SIMULATION AND EXPERIMENTAL STUDY ON VIBRATORY HARVESTING PARAMETERS OF A PLUM HARVESTING MACHINE
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李子采收机振动采收参数仿真与试验研究

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ABSTRACT
The objective of this study is to address the challenges associated with manual, labor-intensive plum harvesting in hilly and mountainous regions. To overcome these limitations, a crawler-type plum harvester was developed based on the operating characteristics of orchards in such terrain. The harvester employs an excitation-and-vibration mechanism to detach fruits and facilitate efficient collection. To investigate the key factors influencing plum detachment under vibratory conditions, a mechanical vibration model of the fruit–stem system was established. The model analysis identified vibration frequency (ω) and vibration amplitude (A) as the primary influencing parameters. A finite element simulation of plum trees was subsequently conducted using ANSYS software. The simulation results indicated that the suitable vibration frequency range for effective plum detachment is between 6.60 Hz and 9.43 Hz. Finally, field experiments were carried out to determine the optimal vibration frequency. The net harvesting rate and fruit loss rate were selected as evaluation indicators. The experimental findings verified the accuracy of the theoretical model, and the optimal vibration frequency for plum harvesting was determined to be 7–8 Hz.

摘要
本研究针对丘陵山区李子收获作业多以人工为主、劳动强度大的问题，根据丘陵山区李子园种植环境设计了一款履带式李子采收机，采用激发振动原理使李子果实脱落，实现采摘作业。为探究振动条件下，影响李子果实脱落的主要因素，构建了李子振动力学模型，通过对模型求解，确定了影响果实振动脱落的主要因素为振动频率 A 和振动幅度 ω。然后，利用 ANSYS 软件对李子树进行仿真试验，确定李子振动采收的振动频率范围为 6.60 Hz~9.43 Hz。最后，通过田间试验以采净率和损失率作为试验指标，确定李子振动采收最佳的振动频率为 7~8 Hz，验证了李子振动力学模型的可靠性。

INTRODUCTION
Plum (Prunus) is a plant that is native to China *(Liu et al., 2020)*. It is classified as a member of the genus Prunus in the family Rosaceae. The fruit of the plum is rich in protein, vitamin C, calcium, iron, magnesium, and potassium *(Zhou et al., 2020).* This makes plum a very nutritious food. It also has medicinal value *(Li Yan et al., 2020)*. It is thought to clear away heat and generate fluids. The adaptability of plums is robust, with a propensity to be cultivated in hilly and mountainous regions at elevations ranging from 400 to 2,600 meters *(Li, Dong et al., 2022)*. The manual harvesting of plums in hilly, mountainous regions is constrained by topographical and landscape limitations *(Jin et al., 2023)*, thereby impeding the advancement of the plum industry. This necessitates the urgent development of a machine capable of mechanized plum harvesting in these areas.

In recent years, a considerable number of researchers have explored vibratory harvesting as a means to facilitate large-scale mechanized harvesting of forest fruits *(Afsah et al., 2022; Junming et al., 2021; Zhuo et al.,2022; Castro et al., 2019; Castro et al., 2018).* This method has been found to possess several advantages, including low cost, high efficiency, and simple operation *(Zheng et al., 2025)*. Researchers have thus directed their efforts towards studying the abscission characteristics of forest fruits when subjected to vibration.

Han et al., (2022), conducted an experimental study on the acceleration response on each branch of a chestnut tree and fruit drop. The study was conducted by exciting the trunk with a single eccentric vibration motor. The optimal excitation frequency for vibratory harvesting of chestnuts was analyzed. *Fan et al., (2025),* designed a vibrating oil tea fruit harvesting actuator and derived the acceleration of oil tea fruit shedding and the optimal excitation frequency of the vibration device. Sun's research focused on the dynamic behavior of apple branches, encompassing the underlying vibration mechanism and the separation deformation law *(Sun et al., 2023)*. This investigation involved the implementation of dynamic tests and simulations to elucidate the underlying physics of the subject. The study revealed that the vibration frequency of 3 Hz resulted in the optimal separation of the apple, accompanied by the most effective shedding effect. *Chen et al., (2025),* proposed a vibration harvesting device for wolfberry. The vibration response of wolfberry fruit under different excitations was obtained by means of finite element transient dynamics analysis and ADAMS dynamics simulation method. *Zhao et al., (2025),* optimized a vibration harvester for lychee, processed the experimental data, and obtained the regression model by using Design-Expert software. They also structurally optimized the vibrator, which improved the harvesting efficiency of lychee and reduced the damage to the fruit. A substantial body of research has been conducted on the optimal harvesting of vibrations from forest fruits. This research has involved the construction of models that analyze the mechanics of vibrations in various forest fruits. These models have been tested in field trials to assess their reliability. However, research on the vibration characteristics of forest fruits, such as plums, in the complex environment of hilly and mountainous areas remains limited.

