Simulation study and field experiments on the optimal canopy shaking action for harvesting *Camellia oleifera* fruits

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Abstract

With the increasing cultivation scale of *Camellia oleifera* in China, the demand for mechanical harvesting machinery is very urgent. Inefficient fruit harvesting has become a bottleneck hindering the development of the *C. oleifera* industry. In order to achieve high fruit harvesting percentage and low detachment percentage of the flower buds, a canopy shaking mechanism is proposed for massively harvesting *C. oleifera* fruits which applies the reciprocating linear motion of multiple beating-bar arrays to the tree canopy. The multiple beating-bar arrays driven by the eccentric disk can generate comb-brushing effects on the tree canopy. Three kinds of *C. oleifera* tree architecture were modelled, and their dynamics were simulated by finite element analysis. Their modal analysis results show that the low-order natural frequencies of the *C. oleifera* trees with different canopy shapes are very close. According to harmonic response analysis, the low-frequency excitation is used to harvest *C. oleifera* fruit. The orthogonal experiments were carried out on the canopy shaker prototype with the motor speed, reciprocating stroke, and duration of vibration as the influencing factors, and the fruit harvesting percentage and the detachment percentage of the flower buds as the evaluation indices. The results show that the same optimal parameter combination can be used for three kinds of *C. oleifera* tree architecture, in which the motor speed is 360 r/min, the reciprocating stroke is 80 mm, and the duration of the vibration is 8 s. The average fruit harvesting percentage is 72.3%, and the average detachment percentage of the flower buds is 13.9%.

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Key words: *Camellia oleifera*; mechanical harvesting; optimal combination parameters; orthogonal experiment.

Acknowledgements: this work was supported by the National Key Research and Development Program of China (Grant No. 2019YFD1001602), the National Natural Science Foundation of China (Grant No. 31971798), the Zhejiang Provincial Key Research & Development Program (Grant No. 2022C02057), the SNJF Science and Technology Collaborative Program of Zhejiang Province (Grant No. 2022SNJF017), the 521 Talent Plan of Zhejiang Sci-Tech University, and the Cultivation Project for Youth Discipline Leader in Zhejiang Provincial Institute.

Received for publication: 28 July 2021.
Accepted for publication: 10 March 2022.

Journal of Agricultural Engineering 2022; LIII:1245
doi:10.4081/jae.2022.1245

Introduction

Camellia oleifera is a kind of camellia plant with high oil content and high economic value. It is rich in various functional components, and its nutritional value is much higher than other general edible oils (Liu *et al.*, 2018; Luo *et al*., 2019; Wang *et al.*, 2019). It is expected that by 2020, China's total *C. oleifera* planting scale will reach 4.6667 million hectares, and the yield will reach 2.5 million tons (Song *et al.*, 2019). At present, *C. oleifera* fruit harvesting mainly depends on manual harvest, which costs a large amount of labour and has very low efficiency. Inefficient fruit harvest has become the weakest link and a bottleneck hindering the rapid development of *C. oleifera* industry. Therefore, it is of great significance for the sustainable development of the *C. oleifera* industry to develop and popularise the harvesting machinery (Feng *et al.*, 2015).

According to different locations where the vibration is applied, tree fruit harvesters can be divided into trunk shakers, branch shakers, and canopy shakers (Fu *et al*., 2016). The trunk shaker is to apply the exciting force to the trunk of fruit trees, which forces the fruit trees to vibrate and achieve the purpose of fruit detachment. Ortiz and Torregrosa (2013) found that almost all the detached fruits fell down in the first two to three seconds once the trunk shaker started to shake the citrus tree and clamping the tree trunk costs most of the harvesting time. The olive damage caused by trunk shaker was 3.5 times that caused by manual harvest (Castro-Garcia *et al.*, 2015).

Tree branch shaker is mainly adopted by a hand-held harvesting machine which often uses the gasoline engine or the electric motor as the power source to shake the branches and detach the fruits. It is reported that the tree branch shaker can harvest more than 80% of the olive fruit of one tree in 5-10 minutes (Aiello *et al.*, 2019). Zhou *et al*. (2014) used a sweet cherry twig shaker for the harvest test and found that the fruit removal rate could reach 97%, but its harvesting efficiency was low due to the limitation of the vibration actuator. Du *et al*. (2019) designed a vibratory harvesting mechanism for Chinese hickory nuts. Based on the orthogonal eccentric masses, it had the potential to make the tree branches vibrate effectively and evenly in the process of vibratory harvesting, which may improve the harvesting efficiency.

