DESIGN AND TESTING OF 4YZ-6 FRESH CORN HARVESTER GRAIN SPLITTING FRONT END COMPONENT
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鲜食玉米联合收获机分禾前端研究与试验

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ABSTRACT
Aiming at the problem of high cob loss in non-opposed row harvesting of 4YZ-6 fresh corn harvester, a front-end part adapted to the grain splitter of this model was designed. The structure of the front-end part was elaborated, the sliding conditions of the stalks under the action of the grain splitter were studied, the forces between the stalks and the front-end part were theoretically analyzed, and the operating effect of the front-end part was verified through field tests. The tests show that the expected operating effect is optimal when the inclination of the grain separator is 27.7°, the clamping angle of the grain splitter is 31°, the stubble height is 270 mm, and the front-end guards half width is 3.8 mm. The verification test for this parameter combination yielded a breakage rate of 8.71% and a loss rate of 9.47%, which were basically consistent with the expected values. The design of this front-end component of the grain splitter provides an effective means to reduce the loss of ears in the harvesting process of fresh corn.

摘要
针对4YZ-6型鲜食玉米收获机在非对行收获时果穗损失大的问题，设计了与该机型分禾器相适应的前端部件。详细阐述了前端部件的结构，研究了茎秆在分禾器作用下的滑动情况，对茎秆与前端部件之间的作用力进行了理论分析，并通过现场试验验证了前端部件的工作效果。试验表明，当谷物分离器倾角为27.7°、谷物分割器夹角为31°、留茬高度为270 mm、前端护板半宽为3.8 mm时，预期运行效果最佳。对这一参数组合进行验证测试的结果是，破损率为8.71%，损失率为9.47%，与预期值基本一致。该分禾器前端部件的设计为减少鲜食玉米收获过程中的果穗损失提供了有效手段。

INTRODUCTION

In recent years, under the support of national policies, the fresh corn industry has been developing rapidly and its planting scale has been expanding *(Zhang et al., 2019)*. Fresh corn refers to corn harvested in the late milk ripening or early wax ripening stage and used for processing or directly consumed, including glutinous corn, sweet corn, shoot corn and colorful corn and other varieties, which are sweet, soft and nutritious, and much loved by the people *(Revilla et al., 2021).* When the harvester carries out field operations, the divider installed at the front end of the harvester takes the lead in interacting with the corn stalks, causing the stalks to move closer to the ear picking gap under the action of the divider *(Bu et al., 2016)*. With the advance of the harvester, the stem and ear enter the picking gap, so that the stem and ear are separated. Therefore, the divider needs to meet the smooth transportation of corn stalks to the picking gap, and at the same time avoid the occurrence of stalk overturning and breaking as much as possible.

Fresh corn harvest in the northeast region generally exists in August to September, when the rainy season leads to poor field conditions, in order to carry out low loss and high efficiency harvesting operation of fresh corn. some plots need to carry out non-opposite row operation. Non-opposite row operation means that the forward direction of the harvester and the forward direction of the planting machine present a certain angle, rather than parallel. In particular, fresh corn is harvested with a high-water content in the stalks, and the stalks are easy to be broken and pushed down when they touch the grain-splitting device, resulting in the loss of cobs *(Wang et al., 2021)*.

Scholars from Anhui Agricultural University used ADAMS to model and simulate the corn stalks and the grain splitter *(Guo et al., 2015)*, and through virtual orthogonal tests, it was found that the smoothness of the surface at the transition of the grain splitter can reduce the chances of the corn stalks being broken or pushed back.

