# MOVEMENT ANALYSIS AND EXPERIMENTAL STUDY ON PEANUT POD HARVEST SEPARATION CONVEYOR

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# 花生荚果收获分离输送装置运动分析与试验研究

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## ABSTRACT

*A peanut harvest separation and conveying device was designed considering the shortage of peanut harvest machinery and poor harvesting effect in China. The interaction between mechanism and pod-soil mixture was analysed to obtain the motion state of peanut relative separation conveyor. ADAMS simulation was applied to obtain the spatial curve of peanut trajectory in the separation process. The study determined that the optimum operating parameters of the separation conveyor were a drum speed of 280 r/min and an inclination angle of 19°. This study provides a theoretical basis for the further design of efficient peanut harvesting device.*

## 摘要

*针对我国花生复收机械短缺、复收效果差的现状，设计一种花生荚果收获分离输送装置。对机构-果土混合物进行互作分析，得到花生荚果相对分离输送装置运动状态。运用 ADAMS 对果土分离输送过程进行仿真，得到花生荚果在分离输送装置上的运动轨迹空间曲线。研究确定分离输送装置最佳工作参数为滚筒转速 280 r/min、倾角 19⁰。为进一步设计高效的花生果土分离机械提供理论基础。*

## INTRODUCTION

Peanut is an important oil crop and cash crop in China. It is the main crop for China's export earnings. The planting area and output are among the highest in the world. At present, the problems of disordered peanut harvesting methods and poor harvesting effect are still prominent in China. Thus, peanut mechanized harvesting has become one of the important factors affecting peanut production. And picking matters most in peanut harvesting process, directly related to the efficiency and quality of the peanut harvest *(Pari et al, 2020*) The loss rate of mechanized harvesting peanut in sandy land is generally about 2%. With the increase of soil viscosity, the loss rate increases to 3%~5%. The loss of artificial harvesting (*Wang et al., 2013*) is especially high. The reference article introduces the methods and technical means to improve the efficiency of grain washing machine (*Babic et al, 2013*). At present, the total loss rate of missing and falling pods of domestic peanut harvesters is 1.8%~4.2%. The loss is about 235.5 kg/hm2 measured in the field.

The pods soil separation and conveying device is the core working mechanism of the peanut harvester. Its quality directly affects the working performance of the peanut harvester. A peanut falling pick-up machine was designed by Li X. et al. The pods soil separation device uses centrifugal force to separate. This machine is controlled by multiple motors. Its pods soil separation effect is good, but the cost is high and the failure rate is high (*Li et al., 2020*). A peanut groundnut picking machine designed by Chen H. and others consists of a lifting mechanism, a soil crushing mechanism, a cleaning mechanism, a vibrating screen and a pods collecting box. The machine has the characteristics of large size and high production cost (*Chen et al., 2019*).

In view of the above problems, this paper deeply studies the theory of pods soil separation of the separation conveyor and obtains the optimal parameter combination of the separation conveyor. The research results can improve the technical level of peanut harvester, enrich the relevant theories of pods soil separation, and reduce the cost of peanut harvester. It is of great significance to promote the development of peanut harvesting machinery in China (*Gao et al., 2017*).

## MATERIALS AND METHODS

### *Determination and analysis of mechanical properties of peanut pods*

Recovery of peanut pods is an important part of peanut harvesting. Peanut pods are susceptible to impact, extrusion, vibration and other conditions in the process of mechanized harvesting. These effects can lead to different degrees of damage to peanut pods (*Liu et al., 2022*). These processes are closely related to their basic physical properties (*Li et al., 2017, Hou, 2017*). According to the physical characteristics of peanut fruit, the separation and conveying roller device is designed. The purpose is to accurately design the gap between each separation conveying roller. The triaxial dimension index of peanut pod was selected as the evaluation index of geometric characteristics in this study. The size mark of peanut triaxial is shown in Fig.1.

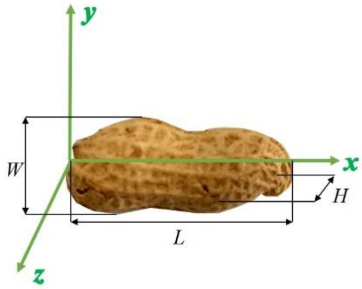



**Fig. 1 - Peanut triaxial dimension marking**

Dabaisha, Silihong and high oleic acid peanut Jihua 16 were used as experimental materials in this study. The moisture content of peanut pods for this trial is 11.2%~14.7%. The trial adopts the method of taking the average value by repeated measurement. The measurement result record is shown in Table 1.

