Design and experiment of brush-roller ginkgo leaf picker for the dwarf dense planting mode

Shanwen Zhang,[1] Yongyuan Sun,[1] Su Lu,[2] Li Wang,[3] Sian Liu,[3] Zhongliu Wang,[1] Min Dai,[1] Jicheng Gao,[1] Hong Miao[1]

[1]College of Mechanical Engineering, Yangzhou University, Jiangsu, China; [2]Department of Electrical, Computer, and Systems Engineering, Case Western Reserve University, Cleveland, OH, USA; [3]College of Horticulture and Plant Protection, Yangzhou University, Jiangsu, China

Abstract

At present, ginkgo leaves are still picked manually. A brush roller ginkgo leaf picker has been designed to improve harvesting efficiency and reduce losses caused by manual failure to pick leaves in time under large-scale planting areas. The ginkgo leaf picker is mainly composed of crawler chassis, gantry frame, brush roller picking parts, and collecting box. The kinematics of the brush roller are analyzed for the picking omission situation. An experimental platform for picking ginkgo biloba leaves was established. Three parameters, namely roller speed, moving speed, and roller inclination were selected for optimization. Then the maximum net harvest rate and the minimum damage rate were achieved. The orthogonal test showed that when the roller speed was 130 rev/min, the moving speed was 0.25 m/s, and the roller inclination was 32°, the picking effect was the best, the net harvest rate was 93.32%, the damage rate was 1.42%, and the damage degree of the trunks was slight. The experiment proved that the brush-roller ginkgo leaf picker has a good picking effect, which can provide a reference for the optimization design of ginkgo leaf harvesting machinery under the dwarf dense planting mode.

Correspondence: Shanwen Zhang, Yangzhou University, 88 South University Ave. Yangzhou 225009, China.
E-mail: swzhang@yzu.edu.cn

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Introduction

Ginkgo biloba is an endemic tree species in China and one of the national key protected tree species. Now it has been widely cultivated around the world. With the continuous development of medicine, ginkgo biloba extract has an irreplaceable therapeutic effect on certain diseases compared to other drugs (Al-Adwani *et al.*, 2019; Guo *et al.*, 2022; Tang *et al.*, 2022). Ginkgo biloba leaves are rich in bioactive substances (Wang *et al.*, 2013; Wang *et al.*, 2018), such as flavonoids, lactones, polypentenols, polysaccharides, organic acids, and alkylphenolic acids. In 2020, the output of ginkgo biloba extract in China reached 775 tons, and the output of ginkgo biloba dry leaves exceeded 40000 tons. Ginkgo biloba resources in China account for 85% of the world's total, and the market capacity is very broad (Yu *et al.*, 2012; Zhou *et al.*, 2021). Three main planting methods have been developed for the seedling raising of ginkgo biloba, the picking of ginkgo biloba and the harvesting of leaves: three-dimensional compound forest of fruit, leaf and seedling, dwarf forest of fruit and leaf type, and dwarf leaf-picking forest with dense planting (Yang *et al.*, 2013). With the increasing demand for raw materials of ginkgo biloba leaves and the limitation of harvesting time of ginkgo biloba leaves, the demand for mechanized harvesting of ginkgo biloba leaves is becoming more and more urgent.

With the continuous maturity of programming languages and various algorithms, fruit and vegetable picking robots have developed rapidly, and the end-effectors of picking are also relatively mature. The study on the harvesting end effector includes: Kultongkham *et al.* (2021) designed a soft fixture for tomato harvesting, Hayashi *et al.* (2010) studied the strawberry picking robot, Arad *et al.* (2020) studied the sweet pepper harvesting robot, and Oyedeji *et al.* (2022) developed an oil palm harvesting robot. Research results on leaf harvesting include Ota *et al.* (2007), who invented a cucumber leaf-picking device. The leaf-picking device could be operated manually or placed on the executive machinery as the executive end. The cucumber leaf-picking device drove the cutter to rotate through the rotor, and the leaves were collected by the vacuum suction device. The picking device needs to be manually held, and the picked cucumber leaves also need to be manually cleaned. Hu *et al.* (2016) designed a reciprocating mulberry leaf-picking machine. The execution device consisted of two semicircle ring cutters, which formed a closed ring. The whole mulberry tree was picked by the mulberry branch positioning device, and the grooved wheel mechanism drove the mulberry branch positioning device to reciprocate. The mulberry leaf-picking device needs to reposition the mulberry tree before each execution. It is a single tree picking, with low picking efficiency and low practicability; Yang *et al.* (2017) designed and developed a spring-type high-branch ginkgo leaf picker. The equipment set the conical spring into the ginkgo branch, and separated the ginkgo branch and leaf by pulling the telescopic rod to make the conical spiral spring contract. The picked ginkgo leaf fell into the leaf storage bag under the conical spring. The equipment was used for picking a single leaf and had great damage to the leaf. Zhang *et al.* (2019) designed a ginkgo leaf harvesting mechanism. The harvesting principle was to achieve continuous harvesting by squeezing and pulling ginkgo leaves. The device was easy to cause damage to ginkgo trees when picking. Yang *et al.* (2019) designed a telescopic ginkgo leaf picker. The picker used the folding of the support rod and the opening and closing of the picker to pick ginkgo leaves. Bubola *et al.* (2019) and Guidoni *et al.* (2008) mentioned in the article the way to turn a leaf stripper and spiral blade cutter to peel and pick grape leaves. At present, no research on ginkgo leaf harvesters has been seen. Most ginkgo leaf harvesters in China are simple equipment, and the feasibility of design has not been verified by experiments. Now, the development of ginkgo leaf harvester is still in the experimental research and development stage. There are still improvements in the working principle and harvesting process. There is no ginkgo leaf harvesting equipment for specific planting modes.