Scholars from China Agricultural University pointed out that when developing a new type of corn stalk and cob combine harvesting machinery cutting table, the tip of the grain splitter is lower than 350 mm, and it is also needed to ensure that the height of the operating plane from the ground is greater than 100 mm *(Zhang et al., 2018)*. Scholars from Gansu Agricultural University conducted a study on the mechanism of vertical roller picking, pointing out that the cone angle of the grain separator and the height of the tip of the grain separator from the ground are the main factors affecting the effect of the grain separator *(Xin et al., 2020; Du et al., 2014)*. Some scholars have optimized the separating performance of the grain separator by conducting simulation experiments on the kinematic and dynamic performance of the separating device, corn plant and picking roller *(Tai et al., 2020)*. Scholars from Shandong Agricultural University evaluated the performance of the separator by analyzing the effects of the operating height of the separator and the forward speed of the harvester on the different displacements of the maize stalks in the X, Y, and Z directions at the time of harvesting *(Wang et al., 2021)*. Some scholars designed a separator suitable for the harvesting of fallen sugarcane *(Bai et al., 2021)*. Scholars from Northeast Agricultural University designed a special divider for a bionic flexible clamping spike picking cutter *(Zhu et al., 2023)*. Some scholars designed a divider for a garlic harvester to investigate the factors affecting the success rate of garlic feeding and conducted a field trial *(Zhu et al., 2023)*.

Although researchers realize that the front end of the divider has an important impact on harvesting performance, they ignore the fact that the actual operation of the harvester will result in the loss of ears due to non-opposed row operation. In the new situation of grain saving and loss reduction to ensure food security, the design of the front part of the grain splitter was carried out *(Felipe et al., 2021).* The deflection angle and force when the stalks contact with the front-end part of the grain separator are analyzed, and field tests are conducted on the key parameters of the front-end part of the grain separator, so as to verify the changes in the breakage rate of the stalks and the loss rate of the cobs, with a view to reducing the breakage rate and the loss rate of the non-opposed rows of the fresh corn harvester, and then provide theoretical support for the optimization and design of the grain separator.

MATERIALS AND METHODS

Key component design

In order to facilitate the processing and manufacturing of the harvesting device and to guarantee the structural strength of the harvesting device, the front-end components of the harvesting device are designed as shown in Fig.1. It mainly consists of a deflector plate, a front guard plate, a plug plate, a front arc plate and an intermediate arc plate. Among them, the front-end guard plate and the middle arc plate are welded with the grain separator in sequence, and the front-end components of the deflector plate, the front-end guard plate and the plug plate assembly are fastened with the grain separator through bolts. While guaranteeing that the front end of the grain separator can be replaced quickly, the amount of bending of the corn stalks by the components can be minimized.

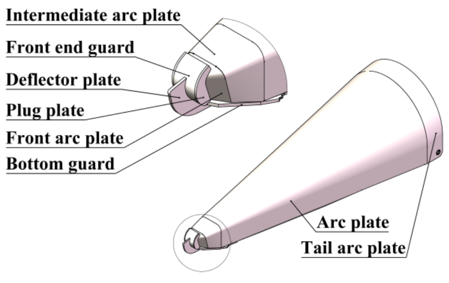

Fig. 1 - Schematic diagram of the front-end structure of the grain splitter

Stalk force analysis

When the 4YZ-6 harvester operates in non-opposed rows, the relative positions of corn stalks and the front-end parts of the divider are shown in Fig. 2, and the stalks may be distributed in the A interval, B interval, and directly on the axis of the guide plate. When the stalks are directly on the axis of the deflector plate, the corn stalks are then directed to both sides of the deflector plate by the divider, and the stalks are again in contact with the front-end guard plate, the front-tip main plate, and the intermediate arc plate.

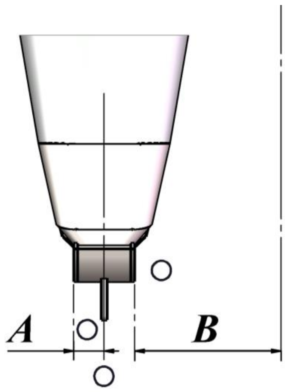

Fig. 2 - Schematic diagram of the relative positions of the stalks and the front of the grain splitter

When the stems are distributed in the interval A shown in Fig.2, between the side edge line of the deflector plate and the side edge line of the plug plate, the component that first contacts with the stems to produce the separating effect at this time is the front-end guard. As shown in Fig.3, the angle between the force F_s of the front-end component on the stalks and the forward direction of the harvester is β, then the stalks satisfy the constraint condition of not being pushed over:

$$\begin{cases} F_t = \frac{F_S}{cos\beta} \\ F_m = \lambda F_s \end{cases} \quad (1)$$

where:

λ is the coefficient of friction; F_s is the force exerted by the component on the stalk; F_m is the reaction force of the stalk on the component; F_t is a combined force in the opposite direction of forward motion; β is the angle between the combined force and the opposite direction of forward motion.