**Table 1**

**Pod parameters of three peanut varieties**

| Name | L/mm | W/mm | H/mm | Minimum Length/mm | Minimum Width /mm | Minimum Height /mm |
|---|---|---|---|---|---|---|
| Da Baisha | 39.84 | 17.88 | 16.12 | 24.52 | 15.17 | 13.90 |
| Si Lihong | 47.83 | 14.69 | 14.57 | 22.62 | 11.77 | 11.69 |
| Ji Hua 16 | 40.11 | 18.99 | 17.03 | 24.87 | 16.33 | 14.94 |

### *Structure and working mechanism*

The working principle of the drum type separation conveyor is as follows. Use six groups of rollers to collide the pod-soil mixture during the rotating work. The crushed soil blocks leak through the gap between the grid bars and the rollers. The soil adhered to the peanut pod is separated by the continuous impact between the grid and the pod-soil mixture. Impurities such as broken soil are removed with the continuous rotation of the separation drum. Peanut pods are transported to the rear of the machine in a jumping shape (*Wei et al., 2019*). The rubber products wrapped on the fence strip can reduce the damage to the peanut pods (*Wang et al., 2020*).

The conditions that can ensure the smooth backward separation and transportation of peanut pods are as follows. The diameter of roller bar is 12 mm. Screen surface width is 1900 mm. The minimum diameter of peanut pod between rods and rollers is 11.69 mm. In addition, the length of conveyor is 1600 mm.

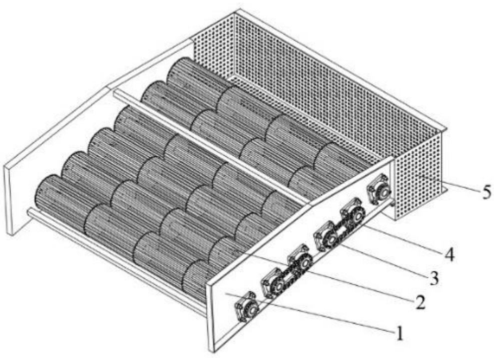


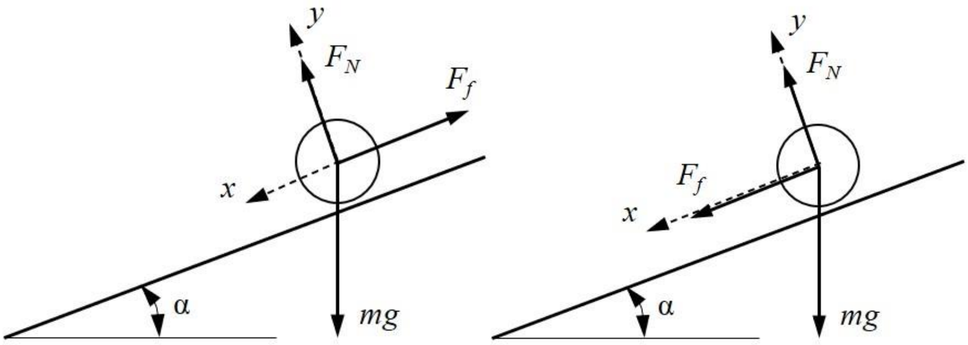

**Fig. 2 - Structural diagram of separation conveyor**

*1. Connecting plate; 2. separating roller conveyor device; 3. Roller shaft; 4. Drive chain; 5. Pods collecting box*

***Movement analysis of peanut pod relative separation conveyor***

It is easy to produce vibration when the separation conveying device is working, which leads to the phenomenon of "jumping" and "backflow" of pod-soil mixture. There are problems such as unclean separation of pods and soil, high damage rate of peanut, etc. In order to avoid the above problems, the movement analysis of peanut pod relative separation conveyor was carried out (*Zhang et al., 2012, Yang et al., 2016*). The optimal parameters are designed through theoretical calculation and analysis.

The separating and conveying device needs to transport the materials on the screen back while separating the pods and soil. The pod-soil mixture will appear relatively static, reciprocating sliding and throwing away from the screen surface when the mechanism of the separation conveyor is different from the selection of working parameters. Fig. 3 shows the forward and reverse slipping force of peanut relative separation sieve.




