Design and trial-produce of a special nail-tooth thresher for pulses crops

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Abstract. Pulses crops are widely distributed in China, but mechanization production-level of this crops is relatively low at present. So, a special nail-tooth thresher for pulses crops was carried out in this project to solve the problem of mechanical threshing. The roller diameter, speed, length, and nail-tooth structure, stripper concave screen, power device and cleaning system are determined by detailed theoretical calculation. Testing result of the trial-production prototype showed that the threshing roller with large diameter and low rotating speed, the nail-tooth threshing mechanism and the concave plate screen with large spacing are suitable for the broad bean thresher. The optimal combination is roller speed 400 /min, feed quantity 1.2 kg/s and concave tolerance 54 mm. Testing results showed that impurity content and breaking rate of the developed nail-tooth type broad bean thresher were respectively 1.09 % and 3.45%, It could improve the efficiency of the pulses crops threshing process significantly.

1 Introduction

Pulses crops are widely distributed in China, there are more than 20 kinds that have been cultivated, and the main varieties are mung bean, adzuki bean, broad bean, pea and kidney bean. The pulses crops have the function of improving the conditions of soil nutrient and feeding for draught animals. It is an ideal crop for grain-legume rotation and organic dry farming, and has important significance for the sustainable development of agriculture. Broad bean is a representative variety of pulses crops.

Broad bean, also known as Buddha bean, LuoHan bean, orchid bean and so on. With a protein content of about 30%, broad bean is nutritious and widely used. It is one of the important legume crops in the world, and broad bean is mainly distributed in northwest, southwest and Yangtze River Delta areas in China. The planting area is about 800,000 hectares (12 million mu), and the total annual production is over 1.6 million tons.

However, mechanization production-level of the broad bean is relatively low at present, and most of them are completed by artificial harvesting (or pod picking), threshing and cleaning. The operation intensity is large and the production cost is high. For the traditional corn or rice thresher, its threshing operations primarily through the installation of the tooth with high-speed rotation on the spindle, is not suitable for pulses crops. So, the demand for mechanized harvesting equipment is very urgent. Due to the large grain size and high straw specific gravity, broad bean is easily broken during mechanical threshing, and the impurities are hard to clean. Therefore, performance requirements of the machine are relatively high [1-3]. In this context, the design and development of

broad bean thresher was carried out in this project to solve the problem of mechanical threshing in the broad bean harvesting process.

2 Design of the main components

Design parameters of the main components include roller diameter, roller speed, nail-tooth structure, length of the roller, stripper concave screen, power device and cleaning system. They are determined by the following methods.

2.1 Roller diameter

Diameter of the roller has an important influence on threshing effect, when the diameter is too small, straw is easily entangled and the separation area of the concave plate is also directly reduced. Large diameter threshing roller can effectively increase the threshing and separating time of ears, and improve the threshing and separating ability and production efficiency. At present, the commonly used diameter of rice and wheat threshing machines is 450~650 mm, then roller diameter of the threshing machine studied in this paper is selected as 400mm through comprehensive analysis [4].

2.2 Roller speed

The nail-tooth threshing mechanism realizes the separation of grains and stalks by the action of the hammer [5-9], line speed range at the end of the nail is usually 7~13 m/s. However, due to the large grain size of broad bean, the linear speed of roller cannot be too high, otherwise it is easy to damage broad bean in the threshing process. While the operation efficiency will be affected if

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it is too low. Therefore, 9 m/s is selected. So, according to formula 1, the speed of roller is 429.93 r/min.

$$n = \frac{60v}{\pi D} \quad (1)$$

Where, D is the diameter (mm) of the roller; v is the linear speed (m/s) of the nail-tooth.

2.3 Nail-tooth structure

The number and arrangement of the nail-tooth has a direct influence on the threshing performance indicators of un-threshing, entrainment loss and broken grain rate. It determines the work quality and productivity of the machine [10].