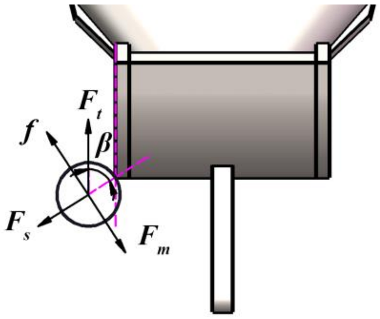

Fig. 3 - Schematic diagram of stalks touching the front-end guards

Combined with Fig.3 and Eq.1, it can be seen that when the angle of deflection of the stalk is less than the critical value of the folding angle, the constraint on whether the stalk can be pushed down at this time is that the product of the elastic force of the stalk on the front end of the divider and the half-angle cotangent value of the tip angle of the front end of the divider is greater than the friction of the front end of the divider on the stalk, i.e. Eq.2:

$$F_S cot\alpha \geq F_m \quad (2)$$

where:

α is the angle between the reaction force and the direction opposite to the forward direction.

When the stalks are distributed in the interval B shown in Fig 2, i.e., the interval from the side line of the plug plate to the side line of the middle arc plate, the edges of the components which have the effect of harvesting on the stalks at the front end of the harvesting are the plug plate, the front arc plate and the middle arc plate in order, and their force relationship is shown in Fig 4. At this time, the corn stalk is subjected to a force pointing to the center of the circle. and perpendicular to the edge of the harvesting action of F_s, the elasticity of the stem to the front end of the divider is F_t, which is opposite to the direction of the harvester. Assuming that there is no relative sliding of the stalks with the front arc plate and the middle arc plate, then there is:

$$\mathrm{F_S cot\alpha \geq F_m} \quad (3)$$

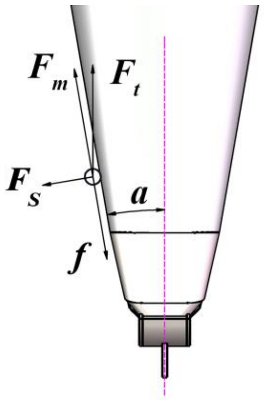

Fig. 4 - Schematic representation of the distribution of stalks in interval A

Front end guard design

From Fig.4 and Eq.3, it can be seen that the angle β between the force A and the forward direction is the key parameter to determine the breaking of the stem. When the stalks touch the front-end guard at the same time, the clamping angle of the grain splitter β takes the value close to 0. As the harvester advances, the stalk is in contact with the front end of the divider, and the force provided by the harvester points to the center of the corn stalk. At this time, as the harvester progresses, the stem is pushed down by the front guard plate. When the stalks are distributed in the interval A, and the distance between the stalks and the deflector plate is increasing, the value of the angle β is still close to 0, and the stalks are still pushed down by the front guard.

When the stalk is tangent to the side line of the blocking plate, the value of clamping angle of the grain splitter β tends to be close to 0, but when the distribution position of the stalk is close to the A interval, the clamping angle of the grain splitter β will increase, and the product of the elasticity of the stalk on the front end of the grain splitter and the cotangent value of clamping angle β is greater than the friction force of the front end of the grain splitter on the stalks, and the stalks won't be broken.

Since the value of the friction coefficient is usually between 0.2 to 0.6, combined with the change trend of the cotangent function image in the range of 0° to 90°, it can be seen that when the angle β is in the range of 59° to 78°, then the corresponding angle β takes the value of 0.6 to 0.21, and there is a possibility of the stalk being pushed over. When the value of the angle β is within the range of 78° to 90°, then the value of the angle β is less than 0.21, and the stalks will be pushed down by the front-end guard as the harvester advances. When the angle β is greater than 90°, the stalks are again tangent to the side line of the blocking plate, and the stalks enter into interval B. The stalks touch with the front guard plate axially, and the stalks move along the side of the blocking plate to the direction of the front arc plate and the middle arc plate of the divider along with the forward movement of the harvesting unit. When the divider moves to the right side of the stalks, the stalks do not touch the front end of the divider, and the stalks enter the separating gap when the harvester advances.