Based on the above considerations, it is necessary to strengthen the research of ginkgo leaf harvesting machinery. A ginkgo leaf picker for dwarf and dense planting mode was developed. Firstly, a ginkgo leaf picker was designed by using Solidworks software, the biological parameters of dwarf and closely planted ginkgo trees were measured, and the harvesting principle was analyzed. Then, a ginkgo leaf-picking experiment platform was built, and the important factors affecting ginkgo leaf-picking were discussed by using the single-factor picking experiment method. The three factors of roller speed, moving speed and drum inclination were selected as the experimental variables of the whole machine. Finally, the response surface method was used to carry out the ginkgo leaf-picking experiment, and the interaction of roller speed, moving speed and drum inclination on the net harvest rate and damage rate was analyzed.

Materials and Methods

Design of picking machine

The structure of the ginkgo leaf picker is shown in Figure 1. In this device, the track part in the crawler chassis is made of rubber material, while the others are made of carbon steel. The gantry frame is mounted on the crawler chassis, and the transverse cylindrical linear guide rail is fixed on both sides of the gantry frame by bolts. The longitudinal cylindrical linear guide rail is fixed on the rear of the gantry frame by bolts. The dual-drive controller, the power battery of the picking device, the drive power supply and the range increaser are respectively fixed on the top of the gantry frame by bolts. Two sides of the support frame are equipped with connecting screws, and the left and right limits of the picking device are realized through double nuts. The connecting screw is connected with the sliders on the transverse cylindrical linear guide rail and the longitudinal cylindrical linear guide rail through bolts. And the height and angle of the picking device are adjusted by adjusting the position of the sliders on the transverse cylindrical linear guide rail and the longitudinal cylindrical linear guide rail. The bearing blocks are fixed on the front and rear sides of the support frame by bolts. The picking round rods on the roller are arranged in an array. The picking round rods in the roller structure on the left and right sides are arranged in a staggered way, and are installed between the bearing blocks by coordination; The motor base is installed on the rear side of the support frame by bolts, and the motor is installed on the motor base by bolts. The output end of the motor is connected with the roller through the bearing base to drive the roller to rotate. The deciduous box is fixed on the inside of the support frame by bolts to collect the ginkgo leaves picked by the roller.

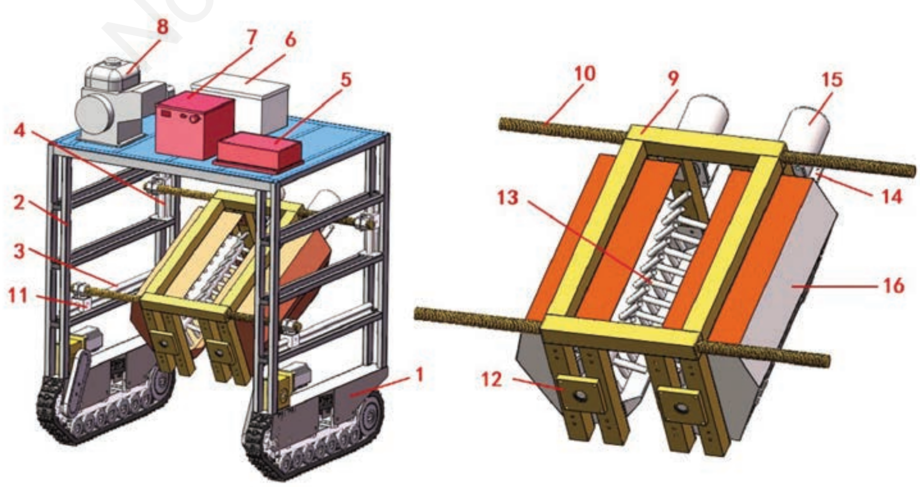

Figure 1. Assembly model of ginkgo leaf picker: 1) crawler chassis; 2) gantry frame; 3) transverse cylindrical linear guide rail; 4) longitudinal cylindrical linear guide rail; 5) dual drive controller; 6) power battery of picking device; 7) drive power supply; 8) range increaser; 9) support frame; 10) connecting screw; 11) slider; 12) bearing block; 13) roller; 14) motor base; 15) motor; 16) deciduous box.