**a) Forward slip** **b) Reverse slip**

**Fig. 3 - The forward and reverse slipping force of peanut relative separation sieve**

The dynamic equation of forward and reverse sliding of peanut pod is as follows according to Fig.3.

$$\begin{cases} m\left(a_{x_{12}}+a_x\right)=mg\sin\alpha\mp F_f \\ ma_y=F_N-mg\cos\alpha \\ F_f=\mu F_N \end{cases} \tag{1}$$

where:

$F_f$- frictional force, N;

$F_N$- supporting force, N;

α- Angle between screen surface and horizontal plane, $^0$.

The instantaneous acceleration of forward slipping can be solved as follows:

$$a_x=g\sin\alpha-\frac{F_f}{m} \tag{2}$$

The instantaneous acceleration of reverse slipping can be solved as follows:

$$a_x=g\sin\alpha+\frac{F_f}{m} \tag{3}$$

The critical conditions when peanut pods are thrown off the screen are as follows:

$$k_2r\omega^2\cos\omega t\bullet\sin(\beta+\alpha)=g\cos\alpha \tag{4}$$

The acceleration of peanut thrown away from the screen surface relative to the screen is obtained from formula 6 as follows:

$$\begin{cases} a_x^{'}=k_1r\omega^2\sin\omega t\bullet\cos(\beta+\alpha)+g\sin\alpha \\ a_y^{'}=k_2r\omega^2\sin\omega t\bullet\sin(\beta+\alpha)-g\cos\alpha \end{cases} \tag{5}$$

According to the above derivation formula, the motion state of the peanut pod relative separation conveyor can be obtained by substituting the known parameters into the solution. This provides an analytical basis for the problem of high damage rate of peanut.

### *Analysis of separation conditions between peanut and soil*

The reason why the surface of peanut pod is easy to bond with soil is that the soil has high moisture content (*Kong, 2016*). The separation conditions of pods and soil were obtained through the mechanical analysis of the adhesion between peanut pods and soil (*Cao et al., 2019*). Thus, it provides a theoretical basis for achieving high-quality separation performance.

In order to facilitate analysis and calculation, peanut and soil are ideally equivalent into two parts for stress analysis. The stress analysis diagram is shown in Fig.4.

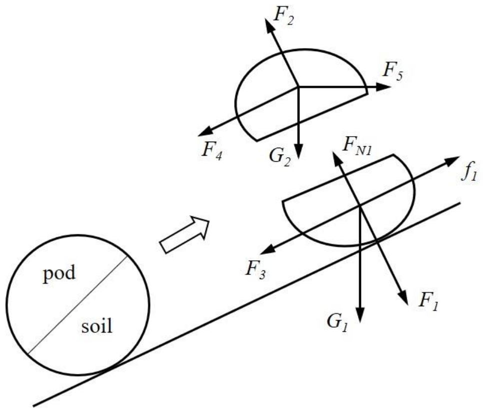



**Fig. 4 - Stress analysis of pod soil separation**

It can be seen from Fig. 4 that the force required to realize the separation of pod and soil is greater than the bonding force.

$$f_1 + G_1 \sin\theta > F_3 \tag{6}$$

According to the data, the calculation formula of soil adhesion is as follows:

$$F_3 = cS \tag{7}$$

where:

$c$ - the soil bond strength, kPa.

$S$ - the area of the soil fracture surface, cm$^2$.

It can be calculated according to the friction principle:

$$f_1 = \mu F_{N1} \tag{8}$$

where: $\mu$- friction factor.

The simultaneous equation is solved to obtain $F_{N1}$ as follows:

$$F_{N1} = \frac{mg}{(\mu+1)\sin(\beta-\theta)+(1-\mu)\cos(\beta-\theta)} \tag{9}$$

where:

$$\beta = \arccos\frac{l}{a+b+D} \tag{10}$$

The friction force of peanut is related to its own weight which can be seen from the above analysis. In addition, it is also related to the inclination of the device and the size of the drum gap.

### *Dynamics analysis of peanut and separating conveyor*

The peanut soil mixture is excavated by the excavation device. The peanut soil mixture is lifted backward to the separation conveyor as the machine moves forward (*Fan et al., 2019*).

The stress analysis of peanut on the separation conveyor is shown in Fig. 5. For the convenience of calculation and analysis, the peanut is simplified as an ellipsoid. Define the length of the long axis and short axis of peanut as a and b respectively, the diameter of the separation and conveying drum as D, and the gap between the two drums as l.