A canopy shaker uses a comb-type actuator to shake the canopy and detach the fruits (Fu *et al*., 2018; Sola-Guirado *et al*., 2016). Castro-Garcia *et al.* (2018) conducted canopy shaker experiments on citrus trees and found that when the vibration frequency was controlled at 4.5 Hz and the average harvesting time on each tree was 4s, an optimal harvesting effect could be achieved. Caprara and Pezzi (2011) evaluated the stresses transmitted by machinery during the harvest of grapes and demonstrated a better energy performance for the self-propelled machine that explaining its higher work efficiency. Sola-Guirado *et al.* (2018) developed a harvester based on canopy shaker technology for work on irregular, large trees in a circular path. This proposed innovation allowed the fully mechanical harvest of previously planted trees with a removal efficiency of over 84%. Castro-Garcia *et al*. (2009) evaluated the damage after harvest with a canopy shaker. Fruit mechanically harvested had 35% more bruising and three times as many fruits with broken skin as that of hand-harvested fruits.

C. oleifera is a shrub with several main branches, so it is suitable for canopy shakers. However, the most challenging thing about mechanically harvesting *C. oleifera* fruits is that the flower buds and fruits grow synchronously (Rao *et al.*, 2019). When mechanical harvesting is applied to *C. oleifera* trees, it is necessary to avoid damaging the flower buds significantly, affecting the yield next year (Feng *et al.*, 2014). A canopy shaker with multiple beating-bar arrays for massively harvesting *C. oleifera* fruits was designed in this study, and the dynamics of the *C. oleifera* trees with different canopy shapes were simulated by a finite element method to determine the shaking frequency. Field experiments of the canopy shaker prototype were conducted to determine the optimal shaking action for harvesting *C. oleifera* fruits.

Materials and methods

Simulation model of *Camellia oleifera* trees with different canopy shapes

Finite element analysis could provide suggestions for the study of tree response under the excitation of the shaker. It can help understand the interaction between the shaker and the tree and find the relationships between the responses and the excitation frequencies (Peng *et al*., 2017). Accurate three-dimensional tree model analysis of mechanised fruit harvesting can be an efficacious solution to obtaining desired parameters and optimal efficiency (Hoshyarmanesh *et al.*, 2017). The physical characteristics investigation was conducted on October 19th, 2018, at the Dongfanghong Orchard, National *C. oleifera* Breeding Base, Jinhua, Zhejiang Province, China. It is found that, according to the canopy shape of the *C. oleifera* tree, the tree could be divided into three types: upright canopy, open canopy, and spherical canopy, as shown in Figure 1. Different tree canopy shapes greatly impact on fruit yield and harvest efficiency (Lavee *et al.*, 2012). Each type of *C. oleifera* tree was measured respectively. Vernier calliper was used to measure the diameter of both ends of the trunk, main branch, and secondary branch of the *C. oleifera* trees. The height, canopy width, and branch length of the *C. oleifera* trees were measured by tape, and a protractor measured the angle of each branch. 20 sample trees were measured for each shape, and a total of 60 sample trees were measured. The measured geometric properties of the sample trees are shown in Table 1, in which d0 means the diameter of the lower end of the branch/trunk and d1 means the diameter of the upper end of the branch/trunk.

A B C

Figure 1. Three canopy shapes of the *Camellia oleifera* trees: A) upright canopy; B) open canopy; C) spherical canopy.

Table 1. Geometric properties of the sample trees.

	Upright canopy			Open canopy			Spherical canopy		
	d_0/mm	d_1/mm	L/mm	d_0/mm	d_1/mm	L/mm	d_0/mm	d_1/mm	L/mm
Trunk	107.61±14.40	107.64±13.45	322.50±96.57	108.16±22.73	116.13±24.33	224.50±80.03	102.71±16.90	106.50±25.39	249.50±100.76
Main branch	71.29±12.62	18.90±6.88	2145.38±398.73	63.14±13.43	21.99±6.04	1862.00±319.59	53.39±14.03	20.75±8.32	2129.00±444.22
Secondary branch	34.17±10.96	15.87±5.54	1369.21±437.15	32.06±11.27	13.76±4.68	1088.89±358.67	28.23±9.97	18.31±5.42	1264.96±479.08

Due to the complexity of the branches of *C. oleifera* trees, the physical and mechanical properties of each branch are regarded as the same, that is, the values of density, modulus of elasticity, and Poisson's ratio of each branch of the *C. oleifera* trees are the same. The branches of the *C. oleifera* trees were sampled to test their density and elastic modulus. The test results are listed in Table 2.

According to the data in Table 1, the three-dimensional models of the *C. oleifera* trees with three canopy shapes were established in SolidWorks, as shown in Figure 2. To simplify the simulation, the fruits, flower buds, and leaves are neglected in the models.