Biological parameters of ginkgo biloba leaves

Figure 2 shows the tree height, tree diameter, leaf width and the maximum and minimum value of cluster leaf spacing were measured by measuring 10 ginkgo trees, which were randomly selected from the ginkgo planting test field. Due to the growth characteristics of plants, there is no leaf growth at a distance from the root. Three-year-old Ginkgo biloba leaves firstly appeared at the place 8cm-12cm above the root, so the tree diameter was measured at the place 10cm above the root and the data were recorded. Measuring tools: tape (measuring range 300cm), vernier caliper (measuring range 200mm, accuracy 0.02mm), and the recorded data are shown in Table 1.

Table 1 shows the average values of tree height, tree diameter and the maximum and minimum values of clustered leaf spacing are calculated respectively. The average value of tree height is 139.7 cm, the average value of tree diameter is 14.45 mm, the average value of leaf width is 71.4 mm, the average value of maximum spacing of clustered leaves is 18.4 cm, and the average value of minimum spacing is 7.5 cm.

Picking principle of picking machine

The 24V DC brushless motor with motor model 130ZYT105 is used as the driving source, with a rated power of 750w and a maximum speed of 1500 rev/min. Figure 3 shows under the control of the control box, the motor drives the traveling mechanism to move forward. A pair of rotary picking rollers are arranged on the left and right sides of the picking device, which expands the contact between the picking round rod and the ginkgo leaves, and improves the picking efficiency; Each roller is controlled by an independent motor, and the rotation directions of the left and right rollers are from the outside to the inside (from top to bottom); As the walking mechanism moves forward, the ginkgo tree enters the channel between the two roller structures. The picking round rod of the picking roller carries out uninterrupted and continuous picking of ginkgo leaves. Ginkgo biloba leaves are picked by the rotating picking roller and dropped into the deciduous box to complete the continuous picking and collection of ginkgo biloba leaves.

To prevent picking omission when the roller rotates, it is necessary to analyze the motion trajectory of the roller. During the picking process, the roller structure rotates and moves in a straight line with the walking platform. The motion trajectory is a composite curve, and only the motion trajectory close to the side of the ginkgo tree is the effective picking track. The impact of speed on the omission of ginkgo trees includes two aspects: the roller speed and the moving speed (Liu *et al.*, 2019; Xue, 2018).

Figure 2. Measurement of biological characteristics. **a**) Height measurement; **b**) tree diameter measurement; **c**) cluster leaf.

Table 1. Biological characteristics.

S/N	Tree height/ (cm)	Tree diameter/ (mm)	Ginkgo leaf width/ (mm)	Clustered leaf spacing/(cm) Minimum value	Minimum value
1	145	14.86	67.36	17	8
2	139	16.06	48.24	20	6
3	135	14.38	55.02	18	7
4	140	15.12	90.64	17	7
5	138	13.54	66.34	16	6
6	139	12.86	69.62	17	6
7	142	15.44	87.08	18	10
8	142	14.32	79.66	23	8
9	136	13.68	75.80	22	7
10	141	14.24	74.28	16	7

To analyze the picking omission, the dynamic analysis is carried out on the running track of a single stripping tooth. The rectangular coordinate system is established by taking the rotation center O of the stripping tooth as the coordinate origin, taking the moving direction of the walking platform as the x-axis, and the vertical direction as the y-axis. Figure 4 shows the running track of the end of a single stripper tooth. The motion track equation of the end A of the stripper tooth is:

$$X_A = R\sin(2\pi nt) + vt \quad (1)$$

$$Y_A = R\cos(2\pi nt)\cos\alpha \quad (2)$$

where: R is the radius of rotation, m; N is the roller speed, rev/min; T is the running time, s; V is the speed of walking platform, m/s; α Is the inclination between the roller and the ground, °;

Figure 4 shows that the blank area between the composite curves (that is, the blank area between x_1x_2, close to the side of the ginkgo tree) is the picking omission area. Therefore, the conditions for no missed picking of Ginkgo biloba leaves are as follows:

$$x_2 - x_1 < b \quad (3)$$

where: b is the width of ginkgo leaf, mm; x_2-x_1 is the effective picking side motion trajectory interval, mm;

The formula (1) indicates that the roller speed and moving speed only affect the density of the motion track, as shown in Figure 5. The roller speed adjustment range is between 75 rev/min and 150 rev/min (Zhang *et al.*, 2021), and the maximum speed of the designed walking platform is 0.5 m/s. Based on the formula (1), when the roller speed is 75 rev/min and the moving speed is 0.5 m/s, the distance of the composite curve x_1x_2 in a single blade removal tooth is the largest, at this time, x_2-x_1=400 mm. The designed roller structure has 6 defoliation teeth at the same circumferential position, that is, the maximum distance of the compound curve of 6 defoliation teeth is (x_2-x_1)/6=66.67mm. According to the above biological parameters of Ginkgo biloba, the average width of Ginkgo biloba leaf b=71.4 mm>66.67 mm. Therefore, the defoliation teeth on the same circumference will not miss the ginkgo leaves. Through the kinematics simulation of the motion trajectory of the defoliation teeth, the change of the roller inclination