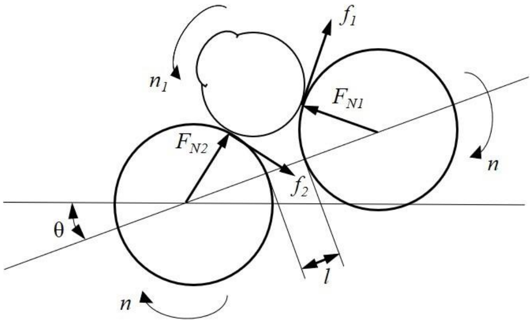



**Fig. 5 - Stress Analysis of peanut**

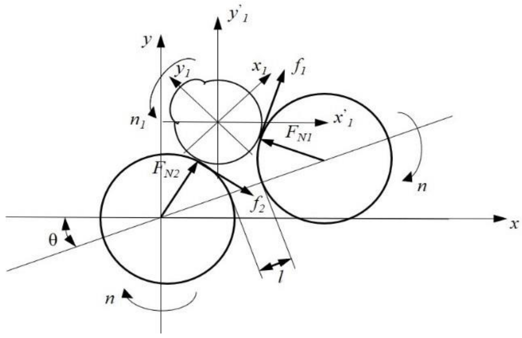



**Fig. 6 - Schematic diagram of coordinate transformation**

The stress of peanut on the separation conveyor is as follows: the supporting forces $F_{N1}$ and $F_{N2}$ of the two rollers, the gravity $mg$ of the peanut pod, the friction $f_1$ and $f_2$. In order to ensure the smooth backward lifting and transportation of peanut pods, the resultant moment of each force on the contact point must be greater than zero.

In order to facilitate the stress analysis when the position of peanut changes at any time, the coordinate transformation method is used for analysis and calculation. The schematic diagram of coordinate transformation is shown in Fig. 6.

Therefore, the elliptic equation of peanut pod in $x_1y_1$ coordinate system is as follows:

$$\frac{x_1^2}{a^2}+\frac{y_1^2}{b^2}=1 \tag{11}$$

According to the rotation formula transformation of the coordinate system, the solution is obtained in the $x'_1y'_1$ coordinate system:

$$\frac{(x_1^{'}\cos\theta+y_1^{'}\sin\theta)^2}{a^2}+\frac{(y_1^{'}\cos\theta-x_1^{'}\sin\theta)^2}{b^2}=1 \tag{12}$$

where, $\theta$ - is the angle between screen surface and horizontal plane, º.

The formula of the coordinate system is as follows after transverse transformation.

$$\begin{cases} x=x_1^{'}+x_0 \\ y=y_1^{'}-y_0 \end{cases} \tag{13}$$

By combining the above equations, the relative coordinates of the peanut centre are as follows:

$$\begin{cases} x_0=-\dfrac{2l\cos\theta}{a+b+D}\cos(\alpha+\theta) \\ y_0=\dfrac{a+b+D}{2}\sin(\alpha-\theta) \end{cases} \tag{14}$$

The coordinates of the right roller in the $xy$ coordinate system is as follows:

$$\begin{cases} x_{o2}=-\dfrac{4Dl\cos(\alpha+\theta)\bullet\cos\theta}{2\sqrt{\left[4l\cos(\alpha+\beta)\bullet\cos\theta\right]^2+(a+b+D)^4\sin(\alpha-\theta)}} \\ y_{o2}=\dfrac{a+b+D}{2}\sin(\alpha-\theta) \end{cases} \tag{15}$$

Calculate the distance from the right roller to $F_{N2}$ as follows:

$$S=\frac{k_1x_{o2}-y_{o2}+k_1l\cos\theta+l\sin\theta}{\sqrt{k_1^2+1}} \tag{16}$$

The distance from the right roller to $f_2$ is as follows:

$$t = x_{o2} - x_o \text{t} \tag{17}$$

The distance from the right roller to the peanut gravity $mg$ is as follows:

$$s_2 = \frac{k_2 x_{o2} - y_{o2} - \dfrac{(a+b+D)^2 \sin(\alpha-\theta)}{4l\cos\theta\cos(\alpha+\theta)}}{\sqrt{k_2^2+1}} \tag{18}$$

where:

$k_1$-The slope of the straight line where the supporting force $F_{N2}$ is located;

$k_2$ -The slope of the straight line where the supporting force $F_{N1}$ is located.

