

DESIGN AND EXPERIMENT OF TELESCOPIC ROD TOOTH-RIBBED ROD ROLLER TYPE BUCKWHEAT THRESHING DEVICE

伸缩杆齿-纹杆式荞麦脱粒装置设计与试验

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ABSTRACT

Aiming at the problems of high moisture content of stems during buckwheat harvesting and easy clogging of grid concave plates, a telescopic rod tooth-ribbed rod roller type threshing device was designed. The device is mainly composed of a ribbed rod roller and telescopic rod teeth. When the ribbed rod roller type rotates, the telescopic rod teeth do reciprocating telescopic motion. When the rod teeth rotate to the minimum threshing gap, the outstretch length is the smallest. When the rod teeth rotate to the top, the outstretch length maximum. The device solves the problems of poor material flow between threshing devices and clogging of grid concave plates. This threshing device was attached to the threshing performance test bench, and the buckwheat threshing test was performed. Through the single factor test, the threshing parameter range under the condition of low loss rate and damage rate of the threshing device was obtained: the speed of the threshing roller is 350~450 r/min, the feeding amount is 0.8~1.2 kg/s, and the threshing gap is 9~11 mm. Through the quadratic orthogonal rotation combination test, the results were fitted by multiple linear regression, and the regression equations of the loss rate and the broken rate were obtained, and the significance test was carried out. The response surface analysis of the main influencing factors was carried out to explore the influence of threshing parameters on the loss rate and damage rate. Through parameter optimization, the threshing parameter combination with the lowest loss rate and damage rate of the threshing device was obtained. The speed of the threshing roller is 405.47 r/min, the feed amount is 1.06 kg/s, and the threshing gap is 10.49 mm. Under these conditions, the loss rate is 0.05%, and the damage rate is 4.05%. The overall performance of the threshing device is good, which provides a theoretical basis for the research and development of buckwheat mechanized harvesting equipment.

摘要

针对荞麦收获时茎秆含水率高,容易堵塞栅格凹板等问题,设计了伸缩杆齿-纹杆式脱粒装置。该装置主要由纹杆滚筒和伸缩杆齿组成,纹杆滚筒旋转时,伸缩杆齿往复伸缩,当杆齿旋转至最小脱粒间隙处时伸出量最小,当杆齿旋转至上方时伸出量最大。该装置很好地解决了物料在脱粒装置间流动不畅、堵塞栅格凹板等问题。将该脱粒装置安装于脱粒性能试验台,进行荞麦脱粒试验。通过单因素试验,获得该脱粒装置损失率和破碎率较低情况下脱粒参数范围为:脱粒滚筒转速 350~450r/min,喂入量 0.8~1.2kg/s,脱粒间隙 9~11mm。通过二次正交旋转组合试验,对结果进行多元线性回归拟合,得到损失率和破碎率的回归方程,并进行显著性检验。对主要影响因素进行响应面分析,探究脱粒参数对损失率和破碎率的影响规律。通过参数优化,获得该脱粒装置损失率和破碎率最低的脱粒参数组合,脱粒滚筒转速 405.47r/min,喂入量 1.06kg/s,脱粒间隙 10.49mm,该条件下损失率 0.05%,破碎率 4.05%。该脱粒装置整体性能良好,为荞麦机械化收获装备研发提供理论依据。

INTRODUCTION

Buckwheat is an internationally recognized multi-purpose multi-grain economic crop that integrates nutrition, health care, medicine, feed and honey, and its development prospects are extremely broad (Huang Xiaona et al., 2018).

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Due to the special harvesting characteristics of buckwheat, the lower grains are already mature, while the upper ends are still blooming, the maturity is extremely inconsistent, and the mature grains are easily shed, making mechanized harvesting of buckwheat difficult (Farooq *et al.*, 2016). At present, most of the existing buckwheat combine harvesters are models of grain combine harvesters after structural transformation. When the buckwheat plants are harvested under the condition of high-water content, there are many problems such as winding braids, clogging grid concave plates, serious grain damage, etc. It seriously affects the quality of mechanized harvesting of buckwheat (Ren Changzhong *et al.*, 2018).

At present, researchers have done a lot of research on threshing and separation devices, mainly based on the material characteristics of different crops, on the basis of traditional threshing forms, to improve threshing elements, structures, etc., and carry out research on threshing performance. Di Zhifeng *et al.* (2018) analysed the structural characteristics of the existing threshing roller, designed a combined axial-flow corn threshing roller, and tested it on a self-made corn threshing test bench. Wang Zhendong *et al.* (2021) studied the structural parameters of the corrugated bar threshing element, and used a combination of static analysis and dynamic analysis to determine the performance of the corrugated bar threshing element to effectively reduce the grain breakage rate. Dhananchezhian *et al.* (2013) developed the nylon rasp bar threshing cylinder to solve the problem of high crushing in the process of rice threshing. Govindaraj *et al.* (2017) studied the effects of different harvesting methods and threshing methods on the quality of rice seeds, which provided the basis for the development of rice breeding threshers. Lachuga *et al.* (2020) studied the adaptability of different threshing devices to different crops, and laid the foundation for the research and development of new threshing devices. Although some staged results have been achieved, the main research objects are wheat, rice, corn and other grain crops, which are not suitable for the threshing and separation of buckwheat, a small grain crop (Petkevichius *et al.*, 2008; Powar *et al.*, 2019; Li Yibo *et al.*, 2020).

