Design and test of a half-feed peanut cleaning picker suitable for clay hilly areas in South China

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Abstract: To improve the quality and efficiency of peanut half-feed harvesting in clay hilly areas in South China and address problems such as excessive soil clumps, broken branches, and seedlings in pods, difficulty in cleaning impurities, and the need for manual picking owing to the high soil viscosity and easy hardening, a new half-feed peanut cleaning picker suitable for southern clay hilly areas, including its overall structure and transmission system, was designed. The picker can perform the operations of soil removal, clamping and conveying of seedlings, and orderly pod picking and pod gathering. The structural design of key components and the analysis and determination of key parameters were carried out. By adopting a crank rocker mechanism, a soil removal device was designed. A single-side chain clamping conveying device, which consists of a clamping chain, a pretightening spring, and a guide rail, was designed. A phase tangent configuration of opposite rollers was used to design a pod picking device. Thus, the functions of the half-feed peanut picker, such as cleaning and removing soil, smooth and reliable clamping and conveying, and flexible pod picking, were realized. The field test revealed that when the picking rate was greater than 97%, the soil removal pods drop rate was less than 10%, and the soil removal rate was greater than 50%. The performance indicators meet the design requirements. This study provides a technical reference for the research and development of clean picking technology for upright peanuts in the clay hilly areas of southern China.

Keywords: peanut, picking device, clamping and conveying device, half-feed, soil removal device, southern clay hilly areas

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1 Introduction

Peanut has become one of the fastest growing oil crops and cash crops in the world, second only to soybean in terms of world oil production and trade, and plays an important role in the safety of edible oil worldwide[1-3]. According to statistics from the World Food and Agriculture Organization (FAO), in 2020, the peanut planting area in China was 4.62×10^6 hm^2, with a yield of 1.80×10^7 t, both of which rank among the top in the world. However, the mechanization level of peanut harvesting in China lags behind that in countries such as the United States, Brazil, and Argentina. Most peanut planting areas are still dominated by manual and semimechanized harvesting[4-8], especially in the clayey soil areas of southern China, where manual harvesting is still the main method[9]. In 2020, the mechanized harvest level of peanuts in China was only 49.61%[10], and it was even lower in southern hilly clayey soil areas, which severely restricted the development of the peanut industry.

In southern clayey soil areas, local farmers usually pull up peanuts by hand after the rain loosens the soil and then use small peanut picking machines for pod picking operations. However, owing to the high soil viscosity and easy compaction, there are many soil lumps on the pulled peanut seedlings, coupled with the lack of special peanut picking and harvesting machines suitable for southern clayey soil areas. The harvested peanut pods contain soil lumps, broken branches, and seedlings that are difficult to clean and require manual sorting, which severely restricts the development of the peanut industry in this region. Therefore, conducting research on methods and technologies for clean peanut harvesting in southern clayey soil has practical significance for improving the mechanization level of peanut harvesting, reducing labor intensity, improving the cleanliness of peanut pods, and facilitating the agricultural season in the hilly areas of southern China.

Research on peanut harvesting technology abroad can be divided into two main forms: full feeding and half feeding. The full feeding is represented mainly by the United States, whereas the half feeding is represented by Southeast Asian and South Asian countries such as India and African countries such as Nigeria[3,11]. Full feed harvesting, represented by the United States, involves early research, high mechanization, and high efficiency, making it suitable for large-scale peanut harvesting. Countries with similar peanut production conditions, such as Brazil, Australia, and

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Argentina, also use full-feed harvesting[12,13]. However, owing to the sandy loam soil in which they grow peanuts, the United States often uses perforated screens to remove a small amount of fine soil, and there are few reports on clean removal techniques for clayey soil blocks. The mechanization level of peanut harvesting in African, Southeast Asian, and South Asian countries such as India is even lower than that in China, relying mainly on manual labor; thus, clean picking technology has not been investigated.

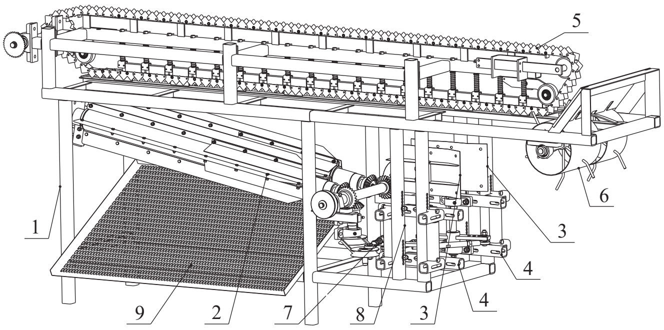
Research on peanut harvesting technology in southern sticky soil in China has focused mostly on peanut digging and plucking machines and small harvesters[14-19], whereas research on clean harvesting technology for half-feed peanuts in sticky soil has rarely been reported. Research on clean crop harvesting technology has focused mostly on potato and sweet potato harvesters[20-22].

