OPTIMIZED DESIGN AND TESTING OF A PEANUT-PICKING DEVICE WITH A LARGE FEEDING VOLUME
/
花生大喂入量摘果装置优化设计与试验

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ABSTRACT

For a peanut-picking device with a feeding rate greater than 5 kg/s, the problem of low picking rate and high damage rate will occur during the picking process. A discrete element model is developed to determine the range of values of the main influencing factors affecting the peanut picking device. A three-factor, three-level orthogonal combination test was carried out with feeding volume, drum speed, and peanut-picking gap as test factors to investigate the effects of the main influencing factors on the quality of peanut picking operation of the peanut-picking device. The results of the field trials showed that the best results were achieved at the optimum combination of drum speed of 508 r/min, peanut-picking gap of 22 mm, and feeding volumes of 6.3 kg/s. At this time, the peanut picking rate was 99.17%, and the peanut breakage rate was 0.91, meeting the standard technical requirements for mechanized peanut harvesting. The study results provide a theoretical basis for further enhancing the development of peanut combine harvesting equipment.

摘要

针对喂入量大于 5kg/s 的摘果装置在摘果过程中会产生摘果装置摘净率低、破损率高的问题。建立离散元模型，确定影响花生摘果装置的主要影响因素的取值范围。以喂入量、滚筒转速、摘果间隙为试验因素开展三因素三水平正交组合试验，探究主要影响因素对摘果装置摘果作业质量的影响。田间试验验证，结果表明，在最优参数组合滚筒转速为508r/min,摘果间隙为36mm,喂入量为6.3kg/s时,摘果作业效果最佳,此时摘果率为99.17%,破损率为 0.91，满足花生机械化收获标准技术要求。研究结果为进一步提升花生联合收获机具研发提供了理论依据。

INTRODUCTION

Peanut is an important oilseed crop and cash crop in China, which not only meets the country's rigid demand for edible oil but also provides a strong guarantee for the healthy development of the agricultural economy (*Li et al., 2020*). However, China's peanut mechanization harvesting technology is relatively lagging, seriously affecting the development of China's peanut industry (Jaime et al., 2015). Peanut picking is a key part of peanut mechanized harvesting, but also the core technology of the peanut combine harvester, peanut picking device structure design and operating parameters directly determine the operational performance of the peanut combine harvester (*Shang et al., 2004; Hu., 2011*).

Improving the operational quality of the picking device is a key part of the picking process and an important measure to improve peanut picking rates and reduce breakage (*Chen et al., 2017*). In recent years, in order to improve the operational quality of peanut-picking devices, scholars at home and abroad have carried out systematic research on peanut-picking devices for root crops such as peanuts and oilseed beans, studying and analyzing the problem from various aspects (*Shang et al., 2004; Chen et al., 2016; He et al., 2022*). Wang Dongwei et al. have designed a spiral-arc panel structure that generates an axial thrust on the peanut during the picking operation and eliminates the need for picking teeth, avoiding roller blockage and reducing breakage rates (*Wang et al., 2013*). Fang Qingliu et al. applied the TRIZ principle to innovate the design of the peanut-picking device, using U-shaped springs to achieve flexible peanut picking, avoiding high-speed impact blows, reducing broken and shattered peanuts, and removing peanuts cleanly (*Fang et al., 2021*). Shang Shuqi et al. used a full-feed axial flow type peanut picking device to improve the peanut picking rate of fresh wet peanuts and reduce the breakage rate by using the shake and stroke working principle (*Shang et al., 2009*).

Guan Meng et al. studied a multi-drum combination peanut picking device, analyzed the peanut picking mechanism of the cutting and axial flow picking drums, determined the basic parameters of each drum, and solved the problem of low picking efficiency and high pod damage rate of the full-feed axial flow single-drum peanut picker (*Guan et al., 2015*).

This paper addresses the problem that peanut picking devices with large feed volumes can produce blockage and entanglement, resulting in low peanut picking rates and high breakage rates, and optimizes the design and picking performance of the peanut picking device structure (*Omori H et al., 2008*). The EDEM software was used to simulate and analyze the peanut picking process to determine the optimum operating parameters of the picking device, thereby achieving an improved peanut picking rate and reduced breakage rate and also providing a theoretical basis for the study of peanut picking devices with large feed volumes (*Shmulevich I et al., 2010; Xie G J et al., 2012; Chen et al., 2020*).

MATERIALS AND METHODS

Overall Structure

The peanut-picking device is a longitudinal full-feed type connected to the feed inlet of the peanut combine. The main working parts are the peanut picking drum, the concave sieve, the top cover of the peanut-picking drum, the deflector plate, the feeding baffle, the feeding blade, the peg teeth, the fixed toothed rod, and the central axis, all in a longitudinal configuration. The overall structure is shown in Fig 1.