Crops such as buckwheat are harvested under high moisture content, which challenges existing threshing devices. At present, the threshing device mainly adopts the threshing method of the nail-toothed roller, the ribbed roller and the grid concave plate (Barac *et al.*, 2011; Ji Jiangtao *et al.*, 2020; Steponavičius *et al.*, 2018). When the moisture content of the crop is high, the threshing roller will be blocked, and there are many impurities after threshing, which makes cleaning difficult. In order to solve the problem of threshing in the state of high moisture content, the main starting point is the structure of the threshing device. The flexible threshing device, the reduction of the roller speed, and the setting of a multi-roller cooperating threshing device are used to solve the problem of difficult threshing of high-water crops to a certain extent (Rahman *et al.*, 2019; Jahanbakhshi *et al.*, 2017; Wang Jiawei *et al.*, 2020; Wang Shengsheng *et al.*, 2021).

In this paper, a new type of threshing device is innovatively designed to effectively solve the problem of buckwheat threshing under high water content. It is the theoretical basis for the research and development of the buckwheat combine harvester, and have great significance to improve the level of mechanized harvesting of buckwheat.

MATERIALS AND METHODS

Telescopic rod tooth-ribbed rod roller type buckwheat threshing device

Overall structure

The overall structure of the telescopic rod tooth-ribbed rod roller type buckwheat threshing device is shown in Fig. 1. It is mainly composed of screw feeding device, telescopic rod teeth, ribbed rod roller type, grid concave plate, frame, feeding inlet, top cover, side cover and so on. When working, the materials enter from the feeding inlet, and under the action of the screw feeding device, enter between the grid concave plate and the ribbed rod roller. Under the rubbing and squeezing action of the ribbed rod roller and the grid concave plate, the separation of the grains and the stalks are realized. The grains and debris fall into the cleaning box through the grid concave plate, and the straws move spirally backward under the action of the ribbed rod roller, which are discharged out of the machine through the grass discharge port. During the rotation process of the ribbed rod roller, it drives the hinged rod teeth to do reciprocating telescopic motion. The 25 telescopic rod teeth arranged in the axial spiral of the threshing roller further impact and beat the materials during the rotation process, so as to realize the difficult-to-thresh grains separation from stalks. During the rotation and telescopic of the rod teeth, the materials can be rolled and pushed backwards well, and the long stalks can be taken away from the minimum gap between the ribbed rod roller and the grid concave plate, thereby avoiding blocking the grid concave plate.

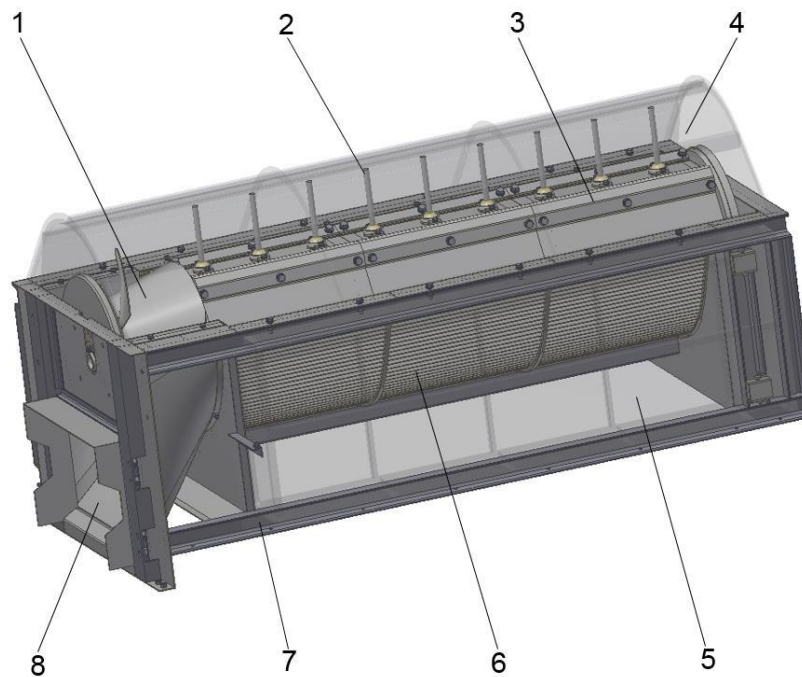


Fig. 1 - Structure of the telescopic rod tooth-ribbed rod type buckwheat threshing device
 1- Screw feeding device; 2- Telescopic rod teeth; 3- Ribbed rod roller; 4- Top cover; 5- Side cover;
 6- Grid concave; 7- Frame; 8- Feeding inlet

Ribbed rod roller type

The structure of the ribbed rod roller type is shown in Fig. 2. It adopts a hexagonal full-covering design, a ribbed rod roller type is installed at each corner, and a row of round holes is opened in the centre of the 3-sided clad iron plate for fixing the hinged ball. The front end of the ribbed rod roller is connected with the screw feeding device, and the rear section is fixed on the frame through bearings, and is driven by the main shaft to realize rotation. The ribbed rod roller's rotation diameter is 455 mm.