In view of the above problems, a half-feed peanut cleaning picker suitable for southern clay hilly areas was designed in this study to provide a technical reference for research on peanut harvesting machinery in the southern clay hilly areas of China. The main research aims are as follows: (1) design of a new half-feed peanut cleaning picker suitable for southern clay hilly areas; (2) design and analysis of key components to address the problems of clean harvesting machinery on the market; and (3) manufacture of prototypes and field performance testing research.

2 Overall structure and working principle

2.1 Overall structure

On the basis of research on peanut varieties, planting patterns, and soil characteristics in southern China, a half-feed peanut cleaning picker suitable for the clay hilly area of southern China was designed. As shown in Figure 1, the machine is mainly composed of a picking device, a soil removal device (including a soil patting plate, installation adjustment frame, and driving mechanism), a clamping and conveying device, a seedling feeding mechanism, and a transmission system. The machine mainly performs operations such as peanut seedling feeding, clamping and conveying, patting and removing soil, and pod picking. The power for seedling feeding, patting and removing soil and conveying, clamping and conveying, and pod picking is provided by a gasoline engine through the transmission system. The main parameters are listed in Table 1.



1. Rack 2. Picking device 3. Soil patting plate 4. Installation and adjustment frame of the soil patting plate 5. Clamping and conveying device 6. Seedling feeding mechanism 7. Soil patting plate driving mechanism 8. Vertical beam for adjusting and installing the soil patting plate 9. Screening inclined plate

Figure 1 Structural components of the picker

2.2 Working principle

When working, the peanut seedlings move backward along the lower conveying guide rail under the push of the tooth of the feeding mechanism and the interaction with the clamping chain of the clamping conveying device. When passing through the soil removal device, the soil on the peanut seedlings is patted and dropped under its flapping action, and the remaining clean seedlings enter the picking device under the drive of the clamping conveying device. The pod is picked under the action of the roller. Moreover, the upper and lower positions, front and rear positions, patting amplitude, and frequency of the soil removal device can be adjusted through the soil patting plate with an adjustment frame and a driving mechanism. The screening inclined plate, below the picking device, is provided with a waist-shaped hole with a diameter of 8 mm, which is smaller than the diameter of peanut pods. During the process of peanut pods and soil falling along the screening inclined plate, soil leaks below the screening inclined plate, and peanut pods slide down to the pods collection place, thereby separating the soil and pods.

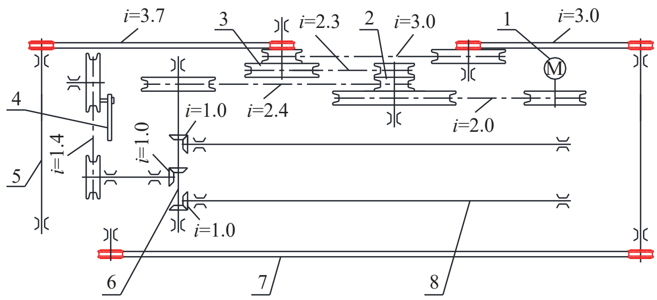
Table 1 Main parameters of the picker

Item	Value
Picker size (length×width×height)/mm	2600×950×1080
Distance adjustment range between the soil removal device and the clamping conveyor device/mm	30-100
Distance adjustment range between the soil removal device and the picking device/mm	50-200
Picker total mass/kg	250
Matched power/kW	3.3
Power source form	Single cylinder gasoline engine
Rated speed of power source/r·min^{-1}	1800

3 Key component structure and parameters

3.1 Transmission system

The picker adopts a split transmission system, including the seedling feeding mechanism transmission, the soil removal and picking device transmission, and the clamping conveying device transmission, as shown in Figure 2. First, the power is transferred from the engine to distribution wheel group one through the belt. Among them, the power of distribution wheel group one is transmitted to distribution wheel group two by a belt, and the main shaft of the seedling feeding mechanism is driven to rotate through the transmission chain, achieving the feeding function of peanut seedlings. The other power of distribution wheel group one drives the main shaft of the soil removal and picking device to rotate through a belt, drives the soil removal device to shake the rocker through a pair of bevel gears and belts, and then drives the slapping plate to swing to achieve the slapping and soil removal functions. Moreover, the other two pairs of bevel gears drive the two picking rollers to rotate in opposite directions, achieving the fruit picking function.