In this study, a plum vibration mechanics model was constructed for the planting characteristics of plum orchards in hilly, mountainous areas. The application of the model facilitated the identification of the primary factors influencing fruit shedding. ANSYS was utilized to execute simulation tests, thereby facilitating the analysis of the vibration response characteristics of the plum tree and the determination of the optimal vibration frequency interval. Consequently, field tests were conducted to ascertain the validity of the plum vibration picking parameters.

MATERIALS AND METHODS

Plum Harvester

The team developed a tracked plum harvester that was utilized for vibration harvesting. The equipment under consideration consists of five primary components: an excitation device, a clamping device, a traveling mechanism, a conveying device, and a control panel. The specific structural configuration is illustrated in Fig.1.

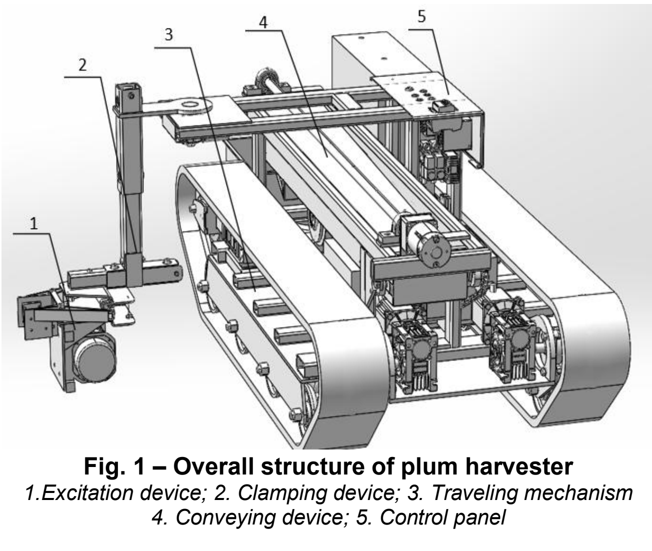

Fig. 1 – Overall structure of plum harvester
1.Excitation device; 2. Clamping device; 3. Traveling mechanism
4. Conveying device; 5. Control panel

The operational process is as follows: first, the main power supply and air compressor are activated. The tracked chassis is then positioned at the harvesting location using remote control. After manually deploying the collection cloth, the operator engages the telescopic mechanism to align the device with the tree trunk. Once aligned, the clamping cylinder actuates the clamping plate, securing the trunk in place.

Next, the vibration motor is activated to generate vibrations at the predetermined frequency, causing the plums to detach and fall onto the receiving cloth. After vibration harvesting is completed, the rolling mechanism retracts the receiving cloth. The detached fruits are transferred onto the conveyor belt and transported to the discharge port by the conveyor motor. Finally, the fruits fall into the collection bin, completing the harvesting cycle. Field testing of the plum harvesting machine was carried out in July 2024 in a plum orchard located in Mopanzhai, Liangping District, Chongqing Municipality. The field test setup is shown in Figure 2.