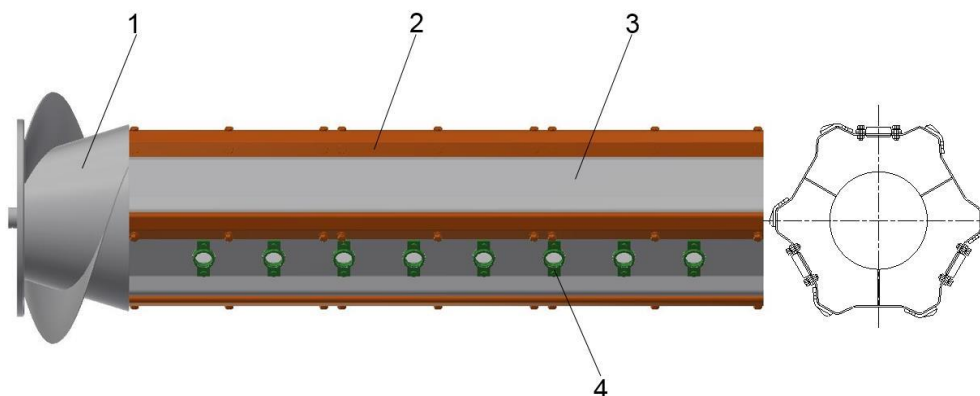


Fig. 2- Structure of ribbed rod roller type
 1- Screw feeding device; 2- Ribbed rod; 3- Iron plate; 4- Fixed hinge seat

Telescopic rod tooth

The structure of the telescopic rod tooth is shown in Fig. 3. The rod teeth are installed on the rod tooth holder through pins, and the rod tooth holder is sleeved on the support rod and can rotate around the support rod. The front end of the support rod is connected with the front fixed support, and the front fixed support is supported on the rotating spindle through the bearing. The rear end of the support rod is connected with the rear fixed support, and the rear fixed support is supported on the rotating shaft through the bearing. The eccentric distance between the support rod and the main shaft is 70 mm. The rod teeth are fixed in the hinge ball seat by linking the hinge ball, and can be freely retracted and rotated at a certain angle. When the ribbed rod roller rotates, the support rod remains stationary, and under the action of the linking ball hinge, the rod teeth rotate around the support rod and reciprocate relative to the ribbed rod roller type. When the rod tooth rotates to the upper position, the maximum outstretch length

is 145 mm, and when the rod tooth rotates to the lower position, the minimum outstretch length is 5 mm. Since there is a minimum threshing gap below the ribbed rod roller type and the grid concave plate, and an open large space just above the ribbed rod roller type and the top cover, the telescopic bar teeth can just realize the overturning, stirring and shaking of the material in a large space, while avoiding clogging of the grid concave at the smallest gap.

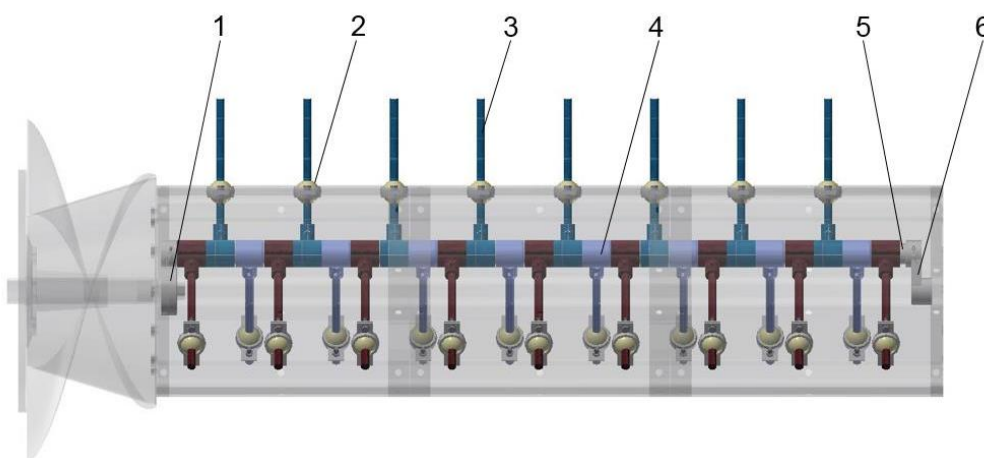


Fig. 3 - Structure of telescopic rod tooth

1- Front fixed support; 2- Link hinge ball; 3- Rod tooth; 4- Rod tooth holder; 5- Support rod; 6- Rear fixed support

Grid concave

The structure of the grid concave is shown in Fig. 4. The grid concave is mainly welded into a whole by the fixed plate, the grid rib and the grid rib fixed plate. The front and rear ends are grid rib fixed plates, and 733 mm thick grid ribs are arranged at equal intervals in the middle circumferential direction. The grid ribs are pierced with iron wires of $\phi 3$ mm at equal intervals of 15 mm in the axial direction, forming a series of grids with a length of $b=15$ mm and a width of $a=12$ mm. The inner diameter of the grid concave is 320 mm, and the right side is inclined outward to form a larger space, which is convenient for the tossing and shaking of materials. The grid concave is connected with the frame by bolts through the fixing plate.

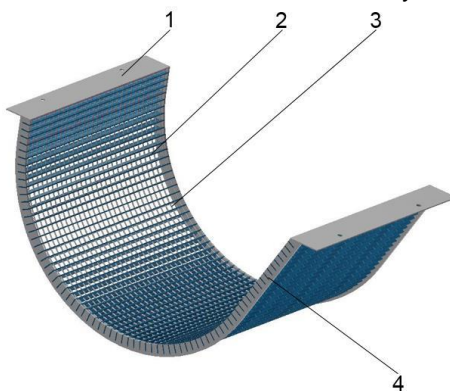


Fig. 4 - Structure of grid concave

1- Fixed plate; 2- Grid rib; 3- Iron wire; 4- Grid rib fixed plate

Telescopic rod tooth-ribbed rod type threshing device performance test bench

The performance test bench of the telescopic rod tooth-ribbed rod roller threshing device is shown in Fig. 5. It is mainly composed of the telescopic rod tooth-ribbed rod roller threshing device, feeding bridge, conveyor belt, receiving box, motor, frame, control unit, grid concave adjustment mechanism, etc. When working, the buckwheat evenly spread on the conveyor belt is sent to the feeding bridge entrance at a constant speed, and reaches the feeding entrance of the threshing device through the feeding bridge, and enters the threshing device under the action of the screw feeding device. After threshing, the grains and mixture fall into the receiving box, and the straw is discharged from the grass discharge port. The conveyor belt and the threshing roller are respectively driven by frequency conversion motors, and the speed can be adjusted through the control unit. The grid concave adjustment mechanism is used to adjust the threshing gap for different types of tests.