Design of the nail teeth is arranged evenly in 4 rows and fixed on the roller, the nail tooth height is 66 mm, diameter is 12 mm, tooth distance is 100 mm and the number of teeth is 40 in this project. In addition, the rubber layer is covered on the teeth to reduce grain broken. When the broad bean straw enters the threshing chamber through the hopper, the nail teeth rotate and agitate the broad bean straw. On the one hand, the roller has a tangential strike force along the cylinder circumference, on the other hand, it has a right thrust along the axial direction, forcing the material to move toward the discharge port.

2.4 Length of the roller

The length of roller threshing section is an important parameter affecting threshing quality, if the roller is too short, the net removal rate will be affected. While the roller is too long, it will increase the manufacturing cost and the size of the threshing machine. The length of roller is calculated as follows.

$$L = a\left(\frac{Z}{K} - 1\right) + 2\Delta L \quad (2)$$

Where, a is the distance between teeth; Z is the total number of teeth; K is the number of teeth rows; ΔL is the distance from the nail teeth to the end of the tooth rod, generally 15-25 mm.

The length of the roller is 950 mm calculated by equation 2.

2.5 Stripper concave screen

In the threshing process, the concave plate can well isolate the straw, and at the same time, the screen holes distributed on the concave plate can make the shedding broad bean seeds leak to the clear screen [11,12].

There are two main types of concave structure: grid and punch, and the grid concave has great strength, good rigidity, large sieve hole and good threshing and separating effect. The threshing process of broad bean is mainly completed in the front part of the roller, and the latter part is mainly used for separating and threshing, so the grid form threshing concave plate is adopted.

The screening efficiency of concave screen depends mainly on the length and effective separation area of the

concave plate. In a certain range, screening efficiency will increase with the length of the concave screen. At the same time, the larger hole ratio of concave plate screen, the higher screen efficiency of concave screen. The hole ratio of concave plate screen A is calculated by equation 3. The hole ratio of concave plate scree of the machine developed in this paper is 72 %.

$$A = \frac{a_1 b}{r \pi L} \times 100\% \quad (3)$$

Where, A is the hole ratio of concave plate scree, a_1 is the number of sieve holes, b is the area of sieve hole, r is the roller radius, L is the roller length.

2.6 Power device

The thresher shall be equipped with motor to provide threshing power, screening power and cleaning fan power. Combined with the structure design and practical application of the thresher, the matching motor with 5.5 kW power is selected under the condition that the threshing capacity is 3 t/h and the thresher works normally.

2.7 Cleaning system

From feeding broad bean material into the threshing section, to obtaining clean bean seeds, a large amount of straw, dust and sundries mixed with materials should be cleaned by the cleaning system. The separation principle is as follows: the fallen bean seeds and small impurities fall through the grid concave hole, during the falling process, the fine impurities are sucked into the fan by the negative pressure fan and discharged from the fan outlet while the grains fall into collection box with the action of reciprocating vibrating screen.

3 Entire design and test verification

The entire design was developed by integrating the above design parameters as shown in Figure 1, then the prototype production was carried out. In order to verify the working performance, the full-scale experiment was finished and the key operating parameters were tested. The operating principle and testing methods of impurity rate and breaking rate are as follows.

3.1 Operating principle

The naturally dried straw after cutting was sent into threshing machine from feeding mouth, motor drive the roller to rotate at a certain speed, then the fast-moving nail keep hitting the straw in the threshing chamber to achieve the rapid separation of grains and straws. Next, grain entered the cleaning system through sieve mesh gap, and the remained straw was discharged out of the machine through crushing device. The clean grain can be obtained at the discharge port.

The main indexes to evaluate threshing machine operation performance include breaking rate and impurity rate.

1-motor, 2-frame, 3-cleaning fan, 4-grading screen, 5-suspension frame, 6-threshing roller, 7-nail-tooth, 8-driving wheel, 9-gravure screen, 10-vibration mechanism

Figure 1. The overall structure diagram of broad bean threshing machine.

3.2 Breaking rate

According to the standard requirements, a random sample of broad bean no less than 2000 g was collected and the seeds with injuries and obvious cracks were selected out and weighted. The breaking rate is calculated according to equation (4).

$$Z_s = \frac{W_s}{W_i} \times 100\% \quad (4)$$

Where, Z_s is grain breaking rate, %. W_s is the mass of broken grains, g; W_i is the total grain mass of the sample, g.

