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Study on Mechanical Law of Vibration Abscission of Camellia Oleifera Fruit Based on High-Speed Camera Technology

Yangcheng[1],Wangqi[2]

[1]Key Laboratory of Modern Agricultural Equipment's and Technology, Ministry of Education, Jiangsu University, Zhenjiang, China;

[2]Engineering College,Anhui Agricultural University,Hefei,Anhui

yangcheng_ujs@126.com

Abstract

The movement and mechanical characteristics of oil-tea camellia fruit coupling with flower simultaneously during the harvest period were studied to provide an indispensable theoretical guideline for the mechanized picking machine. The mechanical properties of Camellia oleifera were obtained by investigating its flowers and fruits, and the vibration harvesting of Camellia oleifera was studied by using dynamic vibration device. The i-Speed3 high-speed camera was used to record the harvesting process, and the image analysis and calculation were carried out by its own Control-Pro software. The results showed that different varieties of Camellia oleifera had different flowering periods, ranging from 30 to 55 days; their weight also varied among varieties; there was no inevitable relationship between the binding force (pulling force and torque) of fruit stalks and their varieties, locations and diameter of fruit stalks. More importantly, during the vibration process, the fruit peeling speed is related to the vibration source clamping position and vibration parameters. Under the condition of short clamping distance and high frequency and low amplitude, the fruit is more likely to fall off.

Keywords: High-Speed Camera Technology, Camellia Fruit, Law of Vibration, Law of Mechanical Properties.

Introduction

Camellia oleifera belongs to Theaceae plant and grows in arid and barren hilly areas. It is a unique woody oil tree species in China and is the preferred healthy edible oil material by Regional Data Exchange System. Has the advantages of not occupying cultivated land and multi-year income for one planting; It has irreplaceable contribution to edible vegetable oil in China and even in the world. At present, there are about 45 million mu of camellia oleifera planted in the country. the annual output of camellia oleifera seeds is about 1 million tons, the output of camellia oil is about 260,000 tons, and the output value is about 11 billion yuan. At the same time, the flowering period of camellia oleifera is about October to December, and the fruit picking period is about 10 to 15 days. The main trunk of camellia oleifera is not obvious, the branches are dense, the tree height and crown shape are different, the buds and fruits are interwoven, and the fruit shapes are different. Camellia oleifera flower fruit synchronization, the harvesting method is mainly manual harvesting [1]. In view of the short harvest of Period, the serious shortage of labor resources, and the need to use ladders and other auxiliary tools to cause damage to branches and buds, camellia oleifera yield generally presents the characteristics of "big and small years" with serious economic losses. Therefore, it is urgent to find a mechanized device that can meet the requirements of walking in harsh environments such as hills and mountains and can effectively complete harvesting.

At present, there are mainly two ways to harvest fruits mechanically [2]: contact type and vibration type. For fresh fruits with high requirements such as tomatoes and grapes, contact type is mainly used. For nuts such as ginkgo, walnut and chestnut, vibration is mainly used. Foreign countries used mechanized equipment earlier to harvest fruits, the technical means were relatively mature [3, 4]. BlancoRoldan G.L et al. [5] used vibration machinery to study olive harvesting. it was found that the strategy of batch harvesting with different vibration frequencies could significantly improve the recovery ratio. Láng Z [6] takes trees as the research object and establishes an optimized mechanical model, which is very close to reality and provides a good foundation for further optimization of fruit harvester. Fu L et al [7] shot blueberry harvesting based on high-speed camera technology. After calculation and analysis, the optimal vibration speed and time were determined. Bora G et al [8] detected the acceleration response during the vibration of citrus and the inertial separation force between the fruit stalk and the fruit using acceleration transducer. Zhou J et al [9] photographed the displacement track of cherry abscission process with High Speed Camera, and analyzed the influence of vibration frequency on fruit abscission speed and damage. Despite the late start of domestic mechanized fruit harvesters, considerable progress has been made in recent years. Cai Fei [10] and others carried out experiments on fruit falling by vibration based on high-speed cameras, and found that the minimum force required for fruit falling is the inertial force of falling, which can provide theoretical parameters of exciting force for vibrating machinery. Wang Yalei et al. [11] studied the law of medlar harvesting movement. The results showed that there were mainly two movement modes of fruit: straight line and torsion. By adjusting different frequencies for energy transfer analysis, Wang Changqin [12] and others found that an appropriate vibration frequency can realize high-efficiency recovery.