Fig. 5- Threshing device performance test bench

Test materials and test methods

Test materials

The experimental buckwheat is Hongshan buckwheat grown in the experimental field of Shanxi Agricultural University. Artificial harvesting and natural drying for testing. The characteristics of buckwheat are shown in Tab. 1.

Table 1

Main properties of buckwheat

Parameter	Value
Average high of buckwheat [mm]	1050-1420
Average grain moisture content [%]	9.24
Average stem moisture content [%]	23.73
Grain to grass ratio	1:2.48
Thousand weight [g]	26.21

Test methods

The test was performed according to GB/T 5982-2017 "Thresher Test Method" and GB/T 5262-2008 "General Provisions for Determination of Agricultural Machinery Test Conditions". Before the test, 6kg of buckwheat was evenly spread on a conveyor belt with a length of 10 m and a width of 1 m, and the stalks of the buckwheat were placed as disorderly as possible to simulate the operation of the combine harvester. Different feeding amounts were achieved by controlling the speed of the conveyor belt, the speed of the threshing roller was adjusted by the frequency converter, and the threshing gap was adjusted by the grid concave plate adjustment mechanism (Wang Jiawei et al., 2020; Bello et al., 2019). In the experiment, the feeding amount, the rotational speed of the threshing roller and the threshing gap were selected as the factors, and the grain damage rate and the loss rate were selected as the indicators. According to the test plan, each test was repeated 3 times. After the test, the prolapsed mixture in the receiving box was manually sorted, cleaned and weighed. Manually clean the discharged straw, count the quality of entrained and unremoved grains, and calculate the loss rate. After cleaning, the grains were manually sampled according to the quartering method, and the broken grains were manually selected and weighed to calculate the damage rate of the grains. The loss rate and damage rate were calculated as follows:

$$Z_s = \frac{W_j + W_w}{W} \times 100\% \quad (1)$$

$$W = W_t + W_j + W_w \quad (2)$$

$$Z_p = \frac{W_p}{W_y} \times 100\% \quad (3)$$

Where: Z_s is loss rate, [%]; Z_p is damage rate, [%]; W_j is entrainment loss of grain quality, [g]; W_w is unremoved loss of grain quality, [g]; W_t is threshed grain quality, [g]; W is total grain quality, [g]; W_p is damage grain quality in the sample, [g]; W_y is grain quality of the sample, [g].

RESULTS

Single factor test

Under the condition that the feeding rate is 0.8 kg/s and the threshing gap is 8 mm, the single factor test of different threshing roller speed is carried out to explore the influence of different threshing roller speeds on the loss rate and the damage rate. From Fig. 6, it can be found that in the range of 300~500 r/min, the loss rate decreases first and then increases with the increase of the threshing roller speed. When the speed of the threshing roller is 400 r/min, the loss rate is at least 0.05%. So, 400 r/min is the best working condition of threshing roller speed for loss rate. It can also be found that in the range of 300~500 r/min, the damage rate gradually decreases with the increase of the threshing roller speed. Starting from 400 r/min, the change trend is relatively gentle, and the speed of 400 r/min is the best working condition of threshing roller speed for the damage rate.

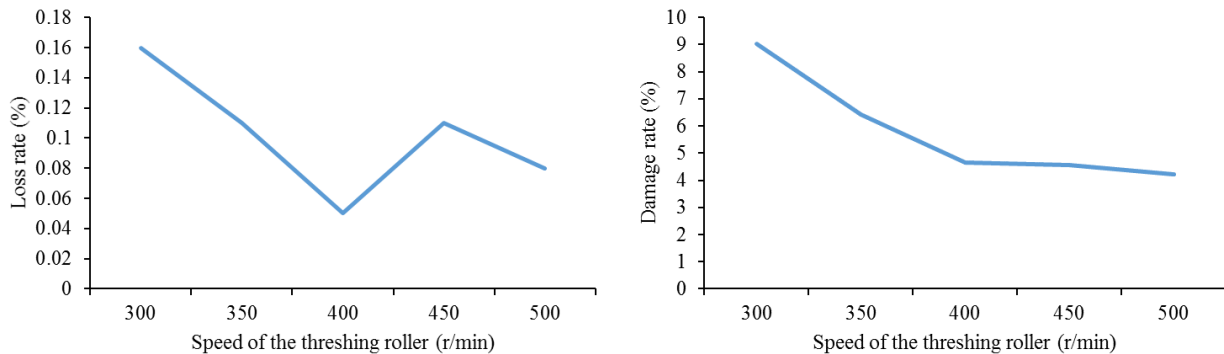


Fig. 6 - Effect of different threshing roller speed on loss rate and damage rate

Under the condition that the threshing roller speed is 400 r/min and the feeding rate is 1.0 kg/s, the single factor test of different threshing gap is carried out to explore the influence of different threshing gaps on the loss rate and the damage rate. From Fig. 7, it can be found that in the range of 8~14 mm, the loss rate first increases, then decreases and then increases with the increase of the threshing gap. When the threshing gap is 10 mm, the minimum loss rate is 0.03%, and the threshing gap of 10 mm is the best working condition of the loss rate. It can also be found that in the range of 8~14 mm, the damage rate first decreases and then increases with the increase of the threshing gap. When the threshing gap is 10 mm, the minimum damage rate is 3.57%, and the threshing gap of 10 mm is the best working condition regarding the damage rate.

