Agriculture and Food Sciences Research
Vol. 10, No. 1, 1-7, 2023
ISSN(E) 2411-6653/ ISSN(P) 2518-0193
DOI: 10.20448/aesr.v10i1.4839

Optimal design of blade parameters for fracturing tea-picking machine

Zehui Jiang[1]
Yongguang Hu[2]✉
Wenchao Wu[3]

(✉ *Corresponding Author*)

[1,2,3]*Key Laboratory of Modern Agricultural Equipment and Technology, Ministry of Education Jiangsu Province, Zhenjiang, Jiangsu University, China.*
[1]*Email: 2222016029@stmail.ujs.edu.cn*
[2]*Email: deerhu@ujs.edu.cn*
[3]*Email: 2111716005@stmail.ujs.edu.cn*

Abstract

The blade is one of the most critical components in the fracturing tea-picking machine, and this study is conducted to optimize the blade's working parameters. In this study, the effects of blade width, blade thickness, and cutting angle on the maximum fracturing force of tea stems were analyzed using the L_9 (3^4) standard orthogonal table, with the maximum fracturing force used as the evaluation index. The results indicate that the main factors affecting the maximum fracturing force (*MFF*) of tea stems are cutting angle (*CA*), blade width (*BW*), and blade thickness (*BT*) in that order. Furthermore, microscopic observation of the fracture surface revealed that compared with the thickness of the other two blades, the thickness of 0 mm caused the cross-section uneven and had lots of burrs, correspondingly resulting in the section's oxidation and the deterioration of tea leaf quality. Therefore, the optimal combination of design parameters was a cutting angle of 90°, a blade width of 2.0 mm, and a blade thickness of 0.5 mm. The findings of this study can provide reference for blade design to reduce the fracturing force of tea-picking machines, lower the working power consumption, and improve the quality of freshly plucked tea leaves.

Keywords: Blade, Famous premium tea, Fracturing force, Optimal design, Orthogonal experiment, Tea-picking machines.

Citation | Jiang, Z., Hu, Y., & Wu, W. (2023). Optimal design of blade parameters for fracturing tea-picking machine. *Agriculture and Food Sciences Research*, *10*(1), 1–7. 10.20448/aesr.v10i1.4839
History:
Received: 13 March 2023
Revised: 26 April 2023
Accepted: 3 July 2023
Published: 18 July 2023

Publisher: Asian Online Journal Publishing Group

Funding: This research is supported by the China and Jiangsu Postdoctoral Science Foundation (Grant numbers: 2022M711396 and 2021K614C).
Institutional Review Board Statement: The Ethical Committee of the Jiangsu University, China has granted approval for this study (Ref. No. JSDX20230717001).
Authors' Contributions: All authors contributed equally to the conception and design of the study. All authors have read and agreed to the published version of the manuscript.
Competing Interests: The authors declare that they have no conflict of interest.

Contents

Contribution of this paper to the literature

This study determined the optimal combination of blade parameters for a breaking-type tea harvester using the orthogonal experiment method. Currently, there is no research available on the optimization of blade parameters for this type of tea harvester.

1. Introduction

China is the largest tea producer in the world, with a tea plantation area of 3307.84 thousand hectares in 2021 [1, 2]. The shortage of tea pickers and high labor cost have become common problems for tea production [3]. In view of the non-uniform planting specifications of tea gardens and the complex terrain of tea-growing areas in China, the development of portable tea-picking equipment is of practical significance [4, 5].

To improve the efficiency and quality of tea picking, people have been constantly exploring and innovating [6]. The hand-held tea harvester is a machine that has emerged under this background [7]. Compared with traditional manual picking, the hand-held tea harvester can quickly pick tea leaves, greatly improving the efficiency and yield of tea picking [8-10]. The fracturing tea-picking machine working principle is to use a rotating leaf-beating rod and a blade to cut off the tender shoots of tea trees, and then collect them through a collection device [11]. Compared with the reciprocating cutting tea picking machine, the hand-held tea harvester has adaptability to be adjusted according to different types of tea trees and crown structures [12] to ensure the quality and efficiency of picking.