Fig. 2 – Field test of the plum harvester

Table 1

Main technical parameters of the plum harvester

Parameter	Numerical value	Parameter	Numerical value
Overall dimensions [mm]	2500×1200×800	Track width [mm]	180
Chassis weight [kg]	180	Maximum Movement Speed [m/s]	2.5
Minimum ground clearance [mm]	160	Vibration frequency range [Hz]	4-12

Modeling Vibration Mechanics

During vibration harvesting *(Wang et al., 2025; Yang et al., 2024)*, the plum fruit is primarily subjected to three forces: gravitational force G, the tensile force T exerted by the fruit stalk, and the inertial force F generated by external vibration. The inertial force can be decomposed into a normal inertial force F_n and a tangential inertial force F_τ. The normal inertial force acts in the direction opposite to the tensile resistance of the fruit stalk, while the tangential inertial force drives oscillatory motion of the fruit. When the combined effect of F_n and F_τ exceeds the bonding strength between the fruit and the stalk, detachment occurs and the fruit separates from the tree. The force interaction model is illustrated in Figure 3.

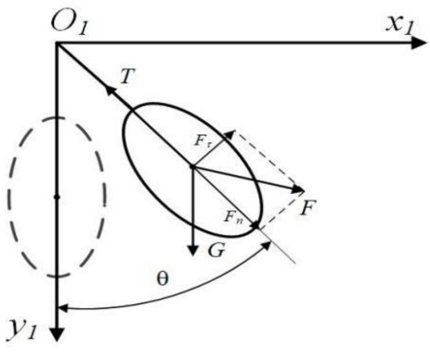

Fig. 3 – Schematic diagram of forces acting on a plum fruit

The tangential and normal inertial forces acting on the plum fruit are calculated using the following equations:

$$\bar{R}_n = ma_n - ma^2R = mR\left(\frac{d^2}{dt^2}\right)$$
$$\bar{z}_n = ma_z - m\bar{R}\frac{dw}{dt} = mR\left(\frac{d^2}{dt^2}\right) \tag{1}$$

where:

F_n is the normal inertial force acting on the plum fruit, [N]; F_τ is the tangential inertial force acting on the plum fruit, [N]; a_n is the normal acceleration of the fruit, [m/s^2], a_τ is the tangential acceleration of the fruit, [m/s^2]. R, is the diameter of the plum fruit, [mm], m, is the mass of the plum fruit, [kg].

During vibratory harvesting, the natural frequency ω_0 of the plum fruit is significantly lower than the externally applied vibration frequency ω_1. Therefore, the natural frequency term can be neglected, and the motion equations can be simplified as follows:

$$\frac{d\theta}{dt} = \frac{A_1\omega_1}{R}\cos\omega_1 t \tag{2}$$

$$\frac{d^2\theta}{dt^2} = -\frac{A_1\omega_1^2}{R}\sin\omega_1 t \tag{3}$$

The summation of (1), (2), and (3) yields the following result:

$$\begin{cases} F_x = m\frac{A_1^2 a_1^3}{R}\cos^2\omega_j t \\ F_z = -mA_1 a_1^2 \sin\omega_j t \end{cases} \tag{4}$$

The condition for plum detachment under vibratory harvesting is determined by the balance of forces acting on the fruit. Detachment occurs when the sum of the normal inertial force F_n and the normal component of gravity G_n exceeds the bonding (tensile) force T between the fruit and the stalk:

$$F_n + G_n > T \tag{5}$$

Based on the previously established relationships between the variables, it can be expressed that $A_1=k_1A$ and $\omega_1=k_2\omega$, where A_1 represents the vibration amplitude, [mm], and ω_1 denotes the vibration frequency, [Hz]. In this model, k_1 and k_2 are constant coefficients. Since the gravitational effect of the fruit is relatively small, the contribution of the gravitational component during the vibration process can be considered negligible. Therefore, its influence on the shedding condition is minimal. Under this assumption, the plum shedding criterion can be simplified to the following form:

$$\frac{mk_1^2k_2^2A^2\omega^2}{R}\cos^2 k_2\,\omega t > T \tag{6}$$

As demonstrated in the above equation, it can be observed that the parameters of mass, m, vibration amplitude, A, and vibration frequency, ω, significantly influence the magnitude of the inertial force generated during vibration harvesting. Since the mass of a single plum fruit is relatively small, its contribution to the inertial force is minimal and can be considered negligible in the analysis. In contrast, both vibration amplitude A and vibration frequency ω have a pronounced effect on the inertial force F, and thus directly determine the efficiency of plum detachment during vibration harvesting.