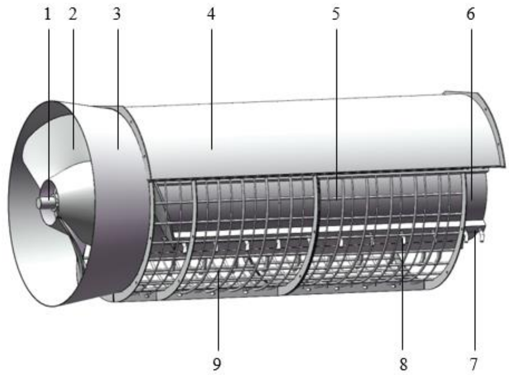


Fig. 1 - Overall structure chart of peanut-picking device

1. central axis; 2. feeding blade; 3. Feeding baffles; 4. Peanut picking drum top cover; 5. concave sieve; 6. peanut picking drum; 7. fixed toothed rod; 8. peg teeth; 9. deflector plate

Working Principle

At work, the dried peanut plants are fed by the feeding blade into the peanut-picking drum, which is rotated by the drive of the central shaft (Zheng et al., 2023). The peanut plant is guided by the deflector plate and the peanut-picking peg teeth, which create a tendency for the peanut plant to move in an axial direction, with the peanut plant wrapped around the high-speed rotating peanut-picking peg teeth (Xu et al., 2020). As the peanut plant is subjected to centrifugal force, the peanut pods face towards the side of the concave plate sieve, which generates a shearing force on the moving peanut pods, thus separating the pods from the peanut seedlings and realizing the peanut-picking process. There is also a part of the peanut pod when entering the drum, subject to peanut picking peg teeth friction, dragging, hitting, rubbing, and falling to achieve the peanut picking process.

Optimized design of peanut-picking roller structure

The performance parameters of the peanut-picking drum have the most direct impact on the quality of peanut-picking operations and are the core components of the peanut-picking device. Therefore, taking into account the peanut picking performance and the cost of construction, a single-cylinder axial flow type peanut picking device is used *(Zheng et al., 2023)*. To achieve a large number of peanuts feeding into the peanut picking operation, a large number of peanut plant movements driven by the peanut picking peg teeth is the strength of the peg teeth and the number of driven seedling vines put forward higher requirements (*Yue et al., 2021*). The design of the peanut-picking peg teeth in this paper is more reasonable in structure and can meet the requirements of a large number of winding peanut plants. The cross-flow peanut-picking device has a low space utilization rate for the whole machine, and it is not convenient to replace parts. In view of the space utilization of the machine and the replacement of parts at a later stage, a longitudinal axial flow type peanut picker has been chosen for this study. The longitudinal axial flow peanut picking drum is shown in Figure 2.

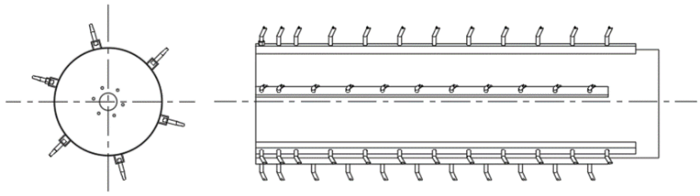


Fig. 2 - Structural Sketch of Picking Drum

Determination of the basic parameters of the peanut-picking drum

The diameter, length, and speed of the peanut-picking drum, as well as the type and order of the included picking elements, have an important influence on the performance indicators and operational quality of the picking unit. The arrangement of the peanut-picking elements is spiral in response to the blockage and entanglement that can occur with peanut-picking devices with large feed volumes. The spiral arrangement increases the axial force on the peanut plant in the peanut picking drum and avoids clogging and entanglement of the peanut plant *(Wang., 2013)*.

For the calculation of the distance between its adjacent plucking nail teeth on the fixed tooth stem, the formula is：

$$E = \frac{XB}{N} \tag{1}$$

where:

E is the distance between adjacent peanut-picking peg teeth, (mm);

B is for the similar nail teeth axial spacing, often taken from 50 to 80 mm, (mm);

X is the number of fixed-toothed rods needed to peanut-picking peg teeth, often taken from 4 to 8;

N is the number of spirals; tests have shown that n ≤ 5.

The length of the rollers is calculated as：

$$L = B\left(\frac{I}{N} - 1\right) + 2\mathrm{h} \tag{2}$$

where:

L is the length of the peanut picking drum, (mm);

B usually between 50 and 80 mm, B = 65 mm, (mm);

I is the total number of peanut-picking peg teeth, I = 84;

h is the distance from the peanut-picking peg teeth to the bottom of the fixing slot, (mm).

According to the formula for the diameter of the peanut-picking drum:

$$D = \frac{X\mathrm{s}}{\pi} + 2\mathrm{h} \tag{3}$$

where:

D is the diameter of the drum, (mm);

s is the distance between adjacent fixed toothed rod, (mm).

