-1	4.73	92.53
16	0	-1	-1	5.39	91.76
17	0	0	0	4.31	94.22

Observing the results, the minimum recorded crushing rate stood at 3.95%. This occurred when the threshing cylinder operated at a speed of 250 rpm, the concave grate speed was set to 150 rpm, and the threshing clearance was fixed at 50 mm. Conversely, the maximum threshing rate reached 94.24% under different conditions, specifically with a threshing cylinder speed of 375 rpm, concave grate speed at 100 rpm, and a consistent threshing clearance of 50 mm.

RESULTS ANALYSIS AND DISCUSSION

Analysis of variance

In the analysis of experimental data, variance analysis was conducted using Design-Expert software. Coefficient items with a significance greater than 0.05 in the model were excluded. The outcomes of this analysis are detailed in Tables 8 and 9. The regression model expressing the relationship between the crushing rate, threshing rate, and the encoded values is provided below:

$$X = 4.36 + 0.48v_r - 0.21v_c - 0.34c - 0.22\, v_r c + 0.13v_c c + 0.16\, {v_r}^2 + 0.27c^2 \quad (R^2=0.992) \tag{4}$$

$$Y = 94.11 - 0.5v_r + 0.46v_c - 1.09c + 0.85\, v_r v_c + 0.29v_r c - 0.87\, {v_r}^2 - 1.46\, {v_c}^2 - 1.56c^2 \quad (R^2=0.996) \tag{5}$$

All regression coefficients in the model exhibited a significance level below 0.05, and the lack of fit was deemed non-significant. These findings affirm a high degree of fitting for the regression model.

Table 8

Crushing rate variance analysis results

source of variance	sum of variance	degree of freedom	mean square deviation	F value	P value
Model	3.88	9	0.43	96.31	< 0.0001
A	1.84	1	1.84	411.82	< 0.0001
B	0.35	1	0.35	78.83	< 0.0001
C	0.94	1	0.94	209.68	< 0.0001
AB	0.0064	1	0.0064	1.43	0.2707
AC	0.19	1	0.19	43.26	0.0003
BC	0.068	1	0.068	15.10	0.0060
A^2	0.11	1	0.11	25.15	0.0015
B^2	0.014	1	0.014	3.22	0.1158
C^2	0.31	1	0.31	70.37	< 0.0001
Residual	0.031	7	0.00448	1.08	
Lack of Fit	0.014	3	0.00468	96.31	0.4512
Pure Error	0.017	4	0.00432		
Cor Total	3.91	16			

Table 9

Threshing rate variance analysis results

source of variance	sum of variance	degree of freedom	mean square deviation	F value	P value
Model	41.20	9	4.58	196.49	< 0.0001
A	1.99	1	1.99	85.41	< 0.0001
B˙	1.67	1	1.67	71.87	< 0.0001

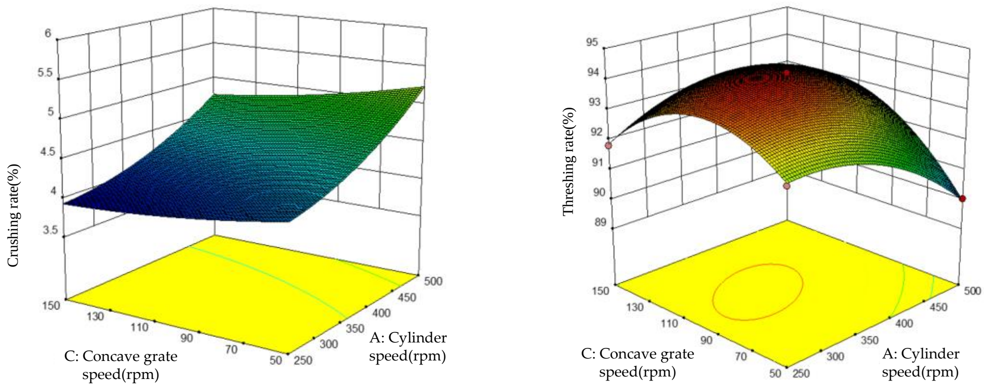
source of variance	sum of variance	degree of freedom	mean square deviation	F value	P value
C	9.44	1	9.44	405.14	< 0.0001
AB	2.92	1	2.92	125.50	< 0.0001
AC	0.34	1	0.34	14.69	0.0064
BC	0.014	1	0.014	0.62	0.4576
A^2	3.17	1	3.17	136.23	< 0.0001
B^2	8.98	1	8.98	385.61	< 0.0001
C^2	10.22	1	10.22	438.80	< 0.0001
Residual	0.16	7	0.023		
Lack of Fit	0.050	3	0.017	0.58	0.6574
Pure Error	0.11	4	0.028		
Cor Total	41.37	16			