Harmonic response of *Camellia oleifer*a trees with different canopy shapes

Vibratory fruit harvesting is applying periodic harmonic excitation to the fruit tree so that the fruit will fall off with the vibration of the branches. Therefore, it is necessary to simulate the dynamic behaviour of the *C. oleifera* tree to determine the effective excitation frequency. The 3D models are imported into ANSYS, and their material properties are defined according to Table 2. After that, the models were meshed by setting the element type as BEAM188 and the element size as 10 mm. The X- and Y-axis of the Cartesian coordinate system were set to be perpendicular to the longitudinal axis of the trunk. The Z-axis was set to be parallel to the longitudinal axis of the trunk.

As shown in Figure 3, the simple harmonic force of 100 N, which can result in an obvious response on the tree, was applied to the two excitation points of the tree canopy, respectively. The excitation point was usually located in the middle of the main branch. The force direction was parallel to the Y-axis. The step size of the simulation was set as 80.

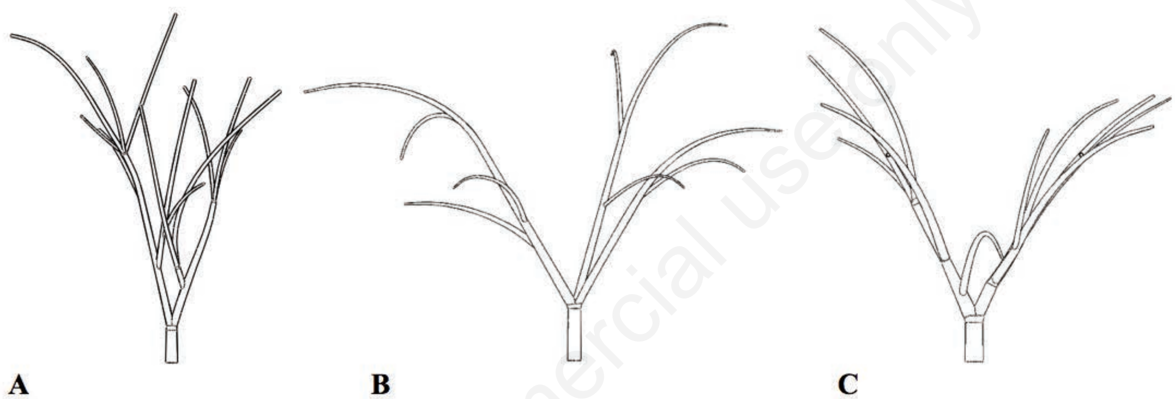

Figure 2. The 3D models of the *Camellia oleifera* trees with three canopy shapes: A) upright canopy; B) open canopy; C) spherical canopy.

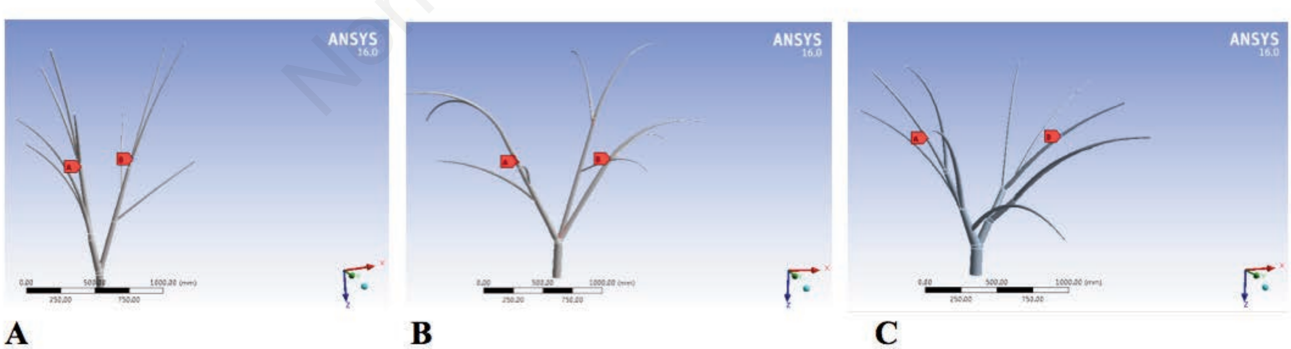

Figure 3. Finite element models of the *Camellia oleifera* tree with different canopy shapes: A) upright canopy; B) open canopy; C) spherical canopy.

Table 2. Physical and mechanical properties of the *Camellia oleifer*a trees.