Pan designed a tea stem shear test device using an electronic universal testing machine and a fixed support to obtain the force-deformation curve when the stem is cut by the blade [13]. Cao specifically designed a mini-test machine that can adjust the entry angle of the tea harvester blade to measure the maximum shear force when the stem is cut [14].

The orthogonal experiment is to be conducted to analyze the effects of cutting angle, blade width, and blade thickness on the maximum fracturing force of tea stems. Their impact level is evaluated through data analysis, and the microscopic structure of the section cut by the blades of different parameters is observed. This study aims to explore the related content of the design experiment of blade parameters for the hand-held tea harvester, providing useful reference and guidance for its research and application. Figure 1 shows the fracturing tea-picking machine. Figure 2 shows the blade of fracture tea-picking machine.

Figure 1. Fracturing tea-picking machine.

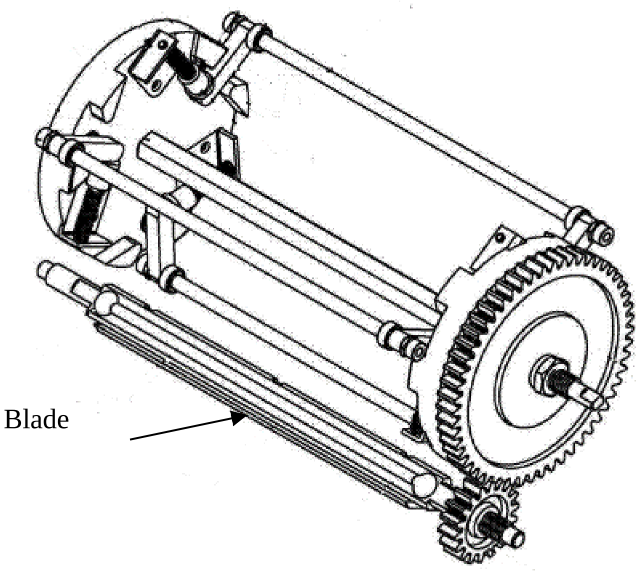

Figure 2. Blade of fracture tea-picking machine.

2. Materials and Methods

2.1 Materials

The selected experiment site is Maichun Tea Farm located in Danyang, Jiangsu Province, China (32°02'26" N, 119°67'44" E), which belongs to the hilly tea region of the middle and lower reaches of the Yangtze River. The tea variety planted is Mao Green, and the planting direction is north-south with a row spacing of 1.5 m and a crown width of 1.2 m. The tea garden was moderately pruned on August 10, 2022, and the experiment was conducted on October 12, 2022.Five square test areas with equal side lengths of 1.0 m were randomly selected, and 45 stems of similar growth stage and stem diameter were randomly selected in each area for leaf removal and subsequent testing. The stems are placed on the fixed holder by fixture.

The maximum fracturing force was measured using a tensiometer (Edinburgh, China, accuracy 0.01 N). The microscopic structure of the stem cross-section was observed using a super depth-of-field three-dimensional microscope (Keyence, Japan, VHX-900F). The position of the tensile tester was adjusted using a lifting platform, and the blade approached the tested stems by a screw push rod.

Three types of blades with different thicknesses were fixed onto the tensile tester using a clamp, and the stem position was measured using a ruler and fixed using a fixture. The experimental instrument is shown in Figure 3.