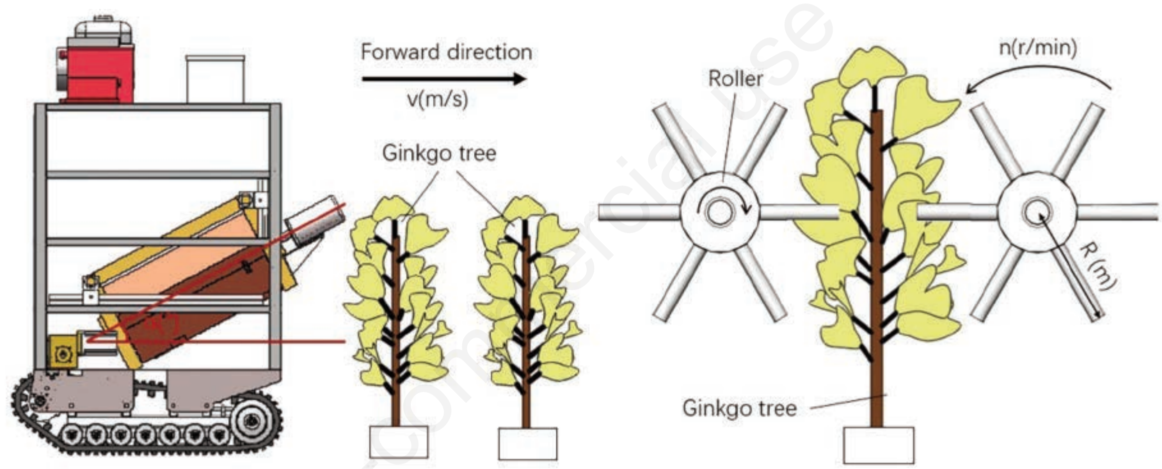

Figure 3. Working principle diagram of picking executive device.

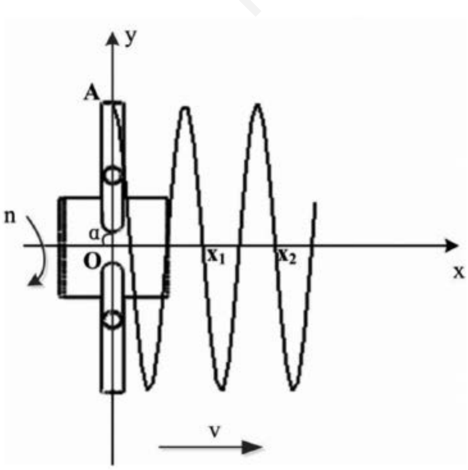

Figure 4. Motion trajectory.

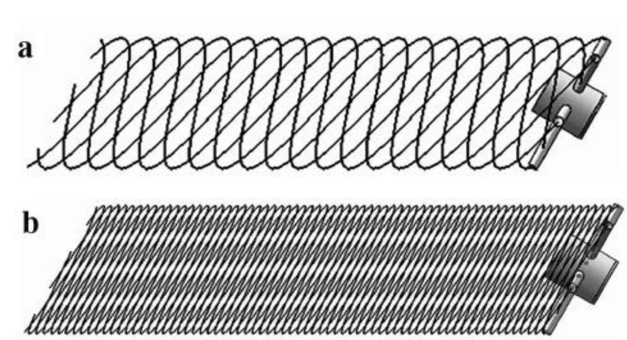

Figure 5. Roller motion trajectory at different speeds. **a**) Motion trajectory at n=75 rev/min, v=0.5m/s; **b**) Motion trajectory at n=75 rev/min, v=0.2m/s.

will also cause the picking omission of the ginkgo tree. Figure 6 shows the motion trajectory of a single blade stripping tooth at different angles. Figure 6c shows that when the inclination of the roller is 90°, the motion trajectory of the defoliation teeth on the same circumference is a straight line. At this moment, the staggered track of the defoliation teeth in the axial direction will not occur, resulting in picking omission. So, it is necessary to analyze the roller inclination for picking omission.

The motion module (Vavro *et al.*, 2017; Li and Han, 2016) in Solidworks software is used to directly simulate the motion track of multi-row blade defoliation teeth under a different roller inclination. The condition of no picking omission of multiple rows of defoliation teeth: there is a staggered curve between the edge motion tracks of two adjacent rows of defoliation teeth.

Through the simulation of the dynamic track of different roller inclination, when the roller inclination is 64° from the ground, the edge of the motion trajectory of the stripper tooth in the axial direction of the roller has a good coincidence (Figure 7). At this time, there will be no picking omission. So, the change range of roller inclination is between 0° and 64°.