Finite Element Modeling

Constructing finite element models of fruit trees is one of the most effective methods to study vibrational harvesting of forest fruits *(Lin et al., 2022)*.

The finite element model of the plum tree was constructed in ANSYS, a simulation and analysis software, according to the data collected in Table 2.

The parameters of the simulation model are shown in Table 3.

Table 2

Growth parameters of plum tree

Trunk diameter [mm]	**Primary branch diameter** [mm]	**Secondary branch diameter** [mm]	**Overall height** [m]	**Crown diameter** [m]
56	32	16	3	3

Table 3

Simulation model parameters

Material density [kg/m^3]	**Elastic modulus** [Pa]	**Poisson's ratio**	**Number of model nodes**	**Number of units**
478	6.658E+09	0.3	401896	217934

The modal simulation of the plum tree model is executed in ANSYS by utilizing the first 20 orders of the modal cloud. As depicted in Figure 4, the plum tree model exhibits enhanced vibration effects in the first, second, and third orders.

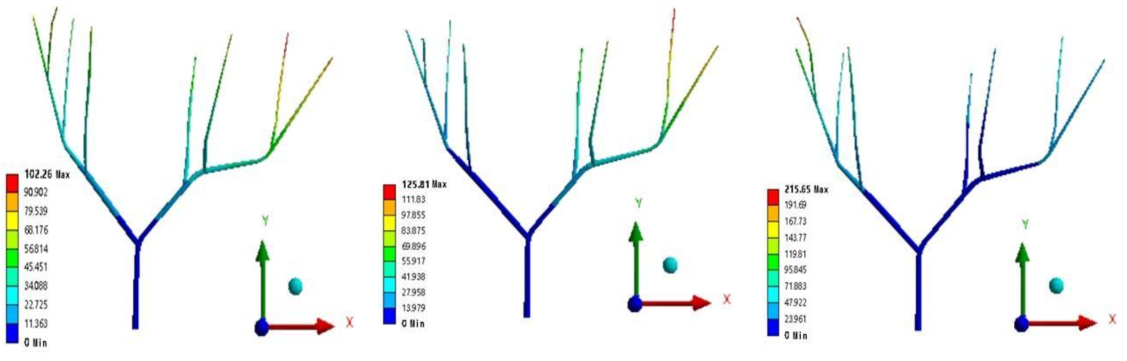

Fig. 4 (a) – 1st order modes | Fig. 4 (b) – 2nd order modes | Fig. 4 (c) – 3rd order modes

As shown in Figure 4, the 1st modal analysis indicates that most lateral branches exhibited vibration predominantly in the middle and upper regions, with the vibration direction aligned with the model's y-axis. The average vibration amplitude in this mode was 8.40 mm. In the 2nd order mode, the lateral branches oscillated mainly along the x-axis, with an average amplitude of 8.57 mm. The 3rd order modal cloud map shows a more uniformly distributed vibration response across the branches, with an average amplitude of 7.33 mm. Following the established analysis method, the mean value of each modal amplitude was increased by 10% of the standard deviation. Based on this adjustment, the effective vibration frequency range suitable for plum harvesting was determined to be 6.60–9.43 Hz.

Test Methods

The net harvesting rate is a metric that can be used to assess the effectiveness of a harvesting operation *(Xu et al., 2022).* This rate is calculated using the following formula:

$$P = \frac{w_1 - w_2}{w_1} \times 100\% \tag{7}$$

where:

P is the picking net rate of plums, [%]; w_1 is the total number of fruits on the plum tree. w_2 is the number of fruits on the plum tree after vibration harvesting.

The harvesting damage rate reflects the extent of fruit damage caused by the harvesting machine (*Jiao et al., 2024)*. The damage rate is calculated as follows:

$$S = \frac{x_2}{x_1} \times 100\% \tag{8}$$

where:

S is the damage rate of harvested plums, [%], x_1 is the total number of harvested plums, x_2 is the number of damaged plums (excluding fruits with pre-existing damage).