Combining the above formula, the resultant torque is obtained as follows:

$$\sum M_{O2} = F_{N2}s - f_2 s_2 - mgt \tag{19}$$

Through the analysis of the above formula and calculation results, it can be seen that as follows: Peanut is mainly affected by the inclination of the device on the separation conveyor. In addition, it is also vulnerable to the impact of other peanut pods in the actual harvest process.

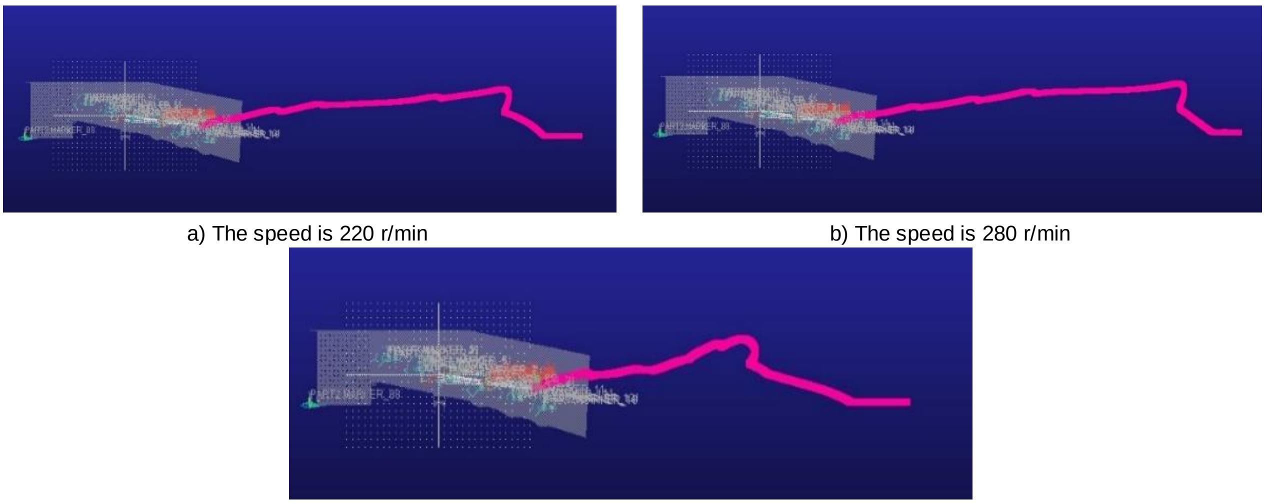
## RESULTS

### *Simulation analysis of separation conveyor*

The whole simulation process of peanut on the separation and conveying device is carried out in Adams view environment. Set the unit system as MMKS. The forward speed of the virtual prototype is set to 1.67 m/s. The rotating speed of the drum of the separation conveyor is 280 r/min. The total time of the whole virtual simulation process is set to 1.8 s, and the step size is set to 800 steps.

Selecting two marker points in the middle of peanut and recording the whole process of its movement can simulate the trajectory and movement law of peanut in the process of separation and transportation (*Wang et al., 2021*). At first, peanuts are excavated and picked up by the excavation device. The peanut enters the separation conveyor and moves forward with the machine. The separating conveying drum rotates, and the peanut jumps backward under the impact force. Finally, all the peanuts enter the rear pods collecting box.

The forward speed of the implement remains unchanged during the simulation. The rotating speed of the separation conveying drum is 220 r/min, 280 r/min and 310 r/min respectively. Record the movement track and law of peanut under different parameters. After the simulation, the simulation trajectory of peanuts at other three different speeds is shown in Fig. 7.



a) The speed is 220 r/min

b) The speed is 280 r/min

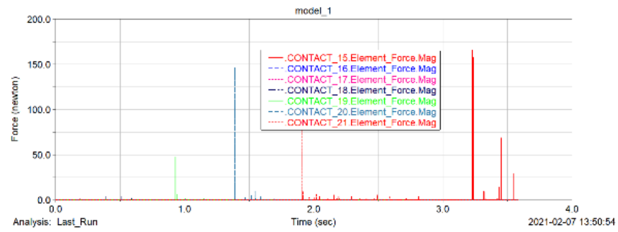
c) The speed is 310 r/min

**Fig. 7 - Simulated trajectory of peanut pods at three different speeds**

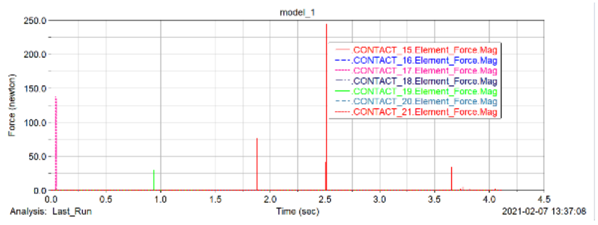
Compared the motion simulation tracks of different drum speeds. It can be seen that the trajectory and motion law of peanut simulation are roughly the same when the forward speed of the machine is the same and the rotating speed of the drum is different.