At present, mechanized harvesting of fruits has been widely used, such as medlar, pear, pistachio, apricot and other single fruits. However, for special fruits, such as camellia oleifera during the same period of flower and fruit, the adoption of ordinary fruit harvesting machines will not only cause serious damage to fruits and flower buds, but also lead to a reduction in output in the coming year. Therefore, it is eager to obtain the movement rule of camellia oleifera flower and fruit during harvesting vibration, including quantitative mechanical characteristic parameters, excitation frequency, etc., so as to provide theoretical guidance for this special mechanical fruit harvesting device.

Materials and Methods

Experimental Instruments

Measuring instruments: high-speed camera, excitation device, tape measure (name: JIANGHUA, No.01953016, precision: 0.1 mm), tension force measuring device (name: VICTORY, Model:VICTORY 50N, S/N: 094798212, precision: 0.01 N), vernier caliper (Logo:Guanglu, precision: 0.01 mm), Torque measuring instrument (name: Amritt instrument, model: HP-10, model:Digital Torque Meter, precision: 0.001 N), and recording pen, etc.

Test Condition

(1) Test site: Qilin Camellia oleifera Cooperative in Qidong County, Hunan Province

(2) Test time: October 29, 2018-November 1, 2018

(3) Camellia oleifera: The tree age is 6-8 years, the plant row spacing is about 2.5 m×3 m, the plant height is about 2-2.5m, the width is about 2m, the branches of Camellia oleifera are dense and disordered, but the toughness is good and it is not easy to break.

(4) Vibration mode: The branches clamped by the vibration exciter vibrate continuously at different vibration frequencies and amplitudes respectively.

Experimental Methods

(1) In the process of field research, 8-year-old camellia oleifera with good growth and moderate maturity was selected as the research object. Weeds around the camellia oleifera were removed and some branches were selectively cut to prevent blind areas from being formed in the shooting process [13-18].

(2) As Camellia oleifera is a special fruit tree with flowers and fruits in the same period, flowering period investigation is an essential work, thus providing reference for the most suitable fruit picking period. In addition, the mechanical properties of flower buds and fruits were tested by tensile force tester, and their characteristics were summarized to provide first-hand materials for mechanical design.

(3) The vibration exciter is used to simulate the mechanized picking of camellia oleifera fruits by selecting picking positions, clamping branches, swinging to remove fruits, loosening branches, reselecting picking positions and other cyclic and continuous operations. The device grabs randomly and shakes branches to remove fruits to avoid the influence of single position factors.

(4) Use the i-Speed 3 high-speed camera for real-time tracking, and fix its suitable shooting position when necessary. Considering the environmental conditions such as on-site illumination, 1000 frames per second and 1024 x 1280 pixels are selected for shooting. I-Speed 3 software is used for playback, calculation and analysis. The mechanical law of camellia oleifera fruit during vibration shedding was studied to provide theoretical basis for further generalization of vibration harvesting mechanized equipment.

Results and Discussion

Growth Characteristics of Camellia Oleifera

Camellia oleifera is most different from other types of fruits such as apples, pears, medlars, apricots, pistachios, etc. in the same period of flowers and fruits. as shown in table 1, the earliest flowering period is XL67, XL56, XL89, which is October 1, and the latest flowering period is XL1, which is November 20. The duration of florescence also varies greatly, ranging from 30 to 55 days. The flowering time of XL27 is 30 days, and that of XL67 is 55 days. According to the length of florescence, varieties can be divided into three types: XL27, XL82, XL210 and XL92 have similar florescence, about 30-40 days; The florescence of XL1, XL78, XL89, XL4, XL70 and XL69 are similar, about 40-50 days. The florescence of XL56 and XL67 are similar, about 50-55 days. In addition, varieties with similar florescence have adjacent growth areas and better mutual pollination, thus improving the fruit setting rate.

Table 1 The blooming period of different kinds of oil-tea camellias

Camellia oleifera varieties	Blooming time	Spending time	Flowering period/day
XL27	Nov.10th	Dec.10th	30
XL82	Nov.10th	Dec.15th	35
XL210	Nov.5th	Dec.10th	35
XL1	Nov.20th	Jan.5th	45
XL92	Nov.10th	Dec.15th	35
XL78	Oct.31th	Dec.10th	40
XL56	Oct.10th	Nov.30th	50
XL89	Oct.20th	Nov.30th	40
XL4	Nov.1th	Dec.10th	40

XL70	Oct.15th	Nov.30th	45
XL67	Oct.1th	Nov.25th	55
XL69	Nov.10th	Dec.20th	40

The varieties with florescence of 30 days (XL27), 40 days (XL89) and 50 days (XL56) were selected to study the physical properties of Camellia oleifera fruits. The related physical properties are shown in Table 2. The results showed that there were differences in the physical characteristics of fruits among varieties in terms of fruit weight, geometric size and stem diameter, but the differences were not significant and the correlation was weak.