The diameter of the peanut-picking drum has an important influence on the performance index of the peanut-picking device. The force analysis of the peanut-picking drum is shown in Fig. 3.

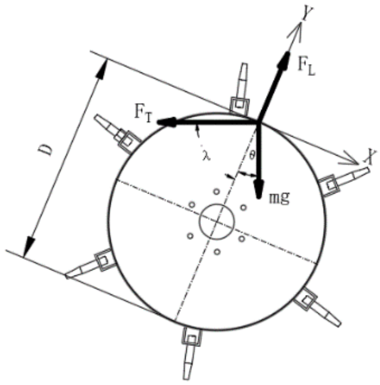


Fig. 3 - Peanut picking roller force analysis diagram

To determine the diameter of the peanut picking drum, the forces at each position are simplified and analyzed as follows: when the peanut plant acts up to the uppermost end, the centrifugal force exerted is the greatest, i.e., the diameter of the drum is the largest, then there is:

$$\begin{cases} F_T - F_L \cos\varphi \cos\lambda - mg\cos\theta > 0 \\ F_L = \mathrm{m}\omega^2 \dfrac{D}{2} \\ F_T = F_{拉} \cos\varphi \end{cases} \tag{4}$$

Where：

F_{pull} for peanut plants subjected to roller tension, F pull = 7 to 20 N, (N);

F_T is the force projected onto the two-dimensional plane by the pulling force, (N);

F_L is the centrifugal force generated by the rotation of the drum, (N);

m is the mass of the peanut plant, m = 7 to 20 g, (Kg);

g is the acceleration of gravity, taken as 10m/s^{-2}, (m/s^{-2});

γ is the angle between F_L and drum diameter, (°);

ω is the angular velocity of the drum, (rad/s);

φ is the angle between the peanut plant and the two-dimensional plane, (°);

θ is the angle between the gravity of the peanut plant and the diameter of the drum, (°).

In order for the peanut picking drum not to produce seedling blockage, it is necessary to satisfy γ = θ = φ = 0, i.e., to satisfy the relation:

$$\mathrm{D} > 2\left(\frac{F_{拉} + \mathrm{mg}}{\mathrm{m}\omega^2}\right) \tag{5}$$

From the above equation, the diameter of the drum should be greater than 350 mm. With reference to the dimensional parameters of commercially available peanut picking devices, analysis of the working performance of existing longitudinal flow picking devices and the performance requirements of this picking device, the picking diameter was determined to be approximately 480 mm (Without spike teeth size).

From the analysis of the above calculations, it follows that: D=480 mm, B=65 mm, N=3, X=6, I=80 pieces, i.e., E=130 mm, L=1800 mm, h=100 mm.

Optimized design of peanut-picking peg teeth

The peanut-picking peg teeth designed in this paper are used to pick the peanut seedlings by rotating the drum through the peg teeth during the picking action (*Kim N.K., 2006*). The top of the peg teeth collide with the peanut pods, as shown in Fig 4.

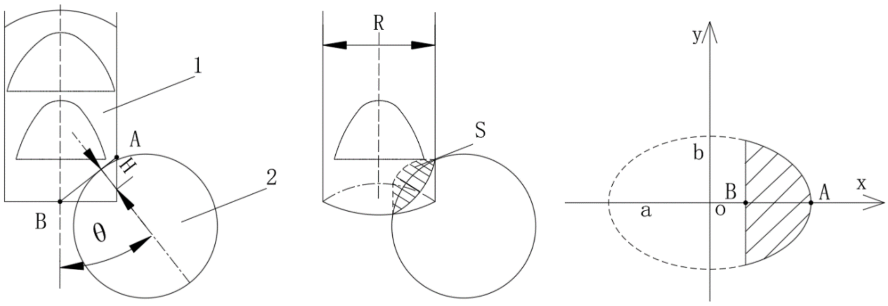


Fig. 4 - Collision diagram

It is assumed that the peanut pod collides with the top of the peg teeth at an angle θ. Taking the direction of the long axis of the ellipse as the x-axis, the direction of the short axis as the y-axis, and the center point of the ellipse as the origin to establish a right-angle coordinate system, the collision areas S are, respectively:

$$S = \int_{-\mathrm{a}}^{-\mathrm{a}+2H} b\sqrt{1-\frac{x^2}{a^2}}dx, \quad x \in (-a, a) \tag{6}$$

where:

H is the compression of the peanut pod when it collides with the peg teeth, (mm);

a is the length of the semi-axis of the elliptical section, (mm).

b in Fig. 5 shows the length of the semi-short axis of the elliptical section, the length of which is equal to the diameter R at the cylinder of the peg tooth. That is, the relationship between a and b is:

$$a = \frac{R}{2\cos\theta} \tag{7}$$

where:

R is the diameter of the peg teeth at the cylinder, (mm).