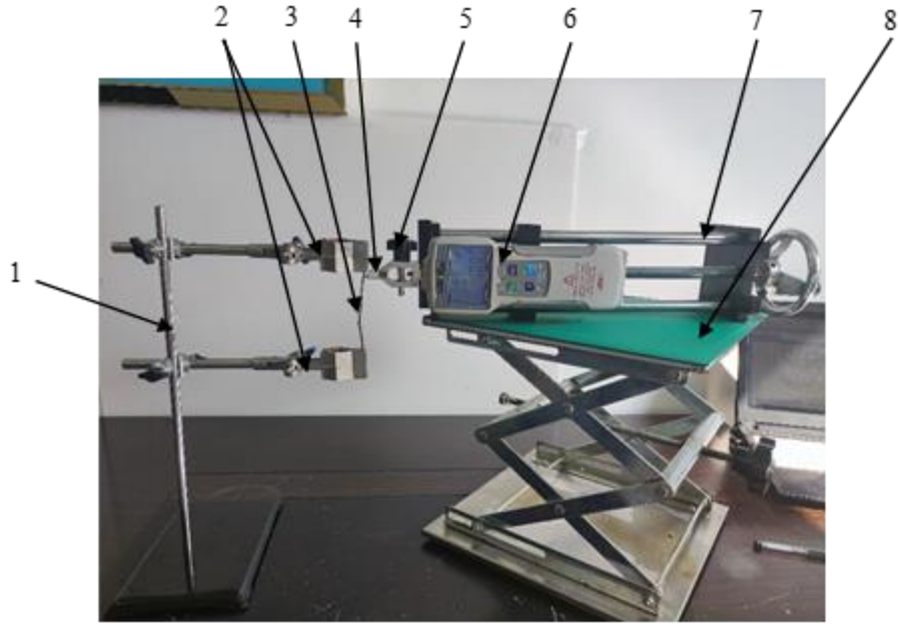

Figure 3. Experiment materials.

Note: 1. Fixed holder 2. Fixture 3. Stem 4. Blade 5. Clamp 6. Tensiometer 7. Screw push rod 8. Lifting platform.

2.2. Orthogonal Experimental Design

By assessing whether the design parameters of the blade affecting the maximum cutting force can be controlled quantitatively, the degree of control difficulty, and the control method selected the main influencing factors are: blade width (*A*), blade thickness (*B*), and cutting angle (*C*). To consider the size of the prototype, blade width(*BW*) range of 2.0-4.0mm, blade thickness(*BT*) of 0-1.0mm, and cutting angle(*CA*) of 90-135 °.

Orthogonal tables are statistical tools used for experimental design and data analysis. Common orthogonal tables include L_4 (2^3), L_8 (8^{27}), L_{16} (2^{15}), L_9 (3^4), etc. Take L_9 (3^4) and so on. In these tables, "L" represents the orthogonal table, while the numbers represent specific parameters of the table.

For instance, L9 (3^4) means there are 9 horizontal rows, which corresponds to 9 experiments to be conducted. There are 3 factors, with each factor having 3 levels, and the maximum number of factors allowed to be arranged is 4. The degrees of freedom for each factor are 2. Based on the principle that the degrees of freedom of the orthogonal table should be greater than or equal to the sum of the degrees of freedom of each factor and the degrees of freedom of interaction, as well as the principle of choosing the smallest number of orthogonal tables, L_9 (3^4) was selected for the experiment [15].

It can be observed that orthogonal tables have two characteristics: (1) In each column, each level of each factor appears an equal number of times in the total number of experiments. (2) An ordered series in which different levels of any two factor columns appear in pairs, with each pair appearing an equal number of times. Therefore, the distribution of each factor level combination in the orthogonal table is balanced dispersed, and neatly comparable among all level combinations. The assignment of the interactions in the orthogonal table header design needs to be done according to the interaction table, which is mentioned in detail in the paper [15]. The level table of experimental factors is shown in Table 1. The experiment was started by replacing each factor level code with a specific level setting, and the experimental arrangement and sequence were shown in Table 2, and the maximum fracturing force was filled in the result column in Table 2 at the end of the experiment.

Table 1. Table of factor levels.

	A	*B*	*C*
Level	**BW/mm**	**BW/mm**	**CA/°**
1	2	0 (Sharp edge)	90
2	3	0.5	120
3	4	1	135

Table 2. Table of orthogonal tests.