The jumping phenomenon of peanut is more serious with the continuous increase of drum speed. In particular, "backflow" occurs in some nodes of peanuts as shown in Fig. 7.

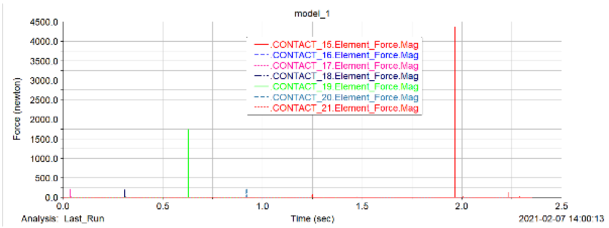
The rotating speed of the drum is set at 280 r/min, and the forward speed of the simulated machine is selected as 1.38 m/s, 1.67 m/s, 1.94 m/s and 2.22 m/s respectively. The impact force on peanuts is shown in Fig. 8.



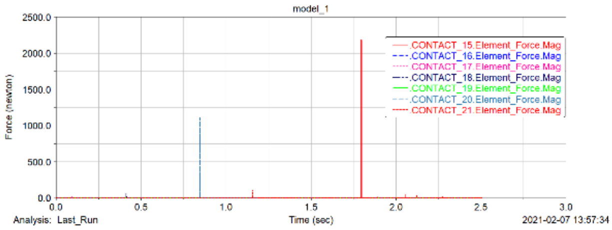
a) The forward speed is 1.38 m/s



b) The forward speed is 1.67 m/s



c) The forward speed is 1.94 m/s



d) The forward speed is 2.22 m/s

**Fig. 8 - The impact force on peanut at different forward speeds**

The following results can be found by comparing the impact force on peanuts obtained from ADAMS simulation process in different states. When the forward speed of the machine is 1.67 m/s and the rotating speed of the drum is 280 r/min, the impact force of the two working parameters is smaller than that of the matched peanut.

***Field test conditions and schemes***

Si Lihong peanut varieties were selected for field experiment in Pingdu experimental field. The test adopts the method of taking the average value of multiple groups of repeated tests. Select 30 meters as the harvest operation test area each time, and randomly select 6 test areas.

**Fig. 9 - The test process**

***Field test results and analysis***

The Box Behnken test design scheme is adopted with the damage rate, soil content and pod leakage rate of peanut as the evaluation indexes. The inclination angle of the separation conveyor, the rotating speed of the drum and the forward speed of the machine are tested and studied. The level code of test factors is shown in Table 2.

**Table 2**

**Test factor level code**

| | Declination angle of separator (°) | Drum speed (r/min) | Forward speed (m/s) |
|---|---|---|---|
| -1 | 19 | 220 | 1.38 |
| 0 | 21 | 250 | 1.67 |
| 1 | 23 | 280 | 1.94 |

This test plan is designed according to the Box-Behnken test principle. The test design scheme and results are shown in Table 3, where the inclination of the separating device is A, the rotation speed of the drum is B, and the forward speed of the machine is C.