ANALYSIS OF RESULTS

Fifteen plum trees with similar growth characteristics were selected for the experiment. The trees were divided into five groups, with each group containing three trees. The applied vibration frequencies were 6 Hz, 7 Hz, 8 Hz, 9 Hz, and 10 Hz. During testing, the clamping position was standardized at 500 mm above the tree base. After harvesting, the net picking rate and loss rate of each group were recorded. The experimental results are presented in Table 4.

Table 4

Plum picking data

Vibration Frequency [Hz]	**Harvesting Rate** [%]	**Damage Rate** [%]
6	72.3	7.2
	74.6	6.8
	73.2	6.9

Vibration Frequency [Hz]	Harvesting Rate [%]	Damage Rate [%]
7	78.4	6.5
	80.5	6.7
	79.6	7.0
8	78.8	6.8
	80.2	6.5
	80.6	6.6
9	78.2	7.2
	76.4	6.8
	77.3	6.9
10	74.8	7.2
	73.3	7.4
	74.2	7.0

As shown in Figures 5 and 6, the net picking rate and loss rate of plum fruits under different vibration frequencies were plotted based on the data presented in Table 4.

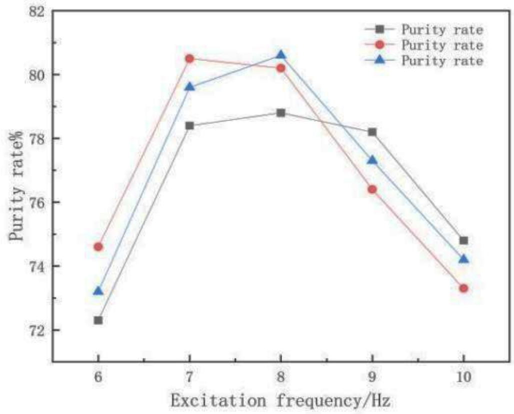

Fig. 5 – Net plum pick rate at different vibration frequencies

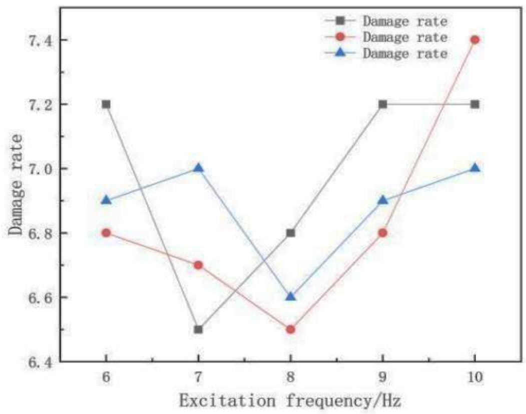

Fig. 6 – Plum harvest loss rate at different vibration frequencies

As shown in Figure 5, the net picking rate of plums increased initially and then decreased as vibration frequency rose from 6 Hz to 10 Hz. The lowest harvesting performance occurred at 6 Hz, after which the rate increased and reached its maximum at 7–8 Hz, with an average net picking rate of 79.7%. Beyond this range, the picking rate gradually decreased at frequencies of 9–10 Hz, indicating that the optimal operational vibration frequency for the harvester is 7–8 Hz.

Similarly, Figure 6 shows that the loss rate displayed an opposite trend. The loss rate decreased from 6 Hz to 8 Hz, where the minimum average loss rate of 6.63% was recorded. However, as vibration frequency increased from 9 Hz to 10 Hz, the loss rate increased sharply, demonstrating a clear positive correlation between excessive vibration frequency and fruit damage or loss.

These results are consistent with the findings of the simulation analysis, which predicted an effective vibration frequency range of 6.60–9.43 Hz for harvesting. The optimal field-tested vibration frequency of 7–8 Hz falls within this interval, demonstrating strong agreement between simulation and field performance and confirming the reliability of the vibration mechanics model.

CONCLUSIONS

(1) An electric tracked plum harvester was successfully developed to meet the operational requirements of plum orchards in hilly and mountainous regions. The machine demonstrates strong adaptability due to its adjustable vibration frequency, ensuring stable operation under varying orchard conditions. Field tests confirmed high picking efficiency with minimal fruit loss, validating the machine's practicality and reliability in complex terrain environments. The integrated vibration mechanism, clamping system, and tracked mobility platform provide an effective mechanized harvesting solution for plum production in hilly and mountainous regions.