The cylindrical diameter of the peg teeth, R, is 17 mm, which, when substituted into equation (7), $a = \dfrac{17}{2\cos\theta}$.

When the peanut pods are impacted by the peanut-picking peg teeth, the impact occurs at an angle of 45° with the greatest force on the peanut pods. The impact of the pods on the peg teeth at an angle of 45°, i.e., θ = 45° is, therefore, analyzed, which gives:

$$S = \frac{289\sqrt{2}}{4}\pi + \left(4\sqrt{2}H - 34\right)\bullet\sqrt{\frac{17\sqrt{2}}{2}H - H^2} + \frac{289\sqrt{2}}{2}\bullet\arcsin\left(\frac{2\sqrt{2}}{17}H - 1\right) \tag{8}$$

Through peanut pod compression tests, the moisture content of peanut plants was between 10% and 20% when the peanuts were dried for 3 to 5 days after starting to be dug. Pod splitting occurred in the widely grown Luhua 12 peanut pods in Shandong with a compression deformation of between 0.95 and 3.25 mm. The amount of compression of the peanut pods without cracking the pods during the operation of the peanut picking peg teeth is H ≤ 0.95 mm, i.e., the contact area between the peanut pods and the peanut-picking peg teeth is S ≤ 4.62 mm^2.

The vertical part of the peanut picking peg teeth is 70 mm long, the curved part is 45 mm long, and the bending angle is 45°. The peg teeth are made from high tensile steel, heat treated to 50 HRC, and galvanized to meet the stiffness and strength requirements of high infeed peanut picking operations.

The peanut plant rotates in the drum with the peanut picking peg teeth, and its forces in the drum are shown in Fig. 5.

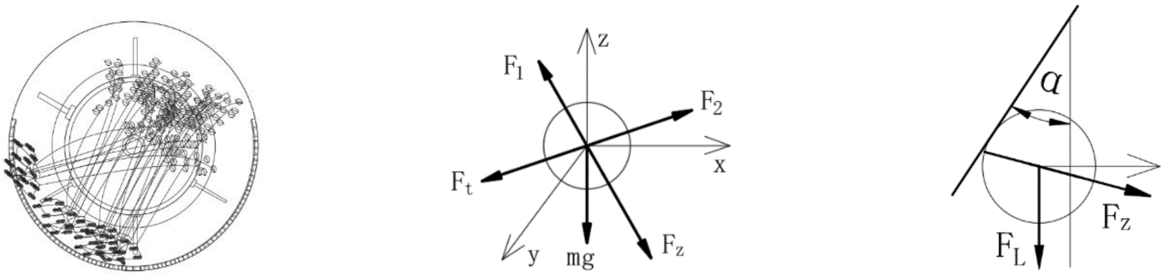


Fig. 5 - Force analysis of peanut pods

The thrust of the peanut plant, Fz:

$$\begin{cases} F_z = F_1 - G\cos\gamma \\ G = mg \\ F_L = F_z \sin\alpha \\ F_1 = \mu F_2 \\ F_2 = \dfrac{mv^2}{R} - mg\sin\gamma \end{cases} \tag{9}$$

where:

F_Z is the thrust on the peanut plant in the drum, (N);

F_1 is the frictional force on the peanut plant, (N);

F_t is the centrifugal force on the peanut plant, (N);

F_2 is the pressure of the peanut plant on the peanut plant by the concave plate screen and the drum, (N);

F_L is the lateral force on the peanut plant, (N);

G is the gravity of the peanut plant, (N);

R is the radius of the peanut picking drum, (mm);

α is the angle between the concave plate screen and the drum axis, (°);

γ is the quadrant angle of the peanut plant when it is in circular motion, (°);

ν is the linear speed of the drum, (m/s);

μ is the coefficient of friction.

To avoid clogging the roller, the lateral force on the peanut vine after picking is greater than the frictional force on the vine. i.e., $F_L > F_1$

$$F_1 \sin\alpha - \text{mg}\cos\gamma\sin\alpha \geqslant F_1 \tag{10}$$

Substituting equation (10) into equation (11) yields:

$$\mu\left(\frac{\text{mv}^2}{R} - \text{mg}\sin\gamma\right)(\sin\alpha - 1) \geqslant \text{mg}\cos\gamma\sin\alpha \tag{11}$$

From the above, it can be seen that the drum speed is 450-500 r/min and the radius of the drum is 240 mm, further simplified to give:

$$\text{mv}^2 / R - \text{mg}\sin\gamma \geqslant 0 \tag{12}$$

Because $\sin\alpha \in [0{,}360°]$, therefore, $\sin\alpha - 1 \leq 0$, So the left-hand side of the inequality is negative. If the inequality is made to hold, i.e., satisfies, $\cos\gamma < 0$, then the lateral force on the peanut vine after picking is greater than the frictional force on the vine.