Analysis of Response Surface

An examination was carried out based on the regression equations for crushing rate and threshing rate. The results of the analysis revealed that the primary and secondary orders of the effects of various factors on the crushing rate were ACB, whereas the primary and secondary orders of the effects of various factors on the threshing rate were CAB.

Effects of Threshing Cylinder Speed and Concave Grate Speed on Threshing Performance

As depicted in Figure 10, both the cylinder speed and concave grate speed exhibited significant independent effects on the crushing rate, without any discernible interaction between them. The crushing rate demonstrated a noticeable upward trend with an increase in threshing cylinder speed, while it exhibited a gradual and less pronounced increase with higher concave grate speed. Concurrently, the cylinder speed, concave grate speed, and their interaction exerted extremely significant effects on the threshing rate. As both cylinder speed and concave grate speed increased, the threshing rate initially rose and then declined.



(a) *(b)*

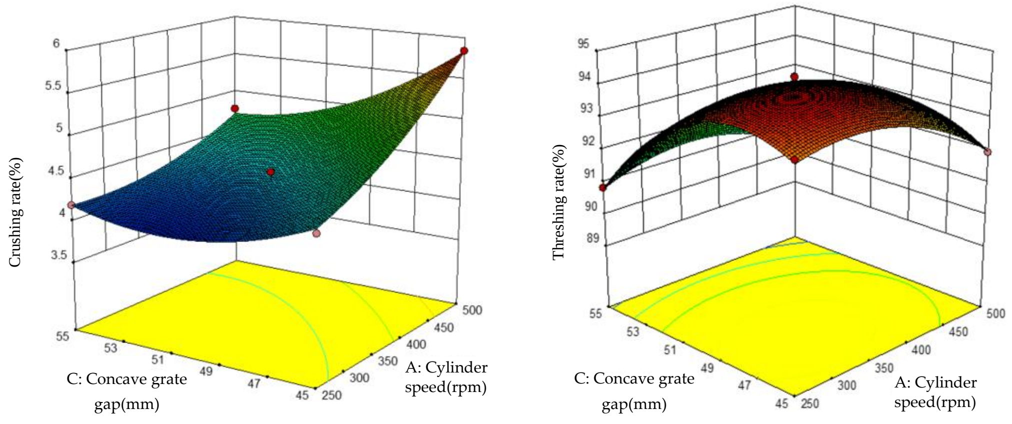
Fig. 10 - The effects of cylinder speed and concave grate speed on threshing performance

(a) Cylinder speed and concave grate speed effect on crushing rate;

(b) (b) Cylinder speed and concave grate speed effect on threshing rate

Effects of Threshing Cylinder Speed and Threshing Clearance on Threshing Performance

As illustrated in Figure 11, both the cylinder speed and threshing clearance exhibited significant effects on both the crushing rate and threshing rate. Notably, the interaction between cylinder speed and threshing clearance had a substantial impact on the crushing rate, while a similar interaction exerted a significant effect on the threshing rate. Specifically, an increase in cylinder speed led to a marked escalation in the crushing rate. Conversely, an increase in threshing clearance resulted in a decline in the crushing rate, stabilizing thereafter. Furthermore, an increase in both cylinder speed and threshing clearance led to an initial rise and subsequent decline in the threshing rate.