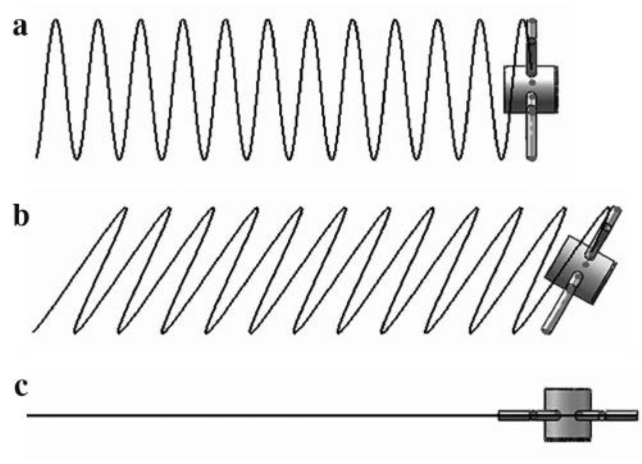

Figure 6. Motion trajectory under different roller inclinations. (**a**) Motion trajectory when the roller inclination is 0°; (**b**) Motion trajectory of roller when the roller inclination is 30°; (**c**) Motion trajectory of roller when the roller inclination is 90°.

Results

Results of ginkgo leaf picking experiment

17 groups of three factors and three levels experiments were carried out by using the combination design of quadratic regression. To avoid accidental experiment, two ginkgo trees were selected for each experiment, and the average number was taken after the experiment. There are 5 groups of repeated central experimental data. The results of net harvest rate, damage rate and branch damage degree are shown in Table 2.

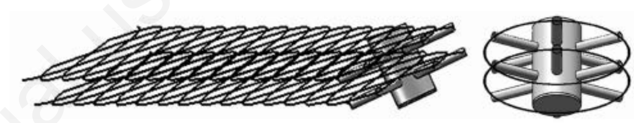

Figure 7. Cross track of roller with roller inclination of 64°.

Table 2. Experimental results.

S/N	A: Roller speed N (rev/min)	B: Moving speed V (m/s)	C: Roller inclination α(°)	R_1: Net harvest rate η_1(%)	R_2: Damage rate η_2(%)	Damage degree of branches
1	150	0.5	22.5	93.81	2.96	No
2	112.5	0.3	22.5	92.94	1.38	Slight
3	112.5	0.5	0	89.19	2.76	Break
4	112.5	0.1	0	93.23	2.98	Serious
5	75	0.5	22.5	81.53	5.89	Slight
6	112.5	0.3	22.5	90.97	1.29	No
7	150	0.3	0	94.61	3.86	Breakage
8	75	0.1	22.5	83.64	5.57	Moderate
9	112.5	0.3	22.5	89.29	1.35	No
10	75	0.3	0	83.21	7.12	Serious
11	112.5	0.3	22.5	93.91	2.22	Slight
12	75	0.3	45	82.62	6.39	Slight
13	150	0.3	45	94.27	3.21	Slight
14	150	0.1	22.5	95.61	3.54	Slight
15	112.5	0.1	45	92.88	1.45	Moderate
16	112.5	0.3	22.5	92.35	2.1	No
17	112.5	0.5	45	88.73	1.31	Slight

The Box-Behnken (response surface design) module in the Design-Expert 10.0 software is used to analyze the experimental data. The analysis of variance of the net harvest rate and the damage rate of the quadratic regression model are shown in Tables 3 and 4, respectively.

The experimental data are fitted by regression analysis, and the following second-order polynomial equation regression model is obtained:

$$\eta_1=91.89+5.91*A-1.51*B-0.22*C+0.077*AB+0.062*AC-0.027*BC-2.79*A^2-0.46*B^2-0.43*C^2 \quad (4)$$

$$\eta_2=1.67-1.42*A-0.078*B-0.55*C+0.02*AC+0.02*BC+2.92*A^2-0.099*B^2+0.56*C^2 \quad (5)$$

Unsignificant items need to be removed from the ANOVA table to finally obtain the coding factor equation:

$$\eta_1=91.50+5.91*A-1.51*B-2.84*A^2 \quad (6)$$

$$\eta_2=1.63-1.42*A-0.55*C+2.92*A^2+0.55*C^2 \quad (7)$$

Result analysis

The effect of interactive factors on the net harvest rate

When analyzing the interaction of the two factors on the net harvest rate, the third factor needs to be kept at the level of 0.

The following is the analysis of the interaction of A-roller speed and B-moving speed on the net harvest rate. When the C-roller inclination is at 0 level (22.5°), the roller speed is 150 rev/min, the moving speed is 0.1 m/s, and the net harvest rate is the highest. When the moving speed is constant, the net harvest rate increases with the increase of roller speed. This is because the moving speed is constant, and the rotating inertia force generated

Table 3. Analysis of variance of net harvest rate by response surface method.