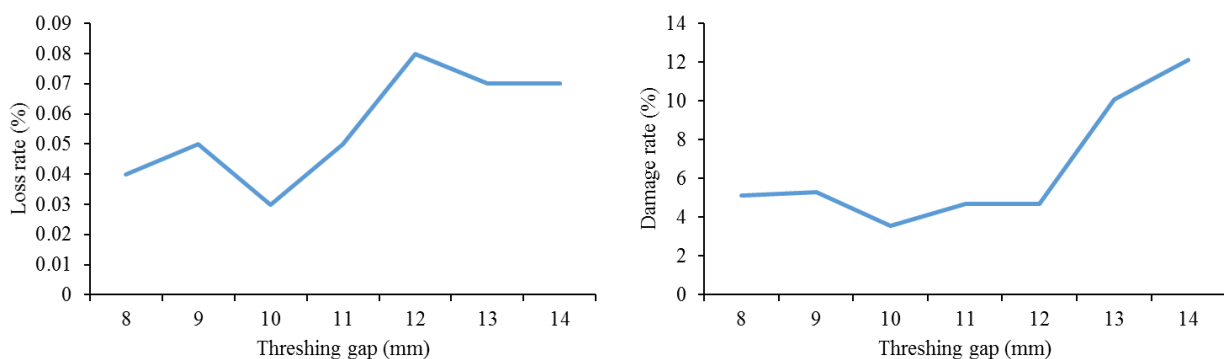


Fig. 7 - Effect of different threshing gap on loss rate and damage rate

Under the condition that the threshing roller speed is 400 r/min and the threshing gap is 10 mm, the single factor test of different feeding amount is carried out to explore the influence of different feeding amounts on the loss rate and the damage rate. From Fig. 8, it can be found that in the range of 0.6~1.4 kg/s, the loss first decreases, then increases and then decreases with the increase of the feeding amount. When the feeding amount is 1 kg/s, the loss rate is at least 0.04%, and the feeding amount of 1 kg/s is the best working condition regarding the loss rate. It can also be found that in the range of 0.6~1.4 kg/s, there is no significant trend in the change of the damage rate with the increase of the feeding amount. When the feeding amount is 1 kg/s, the damage rate is at least 4.5%, and the feeding amount of 1 kg/s is the best working condition with respect to the damage rate.

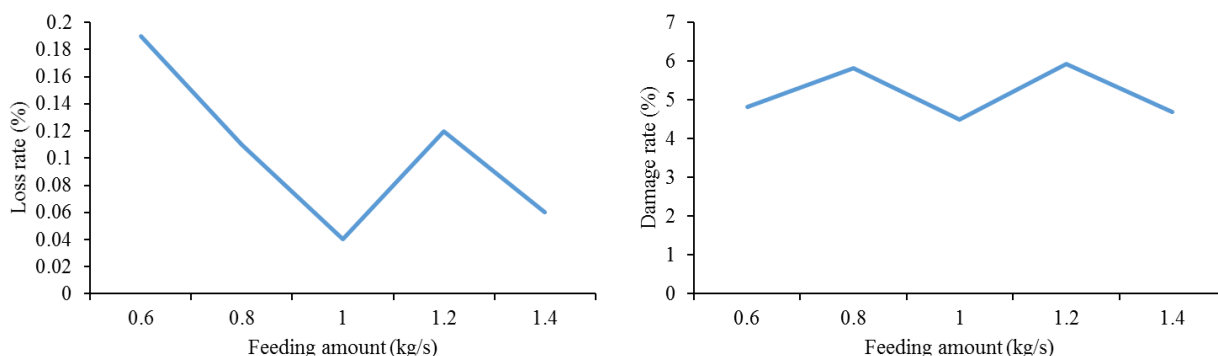


Fig. 8 - Effect of different feeding amount on loss rate and damage rate

Orthogonal test and result analysis

Orthogonal test

Based on the test results and analysis of the above single-factor test, the central composite test design principle is adopted, and the response value is the speed of the threshing roller (X_1), the feeding amount (X_2) and the threshing gap (X_3), and the coding of each test factor is shown in Tab. 2. And 23 groups of response surface analysis tests are carried out, as shown in Tab. 3.

Table 2

Test factors and levels

Coding	Factors		
	Threshing roller speed X_1 (r·min ⁻¹)	Feeding amount X_2 (kg·s ⁻¹)	Threshing gap X_3 (mm)
-1.682	316	0.66	8.32
-1	350	0.80	9.00
0	400	1.00	10.00
1	450	1.20	11.00
1.682	484	1.34	11.68

Table 3

Test design and results

Number	X_1	X_2	X_3	Loss rate Y_1 (%)	Damage rate Y_2 (%)
1	-1	-1	-1	0.147	4.47
2	1	-1	-1	0.176	5.07
3	-1	1	-1	0.043	4.70
4	1	1	-1	0.294	6.17
5	-1	-1	1	0.036	3.10
6	1	-1	1	0.203	5.40
7	-1	1	1	0.053	3.27
8	1	1	1	0.112	4.83
9	-1.682	0	0	0.096	3.67
10	1.682	0	0	0.297	5.77
11	0	-1.682	0	0.096	5.20
12	0	1.682	0	0.136	5.63