Table 2 Physical properties of camellia oleifera fruit

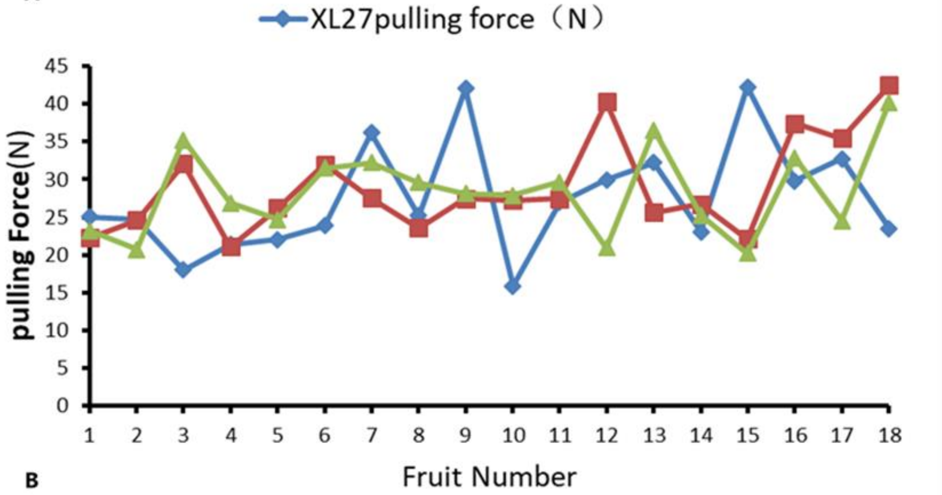
Varieties	Weight of single fruit /g			Geometric mean diameter /mm			Fruit stalk diameter /mm		
	MAX	MIN	AVG	MAX	MIN	AVG	MAX	MIN	AVG
XL27	38.84	11.44	24.73	41.1	26.6	34.1	5.9	4.2	5.4
XL89	37.77	4.93	20.30	42.7	20.6	33.5	6.2	4.6	5.1
XL56	46.74	15.1	21.2	49.2	9.7	34.1	6.6	4.1	5.2

Measurement of Mechanical Properties of Camellia oleifera Fruit

Authors tested the pulling force of camellia oleifera fruit Three varieties XL27, XL89 and XL56 were selected to study the binding force (pulling force and torque) of camellia oleifera fruit. Figure.1 is a physical diagram of camellia oleifera fruit stalk pulling force test. Mature fruits were randomly selected from the three varieties. First, the linear distance between the fruit stalk and the tip of the branch was measured with a 0.1 mm precision tape measure. Second, the pulling force when camellia oleifera fruit just fell off was measured with tensionmeter. Each variety tested 18 sets of data. The results are shown in Figure.2. After calculation, it was found that the average separating power of fruit stalk was about 27.50N for XL27, 28.98N for XL89 and 28.35 N for XL56. , it was found that there was no obvious correlation between the stalk separating force of the three varieties (fig. 2A), so the influence of varieties on the stalk separating force could be ignored. Without considering the variety factor, the three groups of data are integrated together. SPSS software is used to calculate the correlation between the two variables (variable 1: the linear distance between the fruit and the tip of the paper, variable 2: the fruit stalk pulling force). Through the correlation analysis results (Figure.2B, C), the correlation coefficient of variable 1 and variable 2 is 0.358, and the corresponding significance coefficient is 0.008. According to the Pearson Correlation Coefficient range grade, the weak correlation between the fruit stalk pulling force and the distance between the fruit and the tip of the branch can be obtained. Therefore, the influence of the fruit position on the pulling force can be excluded in the subsequent research process.

Fig.1 The tension tests of oil-tea camellia fruits

A



B

C

Correlation Analysis

		Pulling Force	Distance
Pulling Force	Correlation Coefficient	1	0.358
	Significance Coefficient		0.008
Distance	Correlation Coefficient	0.358	1
	Significance Coefficient	0.008	

Fig.2(A)Relationship between fruit stem separation force and camellia varieties

(B,C)Analysis of the Correlation between Tension and Distance by SPSS

Authors tested the torque of camellia oleifera fruit Three varieties In order to facilitate the use of HP-10 torque sensor, firstly, branches with mature fruits are randomly folded from the three varieties of camellia oleifera (XL27, XL89 and XL56), and the fruits on the branches are numbered with a marker pen. Then, the diameter of the fruit handle is measured with a vernier caliper (Figure 3A), and the corresponding number is recorded. Finally, the camellia oleifera fruit is fixed on the torque sensor (Figure 3B), and the fruit handle is slowly rotated. After the handle is separated from the fruit, the torque of the fruit handle is read. Excluding invalid data, the torque of 67 fruits and the diameter data of corresponding fruit stalks were measured. Statistics showed that the diameter of fruit stalks was 7.72mm maximum, 4.05mm minimum and 5.59mm; average. The torque of fruit stalk showed the variation fluctuation of small Period, with the maximum value reaching 0.058N· m and the minimum value 0.006 N· m;; The average value is about 0.021 N· m (fig. 3C). The data of stem diameter and torque were imported into SPSS, and the correlation between stem diameter and torque was analyzed. The correlation coefficient of stem diameter and torque was -0.013, and the corresponding significance was 0.919. Therefore, it can be seen that there is a very weak correlation between stem diameter and torque.