**Table 3**

**Test design scheme and test results**

| Serial number | Declination angle of Separator A / (°) | Drum speed B / (r/min) | Forward speed C / (m/s) | Soil content $Y_1$/ (%) | Breakage rate $Y_2$ / (%) | Pod leakage rate $Y_3$/ (%) |
|---|---|---|---|---|---|---|
| 1 | 1 | 1 | 0 | 2.03 | 2.44 | 0.24 |
| 2 | -1 | 1 | 0 | 2.31 | 1.13 | 0.18 |
| 3 | 1 | -1 | 0 | 3.07 | 2.46 | 0.22 |
| 4 | -1 | -1 | 0 | 2.27 | 1.19 | 0.19 |
| 5 | 1 | 0 | 1 | 4.21 | 2.66 | 0.24 |
| 6 | -1 | 0 | 1 | 2.48 | 2.07 | 0.23 |
| 7 | 1 | 0 | -1 | 3.62 | 2.43 | 0.24 |
| 8 | -1 | 0 | -1 | 2.67 | 2.39 | 0.29 |
| 9 | 0 | 1 | 1 | 3.28 | 2.15 | 0.27 |
| 10 | 0 | -1 | 1 | 3.41 | 2.22 | 0.31 |
| 11 | 0 | 1 | -1 | 2.34 | 2.19 | 0.22 |
| 12 | 0 | -1 | -1 | 2.63 | 2.15 | 0.22 |
| 13 | 0 | 0 | 0 | 2.98 | 2.11 | 0.24 |
| 14 | 0 | 0 | 0 | 2.77 | 2.16 | 0.26 |
| 15 | 0 | 0 | 0 | 3.02 | 2.11 | 0.19 |
| 16 | 0 | 0 | 0 | 2.76 | 2.33 | 0.25 |
| 17 | 0 | 0 | 0 | 2.77 | 2.41 | 0.24 |

It can be directly seen from table 3 that the soil content of peanut is generally between 2.03% and 3.62% during the above test and research. After excavation, separation and transportation, the damage rate of peanuts is generally in the range of 1.13% - 2.66%. The average pod leakage rate is about 2%. It can be directly seen that the device can better ensure the net harvest quality of peanuts. The device is designed to work well.

## Analysis of variance

The test results were imported into SPSS for variance analysis (Tanner-Smith, E.E., 2014, Guo M. et al., 2017). The results were shown in Table 4. The model P for soil content, breakage rate and pod leakage rate were 0.0008, <0.0001 and <0.0001 ($p < 0.01$), respectively, as analysed by the data in the table 4. The data from this regression model are highly significant. The model fit was good and it argues that the error during this experiment is small, and the experimental data has strong reliability. At this time, you can select the combination of A1, B3, and C2 to form the optimal combination of A1B3C2. The resulting optimal combination plan A1B3C2 exists in the orthogonal test table 3. Therefore, the combination of A1B3C2 was the best. The optimal combination plan was that the speed of the separation drum is 280 r/min, the inclination of the separation conveyor is 190, and the forward speed of the machine is 1.67 m/s.

**Table 4**

**Variance analysis table**

| Source of variation | Sum of squares | Degree of freedom | F | p-Value |
|---|---|---|---|---|
| $X_1$ | 153.29 | 9 | 15.41 | 0.0008 |
| $X_2$ | 7.81 | 9 | 31.41 | <0.0001 |
| $X_3$ | 95.532 | 9 | 14.10 | <0.0001 |
| Error | 52.53 | 16 | / | / |

***Field test verification***

The average value is obtained through multiple groups of repeated field experiments, and the test results are shown in Table 5.

Table 5

**Test results**

| Peanut varieties | Soil content / % | Breakage rate / % | Pod leakage rate / % |
|---|---|---|---|
| Sili-hong peanut varieties | 3.99 | 1.16 | 0.18 |

It can be seen from the above table that the damage rate and pod leakage rate of peanuts are low, and the overall harvest effect is great. The damage rate is less than 2.5%, and the pod leakage rate is less than 0.25%.

The walking of machines and tools, soil hardening and other factors cause the soil blocks that are not easy to be broken after re-harvest during the harvest process. This puts forward higher requirements for the structural design of the separation and conveying device.

It can be seen from the test results that the test effect is good when the speed of the separation drum is 280 r/min, the inclination of the separation conveyor is 190, and the forward speed of the machine is 1.67 m/s. The recovery rate of peanut is guaranteed, and the damage and leakage of peanut pods are avoided. The performance of the machine is great.

## CONCLUSIONS

This paper aims at the problems such as poor soil removal effect of peanut recovery. A new type of separating and conveying device is designed. The main conclusions are as follows:

(1) Through the dynamic analysis of the separation conveyor and the analysis of the peanut soil separation conditions, it is found that the peanut is mainly affected by the inclination of the device on the separation conveyor. The influencing factors of peanut and soil separation are mainly related to the inclination of the separation conveyor and the gap between the two rollers.

(2) Through field experiments, it is concluded that the working effect of the machine is the best when the inclination of the separation conveyor is 190, the rotation speed of the separation drum is 280 r/min, and the forward speed of the machine is 1.67 m/s.

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