Source	Net harvest rate η_1 (%) Square sum	Freedom	Mean square deviation	F	P	Significance
Model	333.43	8	41.68	20.53	0.0001	Extremely significant
A- Roller speed	279.66	1	279.66	137.75	<0.0001	
B- Moving speed	18.30	1	18.30	9.01	0.0170	
C-Roller inclination	0.38	1	0.38	0.19	0.6773	
AB	0.024	1	0.024	0.012	0.9161	
AC	0.016	1	0.016	7.697E-003	0.9322	
BC	3.025E-003	1	3.025E-003	1.490E-003	0.9702	
A^2	33.33	1	33.33	16.42	0.0037	
B^2	0.97	1	0.97	0.48	0.5086	
Residual	16.24	8	2.03			
Misfit item	3.24	4	0.81	0.25	0.8965	Insignificant
Error	13.00	4	3.25			
Sum	349.67	16				

Note: P<0.01 (extremely significant), 0.01<0.05 (significant), P>0.05 (insignificant).

Table 4. Analysis of variance of damage rate by response surface method.

Source	Damage rate η_2 (%) Square sum	Freedom	Mean square deviation	F	P	Significance
Model	56.96	9	6.33	31.35	<0.0001	Extremely significant
A- Roller speed	16.25	1	16.25	80.46	<0.0001	
B- Moving speed	0.048	1	0.048	0.24	0.6406	
C-Roller inclination	2.38	1	2.38	11.77	0.0110	
AB	0.20	1	0.20	1.00	0.3500	
AC	1.600E-003	1	1.600E-003	7.925E-003	0.9316	
BC	1.600E-003	1	1.600E-003	7.925E-003	0.9316	
A^2	35.93	1	35.93	177.93	<0.0001	
B^2	0.041	1	0.041	0.20	0.6649	
C^2	1.30	1	1.30	6.45	0.0387	
Residual	1.41	7	0.20			
Misfit item	0.60	3	0.20	0.97	0.4896	Insignificant
Error	0.82	4	0.20			
Sum	58.38	16				

Note: P<0.01 (extremely significant), 0.01<0.05 (significant), P>0.05 (insignificant).

by increasing the roller speed becomes larger. The larger the inertia force is, the easier the ginkgo leaves fall off; When the roller speed is constant, the net harvest rate shows a downward trend with the increase of the moving speed, and the downward trend is small. This is because the number of times that the picking round rod beats the ginkgo leaves in the same area in unit time is reduced with the moving speed increasing, and the shedding ginkgo leaf is reduced to a certain extent. So, the interaction between A-roller rotation speed and B-moving speed has a significant impact on the net harvest rate.

The following is the analysis of interaction of A-roller speed and C-roller inclination on the net harvest rate. When B-moving speed is at 0 level (0.3 m/s), the roller speed is 150 rev/min, the roller inclination is 0°, and the net harvest rate is the highest. When the roller inclination is constant, the net harvest rate increases with the increase of the roller speed. This is because the rotation inertia force generated by increasing the roller speed becomes larger. The larger the inertia force is, the more easily ginkgo leaves fall off; when the roller speed is constant, the net harvest rate has no obvious change with the change of the roller inclination. The result indicates that the interaction between A-roller speed and C-roller inclination has a significant impact on the net harvest rate.

The following is the analysis of interaction of B-moving speed and C-roller inclination on the net harvest rate. When the A-roller speed is at 0 level (112.5 rev/min), the moving speed is 0.3 m/s, the roller inclination is 22.5°, and the net harvest rate is the highest. The interaction of moving speed and roller inclination has no obvious change trend on the net harvest rate. The result indicates that the interaction of B-moving speed and C-roller inclination on the net harvest rate is not significant.

The effect of the interaction factors on the harvest rate shows that the net harvest rate can be improved by increasing the roller speed and reducing the moving speed.

The effect of interaction factors on damage rate

The following is the analysis of interaction of A-roller rotation speed and B-moving speed on the damage rate. When the roller inclination C is at 0 level (22.5°), the roller speed is 112.5 rev/min, the moving speed is 0.3 m/s, and the damage rate is the lowest. When the moving speed is constant, the roller speed increases, and the damage rate decreases first and then increases. This is because the rotating inertia force is gradually increased as the roller speed is gradually increased. When the inertia force is small, ginkgo biloba leaves cannot be picked successfully. Multiple picking results in increased leaf damage and increased damage rate. When the rotational inertia force increases to the appropriate size, ginkgo biloba leaves can be picked at one time, and the damage rate is reduced. When the roller speed continues to increase, while the ginkgo leaves are removed, the rotating inertia force is too large, resulting in increased blade damage and increased damage rate; when the roller speed is fixed, the changing trend of the damage rate is not obvious with the change of the moving speed. So, the interaction between the roller speed and the moving speed has significant impact on the damage rate, and the roller speed has a greater impact on the damage rate.