Table 3
(continuation)

Number	X_1	X_2	X_3	Loss rate Y_1 (%)	Damage rate Y_2 (%)
13	0	0	-1.682	0.143	3.40
14	0	0	1.682	0.205	4.93
15	0	0	0	0.043	5.00
16	0	0	0	0.054	3.67
17	0	0	0	0.050	4.25
18	0	0	0	0.049	4.06
19	0	0	0	0.056	3.68
20	0	0	0	0.044	3.57
21	0	0	0	0.049	4.39
22	0	0	0	0.058	4.02
23	0	0	0	0.053	3.80

Result analysis

Design-Expert 8.0.6 software was used, multiple linear regression fitting was performed on the data in Tab. 3, and the insignificant factors were eliminated to obtain the regression equations of the loss rate Y_1 and the damage rate Y_2 , and the significance test was carried out (Ji Jiangtao et al., 2016).

(1) Loss rate regression model and response surface analysis

Analysis of variance was performed on the loss rate, and the experimental model was significant ($p < 0.01$), indicating that the obtained regression model had a high fitting accuracy. The significance of each factor in the model was judged by comparing the p value. The factors X_1 , X_1^2 and X_3^2 in the model were extremely significant items ($p < 0.01$), X_3 , X_1X_2 , X_2X_3 and X_2^2 are significant items ($p < 0.05$), and other items are not significant ($p > 0.05$). The degree of influence of each factor on the loss rate in descending order was: X_1 , X_3 , X_2 .

The insignificant items were eliminated, and the regression equation of each factor to the loss rate Y_1 was obtained as follows:

$$Y_1 = 0.05 + 0.06X_1 - 0.01X_3 + 0.01X_1X_2 - 0.01X_2X_3 + 0.04X_1^2 + 0.02X_2^2 + 0.04X_3^2 \quad (4)$$

Because the interaction term X_1X_2 and X_2X_3 had a significant impact on the loss rate, the interaction term X_1X_2 and X_2X_3 were used to analyse the loss rate.

It can be seen from Fig. 9 that the speed of the threshing roller has a significant impact on the loss rate. With the increase of the threshing roller speed, the loss rate first decreases and then increases. This is because with the increase of the rotation speed of the threshing roller, the residence time of the material between the threshing roller and the grid concave plate decreases, and the grains and the straws were not sufficiently separated and were entrained in the straws and discharged out of the machine, resulting in an increase of the entrainment loss. However, if the rotation speed of the threshing roller was too small, the grains cannot be completely separated from the stalks, resulting in an increase in the loss of unthreshed.

It can be seen from Fig. 10 that the threshing gap has a significant impact on the loss rate. With the increase of the threshing gap, the loss rate first decreases and then increases. This is because with the increase of the threshing gap, the threshing separation effect of the material between the threshing roller and the grid concave plate becomes poor, and some of the grains were not completely separated from the stalks and were discharged out of the machine with the stalks, resulting in increased entrainment loss. If the threshing gap is too small, the stalks will be broken, which will lead to difficulty in cleaning and separation, and increase the entrainment loss.

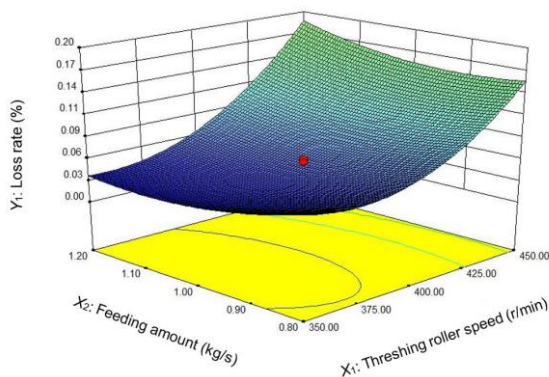


Fig. 9- Response surface of X₁ X₂ on loss rate

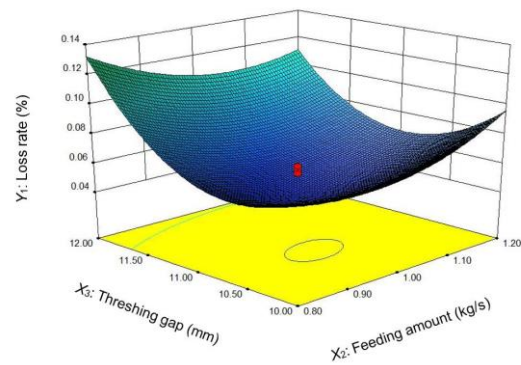


Fig. 10- Response surface of X₂ X₃ on loss rate

(2) Damage rate regression model and response surface analysis

Analysis of variance was performed on the damage rate, and the experimental model was significant ($p < 0.01$), indicating that the obtained regression model had a high fitting accuracy. The significance of each factor in the model was judged by comparing the p value. The factors X_1 and X_2^2 in the model were extremely significant items ($p < 0.01$), X_2 , X_3 , X_1X_2 , X_2X_3 and X_1^2 are significant items ($p < 0.05$), and other items are not significant ($p > 0.05$). The degree of influence of each factor on the damage rate in descending order was: X_1 , X_2 , X_3 . The insignificant items were eliminated, and the regression equation of each factor to the damage rate Y_2 was obtained as follows:

$$Y_2 = 4.05 + 0.69X_1 + 0.12X_2 - 0.09X_3 + 0.02X_1X_2 - 0.22X_2X_3 + 0.20X_1^2 + 0.44X_2^2 \tag{5}$$