Through the measurement of the diameter of the stalks of Wannuo 2000 corn varieties, the average value is 25.5 mm. To sum up can be seen, when the front end guards half width is less than 7.68 mm, the stalks and the front end of the Front End Guards with the theoretical touch will not be pushed over and broken. In summary, whether the stalks are broken or not, or pushed down depends on whether the deflection angle when the stalks arrive at the tail board of the harvesting device is greater than the critical value of the deflection angle when the stalks are broken, and whether the half width of the front-end guard plate is less than 7.68 mm.

Field experiment

Inclination of the grain separator, clamping angle of the grain splitter, height of the front end of the grain splitter from the ground and front-end guards half width were selected as the evaluation indexes to explore the optimal combination of the parameters of the front end of the grain splitter for the field test.

The test period was from September 10 to September 12, 2022; the test site: 47°N planting area in the upstream township of Yian County, Qiqihar City, Heilongjiang Province; and the test equipment consisted of: a 4YX-6 fresh corn combine harvester, a Kubota GPS meter, a tape measure and a stopwatch. The 4YX-6 fresh corn harvester, shown in Fig. 5, is a 6-row fresh corn combine harvester independently developed by the Heilongjiang Provincial Research Institute of Agricultural Machinery Science and Engineering for field harvesting operations.

Fig. 5 - Field operation of 4YX-6 fresh corn combine harvester

The test variety is "Wan Nuo 2000". In accordance with the provisions of "Corn Harvesting Machinery" *(GB/T21962-2020)*, three 50 m-long horizontal non-opposed rows were randomly selected, in which the effective harvesting distance was more than 20 m, and the broken plants, diseased ears and ears with a height of 35 cm or less from the ground were removed from the test area before the test *(Lei et al., 2018)*.

Combining the above analysis with the field operation of the fresh corn harvester, the inclination of the grain separator, clamping angle of the grain separator, height of the front end of the grain separator from the ground and front end guards half width, which have a greater impact on stalk breakage and cob loss, were selected as the test factors.

In the measurement area and cleanup area, collect the missed and fallen ears (including the ear segments of more than 5 cm), weigh out the mass after stripping *(Li, 2019)*, and calculate the loss rate of ears through Eq.4.

$$S_U = \frac{M_U}{M_Z} \times 100\% \quad [\%] \tag{4}$$

where:

S_U is the loss rate of ears; M_U is the lost cob mass; M_Z is the total mass harvested in the test area.

Statistics of the total number of stalks in each test area are made and the average value that is the total number of stalks in the test area is considered. After the harvester completes the harvesting operation, the number of broken stalks in the operating area are counted again and recorded. The total number of stems and the number of broken stems were calculated, and the ratio was recorded as the stem breaking rate, that is, the Eq.5:

$$Z_R = \frac{Z_U}{Z_D} \times 100\% \quad [\%] \tag{5}$$

where:

Z_R is the fracture rate of stalks; Z_U is the number of broken stalks; Z_D is total number of stalks in the test area.

RESULTS

During the field test, the forward speed of the harvester was set to 6.7 km/h, and the Design-Export software was used to carry out the secondary rotary combination design test on the test data, which clarified the optimal coordination of the various parameters of the front-end device of the grain splitter *(Wang et al., 2019)*. The test factors and levels are shown in Table 1, and the selection of each level meets the requirements of field operation, and the average value of the statistical results after repeating the test three times for each test group was recorded as shown in Table 2.