3.3 Impurity rate

After each testing, 2,000g of broad beam seeds were collected from the outlet. Impurities and grains were separated and weighed separately. The impurity rate is calculated according to equation (5).

$$S_w = \frac{W_w}{W_z} \times 100\% \quad (5)$$

Where, S_w is grain impurity rate, %. W_w is the mass of impurity, g; W_z is the total mass of the sample, g.

3.4 Experimental design

The controllable conditions in the experiment are feed quantity, concave tolerance and roller speed. The range of each testing variables is shown in Table 1. Different experiments are arranged by the orthogonal experiment design method. The experiment is adopted $L_9(3^4)$ orthogonal tables to repeat 3 times. The correlation of variables is analyzed and the optimized parameter combinations were obtained.

Table 1. Experimental factors and levels.

Levels	Roller speed r/min	Feed quantity kg/s	Concave tolerance mm
1	400	0.75	50
2	450	1.00	54
3	500	1.25	58

3.5 Testing result

According to the above methods, threshing performance of the prototype was tested. Variety of the testing broad bean was Qidou 2, and moisture content of the bean straw was 12%-16%. Testing results was shown in Table 2, Range analysis of the experimental results was shown in Table 3.

Through range and variance analysis, we found that each factor has different effects on the variables, the roller speed has the greatest impact on the breaking rate and. The primary and secondary sequence of the factors affecting breaking rate is roller speed > feed quantity > concave tolerance, while the optimal combination is roller speed 400 /min, feed quantity 1 kg/s and concave tolerance 54 mm. In addition, the concave tolerance has the greatest impact on the impurity rate and. The primary and secondary sequence of the factors affecting breaking rate is concave tolerance > roller speed > feed quantity, while the optimal combination is roller speed 400 /min, feed quantity 1.25 kg/s and concave tolerance 54 mm.

It can be found that the optimal combinations are significantly different when a certain optimization

variable is chosen. After weighing the influence of impurity rate and breaking rate on the result, the final optimal combination is roller speed 400 /min, feed quantity 1.2 kg/s and concave tolerance 54 mm. Testing results under this combination showed that impurity content and breaking rate were 1.09 % and 3.45% respectively, which met the requirements of application. The threshing effect of the machine is shown in Figure 2.

Table 2. The orthogonal experiment arrangement and results

Experiment No.	Experiment factors			Result	
	Roller speed (r/min)	Feed quantity (kg/s)	Concave tolerance (mm)	Breaking rate (%)	Impurity rate (%)
1	1	1	1	3.25	0.5
2	1	2	2	2.79	0.36
3	1	3	3	3.27	0.2
4	2	1	2	3.86	0.32
5	2	2	3	3.13	0.47
6	2	3	1	3.81	0.65
7	3	1	3	3.91	0.68
8	3	2	1	3.65	0.45
9	3	3	2	3.42	0.31

Table 3. Range analysis of the experimental results.

Evaluating index	Range	Roller speed (r/min)	Feed quantity (kg/s)	Concave tolerance (mm)
Breaking rate	k_1	3.103	3.673	3.57
	k_2	3.6	3.19	3.357
	k_3	3.66	3.5	3.437
	R	0.557	0.483	0.213
Impurity rate	k_1	0.353	0.5	0.533
	k_2	0.48	0.427	0.33
	k_3	0.48	0.381	0.45
	R	0.127	0.113	0.203

(a) impurities (b) the damaged grain (c) the ideal grain
Figure 2. Threshing performance of the prototype

4 Conclusion

(1) In order to improve efficiency of the broad bean threshing process, the threshing roller with large diameter and low rotating speed, the nail-tooth threshing mechanism and the concave plate screen with large spacing are suitable for the broad bean thresher.

(2) The optimal combination is roller speed 400 /min, feed quantity 1.2 kg/s and concave tolerance 54 mm. Testing results showed that impurity content and breaking rate of the developed nail-tooth type broad bean thresher were respectively 1.09 % and 3.45%, achieved relatively ideal operation effect.

Acknowledgments

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