Test number	*A*	*B*	*C*	*D*	*Y*
1	1	1	1	1	1.79
2	1	2	2	2	3.32
3	1	3	3	3	4.34
4	2	1	2	3	3.23
5	2	2	3	1	4.31
6	2	3	1	2	2.54
7	3	1	3	2	4.35
8	3	2	1	3	2.83
9	3	3	2	1	4.48

2.3. Fracturing Experiment

Stem fracturing experiments were performed on a liftable platform and tensiometer. A clamp is used on the tensiometer to fix the blade for fracturing. The measured internode is fractured on the stem, the specimen is placed on the fixed holder, the blade position and the stem inclination are adjusted, the stem is slowly fractured and the maximum fracturing force is read on the tensiometer. The blade width is the distance between the blade and the fixture fixing the stem, the blade thickness is the thickness of the blade, and the cutting angle is the angle formed between the blade cutting into the stem and the stem in the direction of the stem. Each experiment was repeated five times, and the average maximum fracturing force was recorded in the result column of Table 2. Figures 4-6 show the different cutting angle.

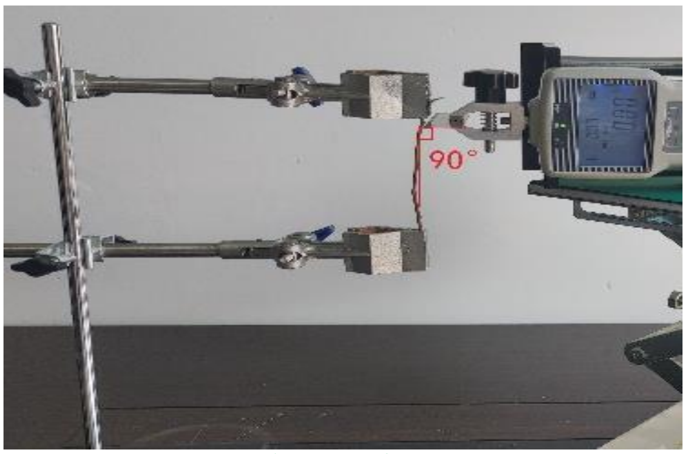

Figure 4. 90°CA.

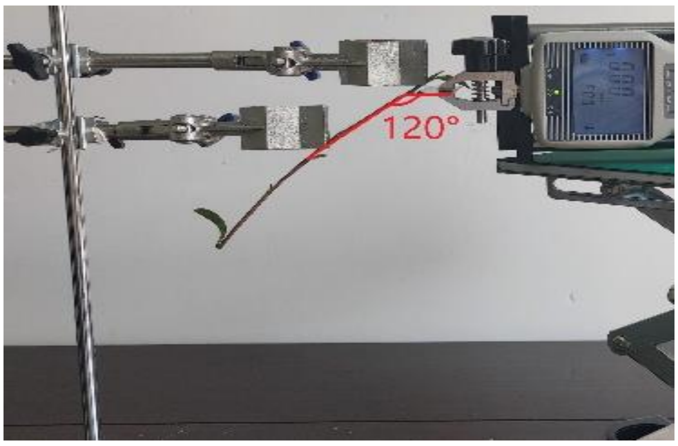

Figure 5. 120° CA.

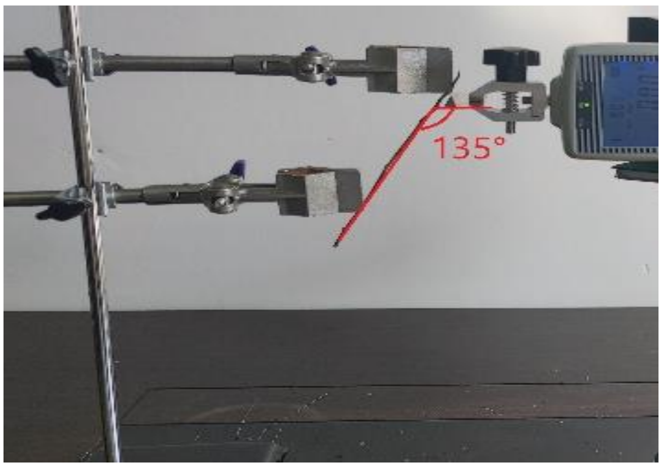

Figure 6. 135° CA.

2.4. Stem Section Observation

Cross-sectional sections of the stems were cut by the conventional sectioning method, and the cross-sectional features were compared under different blade fractures using an ultra-deep field 3D microscope.