Table 1

Table of factors and levels

Level	Factors			
	Inclination of the grain separator Q (°)	Clamping angle of the grain splitter J (°)	Height of divider tip from the ground H (mm)	Front end guards half width L (mm)
1	20	25	100	2.5
2	27.5	32.5	250	7.5
3	35	40	400	12.5

Table 2

Experimental program and results

Number	Factors				Indicators		Number	Factors				Indicators	
	Q	J	H	L	Z_R	S_U		Q	J	H	L	Z_R	S_U
1	20	25	100	2.5	15.79	16.78	16	35	40	400	12.5	27.82	29.26
2	35	25	100	2.5	19.74	18.14	17	20	32.5	250	7.5	12.59	14.39
3	20	40	100	2.5	13.43	15.21	18	35	32.5	250	7.5	14.85	15.47
4	35	40	100	2.5	15.14	16.42	19	27.5	25	250	7.5	19.81	20.13
5	20	25	400	2.5	19.07	20.41	20	27.5	40	250	7.5	17.77	17.59
6	35	25	400	2.5	20.28	21.38	21	27.5	32.5	100	7.5	12.41	13.92
7	20	40	400	2.5	16.79	17.77	22	27.5	32.5	400	7.5	16.32	17.55
8	35	40	400	2.5	18.22	19.24	23	27.5	32.5	250	2.5	8.26	9.27
9	20	25	100	12.5	26.47	27.13	24	27.5	32.5	250	12.5	17.91	18.84
10	35	25	100	12.5	28.59	28.07	25	27.5	32.5	250	7.5	10.6	13.65
11	20	40	100	12.5	22.9	27.18	26	27.5	32.5	250	7.5	11.64	12.84
12	35	40	100	12.5	22.51	26.58	27	27.5	32.5	250	7.5	11.72	13.16
13	20	25	400	12.5	26.75	30.00	28	27.5	32.5	250	7.5	11.59	12.95
14	35	25	400	12.5	29.58	31.53	29	27.5	32.5	250	7.5	12.08	13.30
15	20	40	400	12.5	28.31	28.61	30	27.5	32.5	250	7.5	12.19	12.92

Regression model construction and testing

Combined with the analysis of experimental data results and multiple regression fitting *(Tang et al., 2021; Liu et al., 2015)*, the analysis of variance of fracture rate of stalk Z_R is shown in Table 2. (L_1 is the level corresponding to the inclination angle of the grain sorting machine, L_2 is the level corresponding to the holding angle of the divider, L_3 is the level corresponding to the height of the divider tip from the ground, and L_4 is the level corresponding to the half width of the front guard plate). From Table 2, it can be seen that, among them, the effect of L_1, L_2, L_3, L_4, L_2L_3, L_2^2, L_3^2 on fracture rate of stalk Z_R is highly significant ($P<0.01$); the effect of L_1L_2, L_1^2 on fracture rate of stalk Z_R is more significant ($0.01<P<0.05$); the effect of L_1L_3, L_1L_4, L_2L_4, L_3L_4, L_4^2 on fracture rate of stalk Z_R was not significant ($P>0.1$). The regression sum of squares and degrees of freedom of the non-significant interaction terms were analyzed by ANOVA after incorporating them into the residual terms, which in turn led to the regression equation for the effect of each experimental factor on fracture rate of stalk Z_R as shown in Eq.6:

$$Z_R = 0.81L_1 - 1.29L_2 + 1.45L_3 + 4.67L_4 - 0.49L_1L_2 + 0.75L_2L_3 + 1.22L_1^2 + 6.29L_2^2 + 1.86L_3^2 + 12.07 \quad (6)$$

Doing a loss-of-fit test on Eq.6 yields that $P=0.1266$ is not significant ($P>0.1$), thus indicating that there are no other major factors affecting the test indicator and that there is a significant quadratic relationship between the test indicator and the test factor.

Regression model and significance test for loss rate

Combined with the analysis of the results of the experimental data and multiple regression fitting, the analysis of variance of loss rate of ears S_U is shown in Table 3. As shown in Table 3, which shows that L_1, L_2, L_3, L_4, L_1^2, L_2^2, L_3^2 have a highly significant effect on the loss rate of ears S_U ($P<0.01$); the effect of L_2L_3, L_4^2, is more significant on the loss rate of ears S_U ($0.01<P<0.05$); the effect of L_2L_4 is significant on the loss rate of ears S_U ($0.05<P<0.1$); L_1L_2, L_1L_3, L_1L_4 , L_3L_4 had a non-significant effect on loss rate of ears S_U ($P>0.1$). The regression sum of squares and degrees of freedom of the non-significant interaction terms were analyzed by ANOVA after incorporating them into the residual terms, which in turn led to the regression equation for the effect of each test factor on loss rate of ears as shown in Eq.7:

$$S_U = 0.48L_1 - 0.87L_2 + 1.46L_3 + 5.14L_4 - 0.23L_2L_3 + 0.19L_2L_4 + 1.57L_1^2 + 5.5L_2^2 + 2.37L_3^2 + 0.69L_4^2 + 13.25 \quad (7)$$