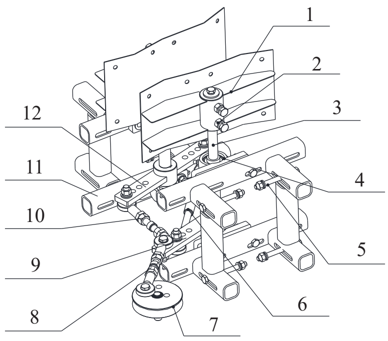


1. Engine 2. Distribution wheel group one 3. Distribution wheel group two 4. Soil removal device drive rocker 5. Main shaft of the seedling feeding mechanism 6. Main shaft of the soil removal and pod picking drive 7. Clamping conveyor chain 8. Picking roller shaft

Figure 2 Schematic of the transmission system

The soil removal device is an important device for the half-feed peanut cleaning and picking machine, which is located below the clamping conveying device of the cleaning picker and in front of the picking device. This process involves the patting and cleaning of peanut seedlings. There is currently no special half-feed soil removal device in southern clay hilly areas on the market. When peanuts are fully fed and harvested in the main production areas of northern China, the soil removal work is mostly performed during the process of picking, conveying, picking and sorting. When half-feeding for combined harvesting, a small amount of sand or sandy loam soil is often removed from peanut seedlings by shaking the soil plate. However, in the clay hilly areas in southern China, local farmers usually manually pull up peanut seedlings after the soil loosens after the rain and then use a small peanut picker to carry out the pod picking operation. However, owing to the high viscosity of the soil and its tendency to compact, the pulled peanut seedlings carry many soil blocks, making it difficult to meet the requirements of clean soil removal with simple shaking. The harvested peanut pods have many soil blocks, broken branches, and seedlings, making it difficult to clean impurities, and manual sorting is needed.

To analyze the above problems, this study designed a kind of peanut half-feed and soil removal device suitable for southern clay hilly areas by using a crank rocker mechanism. It is composed mainly of soil patting plates, soil patting plate installation shafts, bearings with seats, a connecting rod, a driving pulley, a driving rocker for the soil removal device, swing rods, and a soil patting plate installation and adjustment frame, as shown in Figure 3.



1. Soil patting plate 2. Soil patting plate locking bolt set 3. Soil patting plate installation shaft 4. Bearing with seat 5. Soil patting plate installation and adjustment bracket locking bolt set 6. Connecting rod one 7. Drive pulley 8. Soil removal device driving rocker 9. Swing rod one 10. Connecting rod two 11. Soil patting plate installation and adjustment bracket 12. Swing rod two

Figure 3 Diagram of the soil removal device

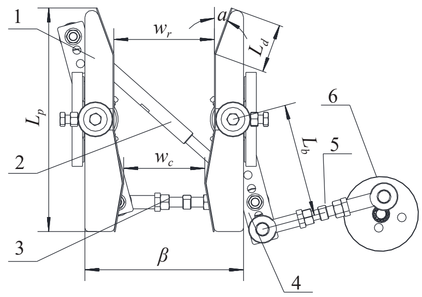
The soil patting plates are installed on the installation shaft of the two soil patting plates facing each other and are locked and fixed by the locking bolt set. Swing rods one and two are fixed to the two installation shafts through keys, and the two swing rods are connected through connecting rod two. The swing rod is hinged to the driving pulley by the soil removal device driving the rocker.

When working, the two soil patting plates swing synchronously, and the soil blocks and soil are removed from the peanut seedlings and pods when the peanut seedlings enter between the two soil patting plates, which are affected by the swing of the soil patting plates. The remaining clean seedlings enter the subsequent picking device under the drive of the clamping and conveying device. Moreover, for highly viscous soil, connecting rods can be used to connect the two swing rods so that the soil patting plates can be patted in opposite directions to enhance the soil removal effect of patting.

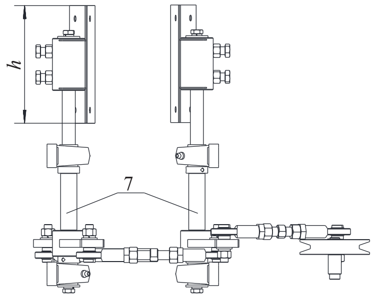
Moreover, to ensure that the part of the peanut seedlings carrying soil (i.e., the part buried in the soil with pods) is beaten by the soil patting plates (as shown in Figure 4) and to enhance the soil removal effect, the height h of the soil patting plates should meet the following conditions:

$$h \geq l \tag{1}$$

where, l is the length of the part of peanut seedling with pods, mm.



a. Top view



b. Rear view

1. Soil patting plate 2. Connecting rod one 3. Connecting rod two 4. Swing rod one 5. Soil removal device driving rocker 6. Drive pulley

Note: w_c is the minimum distance between the two soil patting plates，mm；w_r is the width at the entrance of the channel, mm; β is the angle of the two soil patting plates, mm; L_d is the length of the guide plate, mm; α is the guiding angle, (°); L_b is the effective length of swing rod one, mm; L_p is the length of the soil patting plate, mm; r is the length of the crank of the drive pulley, mm; h is the height of the soil patting plate, mm.

Figure 4 Schematic of the main dimensions of the soil removal device

On the basis of the actual research situation in the main peanut production area (l=50-150 mm) and referring to relevant research[21], while meeting the needs of adjusting the upper and lower positions of the soil patting plate, h=180 mm.

To ensure the smooth passage of peanut seedlings through the channels of the two soil patting plates without congestion, the minimum distance between the two soil patting plates, i.e., the distance w_c at the exit, should meet the following conditions:

$$w_c \geq d \tag{2}$$

where, d is the diameter of the part of the peanut seedling with pods, mm.