Because the interaction term X_1X_2 and X_2X_3 has a significant impact on the damage rate, the interaction term X_1X_2 and X_2X_3 were used to analyse the damage rate. It can be seen from Fig. 11 that the speed of the threshing roller has a significant effect on the damage rate. With the increase of the speed of the threshing roller, the damage rate gradually increases. This is because with the increase of the rotational speed of the threshing roller, the impact and collision force of the ribbed rod roller and the telescopic rod teeth on the grains increases, thus resulting in an increase in the damage rate of the grains. With the increase of the feeding amount, the crushing decreases first and then increases. This is because when the feeding amount was small, the material entering between the threshing drum and the grid concave plate per unit time was less, and the probability of direct collision between the grain and the threshing element increased, thereby increasing the damage rate. When the feeding amount was large, the direct extrusion of the material also led to an increase of the damage rate. It can be seen from Fig. 12 that the threshing gap has a significant effect on the damage rate. As the threshing gap decreases, the damage rate gradually increases. This is because the threshing gap was reduced, the space between the threshing roller and the grid concave plate becomes smaller, and the impact of the material by the threshing element becomes larger, resulting in a larger grain damage rate.

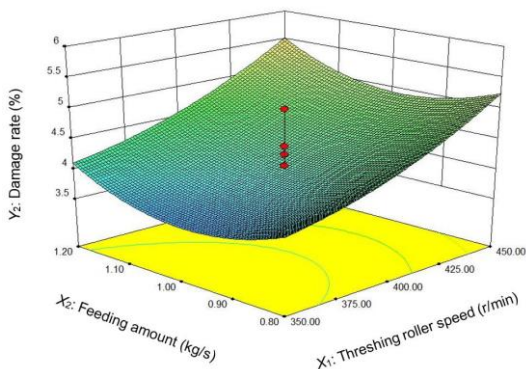


Fig. 11 - Response surface of X₁ X₂ on damage rate

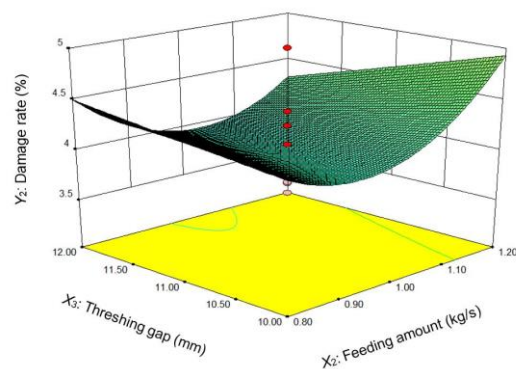


Fig. 12 - Response surface of X₂ X₃ on damage rate

(3) Parameter optimization

In order to obtain the optimal parameter combination of each factor of the telescopic rod tooth-ribbed rod roller type threshing device, the optimization constraints were selected according to the loss rate and the damage rate, and the multi-objective optimization algorithm of the Design-Expert 8.0.6 software was used to optimize the parameters. The constraints are as follows:

$$\begin{cases} \min Y_1(X_1, X_2, X_3) \\ \min Y_2(X_1, X_2, X_3) \\ 350\text{r/min} \leq X_1 \leq 450\text{r/min} \\ 0.8\text{kg/s} \leq X_2 \leq 1.2\text{kg/s} \\ 9\text{mm} \leq X_3 \leq 11\text{mm} \end{cases} \quad (5)$$

The optimization results are: when the speed of the threshing roller is 405.17 r/min, the feed amount is 1.06 kg/s, and the threshing gap is 10.49 mm, the loss rate is 0.05%, and the crushing rate is 4.05%.

CONCLUSIONS

(1) A telescopic rod tooth-ribbed rod roller type buckwheat threshing device was designed. When the ribbed rod roller rotates, the matched rod teeth do reciprocating telescopic motion. The device can well toss, rub and brush the material in the threshing device, and at the same time reduce the threshing loss rate and the damage rate, and avoid the clogging of the grid concave plate in the state of high-water content of the material, and the effect is remarkable.

(2) The telescopic rod tooth-ribbed rod roller type threshing device was installed on the threshing performance test bench to carry out the buckwheat threshing test. Through the single factor test, the working parameters of the threshing device were obtained under the condition of loss rate and damage rate as follows: the speed of the threshing roller was 350~450 r/min, the feeding amount was 0.8~1.2 kg/s, and the threshing gap was 9~11 mm.

(3) Through the quadratic orthogonal rotation test, the regression equations of loss rate and breakage rate were established, and the response surface analysis was carried out on the influencing factors, and the influence law of threshing parameters on loss rate and breakage rate was obtained. Through the optimization analysis, the best working parameter combination of the device was obtained as: the speed of the threshing roller was 405.17 r/min, the feed amount was 1.06 kg/s, and the threshing gap was 10.49 mm. Under this condition, the loss rate was 0.05%, and the crushing rate was 4.05%.