To sum up, the binding force (pulling force and torque) of the fruit stalk is only weakly correlated with its variety, location and diameter, so the influence of these factors on mechanical picking can be excluded in the process of mechanical picking. In order to control the missed harvest rate, discrete statistics are adopted (fig. 2A). in order to ensure a harvest rate of more than 90%, and to realize mechanized harvest, the inertial force generated by the vibration excitation device on the fruits on the branches should be ensured to be more than 30N.

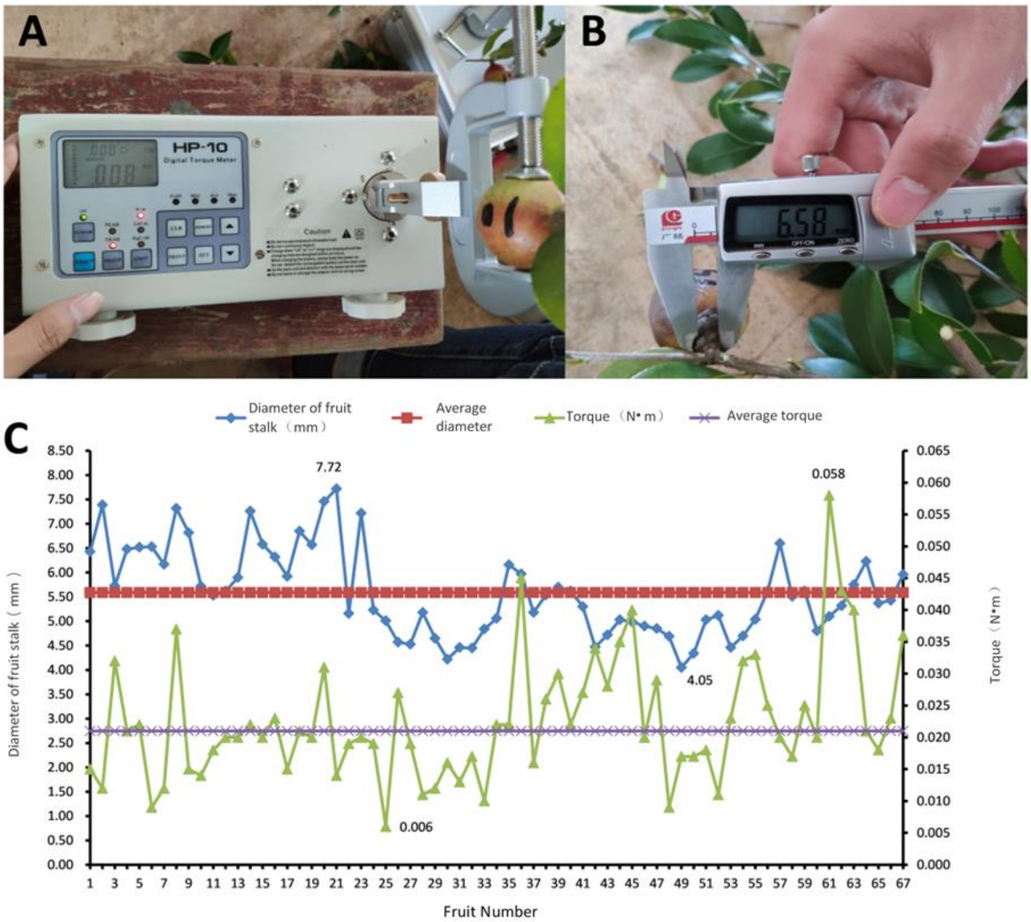


Fig.3 (A,B)Camellia fruit measurement,

(C) Data Diagram of fruit stem Diameter and Torque

Changes of Instantaneous Velocity, Acceleration and Inertia Force of Camellia oleifera Fruit Vibration Dropping