Doing a loss of fit test on Eq.7 yields $P=0.2059$ is not significant ($P>0.1$), thus indicating that there are no other major factors affecting the test indicator and that there is a significant quadratic relationship between the test indicator and the test factor.

Table 3

ANOVA of variance between stem breakage and corn ear loss rate

Indicators	Z_R					S_U				
Source	**Sum of Squares**	**df**	**Mean Square**	**F-value**	**P-value**	**Sum of Squares**	**df**	**Mean Square**	**F-value**	**P-value**
Model	1091.67	14	77.98	108.76	<0.0001***	1145.01	14	81.79	502.52	<0.0001***
L_1	11.89	1	11.89	16.58	0.001**	4.12	1	4.12	25.3	0.0001**
L_2	29.88	1	29.88	41.67	<0.0001***	13.71	1	13.71	84.25	<0.0001***
L_3	38.02	1	38.02	53.03	<0.0001***	38.49	1	38.49	236.47	<0.0001***
L_4	393.12	1	393.12	548.3	<0.0001***	476.17	1	476.17	2925.71	<0.0001***
L_1L_2	3.85	1	3.85	5.37	0.035**	0.2678	1	0.2678	1.65	0.219
L_1L_3	0.363	1	0.363	0.5063	0.4877	0.1828	1	0.1828	1.12	0.3061
L_1L_4	1.12	1	1.12	1.56	0.2308	0.3875	1	0.3875	2.38	0.1437
L_2L_3	9.11	1	9.11	12.7	0.0028**	0.8603	1	0.8603	5.29	0.0363**
L_2L_4	0.1314	1	0.1314	0.1833	0.6747	0.5513	1	0.5513	3.39	0.0856*
L_3L_4	0.1871	1	0.1871	0.2609	0.6169	0.2048	1	0.2048	1.26	0.2797
L_1^2	3.83	1	3.83	5.35	0.0354**	6.35	1	6.35	38.99	<0.0001***
L_2^2	102.39	1	102.39	142.81	<0.0001***	78.24	1	78.24	480.7	<0.0001***
L_3^2	8.98	1	8.98	12.52	0.003**	14.55	1	14.55	89.42	<0.0001***
L_4^2	0.8761	1	0.8761	1.22	0.2864	1.23	1	1.23	7.58	0.0148**
Residual	10.75	15	0.717			2.44	15	0.1628		
Lack of Fit	9.17	10	0.9168	2.89	0.1266	1.98	10	0.1981	2.15	0.2059
Pure Error	1.59	5	0.3173			0.4605	5	0.0921		
Cor Total	1102.42	29				1147.45	29			

*Note: *** means highly significant ($P < 0.01$), ** means more significant ($0.01 \le P < 0.05$); * means significant ($0.05 \le P < 0.1$).*

The experimental data were processed using Design-Export 13, and the response surface of the interaction of factors on fracture rate of stalk and loss rate of ears was obtained by regression equation as shown in Fig. 6.