The following is the analysis of interaction of A-roller speed and C-roller inclination on the damage rate. When B-moving speed is at 0 level (0.3 m/s), the roller speed is 112.5 rev/min, the roller inclination is 22.5°, and the damage rate is the lowest. When the roller inclination is fixed, the roller speed increases, and the damage decreases first and then increases slightly. When the roller speed is constant, the roller inclination increases, and the damage rate decreases slightly. When the roller speed is 75 rev/min and the roller inclination is 0° and 45°, the difference of damage rate is 0.73%, with the largest amplitude. The greater the roller speed, the smaller the decrease of the damage rate with the change of the roller inclination. Based on the analysis of the damage degree of the branches, the roller inclination mainly has a large impact on the damage law of the branches. And the interaction between the A-roller speed and C-roller inclination has a significant impact on the damage rate.

The following is the analysis of interaction of B-moving speed and C-roller inclination on the damage rate. When the A-roller speed is at 0 level (112.5 rev/min), the moving speed is 0.3 m/s, the roller inclination is 22.5°, and the damage rate is the lowest. When the moving speed is constant and the roller inclination is 0~15°, the damage rate decreases significantly. At 15~45°, the damage rate basically remains unchanged. This is because the roller inclination is small, the effective picking length is short, and the number of times that the stripping teeth beat the ginkgo leaves in the same area is more, which increases the damage rate. When the roller inclination increases to a certain angle, the number of times that the defoliation teeth beat the ginkgo leaves in the same area is less, thus reducing the damage rate, and the damage rate is basically unchanged. When the roller inclination is fixed, the moving speed increases and the damage rate remains unchanged. This is because the inertia force generated by the roller speed (112.5 rev/min) is appropriate, and the change in moving speed will not affect the change in damage rate. Therefore, the interaction between B-moving speed and C-roller inclination on the damage rate is not significant. The above analysis shows that the roller inclination should avoid 0°, and the roller speed should not be too small (75 rev/min) or too large (150 rev/min), which can reduce the damage rate.

Parameter optimization and experimental verification

Parameter optimization

To obtain the maximum net harvest rate, the minimum damage rate and the minimum impact on the damage degree of the branches, multi-objective parameter optimization is required. The Optimization module in Design-Expert 10.0 is used to optimize parameters. The Optimization module can set goals for each response, set minimum or maximum limits, and generate the best conditions. From the above results, the roller inclination should be avoided 0° to reduce the damage to the branches and trunks of Ginkgo biloba; To reduce the damage rate, the roller inclination should be greater than 15°; at the same time, on the premise of improving the net harvest rate and reducing the damage rate, the ginkgo leaf picker needs to have a certain work efficiency. Therefore, the moving speed is not easy to be too low. Considering the interaction of various factors, the optimal constraint conditions are set as follows:

$$\begin{cases} \max \eta_1(A, B, C) \\ \min \eta_2(A, B, C) \\ 75 \le A \le 150 \\ 0.25 \le B \le 0.5 \\ 15 \le C \le 45 \end{cases} \tag{8}$$

According to the constraint conditions, solve the model to obtain the optimal working parameters, A=130.401 rev/min, B=0.25 m/s, C=31.8581°. Under this working parameter, the predicted net harvest rate is 94.1579%, and the damage rate is 1.56481%.

Experimental verification

For the rounding experiment of optimization parameters, the roller speed is set to 130 rev/min, the moving speed is set to 0.25 m/s, and the roller inclination is set to 32°. Two groups of experiments were repeated with the optimized working parameters, and the average value of the data was taken after the experiment. The optimized experimental diagram is shown in Figure 8. After optimization, the experimental results showed that the net harvest rate was 93.32%, the damage rate was 1.42%, and the damage degree of branches was slight. The error between the optimized theoretical value and the experimental value of the net harvest rate is 0.84%, and the error between the optimized theoretical value and the experimental value of the damage rate is 0.14%, and the error value is less than 1%. The optimization model is reasonable and feasible. The optimized experimental results show that the roller brush ginkgo leaf picker has good working performance under the working parameters.

Discussion

The design and experimental test of the ginkgo leaf picker provide a reference for future optimization experiments. In this study, the representative moving speed, roller inclination and roller speed are selected through single factor experiment and response surface method for performance test, which is intuitive and efficient. However, other factors are ignored in this study. Ginkgo biloba has a variety of planting modes and multiple growth stages, and the biological characteristics of ginkgo biloba with different maturity under different planting modes are different. The design of this experimental prototype only focuses on the biological characteristics of Ginkgo biloba under dwarf and dense planting mode, such as tree height, tree diameter, leaf width, cluster leaf spacing, *etc*. There is a lack of consideration for the impact of factors such as leaf growth differences and the growth morphology of ginkgo trees on the picking of ginkgo leaves by the picking roller. This study was carried out in the ideal environment of the laboratory. During the actual picking, the weather conditions, wind power and other factors of the site will change the shape of the ginkgo leaves. The soil conditions and road conditions of the ginkgo forest will affect the path of the walking platform, resulting in changing the dip angle and height of the picking mechanism. These factors are not considered in laboratory experiments.