In order to study the dynamic response of oil-tea camellia fruit in the process of mechanical vibration harvesting, the motion parameters of oil-tea camellia fruit were analyzed. The instantaneous velocity, acceleration and inertial force of oil-tea camellia fruit in the process of vibration were mainly studied. Camellia oleifera branches with mature fruits, regular biological morphology and no visual impairment on their lateral branches were selected as experimental objects. Three fruits were selected as camera capturing points, and vibration excitation devices were loaded on branches. The distance from tape measure fruits to the center of vibration source (Figure 4) was respectively fruit I (328 mm), fruit II (256 mm) and fruit III (183 mm). Finally, high-speed camera i-Speed 3 was used to photograph and track the whole vibration process of camellia oleifera fruit (fig. 5A). then, its own software i-SPEED Control Pro was used to carry out subsequent analysis and calculation of high-speed video (fig. 5B) on the speed, acceleration and inertial force of camellia oleifera fruit during the shedding process. After the fruit falls off, the weight of the fruit is weighed by an electronic scale (fig. 4), i.e. fruit I (0.02658kg), fruit ii (0.02016 kg) and fruit iii (0.02138 kg).

Fig.4 Camellia fruit measurement

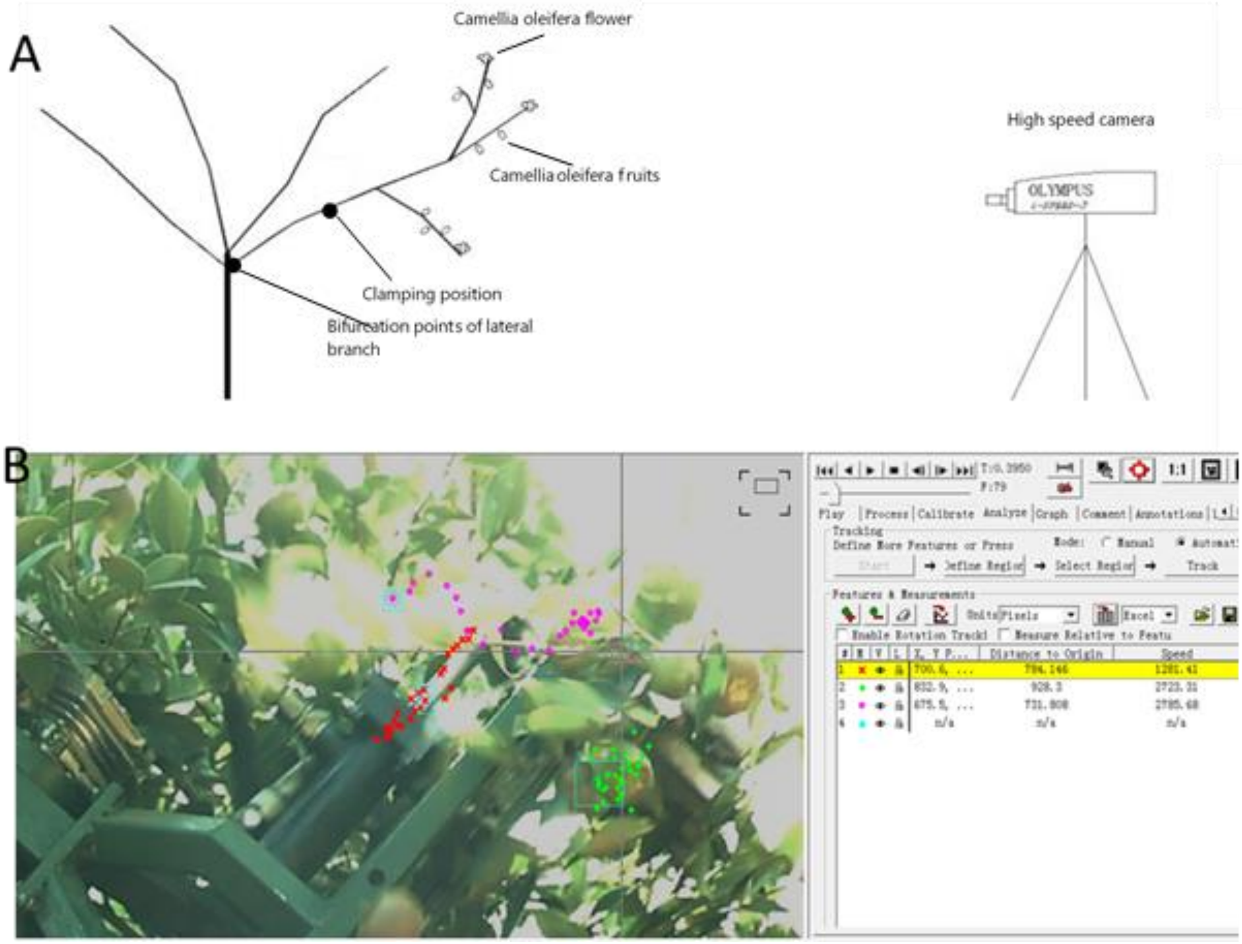


Fig.5 The model picture taken by the high-speed camera (i-speed 3) and its supporting software are played back for analysis and calculation