Density ($g{\cdot}cm^{-3}$)	Elastic modulus (MPa)	Poisson's ratio
1.0506	294.8333	0.3

Canopy shaker for harvesting *Camellia oleifer*a fruits

The main structure of the canopy shaker for harvesting *C. oleifera* fruits includes multiple beating-bar arrays, a moving frame, fixed rack, DC motor, reducer, crank slider mechanism, and self-propelled track chassis. The 3D model is shown in Figure 4A.

The multiple beating-bar arrays are installed on the moving frame and divided into two groups, and each group is driven by a DC motor, a reducer, and a crank slider mechanism. When the multiple beating-bar arrays are inserted into the *C. oleifera* tree canopy, the upper and lower DC motors start to drive the crank slider mechanism. The multiple beating-bar arrays will make reciprocating linear motion along the moving direction of the track chassis and impact the branches. So the branches will vibrate at a specific frequency and amplitude under the excitations. Due to the big spaces between the beating bars, the multiple beating-bar arrays will comb the fruits and flower buds as well.

According to the studies on the multiple beating-bar arrays for harvesting citrus (Pu *et al.*, 2018), a rigid vibrating bar can effectively improve the vibration performance but damage the trees. The beating bar in this study is made of an aluminium tube covered by a PVC hose which can obtain high stiffness and enough elasticity, as shown in Figure 4B. According to the physical characteristics of the *C. oleifera* trees, the fruits are mainly distributed within 0-550 mm away from the outer surface of the tree canopy. So, the beating bar is designed with a length of 550 mm and a cylindrical section with a diameter of 20 mm. The layout of the beating-bar array is designed as shown in Figure 4C. The horizontal spacing of the beating bars is 160 mm, and the vertical spacing is 100 mm.

The reciprocating motion of the multiple beating-bar arrays can generate the exciting force for harvesting *C. oleifera* fruits, which is provided by a crank slider mechanism, as shown in Figure 5A. In order to ensure the slider-crank mechanism stability, the crank is replaced by an eccentric disk. A slider is fixed on the disk while moving along a slideway. The slideway is connected with the frame where the multiple beating-bar arrays are installed, and

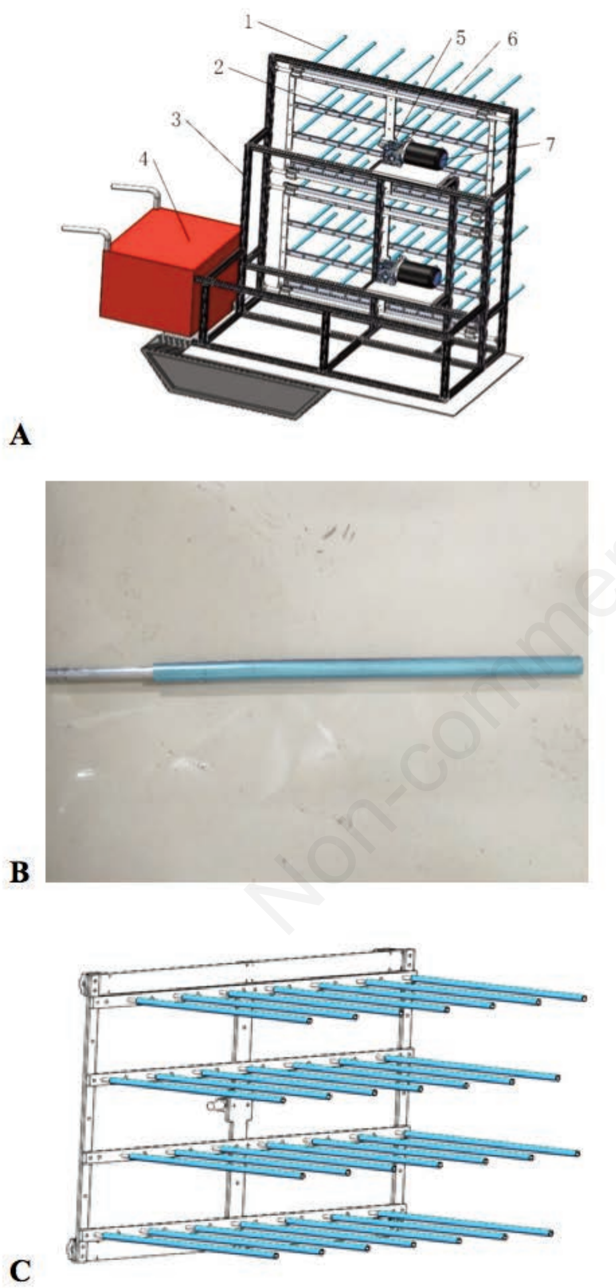

Figure 4. A) General structure of the canopy shaker for harvesting *Camellia oleifera* fruit: (1) multiple beating-bar arrays; (2) moving frame; (3) fixed rack; (4) self-propelled tracked chassis; (5) reducer; (6) crank slider mechanism; (7) DC motor. B) The beating bar. C) Layout of the multiple beating-bar arrays.