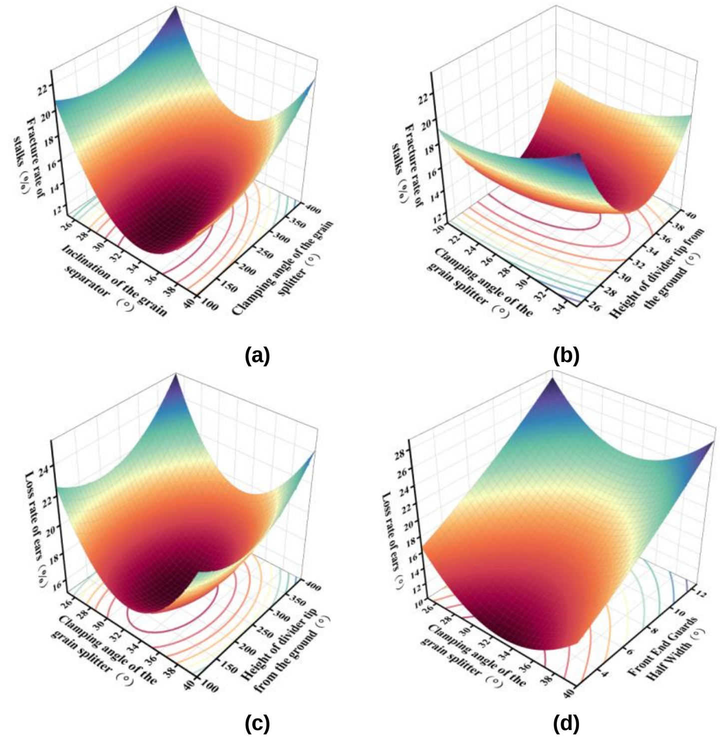

Fig. 6 - Response surface for the effect of interactions on indicators

Combined with Fig.6a, it can be seen that when the height of the front end of the grain separator is 250 mm, the half width of the front end guard plate is 7.5 m, and the inclination angle of the grain separator is kept constant, the breaking rate of the stem decreases first and then increases with the increase of the clamping angle of the grain separator. When the holding angle of the grain separator is constant, then the fracture rate of stalks with the increase of the clamping angle of the grain separator shows the trend of first decrease and then increase; when the grain separator clamping angle is constant, the fracture rate of stalks with the increase of the inclination of the grain separator is slightly showing the trend of decreasing. The reason is that the fixed width of the rear end of the grain splitter is 296 mm, with the increasing clamping angle of the grain splitter, the front edge of the grain splitter keeps approaching to the front guard plate, the short edge of the grain splitter leads to the poor effect of the grain splitter, and the deflection angle of the edge of the grain splitter and the maize stalks increases when touching, and the number of stalks pushed down and broken directly increases with the forward movement of the harvester. When the clamping angle of the grain separator is constant, the fracture rate of stalks with the increase of the inclination angle of the grain separator slightly shows a downward trend, because the inclination angle of the grain separator is constantly increasing, and the deflection angle of the corn stalks when touching them is constantly becoming smaller, the number of stems entering the snapping device increased. Therefore, in the interaction between the inclination of the grain separator and the clamping angle of the grain splitter, the clamping angle of the grain splitter is the main factor affecting the fracture rate of stalk.

In Fig. 6b it can be seen that when the clamping angle of the grain separator is 27.5° and the front end guards half width is 7.5 mm, keeping the height of the front end of the grain separator from the ground is constant, the fracture rate of stalks shows a trend of decreasing and then increasing with the increase of the clamping angle of the grain separator. The reason is that when the height of the front end of the grain separator is constant, the angle of the deflection of the stalks and the edges of the grain separator is increasing with the clamping angle of the grain separator and the amount of the fracture rate of stalks is increasing; maintaining the clamping angle of the grain separator is constant. Fracture rate of stalks showed an increasing trend with the increase of the height of the front end of the grain separator from the ground. The reason is that when the clamping angle of the grain splitter is constant, with the increasing height of the front end of the grain splitter from the ground, the stalk deflection angle increases, and the number of corn stalks broken to both sides increase. Therefore, in the interaction between the clamping angle of the grain splitter and the height of the front end of the grain splitter from the ground, the clamping angle of the grain splitter was the main factor affecting the fracture rate of stalks.