The instantaneous speed of fruit movement is analyzed by i-SPEED Control Pro and drawn into a line chart as shown in fig. 6. The abscissa indicates the shedding time of the fruit during the vibration process, with the unit being ms, and the ordinate indicates the instantaneous speed of camellia oleifera fruit corresponding to each time during forced vibration, with the unit being m/s. After comparative analysis, the time for the three fruits I, II and III to fall off was 740ms, 670ms and 590ms respectively. According to the distance of the three fruits from the vibration source, it can be concluded that the fruit Ⅲ falls off the fastest and the fruit Ⅰ falls off the slowest, i.e. the closer the fruit is to the vibration source, the shorter the time it takes for the fruit to fall off. After comparing and analyzing the speed among the three, it is found that the movement speed of the fruit III closest to the vibration source has obvious change trend, and its size is obviously larger than that of the fruits I and II. The speed changes of fruits Ⅰ and Ⅱ show Periodicity growth, which can be divided into three stages: the first stage is the initial stage of vibration, during which the instantaneous speed of fruits is the smallest during the vibration process, and the change trend is relatively gentle, with no particularly large fluctuations; The second stage is the middle stage of vibration, in which the curve of fruit instantaneous velocity tends to be irregular sine curve and the peak value of the curve increases continuously. The third stage is the early stage of fruit shedding. In this stage, the instantaneous speed drops obviously, that is, the acceleration drops obviously, and the inertial force produced reaches the peak value, thus causing the fruit to shed.

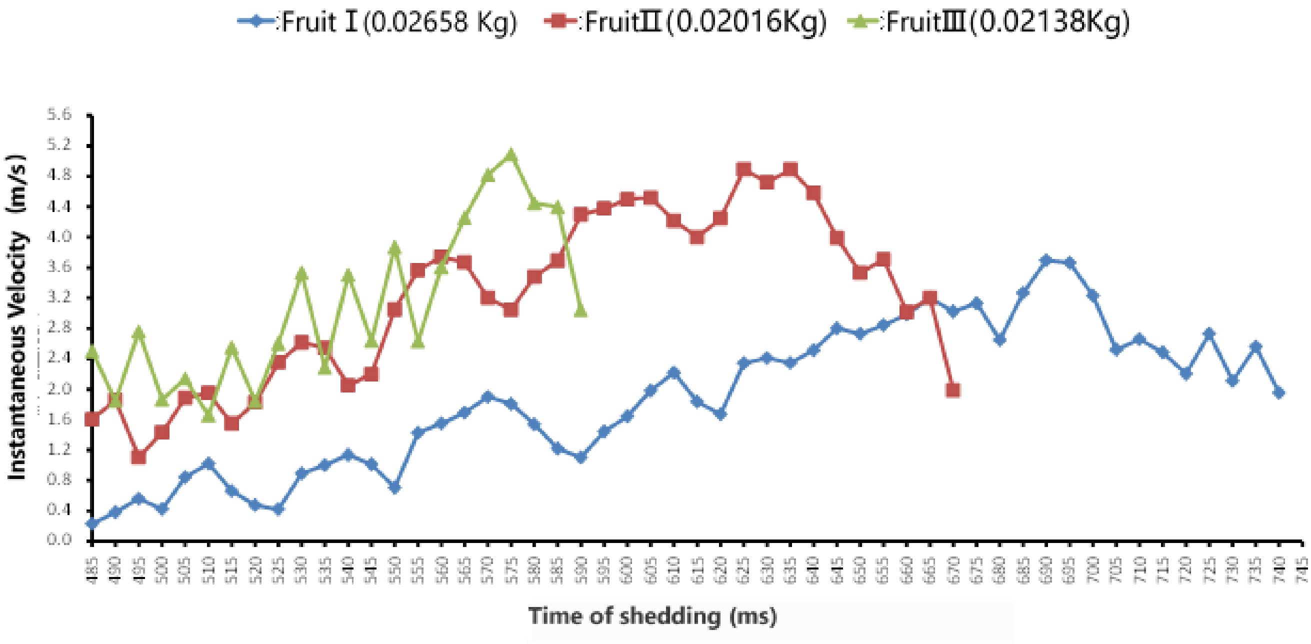


Fig.6 Contrast Chart of Instantaneous Velocity of Fruit Ⅰ, Ⅱ and Ⅲ before Complete Abscission

Under the Inertial frame of reference, the calculation of inertial force conforms to Newton's law. The inertial force of the fruit is calculated according to the acceleration during the vibration of the camellia oleifera fruit, that is, the inertial force is equal to the product of the acceleration and the mass of the fruit:

$$F_i=m \cdot a$$

Where F_i refers to the shedding inertia force of fruit under forced excitation, unit/n; M is the mass of the fruit in kg; A is acceleration in ($m \cdot s^{-2}$);According to the chart and the speed data, the instantaneous detachment inertia force of camellia oleifera fruits is calculated and plotted into a line chart as shown in fig. 7.