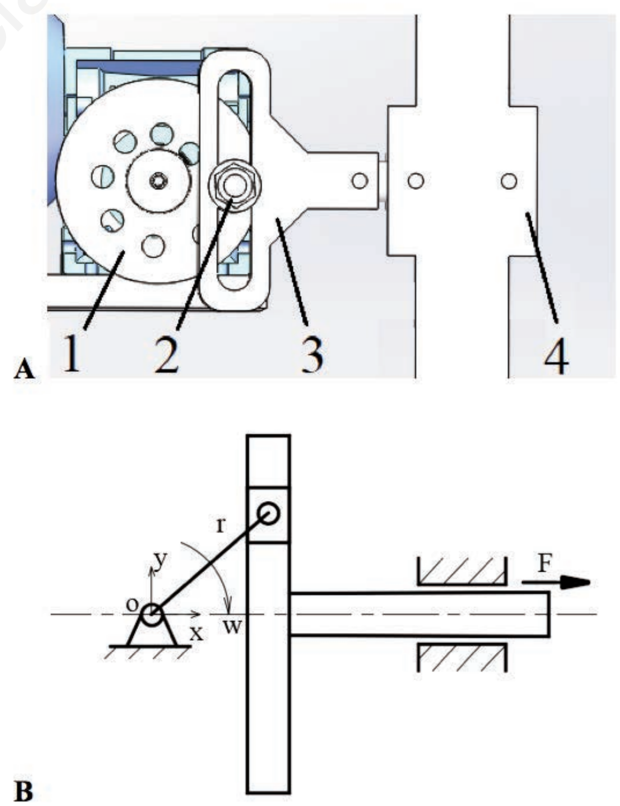

Figure 5. Sketch diagram of the shaking mechanism. A) The key components of the shaking mechanism: (1) eccentric disk; (2) slider; (3) slideway; (4) frame. B) The motion diagram of the shaking mechanism.

the frame can move along its guide rail. The motion diagram of the shaking mechanism is shown in Figure 5B.

The Cartesian coordinate system with the crank centre as the coordinate origin is established, and the circular motion is decomposed into x- and y-direction motion. The reciprocating motion of the beating bars is the x-direction motion. So the displacement equation of the shaking mechanism in x-direction is:

$$x_s = r\cos(\omega t) \tag{1}$$

where, r is the crank length, m; ω is the angular velocity of the crank, rad/s, and ω=2πf where f is the excitation frequency. So, the velocity and acceleration of the shaking mechanism in x-direction is:

$$\begin{cases} v_s = -r\omega \sin(\omega t) \\ a_s = -r\omega^2 \cos(\omega t) \end{cases} \tag{2}$$

In order to detach the *C. oleifera* fruits from the trees, the multiple beating-bar arrays beat the canopy, which causes the branches to vibrate, and the fruits on the branch will vibrate consequently. When the inertia force of the fruits is greater than the binding force, the fruits are detached (Hafezalkotob *et al*., 2018).

Field experiments

A canopy shaker prototype was built according to the design, and the field experiments on three types of *C. oleifera* tree canopies were carried out on October 18th, 2019, at the Dongfanghong Orchard, National *C. oleifera* Breeding Base, Jinhua, Zhejiang Province, China. The tested *C. oleifera* trees are 9 years old the canopy of the trees is about 3×3 m, the height of the trees is 2.5~3 m, the plant spacing is 2 m, the row spacing is 4 m, and the canopy is 40 cm from the ground.

The field experiment setup includes two switching power supplies (model: s-1500w-48v, Liyao Power Technology Co., Ltd, China), two DC motors (model: DM110RB-225i4RV48, Xuecheng Electric Appliance Co., Ltd, China), four reducers (model: NMRV, two ratio specifications: 5 and 7.5, Xuecheng Electric Appliance Co., Ltd, China), one gasoline generator (model: BR6500E, Shanghai Dongming Power Equipment Co., Ltd, China), and a tracked chassis (model: EDH500C, Zhong Yun Intelligent Machinery Group Co., Ltd, China), as shown in Figure 6A. *C. oleifera* planting area is mostly hilly and mountainous. In order to better adapt to the terrain, a crawler chassis is adopted. In the experiments, the motor speed, reciprocating stroke, and duration of vibration (mechanical harvesting time) are the influencing factors. The levels of the factors are determined according to the flexible-body dynamics simulation results.