3. Results and Discussion

3.1. Orthogonal Test Results and Analysis

For the processing and analysis of experimental results, there are usually two methods. One is the visual analysis method, also called range analysis method; the other is the analysis of variance method. The following two methods are used to compare and analyze the results of orthogonal experiments.

3.1.1. Range Analysis

The analysis steps of range analysis method are as follows: first, the experimental results of level one for each factor of each experiment are calculated, and the mean of *k1*. then the mean of level two for each factor of each experiment is calculated and the mean of *k2*, then the mean of level three for each factor of each experiment is calculated, and the mean of *k3*. then the range *R* of the mean of the three levels and *k1*, *k2* and *k3* is found, and finally, *R* is sorted from largest to smallest to determine the degree of influence of the factors. The results of range analysis are shown in Table 3. The principle of range analysis is the larger range, the more important the influence of the corresponding factor. In addition, the optimal level of each factor can be determined according to the average size of the results corresponding to the level of each factor. If the indicator is expected to be larger and better, the larger the average level is taken; if the indicator is expected to be smaller and better, the smaller the average level is taken. It can be seen that the required indicator in this test is the smaller the better, so the preliminary optimal level derived by the range analysis is *A*1*B*1*C*1.

Table 3. Table of range analysis.

Test number	*A*	*B*	*C*	*D*	*Y*
1	1	1	1	1	1.79
2	1	2	2	2	3.32
3	1	3	3	3	4.34
4	2	1	2	3	3.23
5	2	2	3	1	4.31
6	2	3	1	2	2.54
7	3	1	3	2	4.35
8	3	2	1	3	2.83
9	3	3	2	1	4.48
K1	9.45	9.37	7.16	10.58	/
K2	10.08	10.46	11.03	10.21	/
K3	11.66	11.36	13	10.4	/
k1	3.15	3.12	2.39	3.53	/
k2	3.36	3.49	3.68	3.40	/
k3	3.89	3.79	4.33	3.47	*A1B1C1*
Range *R*	0.74	0.66	1.95	0.12	*C>A>B*

The orthogonal tests were performed according to the designed L9 (3^4) with a total of 9 test combinations, and the obtained test results are shown in Table 3. In order to accurately estimate the importance of the influence of the three design parameters of the blade on the maximum fracturing force, especially considering the interaction between the factors, it is necessary to conduct ANOVA on the orthogonal test results. The ANOVA results are shown in Table 2. The variances of *A*, *B* and *C* are less than 0.05, so *A*, *B* and *C* all have a significant influence on the test results, and the main order of the factors is: *C>A>B*.

3.1.2. Analysis of Variance

ANOVA is used to distinguish whether the differences in the investigated factors corresponding to experimental results due to different levels are caused by level changes or by experimental errors, in order to further test which factors have an effect on the results and which don't and to distinguish which factors are major and which are minor. The analysis steps of ANOVA are as follows: first, the degrees of freedom of each factor, the degrees of freedom of interaction, the degrees of freedom of error, and the total degrees of freedom are listed. Then the sum of squares of deviations corresponding to each of these factors is calculated as Equation 1.

$$SS_T = \sum_{i=1}^{n}(x_i - \bar{x})^2. \tag{1}$$

Then the mean sum of squares of deviations corresponding to each factor is found by dividing the sum of squares of deviations by the degrees of freedom (*DF*). Equation 2 yields the mean sum of squares of deviations corresponding to A factor.

$$S_A^2 = \frac{SS_A}{f_A}. \tag{2}$$

Then the *F*-value corresponding to each item is found by dividing the average deviation sum of squares by the average deviation sum of squares of errors. Equation 3 yields the F-value of A factor.

$$F_A = \frac{S_A^2}{S_e^2}. \tag{3}$$

The *P*-value is calculated using Excel's F.DIST.RT function. If the factor's *P*-value is ≤ α, there is (1-α) certainty that the factor has a significant impact. Commonly used values of α are α=0.01, α=0.05, and α=0.10. When *PA*≤0.01, it indicates an extremely significant impact, noted as "**"; when 0.01≤*PA*≤0.05, it indicates a significant impact, noted as "*"; and when *PA*≥0.05, there is no significant impact. Table 4 shows the ANOVA results for the orthogonal experiments. Factor *C* had an extremely significant impact, while factors *A* and B had a significant impact, with the main order of factors being *C>A>B*. This is consistent with the results of the range analysis.