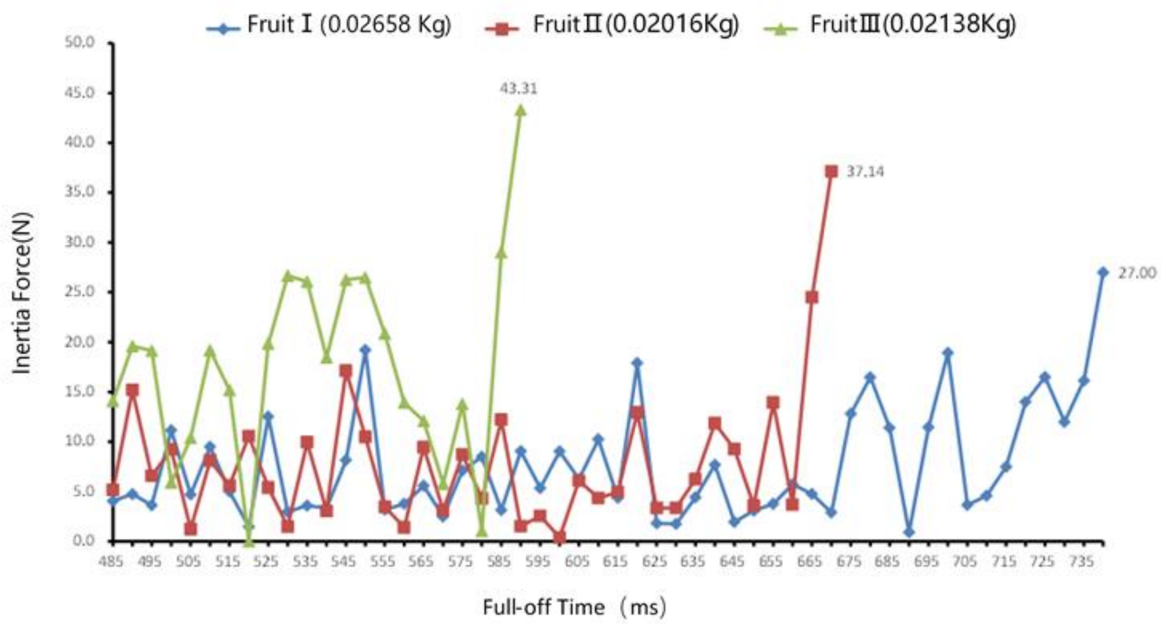


Fig.7 Contrast Chart of Instantaneous Inertial Force of Fruit Ⅰ, Ⅱ andⅢ before Complete Abscission

According to fig. 7, when fruits, Ⅱ,Ⅲ and iii fall off, the corresponding falling inertia forces are 27.00N, 37.14N and 43.31N respectively. Among them, the inertial force on the fruit III closest to the vibration source is generally large, fluctuating in the range of 0-20N before 580ms, and increasing significantly after 580ms until the fruit falls off after being greater than the binding force of the fruit stalk. Fruit II slightly away from the vibration source is relatively gentle before 660ms, and the fluctuation range of inertial force is about 0-15 N. After 660ms, it also starts to increase significantly until the fruit falls off. Before 675ms, the inertial force of the fruit I farthest from the vibration source was in the stationary phase, and the fluctuation range was between 0-10N, and between 675-730ms, and a large fluctuation began to appear, with the peak value of nearly 20 N. However, the fruit still could not be detached, but after 730ms, the inertial force began to increase significantly until the fruit fell off.According to the above analysis, under the condition of little difference in fruit weight, the magnitude of inertial force on fruit is inversely proportional to the distance from fruit to vibration source. The farther the distance is, the smaller the inertial force is, the less likely it is to fall off. The analysis of the variation law of inertia force provides theoretical research basis for the later vibration picking device test.

In order to compare and analyze the effects of frequency, amplitude and action time on vibration and fruit drop, referring to relevant research conclusions at home and abroad, this test adopts the method of randomly grabbing branches separately for vibration. During the vibration test, the action time is set at 5s, and the excitation frequency and amplitude are respectively set as follows: (10Hz, 20mm), (8Hz, 30mm), (6Hz, 40mm). The vibration fruit drop test was conducted in three groups. Five branches with ripe fruits and similar biological characteristics were selected as test objects in each group. The whole process was carried out by using high-speed camera to carry out follow shot and Late Pass software to analyze and study the vibration law of fruits, collate data, take average value and draw a map.