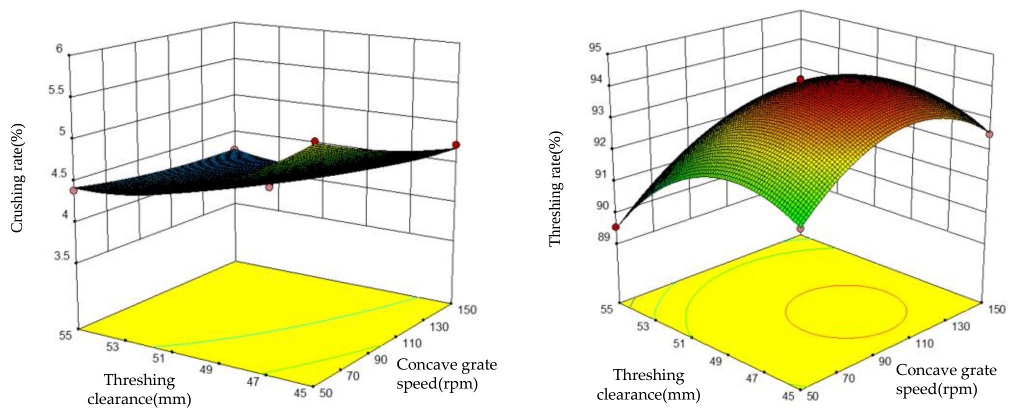
(a) *(b)*

Fig. 11 - Effects of cylinder speed and concave grate gap on the threshing performance

(a) Cylinder speed and concave grate gap effect on crushing rate; (b) Cylinder speed and concave grate gap effect on threshing rate

Effects of Concave Grate Speed and Threshing Clearance on Threshing Performance

According to Figure 12, the velocity of the concave grate and the clearance for threshing exhibited noteworthy impacts on the crushing rate, with their interaction significantly influencing the overall crushing rate. An escalation in threshing clearance resulted in a substantial decrease in the crushing rate, whereas an increase in the concave grate speed led to a modest reduction in the crushing rate. Simultaneously, both the concave grate speed and threshing clearance wielded substantial influence on the threshing rate, though their interaction demonstrated no discernible effect on the threshing rate. Consequently, elevations in both concave grate speed and threshing clearance yielded an initial increase followed by a subsequent decrease in the threshing rate.



(a) *(b)*

Fig. 12 - Effects of concave grate speed and threshing clearance on threshing performance

(a) Concave grate speed and threshing clearance effect on crushing rate;
(b) Concave grate speed and threshing clearance effect on threshing rate

Utilizing variance analysis and response surface analysis, the optimized combination of operational parameters was derived. The corn ear's kernel crushing rate achieved 4.12%, and the threshing rate reached 94.18% under the following conditions: a threshing cylinder speed of 287 revolutions per minute (rpm), concave grate speed of 106 rpm, and a threshing clearance of 49 millimeters.

CONCLUSIONS

This study introduces an innovative threshing device, wherein the threshing cylinder and concave grate can execute staggered rotational motions. The ensuing conclusions are as follows:

This device demonstrated a notable enhancement in the threshing rate while concurrently diminishing fragmentation and damage to corn kernels. The bench test showed that the optimal speed range for the threshing cylinder was 250–500 rpm, the concave grate should operate within the range of 50–100 rpm, and the threshing clearance should be set between 45–55 mm.

Utilizing the optimization function in Design-Expert 11.0, the optimal parameter combination was determined as follows: threshing cylinder speed = 287 rpm, concave grate speed = 106 rpm, and threshing clearance = 49 mm. Correspondingly, the corn kernel exhibited a crushing rate of 4.12% and a threshing rate of 94.18%. The most influential factor affecting the kernel crushing rate was the threshing cylinder speed, followed by threshing clearance and concave grate speed. Simultaneously, the most impactful factor influencing the threshing rate was the threshing clearance, followed by the threshing cylinder speed and concave grate speed.

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