To further improve the picking quality of ginkgo biloba leaves, there are still some areas to be improved in the experiment. The material of the picking round bar on the roller is hard, and the leaves will be damaged when picking. Therefore, we need to improve the processing technology of the roller and select flexible and lightweight materials. The power consumption required for picking has not been determined yet. In the future, the specific consumption per ton of Ginkgo biloba leaves needs to be conducted to obtain a complete evaluation of the quality of picking. It is necessary to study the relationship between the soil conditions, the road conditions of the ginkgo forest, the growth form of the ginkgo tree and the working performance of the prototype in combination with the planting agronomy of the ginkgo tree. It is difficult to quickly realize the mechanization of ginkgo leaf harvesting due to its high requirements. We can only start with small and practical harvesters, determine feasible harvesting technology, and then gradually improve it.

Conclusions

The planting mode of dwarf Ginkgo biloba was investigated. According to the biological characteristics of Ginkgo biloba, the overall design scheme of Ginkgo biloba picker was defined. To improve the harvest efficiency, the roller-brush harvesting execution mode is adopted; The fresh leaf collection scheme uses the wrapped collection scheme to ensure the compactness of the overall structure, and the collection of ginkgo leaves is more convenient. The detailed structural design of the ginkgo leaf picker was

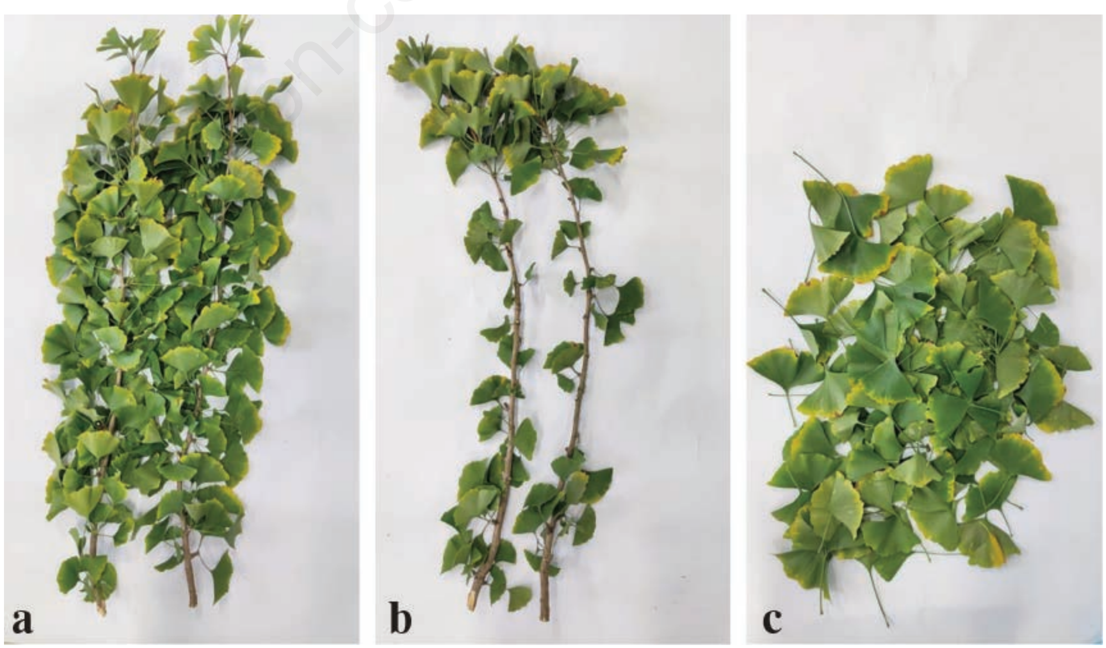

Figure 8. Experimental diagram after optimization: **a**) before experiment; **b**) after the experiment; **c**) picked ginkgo leaves.

carried out; according to the design structure of the picking executive device, the situation of picking omission is analyzed.

According to the experimental results of the roller experimental platform, the response surface method was used to carry out the whole machine experiment of the roller brush ginkgo leaf picker, and analyze the impact of each interaction on the net harvest rate, the damage rate and the damage degree of branches.

The results show that when the roller speed is 130 rev/min, the moving speed is 0.25m/s, and the roller inclination is 32°, the net harvest rate is 93.32%, the damage rate is 1.42%, and the damage degree of the branches is slight. The error between the theoretical value and the experimental value of the net harvest rate is 0.84%, the error between the theoretical value and the experimental value of the damage rate is 0.14%, and the error value is less than 1%. In this working parameter, the roller brush ginkgo leaf picker has good working performance.

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