Concave plate screen design

In this paper, the design of the concave plate screen has a certain frictional conveying effect to meet the large feeding volume of peanut seedlings after picking to convey to the seedling discharge mechanism. The overall structural dimensions of the concave sieve are compatible with the peanut picking drum, with a length L of 1800 mm and a width D of 800 mm. A schematic diagram of the concave plate sieve structure is shown in Fig 6.

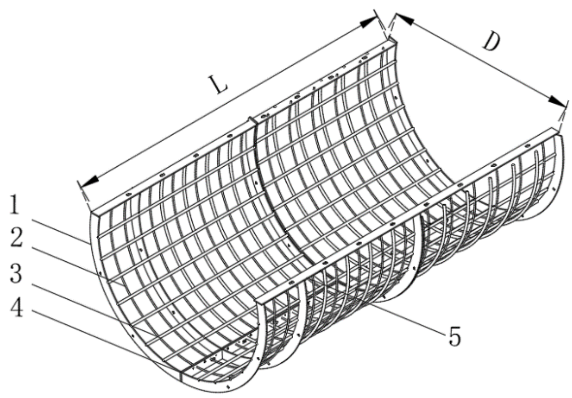


Fig. 6 - Schematic diagram of concave sieve structure

1. lateral arcuate plate 2. horizontal partition 3. round crossbar 4. connection plate 5. mounting plate

Peanut-picking gap design

The peanut-picking gap is an important parameter affecting the quality of peanut-picking operations once the peanut-picking gap parameters are selected unreasonably, directly affecting the peanut-picking performance indicators, which in turn affects the overall performance of the peanut combine harvester. The peanut-picking gap parameter is, therefore, an extremely important working parameter, and the impact of the size of the peanut-picking gap on the picking performance index has to be measured in order to make a reasonable design. A diagram of the peanut picking gap is shown in Fig 7.

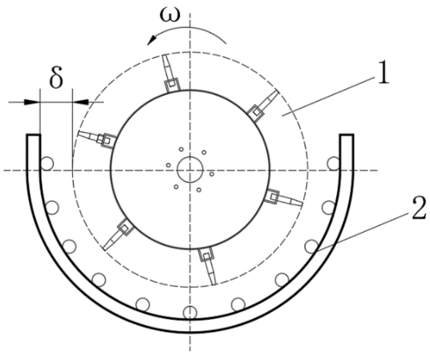


Fig. 7 - Schematic diagram of peanut picking gap
1. peanut picking drum; 2. concave sieve

Considering the movement of the peanut plant during the picking operation, the size of the peanut pods, and the analysis of the existing models, the peanut picking gap of the large feeding volume picking device was designed. The length of the peanut pods is approximately 35 mm, and the adjustable peanut picking gap is designed to be 35 to 55 mm to meet the requirements of different peanut varieties and feeding volumes.

Peanut picker model

Apply Solidwork2019 to build a 1:1 scale model of the peanut picking device, save it in STL format, and import it into EDEM2021. The simulation model is shown in Fig. 8.

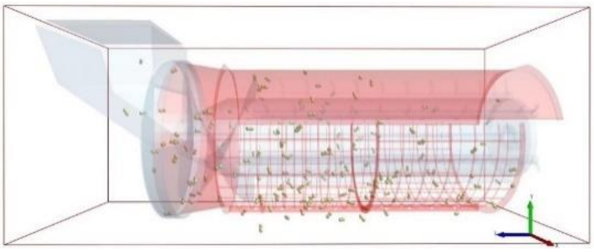


Fig. 8 - ***Peanut picker model***

Peanut model construction

Apply Solidwork2019 to build a peanut model according to a 1:1 scale, save it in STL format, and import it into EDEM2021. The discrete element model is shown in Fig 9.

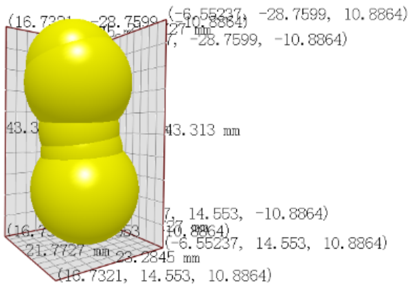


Fig. 9 - ***Peanut model***

Table 1

Basic parameters of discrete element simulation

Parameters	Numerical value
Peanut Poisson's ratio	0.32
Peanut shear modulus（MPa）	7
Peanut density（kg/m^3）	257

Parameters	Numerical value
Steel Poisson's ratio	0.27
Steel shear modulus（MPa）	8240
Steel density（kg/m³）	7850
Coefficient of restitution between peanut particles	0.50
Coefficient of static friction between peanut particles	0.30
Coefficient of dynamic friction between peanut particles	0.20
Coefficient of restitution between peanut and steel	0.37
Coefficient of static friction between peanut and steel	0.40
Coefficient of dynamic friction between peanut and steel	0.10

Peanut-Picking Simulation Results and Analysis

In order to investigate the range of values of the main influencing factors affecting the quality of peanut picking operation, the peanut picking rate and breakage rate were taken as indicators, and the feeding volume, drum speed, and peanut picking gap were taken as experimental factors. The simulation analysis is shown in Fig. 10.