(2) A dynamic vibration model of the plum fruit–pedicel system was established based on measured physical parameters, including fruit diameter, mass, and pedicel detachment strength. The analysis identified vibration amplitude (A) and vibration frequency (ω) as the key factors influencing fruit detachment. Modal simulation performed using ANSYS software yielded the first three modal vibration responses of the plum tree, resulting in a predicted optimal harvesting frequency range of 6.60–9.43 Hz. The close agreement between the simulation outcomes and the theoretical model confirms the model's validity and provides a theoretical basis for parameter optimization.

(3) Field trials were conducted using the harvest cleanliness rate and damage rate as evaluation indicators to assess the performance of the harvester across vibration frequencies from 6 Hz to 10 Hz. The highest average picking efficiency (79.7%) was achieved at 7–8 Hz, while the lowest damage rate (6.63%) occurred at 8 Hz. These results are consistent with the simulation-based predictions, reinforcing the recommended vibration frequency range and demonstrating the effectiveness of the developed harvesting model.

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REFERENCES

[1] Afsah-Hejri L., Homayouni T., Toudeshki A., Ehsani R., Ferguson L., Castro-Garcia S. (2022). Mechanical harvesting of selected temperate and tropical fruit and nut trees [J]. *Horticultural Reviews*, Vol. 49, pp. 171-242, Malaysia

[2] Castro-Garcia S., Aragon-Rodriguez F., Sola-Guirado R.R., Serrano Gil-Ribes. (2019). Vibration monitoring of the mechanical harvesting of citrus to improve fruit detachment efficiency [J]. *Sensors*, Vol. 19, pp. 1760, Spanish.

[3] Castro-Garcia S., Sola-Guirado R.R., Gil-Ribes J.A. (2018). Vibration analysis of the fruit detachment process in late-season 'Valencia' orange with canopy shaker technology [J]. *Biosystems Engineering,* Vol. 170, pp. 130-137, Spanish.

[4] Chen Qingyu, Zhang Yesia, Wei Naisuo, Fan Yunlei, Zhang Wei, Wang Zeyu, Cheng Jun, Cheng Yu. (2025). Simulation and test of vibration picking of wolfberry under different excitation modes (不同激振方式下枸杞振动采摘仿真与试验) [J]. *Transactions of the Chinese Society of Agricultural Engineering*, Vol. 41, pp. 32-42, Shanxi/China.

[5] Fan Zhiyuan, Tang Jingyu, Kou Xin, Wang Dong, Qu Zhengxing. (2025). Design and test of vibrating oil tea fruit harvesting actuator (振动式油茶果采收执行器设计与试验) [J]. *Journal of South China Agricultural University*, Vol. 46, pp. 265-277, Guangdong/China.

[6] Han Yuanshun, Xu Linyun, Zhou Jie, Yu Bin. (2022). Experimental study on vibration response characteristics and fruit drop of chestnut trees (板栗树振动响应特性与落果情况试验研究) [J]. *Acta Agriculturae Zhejiangensis*, Vol. 34, pp. 599-613, Zhenjiang/China.

[7] Jiao H., Luo J., Tang A. (2024). Design and Testing of the Double-Symmetric Eccentric Exciter for Fruit Tree Vibration Harvest [J]. *Agriculture*, Vol. 14, pp. 26-34, Chongqing/China.

[8] Jin Wenzhuang, Zhao Jinhui, Zhong Tengfei, Lliu Zhongxue, Yang Xuejun, Liu Lijin. (2023). Research progress on the theory and equipment of mechanical vibration picking of forest fruits (林果机械振动采摘理论与装备研究进展) [J]*. Transactions of the Chinese Society for Agricultural Machinery*, Vol*.* 54, pp. 144-160, Beijing/China.

[9] Junming H., Weixue H., Wei W., Hongjie Z., Zhu H., Zhi R. (2021). Fruit vibration harvesting technology and its damage [J]. *A review. INMATEH-Agricultural Engineering,* Vol. 63, pp. 16-25, Romania.