C. oleifera fruit and flower grow synchronously, as shown in Figure 6B. For *C. oleifera*, fruit damage is not dangerous. Because it needs to be dehulled, it will not affect the seeds. During the picking process, the flower buds will be detached directly without damage to the bud itself, as shown in Figure 6C. Therefore, the harvesting percentage of *C. oleifera* fruits and the detachment percentage of the flower buds are the evaluation indices. In each test, the fruit/flower bud number is counted, including the number of non-detached and detached *C. oleifera* fruits, as well as the number of non-detached and detached flower buds. The fruit harvesting percentage and the detachment percentage of the flower buds are calculated according to the following equations:

$$R_f = \frac{Q_{af}}{Q_{af}+Q_{nf}} \times 100\% \tag{3}$$

where: R_f is the harvesting percentage of *C. oleifera* fruits;
Q_{af} is the number of detached fruits;
Q_{nf} is the number of undetached fruits.

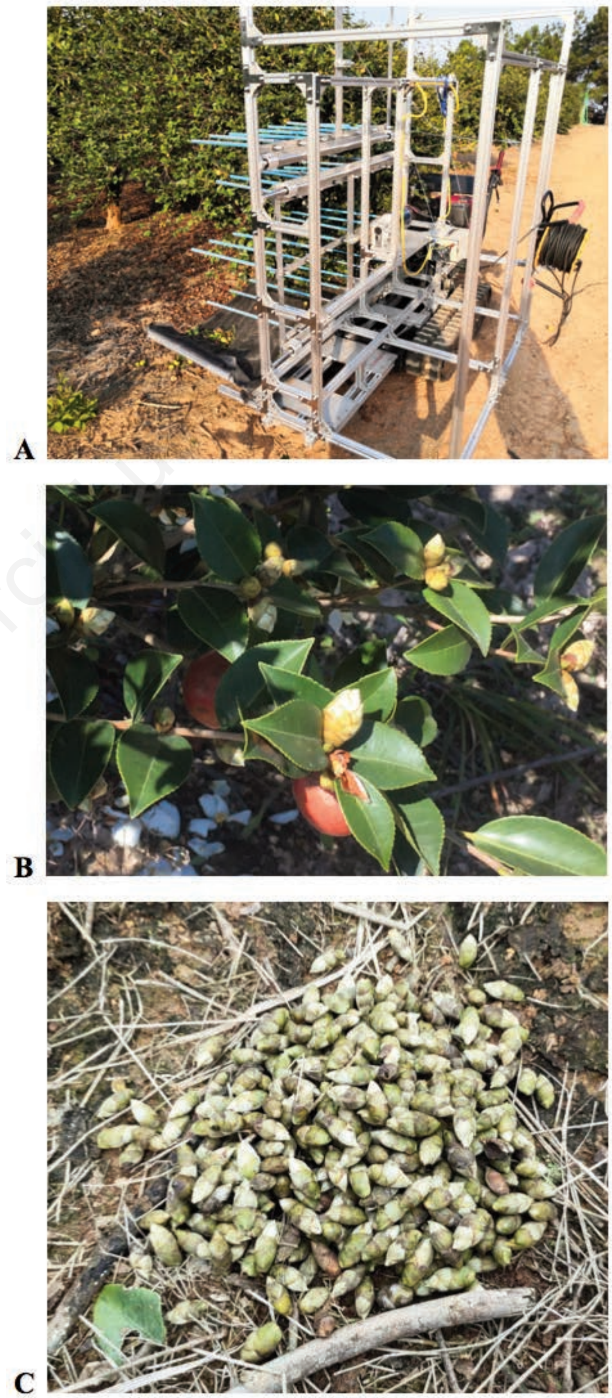

Figure 6. A) Field experiment setup; B) synchronous growth of fruits and flower buds; C) detachment of the flower buds.

$$R_b = \frac{Q_{ab}}{Q_{ab}+Q_{nb}} \times 100\% \quad (4)$$

where: R_b is the detachment percentage of the flower buds;
Q_{ab} is the number of detached flower buds;
Q_{nb} is the number of undetached flower buds.

Results and discussion

Modal analysis of the *Camellia oleifera* trees with different canopy shapes

The modal analysis of the *C. oleifera* tree models was carried out in ANSYS, and the natural frequencies were obtained. In the modal analysis, the influence of the tree's roots and the soil on the tree model is ignored, and the bottom of the trunk of the tree model is fixed (Bentaher *et al*., 2013). According to the working frequency range of the existing vibratory harvester (Castro-Garcia *et al*., 2019), the modes within the 40-order range of the *C. oleifera* trees were analysed, which can better observe the difference in the frequencies among three types of the tree canopy. Since the modal frequencies of the tree were dense, only the modal frequencies of every 5 orders were listed in Table 3.