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REFERENCES

- [1] Barać S.R., Biberdžić M., Đikić A., (2011), Result of testing of seeds and quality losses of harvested mass depending on the drum-underdrum interspace at buckwheat harvest grain combines. (Rezultatul testării semințelor și a pierderilor de calitate ale masei recoltate în funcție de spațiul intersecție tambur-subdrum la combinele de boabe de recoltare din hrișcă). *Research Journal of Agricultural Science*, Vol. 43, Issue 1, pp. 283-288, Timisoara / Romania;
- [2] Bello B., Tokan A., Jiya D. et al., (2019), Design model of automated groundnut threshing machine, *Majlesi Journal of Mechatronic Systems*, Vol. 8, Issue 1, pp. 19-24, Tehran / Iran;
- [3] Dhananchezhayan P., Parveen S., Rangasamy K. et al., (2013), Development of a nylon rasp bar threshing cylinder for portable paddy thresher and its performance evaluation, *Madras Agricultural Journal*, Vol. 2013, Issue 100, pp. 623–626, New Delhi / India;

- [4] Di Zhifeng, Cui Zhongkai, Zhang Hua et al., (2018), Design and experiment of rasp bar and nail tooth combined axial flow corn threshing cylinder. *Transactions of the Chinese Society of Agricultural Engineering*, Vol. 34, Issue 1, pp. 28-34, Beijing / China;
- [5] Farooq S., Rehman R.U., Pirzadah T. et al., (2016), Cultivation agronomic practices and growth performance of buckwheat. Molecular breeding and nutritional aspects of buckwheat, Elsevier, Amsterdam/Netherlands;
- [6] Govindaraj M., Masilamani P., Asokan D. et al., (2017), Effect of different harvesting and threshing methods on seed quality of rice varieties. *International Journal of Current Microbiology and Applied Sciences*, Vol. 2017, Issue 6, pp. 2375-2383, Tamil Nadu / India;
- [7] Huang Xiaona, Zhang Weiguo, Dang Weilong et al., (2018), Research status and development trend of buckwheat harvesting machinery. *Farm Machinery*, Vol. 2018, Issue 10, pp. 84-90, Beijing/China;
- [8] Jahanbakhshi A., Ghamari B., Heidarbeigi K., (2017), Assessing acoustic emission in 1055l John Deere combine harvester using statistical and artificial intelligence methods, *International Journal of Vehicle Noise and Vibration*, Vol. 13, Issue 2, pp. 105-117, Geneva/Switzerland;
- [9] Ji Jiangtao, Li Xinping, Jin Xin et al., (2016), The present situation, technical analysis and equipment demand of characteristic grain harvesting mechanization, *Agricultural Engineering*, Vol. 6, Issue 6, pp. 1-3, Beijing / China;
- [10] Ji Jiangtao, Hu Jingpeng, Wang Shengsheng et al., (2020), Vibration and impact detection of axial-flow threshing unit under dynamic threshing conditions, *INMATEH-Agricultural Engineering*, Vol. 60, Issue 1, pp. 183-192, Bucharest / Romania;
- [11] Lachuga Y.F., Bur'yanov A.I., Pakhomov V.I. et al., (2020), Adaptation of threshing devices to physical and mechanical characteristics of harvested crops. *Russian Agricultural Sciences*, Vol. 46, Issue 2, pp. 198-201, Moscow / Russia;
- [12] Li Yibo, Jiang Jianjun, Xu Yang et al., (2020), Preparation and threshing performance tests of rubber composite nail teeth under maize with high moisture content, *Transactions of the Chinese Society for Agricultural Machinery*, Vol. 51, Issue 11, pp. 158-167, Beijing / China;
- [13] Petkevichius S., Shpokas L., Kutzbach H.D., (2008), Investigation of the maize ear threshing process. *Biosystems Engineering*, Vol. 99, Issue 4, pp. 532-539, London / England;
- [14] Powar R.V., Aware V.V., Shahare P.U., (2019), Optimizing operational parameters of finger millet threshing drum using RSM. *Journal of Food Science and Technology*, Vol. 56, Issue 7, pp. 93-99, Mysore / India;
- [15] Rahman M.M., Ishii K., Noguchi N., (2019), Optimum harvesting area of convex and concave polygon field for path planning of robot combine harvester, *Intelligent Service Robotics*, Vol. 2019, Issue 12, pp. 167-179, Berlin / Germany;
- [16] Ren Changzhong, Cui Lin, He Feng et al., (2018), Construction and development of China oat and buckwheat industrial technology system. *Journal of Jilin Agricultural University*, Vol. 40, Issue 4, pp. 524-532, Changchun / China;
- [17] Steponavičius D., Pužauskas E., Špokas L. et al., (2018), Concave design for high-moisture corn ear threshing, *Mechanika*, Vol. 24, Issue 1, pp. 80-91, Kaunas / Lithuania;
- [18] Wang Jiawei, Hussain Saddam, Lu Qi et al., (2020), Performance experiment of buckwheat threshing device with inner and outer roller rotation, *International Agricultural Engineering Journal*, Vol. 29, Issue 2, pp. 174-181, Beijing / China;
- [19] Wang Jiawei, Li Zhiwei, Hussain Saddam et al., (2020), Design and threshing outputs study of internal and external rotary roller buckwheat thresher, *INMATEH-Agricultural Engineering*, Vol. 60, Issue 1, pp. 173-182, Bucharest / Romania;
- [20] Wang Shengsheng, Chen Pan, Ji Jiangtao, (2021), Design and experimental study of flexible threshing unit for Chinese cabbage seeds, *INMATEH-Agricultural Engineering*, Vol. 65, Issue 3, pp. 333-344, Bucharest / Romania;
- [21] Wang Zhendong, Cui Tao, Zhang Dongxing et al., (2021), Design and experiment of rasp bar threshing element of corn combine harvester, *Transactions of the Chinese Society for Agricultural Machinery*, Vol. 52, Issue 9, pp. 115-123, Beijing / China.