For the cob loss rate S_{u}, Fig.6c shows that when the clamping angle of the grain separator is 27.5° and the front end guards half width is 7.5.mm, the cob loss rate with the increase of the height of the front end of the grain separator from the ground shows a decreasing trend. The reason is that the height increase of the deflection degree of the stalks decreases, and the number of stalks smoothly entering the spike picking gap increases, the number of cobs picked increases. When the height of the front end guards half width of the grain separator from the ground is a certain height, the loss rate of ears shows a decreasing and then increasing trend. When the height of the front end of the grain splitter from the ground is constant, the loss rate of ears decreases with the increase of the clamping angle of the grain splitter. The reason is that the increase of the clamping angle of the grain splitter, the force edge of the divider increases, the number of stalks entering the spike picking gap increases, and the number of spikes lost and missed becomes less, and the loss rate of ears decreases relatively. In the interaction between the clamping angle of the grain splitter and the height of the front end of the splitter from the ground, the clamping angle of the grain splitter was the main factor affecting the loss rate of ears.

Fig.6d shows that when the inclination angle of the grain separator is 27.5°, and the height of the front end of the grain separator from the ground is 250 mm, when the clamping angle of the grain separator is maintained at a certain level, the loss rate of ears increases with the increase of the front end guards half width, because when the half width of the front end guards is increased, the wider the front end of the grain separator, the probability of the stalk touching the front end guards half width in the front section of the grain separator increases, and the stalk pushed back by the harvester increases, and the loss rate of ears increases. When the front-end guards half width is constant, the loss rate of ears increases with the increase of the clamping angle of the grain splitter, because when the clamping angle of the grain splitter increases, the force edge of the divider reduced and the fracture rate of stalks increases, resulting in an increase in the fracture rate of stalks, and the loss rate of ears increases as a result. In the interaction between clamping angle of the grain splitter and front end guards half width, the main factor affecting the loss rate of ears was the length of front end guards half width.

Combined with the fresh corn harvester field operation requirements, quadratic regression model and response surface analysis, the set constraints and mathematical models for each test factor are:

$$\begin{cases} minZ_R(L_1, L_2, L_3, L_4) \\ minS_U(L_1, L_2, L_3, L_4) \\ s.t. \begin{cases} 20° \le L_1 \le 35° \\ 25° \le L_2 \le 40° \\ 100mm \le L_3 \le 400mm \\ 2.5mm \le L_4 \le 12.5mm \end{cases} \end{cases}$$

Optimization module was applied to optimize the experimental parameters *(Zhu et al., 2023;Zhu et al., 2022)*, combined with the constraints interval to select the optimal level combination, to obtain the inclination of the grain separator of 27.7°, clamping angle of the splitter of 31°, the height of the front end of the grain separator from the ground is 270 mm and the front end guards half width of 3.8 mm, corresponding to the indicators of the stalk breakage rate of 8.63%, the loss rate of ears of 9.42%. At this time, the experimental index effect was optimal. Using the optimized front-end parameters for verification tests, the fracture rate of stalks was 8.71% and the loss rate of ears was 9.47%, which was basically the same as the optimized results, and effectively improved the fracture rate of stalks and the loss rate of ears of the fresh maize harvester in the horizontal non-opposed row operation.

CONCLUSIONS

Aiming at the problem of high stalk breakage and large cob loss in non-opposed row harvesting of fresh corn, the front part of the grain splitter was designed, and combined with the deflection angle of the stalk and the front edge of the front end of the grain splitter to the force of the contact between the corn stalk and the front end of the distributor was analyzed. and clarified the design requirement of the clamping angle of the grain splitter to be less than 59°, it provides a reference for the design of corn harvester divider.

Inclination of the grain separator, clamping angle of the grain splitter, height of the front end of the grain splitter from the ground and front end guards half width were selected as the factors, and the regression orthogonal test was conducted with the indexes of fracture rate of stalk and loss rate of ears, combined with the analysis of variance (ANOVA) and the analysis of response surface (ASRS), and it was concluded that the inclination angle of the grain splitter is 27.7°, the clamping angle of the grain splitter is 31°, the height of the front end of the grain separator from the ground is 270 mm, and the front end guards half width of 3.8 mm is the maximum of the front end guards half width. When the half-width is 3.8 mm, the expected effect is optimal, and the corresponding indexes of stalk breakage rate is 8.63% and loss rate of ears is 9.42%. The verification test on the optimized parameters yielded a stalk breakage rate of 8.71% and a cob loss rate of 9.47%, which were basically consistent with the expected results and the operation effect was ideal.

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