According to the modal analysis results, the open canopy and the spherical canopy have a similar development, while the upright canopy shows an apparently more compact conformation. At the same time, it can be found that the first 15-order natural frequencies of the three models have very little difference. It indicates that low-order natural frequencies of the *C. oleifera* trees of different canopy shapes are close and have little correlation with the canopy shape.

Harmonic response analysis of the *Camellia oleifera* tree

The simulated acceleration response curves of the *C. oleifera* trees under the excitation forces are shown in Figure 7. It can be seen that the response of the tree with an upright canopy is higher than the others. The vibration response of the tree with a spherical canopy is higher than that of the tree with an open canopy. The acceleration responses of the trees decrease while the frequency increases. Nevertheless, in the low-frequency range within 10 Hz, the acceleration response is much larger. Thus, the low-frequency excitation is used in the following experiments of harvesting the *C. oleifera* fruits.

Effects of shaking parameters on *Camellia oleifera* fruit harvesting

There exist flower buds when the *C. oleifera* fruits mature, so some flower buds will fall off due to the harvest action. In the field experiments, motor speed A, reciprocating stroke B, and duration of vibration (mechanical harvesting time) C are the influencing factors. Each factor is set to 2 levels respectively. According to the harmonic response analysis, set the motor speed level and adopt low-frequency excitation. Through the pre-test on the *C. oleifera* tree, the vibration duration and reciprocating stroke were determined. The results showed that the vibration time of 8-12 s and the reciprocating stroke of 60-80 mm would not cause too much detachment of the flower buds and damage to the tree canopy. An orthogonal test table L4 (23) is designed to carry out 4 tests for each type of tree canopy, and each test is conducted twice on average. The levels of the test factors are shown in Table 4. Tables 5-7 show the orthogonal test results of three tree canopy shapes and the corresponding range analysis.

It can be seen from the range analysis results that the effects of the factors on the fruit detachment percentage and the detachment percentage of the flower buds have no relationship with the tree canopy shape. The influence levels of three factors on the fruit

Table 3. Modal analysis results of the *Camellia oleifera* trees with three canopy shapes.

Order	Natural frequency/Hz		
	Upright canopy	Open canopy	Spherical canopy
1	1.4540	1.2485	1.9163
5	2.1763	2.2222	2.2226
10	2.7939	3.0426	2.6820
15	4.3638	3.6851	3.4553
20	6.8675	4.7051	3.7837
25	9.9388	7.2868	6.8921
30	12.0410	9.1285	8.5258
35	16.5650	12.1180	11.0080
40	20.8620	13.6590	12.7900

Table 4. Three factors and two levels for the field experiments.

Levels	A Motor speed (r/min)	B Reciprocating stroke (mm)	C Duration of vibration (s)
1	240	60	8
2	360	80	12

Table 5. Experiment results and range analysis of the *Camellia oleifera* trees with upright canopy.

Test		Factor A	Factor B	Factor C	Fruit detachment percentage	Detachment percentage of the flower buds
1		1	1	1	0.612	0.111
2		1	2	2	0.681	0.120
3		2	1	2	0.708	0.151
4		2	2	1	0.763	0.143
Fruit detachment percentage	K1	1.293	1.320	1.375		
	K2	1.471	1.444	1.389		
	k1	0.647	0.66	0.688		
	k2	0.736	0.722	0.695		
	R	0.089	0.062	0.007		
Detachment percentage of the flower buds	K1	0.231	0.262	0.254		
	K2	0.294	0.263	0.271		
	k1	0.116	0.131	0.127		
	k2	0.147	0.132	0.136		
	R	0.031	0.001	0.009		

K represents the sum of experimental data at a certain level of a certain factor; k represents the corresponding average value of K.

Table 6. Experiment results and range analysis of the *Camellia oleifera* trees with an open canopy.

Test		Factor A	Factor B	Factor C	Fruit detachment percentage	Detachment percentage of the flower buds
1	1	1	1	0.655	0.095	
2	1	2	2	0.707	0.123	
3	2	1	2	0.782	0.145	
4	2	2	1	0.810	0.138	
Fruit detachment percentage	K1	1.362	1.437	1.465		
	K2	1.592	1.517	1.489		
	k1	0.681	0.719	0.733		
	k2	0.796	0.759	0.745		
	R	0.115	0.04	0.01		
Detachment percentage	K1	0.218	0.24	0.233		
	K2	0.283	0.261	0.268		
	k1	0.109	0.12	0.117		
	k2	0.142	0.131	0.134		
	R	0.033	0.011	0.017		

K represents the sum of experimental data at a certain level of a certain factor; k represents the corresponding average value of K.