The spacing w_c can be adjusted by using the soil patting plate adjustment bracket (as shown in Figure 3). According to the actual investigation of the main producing areas of peanuts (d=70-110 mm), w_c=120 mm.

To ensure that the peanut seedlings enter the two soil patting plate channels smoothly, the width w_r at the entrance of the channel is generally greater than the width at the exit. Combined with the installation space, the design is as follows:

$$w_r = 1.25w_c \tag{3}$$

In the process of operation, the angle β of the two soil patting plates can be adjusted according to the actual situation by adjusting the length of connecting rod two, and then the relationship between w_r and w_c can be adjusted so that the two soil patting plates form a funnel-shaped channel with a large mouth inlet and small mouth outlet, which can impact the soil inside and outside the peanut seedling and pod bunch and improve the soil removal effect.

To prevent dynamic changes in the entrance width from affecting the passability of peanut seedlings during the swinging or opposite patting process of the soil patting plates, a guide plate is provided at the entrance of the soil patting plates, and the following conditions should be met:

$$L_d \sin\alpha \geq \frac{2r}{L_b} \cdot \frac{L_p}{2} \tag{4}$$

where, L_d is the length of the guide plate, mm; α is the guiding angle, °; L_b is the effective length of the swing rod, mm; L_p is the length of the soil patting plate, mm; and r is the length of the crank of the drive pulley, mm.

In actual harvesting, the length r of the crank and the effective length L_b of swing rod one can be changed by changing the hinge position of the driving rocker of the soil removal device with the drive pulley and swing rod one.

Preliminary design: r=25 mm and L_b=160 mm. Combined with the space size, the length of the soil patting plate is designed as L_p= 320 mm. By substituting the above data into Equation (4), the following can be obtained:

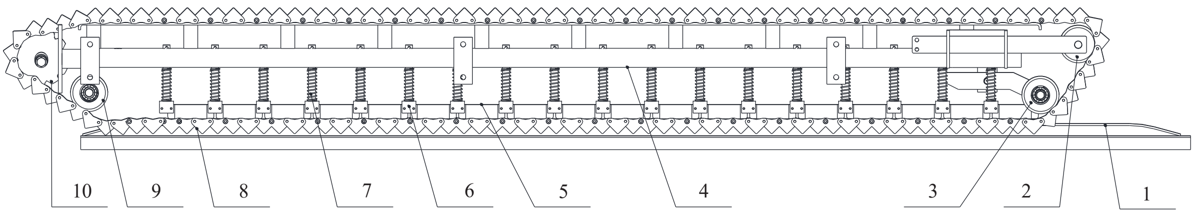
$$L_d \sin\alpha \geq 50 \tag{5}$$

To ensure that all the peanut seedlings enter the two soil plate channels, the longer the guide plate length L_d is, the greater the guide angle α is, the larger the opening range of the guiding space is, and the more favorable it is for the peanut seedlings to enter. However, excessive L_d results in imbalanced rotational inertia on the installation axis of the soil plate. If α is too large, such as greater than 45°, it will not favor the entry of peanut seedlings. After comprehensive consideration, the guidance angle is α= 25°, and the length of the guide plate is L_d=120 mm.

3.2 Clamping and conveying device

The clamping and conveying device is an important device for a half-feed peanut cleaning and picking machine. This device is located behind the seedling feeding mechanism, above the soil patting device and picking device, and transports peanut seedlings from front to back. Currently, the main clamping methods are belt clamping and chain clamping[23-25]. The belt clamping cost is low, but problems such as a lack of tight clamping and easy slip exist. When peanuts are under the impact of the picking roller, problems such as unclean picking of pods, seedlings falling off, and severe breaking of branches and leaves easily occur. The radial axial force of chain clamping is small, the installation accuracy requirement is low, and the clamping is relatively reliable and stable.

This study adopts a single clamping chain and conveying guide rail clamping conveying structure, which is composed of a guide rail, a tensioning wheel, a support frame, a rubber press block, a pressing rod, a pressing spring, a clamping chain, and a driving sprocket, as shown in Figure 5. The lower end of the rubber press block is pressed onto the clamping chain, causing the clamping chain to be tightly pressed onto the guide rail. The upper end is connected in series with each rubber press block through the clamping groove at the lower end of the press rod. The upper end of the press rod is sleeved with a press spring and fixed in the guide hole of the support frame through a cotter pin. When many peanut seedlings are fed, the clamping chain is squeezed. When the squeezing force is greater than the pre-tightening force of the press spring, the press rod is pushed upward to prevent the seedlings from being congested and stuck.