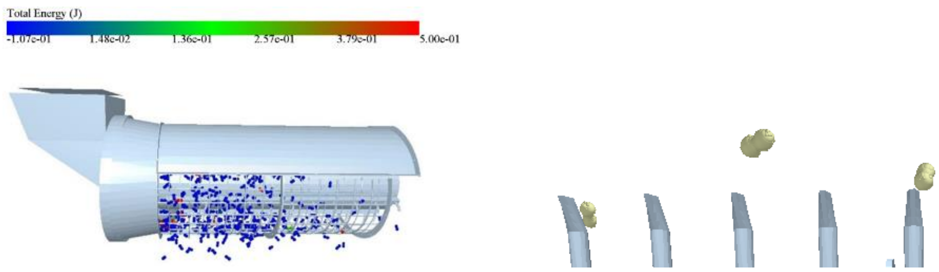


Fig. 10 - Peanut Picking Simulation Schematic

In this paper, theoretical calculations have been carried out to analyze the laws affecting the stress on peanut pods. For further validation, therefore, the simulation test was carried out according to different factors. Depending on the factors, the operating parameters affecting the factors feed, drum speed, and peanut picking gap are changed. Apply the controlled variable method to explore more intuitively the changing law of force on peanut pods.

(1) Influence of feeding volume on peanut-picking operations

Determine the drum speed as 500 r/min and the peanut picking gap as 45 mm. Observe the changing pattern of force on peanut pods by varying the size of the feeding volumes. The resulting comparison is shown in Fig 11:

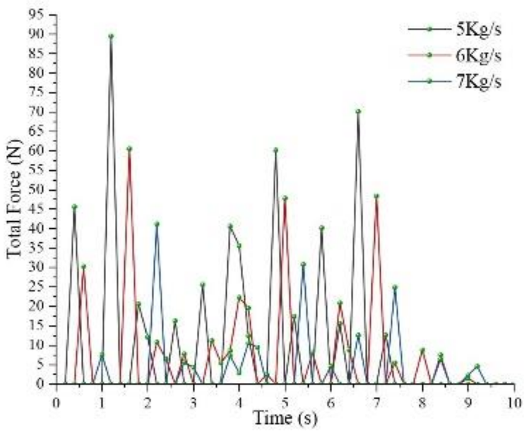


Fig. 11 - Comparison of force analysis of peanuts with different feeding levels

(2) Effect of drum speed on peanut-picking operations

Determine the feeding volumes of 6 kg/s and the peanut picking gap of 45 mm. By changing the size of the rotational speed of the drum, observe the change rule of the force on the peanut pods. The resulting comparison is shown in Fig. 12:

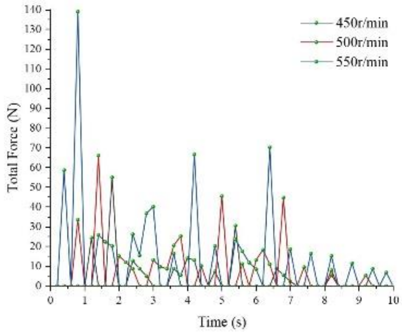


Fig. 12 - Comparison of force analysis of peanuts at different rotational speeds

(3) Influence of peanut picking gaps on peanut picking operations

Determine the feeding volume 6 kg/s, drum speed 500 r/min. By changing the size of the peanut picking gap, observe the changing law of peanut pod force. The resulting comparison is shown in Fig. 13:

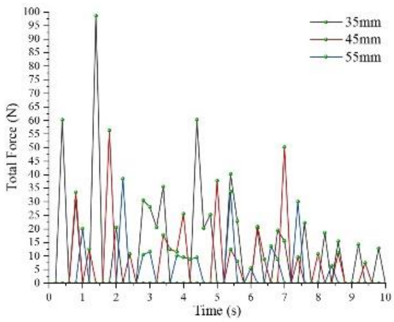


Fig. 13 - Comparative force analysis of peanuts with different picking gaps

Field Test

The quality of the peanut used in the experiment was Luhua 12, which is widely grown in Shandong. The experimental site was selected in Yishui County, Shandong Province, China. After spreading and after three days of drying, the combined water content of the seedling peanut reached 20-30 percent, which satisfied the test conditions.