[10] Li Yalan., Tong Kai., and Lei Yu., Jiang Bin., Li Jieyuan., Tang Xuan., Li Dong. (2020). Present a review of the production process of plum fermented fruit wine in the following article (李子发酵果酒生产工艺研究综述) [J]. *China Brewing*, Vol*.* 39, pp. 21–24. Sichuan/China.

[11] Li Dong, Li Jingya, Lei Yu, Zhang Shiqi, Hao Wang, Jin Lei. (2022). Research Progress on Quality Characteristics of Plum and Its Deep Processing Products (李子的品质特性及其精深加工产品研究进展) [J]. *Northern Horticulture*. Vol*.* 19, pp. 128–135, Sichuan/China.

[12] Lin Huan, Xu Linyun, Xuan Yan, Zhou Jie, Liu Guanhua, Cheng Qin. (2020). Finite element-based multistage Y-shaped ginkgo tree modal analysis and test (基于有限元的多级 Y 型银杏树模态分析与试验) [J]. *Journal of Forestry Engineering*, Vol. 5, pp. 148-155, Jiangsu/China.

[13] Linyun Xu, Guanhua Liu, Jie Zhou, Zhou Hongping. (2020). Construction of a vibration model of fruited and leafy fruit trees for vibratory harvesting (用于振动采收的有果有叶果树振动模型构建) [J]. *Transactions of the Chinese Society of Agricultural Engineering*, Vol. 36, pp. 1-12, Hebei/China.

[14] Liu C.Y., Feng C., Peng W Z., Hao J., He Y. (2020). Chromosome-level draft genome of a diploid plum (*Prunus salicina*) [J]. *GigaScience,* Vol. 9, pp. 12, Guangzhou/China.

[15] Sun W.D., Wu C.M., Cao L., Xu Y. (2023). Research On Vibration Response Characteristics and Separation Deformation Law of Fruit-Branch System [J]. *AIP Advances,* Vol. 13, pp. 1-10, Shandong/China.

[16] Wang Pan, He Tingting, Wang Chunxia, Ying Qing, Yi Wenyu. (2025). Current status of mechanized harvesting technology for specialty forest fruits in China (我国特色林果机械化采收技术现状) [J]. *Journal of Chinese Agricultural Mechanization*, Vol. 46, pp. 48-54, Sichuan/China.

[17] Yang Xin, Jiang Zunhao, Li Jianping, Xie Jinyan, Gu Haoyuan, Bian YongLiang. (2024). Simulation optimization and test of vibration parameters of swinging branch type processing apple picking (摇枝式加工型苹果采摘振动参数仿真优化与试验) [J]. *Transactions of the Chinese Society for Agricultural Machinery*, Vol. 55, pp. 28-39, Jiangsu/China.

[18] Zhao Ziyan, Wang Huizu, Wang Yanfei, Li Jun, Xi Haolan. (2025). Structural optimization of litchi shaker based on vibration separation characteristics (基于振动分离特性的荔枝振动器结构优化) [J]. *Journal of Agricultural Mechanization Research*, Vol. 47, pp. 9-17, Guangdong/China.

[19] Zheng Zhouzhou, Hu Yaohua, Zhao Pengfei, Dong Jianxing, Huang Yuxiang. (2025). Optimization and test of parameters of vibration harvesting device for picking ripe and keeping green jujube in gripping and shaking type facility (抓摇式设施冬枣摘熟留青振动采收装置参数优化与试验) [J]. *Transactions of the Chinese Society for Agricultural Machinery*, Vol. 56, pp. 245-253, Shanxi/China.

[20] Zhou Yan, Chen Ya, Liao Maowen, Li Ke, Li HuaJia, Liu Jia, Liu Dayu, Zhu Yongqing. (2024). An evaluation of the quality characteristics of different plum varieties and their suitability for winemaking purposes (不同品种李子品质特性及其酿酒适宜性评价) [J]. *Food Industry Science and Technology,* Vol. 45, pp. 272-282, Sichuan/China.

[21] Zhuo P., Li Y., Wang B., Sun S., Cui Y. (2022). Analysis and experimental study on vibration response characteristics of mechanical harvesting of jujube [J]. *Computers and Electronics in Agriculture,* Vol.203, pp. 107446, Chongqing/China