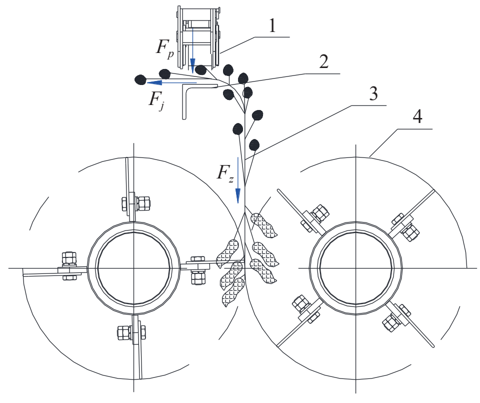


1. Guide rail 2. Tension wheel 3. Guide press wheel 4. Support frame 5. Rubber press block 6. Press rod 7. Press spring 8. Clamping chain 9. Guide wheel 10. Drive sprocket

Figure 5 Structural diagram of the clamping and conveying device

3.3 Soil removal device

During the process of clamping and conveying, peanut seedlings are subjected to the squeezing force of the clamping chain and guide rail, the striking force of the soil patting plate, and the striking force of the picking roller. The striking force of the soil patting plate is in the horizontal direction, and the component force in the vertical direction is relatively small and can be disregarded. The force applied in the vertical direction is derived mainly from the brushing force on the peanut seedlings during the process of picking the peanut pods by the picking roller, as shown in Figure 6. Peanut seedlings can be approximated as soft ropes. To prevent peanut seedlings from slipping off the clamping chain and falling into the pod collection device during the pod picking process, which would increase the impurity content and non-picking rate of the pods, the stress on peanut seedlings should meet the following conditions:



1. Clamping chain 2. Guide rail 3. Peanut plant 4. Picking roller

Figure 6 Schematic of force analysis of peanut seedlings

$$F_j \geq F_z \tag{6}$$

$$F_j = F_p f \tag{7}$$

where, F_j is the clamping force between the clamping chain and the guide rail on the peanut seedlings, N; F_z is the vertical component of the striking force of the picking roller on the peanut seedlings, N; F_p is the pressure of the clamping chain on the peanut seedlings, N; and f is the friction coefficient between the peanut seedling and the guide rail.

According to previous measurement research results [26], F_z is concentrated in the range of 7-25 N, and the friction coefficient f between different varieties of peanut seedlings and steel plates is concentrated in the range of 0.4-0.5. The median value f=0.45. By substituting the above data into Equations (6) and (7), the following can be obtained:

$$F_p \geq 55.56 \tag{8}$$

When the weight of the clamping chain, rubber press block, and press rod is disregarded, the pre-pressure of the press spring F_y=F_p, and F_y should be greater than or equal to 55.56 N. The larger the clamping chain is, the tighter it is on the peanut seedlings, and the less likely it is to slip off. However, if the pre-pressure is too high, the peanut seedlings will be crushed, and the wear between the clamping chain and the guide rail will increase. After comprehensive consideration, the designed pre-pressure of the press spring is F_y =60 N, and the stiffness is k=2000 N/m.

3.4 Picking device

The clamping and conveying device is an important device for a half-feed peanut cleaning and picking machine. This device is located behind the seedling feeding mechanism, above the soil patting device and picking device, and transports peanut seedlings from front to back. The picking device is one of the key components of the half-feed peanut cleaning and picking machine. This device is located below the clamping conveying device, above and behind the soil patting device, and performs the picking of peanut pods. It is mainly composed of picking rollers, a driving pulley, bevel gears, a locking sleeve, a driving shaft, bearings with seats, picking blades, and an installation bracket. The structure is shown in Figure 7. The drive pulley drives the drive shaft to rotate, and through two sets of bevel gears, it drives the two picking roller shafts to rotate in opposite directions, thereby driving the picking blades installed on the picking roller to rotate and pick peanut pods.

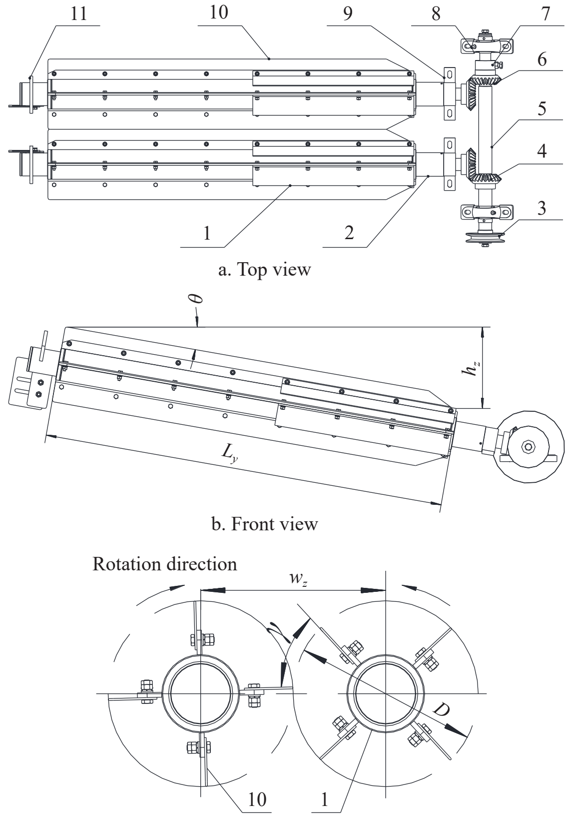
To make the peanut pod pick and fall smoothly and not fall on the peanut seedling, which would cause a secondary impact and then cause the pod to break, the picker adopts a bottom-up sequential picking method. Therefore, the picking device adopts an inclined configuration with a low front and high back and presents angle θ with the clamping and conveying device, as shown in Figure 7b. To remove all the pods on the peanut plant, the vertical height of the picking device should cover the height of the peanut plant with pods; that is, the following conditions should be met:

$$h_z \geq l \tag{9}$$

$$h_z = L_y \sin\theta \tag{10}$$

where, l is the length of the part of the peanut seedling with pods, mm; h_z is the vertical height of the picking device, mm; L_y is the length of the picking roller, mm; and θ is the angle between the picking device and the clamping conveying device, (°).

According to the above analysis, l=50-150 mm; combined with machine vibration and space size, the length of the picking roller L_y=1000 mm was designed. By substituting the above data into Equations (9) and (10), θ≥8.63° is obtained, and θ=9° is obtained after rounding to the nearest whole number.



1. Picking roller 2. Picking roller shaft 3. Drive pulley 4. Fixed bevel gear 5. Drive shaft 6. Adjustable bevel gear 7. Locking sleeve 8. Seat bearing one 9. Seat bearing two 10. Picking blade 11. Installation bracket

Figure 7 Schematic of the picking device

To reduce damage to peanut pods during the picking process, the two picking rollers adopt a tangential and staggered phase configuration, as shown in Figure 7c, namely:

$$w_z = D \tag{11}$$

where, w_z is the axis center distance of the two picking rollers, mm, and D is the diameter of the picking blade, mm.

Moreover, to increase the striking uniformity of the picking blade on peanut plants, the staggered phase was designed such that γ=45°.

In the actual work process, the axis center distance of the two picking rollers w_z can also be adjusted through adjustable bevel gears, locking sleeves, and installing brackets according to the picking difficulty of different varieties of peanut pods to form a staggered or gap configuration between the two picking rollers.

4 Test and analysis

4.1 Test conditions and materials

To evaluate the operational quality of the designed clean picker, a prototype performance test was conducted on the peanut experimental field of the Jiangxi Academy of Agricultural Sciences in Nanchang, Jiangxi Province. In reference to GB/T5262-2008 “Measuring methods for agricultural machinery testing conditions—General rules”[27], the field conditions of peanut harvests were investigated: the peanut variety is Yueyou No. 256, the soil is clay, the planting mode is flat planting with medium planting density, the row spacing is 350-400 mm, the plant spacing is 150-180 mm, the peanut plant height is generally 520-560 mm, and the range of peanut seedlings with pods is concentrated at approximately 120 mm.

4.2 Test methods

With reference to NY/T 502-2016 "Operating quality for peanut harvesters"[28] and NY/T 2204-2012 "Technical specifications for quality evaluation for peanut harvesters"[29], the picking rate, soil removal pod drop rate, and soil removal rate, which are related to cleaning picking, were selected as performance evaluation indicators of the test. In the experimental field, 5 sample areas were randomly selected for testing, and each sample area was 4×4 m². Before the experiment, the peanut seedlings were excavated via a 5HZ-175 peanut digging and harvesting machine commonly used on the market and then placed in the field for natural drying for 3 d. The moisture content of the peanut seedlings ranged from 20%-30%, the average moisture content of the soil blocks ranged from 13%-19% (5-15 cm), and the hardness of the soil blocks ranged from 45-78 N (5-15 cm). Before the test, the engine throttle was adjusted to keep the engine at the rated speed, that is, 1800 r/min. The results of the field experiments are shown in Figure 8.

Figure 8 Prototype field test situation

4.2.1 Picking rate measure

Fifty peanut seedlings were selected from the sampling area for each experiment, and the test was conducted after the speed of each component of the picker stabilized and reached the rated speed. The unpicked pod on the seedling after picking was manually picked, the peanut pod knocked down by the soil removal device was picked up and cleaned, and the weight was measured separately. The test was repeated 5 times, and the average value was calculated. The calculation formula is as follows:

$$\eta_z = \frac{m_1 + m_2}{m_1 + m_2 + m_3} \times 100\% \tag{12}$$

where, η_z is the picking rate, %; m_1 is the mass of the picked peanut pods, g; m_2 is the mass of peanut pods shot down by the soil removal device, g; and m_3 is the mass of peanut pods that have not been picked from the peanut seedlings, g.

4.2.2 Soil removal pod drop rate measure

The method used to determine the soil removal pod drop rate was the same as that used to determine the picking rate. The calculation formula is as follows:

$$\eta_{ql} = \frac{m_2}{m_1 + m_2 + m_3} \times 100\% \tag{13}$$

where, η_{ql} is the soil removal pod drop rate, %.