Fig. 14 - Field test chart

Test program

In order to explore the effects of drum speed, peanut picking gap and feeding volume on the performance index of peanut-picking device. The drum speed X_1, picking gap X_2, and feeding volume X_3 were selected as three test factors, while peanut picking rate Y_1 and breakage rate Y_2 were selected as test indexes to carry out orthogonal rotating combinatorial design tests on the peanut picking device. The feeding volume was selected to be 5.0-7.0 kg/s, the drum speed to be 450-550 r/min, and the peanut picking gap to be 35-55 mm. The experimental data were analyzed by quadratic regression orthogonal rotating combination experimental design using Design-Expert 10 software. Analytical tests were designed according to the Central Composite Design principle. The coded list of test factors is shown in Table 2, and the experimental program and results are shown in Table 3:

Table 2

Experimental factors and levels

Factor level	**—1**	**0**	**1**
Drum speed	450	500	550
Peanut picking gap	15	25	35
Feed rate	5.0	6.0	7.0

Table 3

Test plan and results

Serial number	**X_1 Drum speed r/min**	**X_2 Peanut picking gap mm**	**X_3 Feed rate Kg/s**	**Y_1 Peanut picking rate %**	**Y_2 Breakage rate %**
1	-1	-1	0	99.27	1.74
2	1	-1	0	99.01	1.97
3	-1	1	0	99.10	0.92
4	1	1	0	98.71	1.41
5	-1	0	-1	99.24	1.54
6	1	0	-1	98.89	1.53
7	-1	0	1	99.15	0.97
8	1	0	1	98.84	1.41
9	0	-1	-1	99.21	2.04
10	0	1	-1	99.06	1.43
11	0	-1	1	99.12	1.65
12	0	1	1	98.94	0.85
13	0	0	0	99.17	1.58
14	0	0	0	99.21	1.55
15	0	0	0	99.15	1.52
16	0	0	0	99.27	1.61
17	0	0	0	99.18	1.54

It can be derived from Table 3: drum speed and peanut picking gap and feed are used as test factors to explore the findings that affect the peanut picking rate and breakage rate of peanut picking devices. The peanut picking rate Y_1 generally ranged from 98.71 to 99.27 percent, and the breakage rate Y_2 ranged from 0.85 to 2.04 percent.

Quadratic multiple regression was fitted to the data in Table 3. After processing by Design-Expert 10.0 software, the results of ANOVA regarding the rate of peanut picking rate and breakage rate were obtained, as shown in Tables 4 and 5.

Table 4

Analysis of variance for peanut picking rate

Sources	Squares	DF	MS	F value	P
Model 1	0.40	9	0.045	26.62	0.0001
X_1	0.21	1	0.21	127.31	<0.0001
X_2	0.080	1	0.080	47.48	0.0002
X_3	0.015	1	0.015	9.09	0.0195
X_1X_2	4.225E-0.03	1	4.225E-0.03	2.51	0.1573
X_1X_3	4.000E-0.04	1	4.000E-0.04	0.24	0.6410
X_2X_3	2.250E-0.04	1	2.250E-0.04	0.13	0.7256
X_1^2	0.054	1	0.054	31.91	0.0008
X_2^2	0.015	1	0.015	9.15	0.0193
X_3^2	0.012	1	0.012	7.02	0.0330
Residual	0.012	7	1.685E-0.03		
Lack of Fit	3.075E-0.03	3	1.025E-0.03	0.47	0.7193
Pure Error	8.720E-0.03	4	2.180E-0.03		
Cor Total	0.42	16			

Note: highly significant (P<0.01); significant (P<0.05).

Table 5

Analysis of variance for breakage rate

Sources	Squares	DF	MS	F value	P
Model 2	1.65	9	0.18	50.48	<0.0001
X_1	0.17	1	0.17	45.51	0.0003
X_2	0.97	1	0.97	267.89	<0.0001
X_3	0.34	1	0.34	94.83	<0.0001
X_1X_2	0.017	1	0.017	4.65	0.0679
X_1X_3	0.051	1	0.051	13.94	0.0073
X_2X_3	9.025E-0.03	1	9.025E-0.03	2.48	0.1590
X_1^2	0.034	1	0.034	9.39	0.0182
X_2^2	6.737E-0.03	1	6.737E-0.03	1.85	0.2154
X_3^2	0.049	1	0.049	13.40	0.0081
Residual	0.025	7			
Lack of Fit	0.020	3		5.45	0.0676
Pure Error	5.000E-0.03	4			
Cor Total	1.68	16			

Note: highly significant (P<0.01); significant (P<0.05).