Table 7. Experiment results and range analysis of the *Camellia oleifera* trees with a spherical canopy.

Test		Factor A	Factor B	Factor C	Fruit detachment percentage	Detachment percentage of the flower buds
1	1	1	1	0.636	0.103	
2	1	2	2	0.722	0.114	
3	2	1	2	0.773	0.139	
4	2	2	1	0.824	0.135	
Fruit detachment percentage	K1	1.358	1.409	1.460		
	K2	1.597	1.546	1.495		
	k1	0.679	0.705	0.730		
	k2	0.799	0.773	0.748		
	R	0.120	0.068	0.018		
Detachment percentage	K1	0.217	0.242	0.238		
	K2	0.274	0.249	0.253		
	k1	0.109	0.121	0.119		
	k2	0.137	0.125	0.127		
	R	0.028	0.004	0.008		

K represents the sum of experimental data at a certain level of a certain factor; k represents the corresponding average value of K.

Table 8. Comprehensive scoring results.

Experiment number	Factor A	B	C	Score of fruit detachment percentage	Score of bud non-detachment percentage	Comprehensive score
1	1	1	1	25.36	6.81	31.54
2	1	2	2	28.12	7.14	35.53
3	2	1	2	30.16	8.7	38.86
4	2	2	1	31.96	8.34	40.3

detachment percentage from high to low are motor speed, reciprocating stroke, and continuous vibration time. The influence levels of three factors on the detachment percentage of the flower buds from high to low are motor speed, continuous vibration time, and reciprocating stroke. The combination of factor and level for the highest fruit detachment percentage is A2B2C1, and the combination of factor and level for the lowest detachment percentage of the flower buds is A1B1C1.

Optimal shaking action

High detachment of the flower buds will reduce the *C. oleifera* fruit yield in the next year (Feng *et al.*, 2014). So, it is necessary to choose the optimal shaking action to obtain a high fruit detachment percentage but a low detachment percentage of the flower buds. From the results of the field test analysis, the optimal scheme is determined by the comprehensive scoring method. The fruit detachment percentage and the bud non-detachment percentage were used as evaluation indices. The coefficient of variation of fruit detachment percentage is 0.09117, and the coefficient of variation of the bud non-detachment percentage is 0.13645, so their respective weights account for 40% and 60%. The calculation equations are shown in Eqs. (5)-(7), and the comprehensive scoring results are shown in Table 8.

$$R=R'_1+R'_2 \quad (5)$$

$$R'_1=R_1\times100\times40\% \quad (6)$$

$$R'_2=(1-R_2)\times100\times60\% \quad (7)$$

where: R is the comprehensive score of harvesting;
R'_1 is the score of fruit detachment percentage;
R'_2 is the score of the bud non-detachment percentage.

It can be seen from Table 7 that the highest score of experiment No. 4 is 40.3, and the optimal scheme is A2B2C1 (motor speed 360 r/min, reciprocating stroke 80 mm, and vibration time 8 s). According to Tables 4-6, the average fruit detachment percentage of the three tree shapes under this shaking scheme is 79.9%, and the average detachment percentage of the flower buds is 13.9%.

Conclusions

The models with three canopy shapes were built based on the investigated geometric properties of the *C. oleifera* trees. Their modal analysis results show that the low-order natural frequencies of the *C. oleifera* trees with different canopy shapes are very close. According to the harmonic response analysis, the low-frequency excitation is used to harvest *C. oleifera* fruit.

In order to achieve high fruit harvesting percentage and low detachment percentage of the flower buds, an eccentric mechanism with an adjustable reciprocating stroke was designed, and its kinematic analysis was made. The multiple beating-bar arrays driven by the eccentric disk can generate comb-brushing effects on the tree canopy.

After building the prototype, the field test was carried out. Through orthogonal picking experiments, it was found that *C. oleifera* trees with different tree canopy shapes could be picked with the same combination of parameters. The influence levels of three factors on the fruit detachment percentage from high to low are motor speed, reciprocating stroke, and continuous vibration time. The influence levels of three factors on the detachment percentage of the flower buds from high to low are motor speed, continuous vibration time, and reciprocating stroke. The optimal combination was determined based on the comprehensive scoring method. Under this scheme, the average fruit detachment percentage was 79.9%, and the average detachment percentage of the flower buds was 13.9%.

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