4.2.3 Soil removal rate measure

Fifty peanut seedlings were selected from the sampling area for each experiment, and the test was conducted after the speed of each component of the picker stabilized and reached the rated speed. Before the experiment, the canvas was manually laid on the ground below the soil removal device, picking device, and seedling throwing area to collect soil from each part, and the sticky soil on the picked peanut pods was manually removed and measured. A total of 5 tests were performed, and the average value was taken. The calculation formula is as follows:

$$\eta_q = \frac{M_1}{M_1 + M_2 + M_3 + M_4} \times 100\% \tag{14}$$

where, η_q is the soil removal rate, %; M_1 is the mass of soil beaten by the soil removal device, g; M_2 is the mass of soil beaten by the picking device, g; M_3 is the mass of soil adhered to the picked pods, g; and M_4 is the mass of soil left on the seedlings after picking, g.

4.3 Test results and analysis

The performance parameters of the picker measured according to the test method are listed in Table 2. All the operating performance indices of the picker meet the technical requirements. While ensuring the picking rate, the soil removal effect is obvious.

Table 2 Performance parameters of the cleaning picker field test

Test No.	Picking rate/%	Soil removal rate/%	Soil removal pods drop rate/%
1	98.18	50.64	9.62
2	97.80	55.86	8.91
3	96.54	64.71	10.24
4	97.26	60.53	7.35
5	98.27	46.89	8.67
Mean	97.61	55.73	8.96
Technical requirements	≥95	≥50	≤10

Table 2 shows that the picking rate of the cleaning picker reaches 97.61%, which is superior to the technical requirements. The analysis of unpicked peanut seedlings revealed that most of the unpicked pods were located between two peanut seedlings and could not be struck by the blades of the two picking rollers. Moreover, the soil in this location is also difficult to remove because of the "protection" of the surrounding seedlings. To avoid this phenomenon and improve the picking rate and soil removal rate, two peanut seedlings can be separated and fed one by one into the machine.

The main reason for soil removal pods drop is that some peanut pods are covered with soil, increasing the weight of the pods, which is coupled with the root of the pod stalks and low connection strength. In addition, some peanut seedlings have been broken due to the excavation process, and the pod stems have been damaged, resulting in soil removal pods drop.

In future design research, the optimized combination of structural parameters and working parameters can be strengthened to improve the adaptability to different peanut seedlings and soil characteristics and optimize the operation quality.

5 Conclusions

(1) A new half-feed peanut cleaning picker suitable for southern clay hilly areas was designed. The overall structure and transmission system design, and the structural design of key components and the analysis and determination of key parameters, were carried out. By adopting a crank rocker mechanism, a soil removal device was designed to address the problems of high soil content and difficult cleaning in traditional picking machines. A single-side chain clamping conveying device, which consists of a clamping chain, pretightening spring, and guide rail, was designed,

and phenomena such as easy slipping of seedlings and jamming of the conveying device were avoided. A phase tangent configuration of opposite rollers, which addressed the problems of a high fruit crushing rate and imbalanced vibration during fruit picking, was used to design a pod picking device. With these technologies, the operation quality and efficiency of peanut cleaning pickers have improved.

(2) The picker can perform the operations of soil removal, clamping and conveying of seedlings, and orderly pod picking and pod gathering. The field test revealed that when the picking rate was greater than 97%, the soil removal pods drop rate was less than 10%, and the soil removal rate was greater than 50%. The performance indicators meet the design requirements. This study provides a technical reference for the research and development of clean picking technology for upright peanuts in the clay hilly areas of southern China.

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[References]

[1] Wang S Y, Hu Z C, Chen Y Q, Wu H C, Wang Y W, Wu F, et al. Integration of agricultural machinery and agronomy for mechanized peanut production using the vine for animal feed. Biosystems Engineering, 2022; 219: 135–152.

[2] Negrete J C. Current status and strategies for harvest mechanization of peanut in Mexico. SSRG International Journal of Agriculture & Environmental Science (SSRG-IJAES), 2015; 2(1): 7–15.

[3] Xu N, Shang S Q, Wang D W, He X N, Gao Z, Liu J Q, et al. Design and experimental study of a pin-type longitudinal axial flow peanut picking device. Journal of Agricultural Mechanization Research, 2020; 42(8): 197–201. (in Chinese)

[4] Antiaobong E A, Bhattaraik R. Growth trends and sources of output growth for oil palm and groundnut production in Nigeria (1961-2007). Trends in Agricultural Economics, 2012; 5(3): 96–103.

[5] Gao L X, Chen Z Y, Chen C, Butts C L. Development course of peanut harvest mechanization technology of the United States and enlightenment to China. Transactions of the CSAE, 2017; 33(12): 1–9. (in Chinese)

[6] Wang S Y, Hu Z C, Peng B L, Wang B, Wang Y W. Simulation and parameter optimization of pickup device for full-feed peanut combine harvester. Computers and Electronics in Agriculture, 2022; 192: 106602.