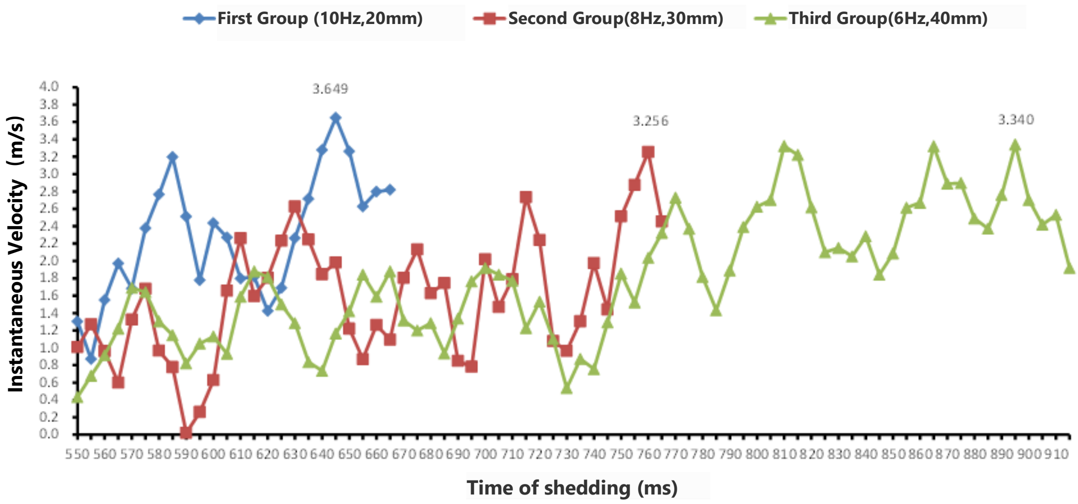


Fig.8 Instantaneous Velocity Contrast Chart of Fruit under Different Frequency and Amplitude Conditions in the Same Time

As can be seen from fig. 8, the time required for the first group of fruits to fall off is the shortest, about 665ms;; The fall-off time of the second group was 765ms; The shedding time of the third group was 915 ms. Therefore, under the excitation of high vibration frequency of 10Hz and low amplitude of 20mm, camellia oleifera fruit shedding time is the fastest, and the maximum instantaneous speed can reach 3.649m/s, while under the excitation of low vibration frequency of 6Hz and high amplitude of 40mm, fruit shedding is relatively slow. In addition, under the conditions of low vibration frequency of 6Hz and high amplitude of 40mm, the instantaneous velocity law of Camellia oleifera fruits presents 8 vibration Period, and its peak value and Period are gradually increasing, while compared with the conditions of high vibration frequency of 10Hz and low amplitude of 20mm, only 2 vibration Period appear.

To sum up, under the same vibration time, comparing the two working conditions of high frequency low amplitude and low frequency high amplitude, it is found that high frequency low amplitude is easier to make fruits fall off, and the vibration Period is short, which will reduce the damage to branches and flower buds, thus ensuring the fruit setting rate of camellia oleifera in the coming year to a certain extent.

Conclusions

Through in-depth research on camellia oleifera flowers and fruits, it is found that there is a weak correlation between the binding force (pulling force and torque) of camellia oleifera fruits and branches and their varieties, the location of fruits and the diameter of fruit stalks, which can eliminate the influence of these factors on mechanized picking; In order to ensure more than 90% picking rate, mechanical stress should be around 30 n.

The binding force of flower bud is approximately inversely proportional to its height, i.e. the higher the height of flower bud, the smaller the binding force; The distance from flower to branch is directly proportional to the pulling force of flower, and the binding force of flower at the edge is often greater than that inside.

Under the condition of little difference in fruit weight, the magnitude of inertial force on the fruit is inversely proportional to the distance from the fruit to the vibration source. The farther the distance is, the smaller the inertial force is, the less likely it is to fall off.

Under the condition of high frequency and low amplitude, the machine vibration picking has the best effect, the fruit falls off quickly and the vibration Period is less, which can effectively reduce the damage to branches and leaves and flower buds.

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Authors	Name	Biography	Photo
1st Authors	Yang Cheng	Master of Engineering, research interest:engaged in the research of intelligent agricultural equipment technology. Tel: +86-18851401890 Email: yangcheng_ujs@126.com	
2nd Authors	Wang Qi	Master of Engineering, research interest:engaged in the research of intelligent agricultural equipment technology. Email: 15715694772@qq.com	