Using Design-Expert 10.0 software, the three insignificant terms in the test were removed, and the quadratic term regression model for peanut picking rate Y_1 was obtained as:

$$Y_1 = 99.20 - 0.16X_1 - 0.10X_2 - 0.044X_3 - 0.11X_1^2 - 0.053X_3^2 \tag{13}$$

Using Design-Expert 10.0 software, the three insignificant terms in the test were removed, and the quadratic term regression model for peanut picking rate Y1 was obtained as:

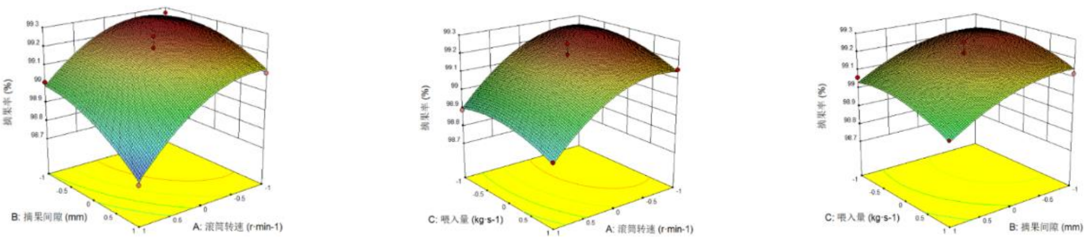
$$Y_2 = 1.56 + 0.14X_1 - 0.35X_2 - 0.21X_3 - 0.11X_1X_3 - 0.090X_1^2 - 0.11X_3^2 \tag{14}$$

RESULTS

Response surface analysis

Response surface analysis of the experimental results using the software can demonstrate more intuitively the effects of drum speed, peanut picking gap, and feeding volume on peanut picking rate and breakage rate.

(1) Interaction analysis of the effects of drum speed, picking gap, and feeding volume on peanut picking rate:

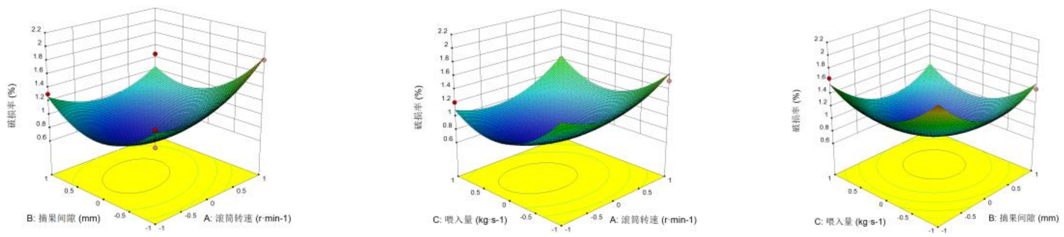


(a) (b) (c)

Fig. 15 - Interaction effects on peanut picking rate

The trend analysis of the response surface change of peanut picking rate in two two-factor intersection operations is shown in Fig. 15. It shows that the peanut picking rate increases with the increase of drum speed X_1, first increases and then decreases with the increase of peanut picking gap X_2, and first increases and then decreases with the increase of feeding volume X_3.

(2) Interaction effects of drum speed, picking gap, and feeding volume on breakage rate



(a) (b) (c)

Fig. 16 - Interaction effects on breakage rate

Trend analysis of response surface variation of peanut breakage rate in two two-factor intersection operations is shown in Fig. 16. It shows that the peanut picking rate increases with the increase of drum speed X_1 decreases with the increase of peanut picking gap X_2, and decreases first and then increases with the increase of feeding volume X_3.

Determination of optimal operating parameters

In order to obtain the best performance index of the peanut large feeding volume picking devices. Based on the results of the above analysis, the quadratic regression model for the peanut picking rate and breakage rate of the peanut picking operation was optimally solved under the constraints using Design-Expert 10.0 software. The objective function of the peanut picking performance index is:

$$\begin{cases} \max Y_{1i} = f\left(X_1, \ X_2, \ X_3\right) \\ \min Y_{2i} = f\left(X_1, \ X_2, \ X_3\right) \\ 0 \le Y_{1i} \le 1 \\ 0 \le Y_{2i} \le 1 \\ X_i \in \left[-1, 1\right], \quad (i=1, \ 2, \ 3) \end{cases} \tag{15}$$

The optimal combination was obtained as drum speed 508 r/min, peanut picking gap 22 mm, feeding volume 6.3 kg/s, at which time the peanut picking rate was 99.18%, and the breakage rate was 0.91%.

CONCLUSIONS

(1) The optimized design of the large feeding volume picker is characterized by its high feeding volume and high efficiency. To a certain extent, it solves the problem that the currently existing ordinary peanut picking device is prone to cause a low peanut picking rate and high breakage rate when there is a large feeding volume.

(2) Through the EDEM software on the peanut picking device picking operation process simulation analysis, were determined the drum speed in the 500 r/min or so, picking gap of 25 mm or so, feeding volume of 6 kg/s or so of the optimal range of work values.

(3) Verified by field trials, the optimal working parameters were determined by a three-factor, three-level combination method using drum speed, peanut picking gap, and feeding volume as test factors and peanut picking rate and breakage rate as evaluation indexes. The results of the field test showed that the best peanut-picking operation was achieved when the drum speed was 508 r/min, the peanut-picking gap was 36 mm, and the feed rate was 6.3 kg/s. At this time, the peanut picking rate is 95.01%, and the breakage rate is 0.91%, which meets the requirements of the peanut picking operation.

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