[7] Wang B, Hu Z C, Peng B L, Zhang Y H, Gu F W, Shi L L, et al. Structure operation parameter optimization for elastic steel pole oscillating screen of semi-feeding four rows peanut combine harvester. Transactions of the CSAE, 2017; 33(21): 20–28. (in Chinese)

[8] Yao L J, Hu Z C, Wang S Y, Cao M Z, Wang B, Yu Z Y. Research status and key technology analysis of peanut harvester. Jiangsu Agricultural Sciences, 2016; 44(12): 33–38. (in Chinese)

[9] Wang B B, Zhang X. Design and experiment of peanut harvester in South China. Modern Agricultural Equipment, 2020; 41(4): 33–38. (in Chinese)

[10] Chen Q M. 2022 China Agricultural Mechanization Yearbook. Beijing: China Agricultural Science and Technology Press, 2022. (in Chinese)

[11] Wang S Y, Hu Z C, Xu H B, Cao M Z, Yu Z Y, Peng B L. Design and test of pickup and conveyor device for full-feeding peanut pickup harvester. Transactions of the CSAE, 2019; 35(19): 20–28.(in Chinese)

[12] Liu Y C, He K, Wang Q, Geng D Y, Li Z P, Zhang S H. Design and experiment of 4HJZ-4A peanut collecting and picking machines. Agricultural Mechanization Research, 2019; 41(5): 121–126, 132. (in Chinese)

[13] Jaime C N. Current status and strategies for harvest mechanization of peanut in Mexico. SSRG International Journal of Agriculture & Environmental Science (SSRG-IJAES), 2015; 2(1): 7–15. https://www.researchgate.net/publication/275214348

[14] Jiang Y J, Chen L D, Li G F, Wang Y F, Du F Y. The research progress on the peanut harvester digging device. Journal of Hebei Normal University of Science & Technology, 2021; 35(4): 59–63. (in Chinese)

[15] Lv X L, Hu Z C, Zhang Y H, Wang B K. Study on properties of two-step type peanut stripping. Agricultural Mechanization Research, 2017(6): 183–187.

[16] Guo W H, Guo H, Yu X D, Wang M H, Xing S K, Peng B. Design and experiment of peanut digger based on two-stage harvesting process. Journal of Chinese Agricultural Mechanization, 2020; 41(7): 34–39. (in Chinese)

[17] Yu J D, Liu Y F, Wang D W. Design and experimental study of movable peanut picker. Agricultural Mechanization Research, 2021; 43(9): 59–65.

[18] Lv X R, Lv X L, Wang T Y, Zhang X Q, Zhang L H. Virtual simulation and experimental research of half-feed peanut picker. Journal of Northwest A&F University (Nat. Sci. Ed.), 2020; 41(4): 33–38. (in Chinese)

[19] Wang T, Liu G G, Lou T T, Yao A P, Wu L H. Development and test of sweet potato harvester in hilly areas. Journal of Chinese Agricultural Mechanization, 2019; 40(12): 41–46. (in Chinese)

[20] Xin S L, Zhao W Y, Shi L R, Dai F, Feng B, Yan Z B, et al. Design and experiments of the clamping and conveying device for the vertical roller type corn harvesting header. Transactions of the CSAE, 2023; 39(9): 34–43. (in Chinese)

[21] Wang H Y, Zhang Z G, Ibrahim I, Xie K T, Wael E, Cao Q Z. Design and experiment of small-sized potato harvester suitable for hilly and mountainous areas. Acta Agriculturae Zhejiangensis, 2021; 33(4): 724–738.

[22] Zhang Z G, Wang H Y, Li Y B, Yang X, Ibrahim I, Zhang Z D. Design and experiment of multi-stage separation buffer potato harvester. Transactions of the CSAM, 2021; 52(2): 96–109. (in Chinese)

[23] Chen Z Y. Experimental study on axial-flow peanut picking device with benting-tooth screw roller. Shenyang Agricultural University, 2017. (in Chinese)

[24] Feng Y L, Yin X C, Jin H R, Tong W Y, Ning X F. Design and experiment of a Chinese chive harvester. Int J Agric & Biol Eng, 2023; 16(2): 125–131.

[25] Zhang J, Wang J, Du DD, Long S F, Wang Y W, You X R. Design and experiment of crawler self-propelled single-row harvester for Chinese cabbage. Transactions of the CSAM, 2022; 53(12): 134–146. (in Chinese)

[26] GB/T5262-2008. General regulations for the determination of test conditions for agricultural machinery. Chinese Standard, 2008. (in Chinese)

[27] GB/T5262-2008. Measuring methods for agricultural machinery testing conditions—General rules. Chinese Standard, 2008. (in Chinese)

[28] NY/T 502-2016. Operation quality of peanut harvesters. Chinese Standard, 2016. (in Chinese)

[29] NY/T 2204-2012. Technical specification for quality evaluation of peanut harvesters. Chinese Standard, 2012. (in Chinese)