Table 4. Analysis of variance (ANOVA) table.

Source of variance	SS_T	DF	S^2	F	P	Significance
A	0.864	2	0.432	37.865	0.026	*
B	0.662	2	0.331	29.008	0.033	*
C	5.885	2	2.942	257.855	0.004	**
D (Difference)	0.023	2	0.011	1.000	1.000	/

3.2. Analysis of Microscopic Features of the Cross-Section

The difference in stem fracture between the different groups was in the fracture caused by the blade with a sharp edge and the blade without a sharp edge. The blade with a sharp edge fracture is shown in Figure 7, the 0.5 mm thick blade fracture is shown in Figure 8, and the 1 mm thick blade fracture is shown in Figure 9. Under the blade with a sharp edge fracturing picking, the blade squeezed the stem and formed an oval incision. The fracture interface was uneven and showed a large number of burrs. The stem tissue was torn at the fracture point and the fractured interior was also damaged by the squeezing action, resulting in the cavity observed in the wood pith. After fracturing picking, the fractured portion and the damaged internal tissues are extensively oxidized. The oxidation produces substances that darken the tea leaves [9]. Fracturing picking with a blade with a sharp edge disrupts the tissue within the stem, and this rupture produces excessive tissue fluid, which further increases the rate of oxidation. In contrast, fracturing with an unopened blade produces a flat, burr-free fracture. The oxidized area in the incisions of hand-picked shoots was significantly smaller than that of the blade fracturing picked ones. After the incisions were oxidized by ambient air, the xylem and pith in the stem tissue took on a brownish-red color, which could affect the color and flavor of the finished tea [16].

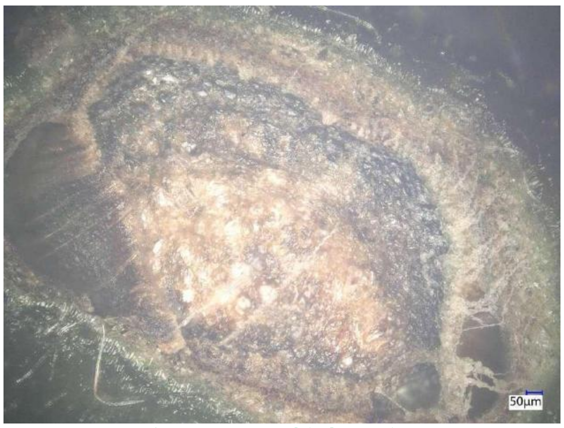

Figure 7. 0mm blade section.

Figure 8. 0.5 mm blade section.

Figure 9. 1mm blade section.

4. Conclusion

(1) Through the orthogonal test of three design parameters of the blade, the results show that the main and secondary factors affecting the maximum fracturing force in the order of cutting angle, blade width, and blade thickness. Among them, the cutting angle on the maximum fracturing force is very significant, the blade width, and blade thickness on the maximum fracturing force is significant, the preliminary optimal combination of design parameters level for the cutting angle: 90 °, blade width: 2.0 mm, blade thickness: 0 mm.

(2) Analysis of the stem sections fractured by different blades revealed that the fracture interface formed by the 0mm blade was uneven relative to the other blades and showed a large number of burrs. The stem tissue was torn at the fracture point and the fractured interior was also damaged by the crushing action, with extensive oxidation of the fractured portion and the damaged tissue inside. The substance produced by oxidation will darken the tea leaves and affect the color and taste of the finished tea leaves. Therefore, a blade thickness of 0.5 mm should ultimately be selected. The optimal structural parameter level combination is the optimal structural parameter level combination of cutting angle: 90°, blade width: 2.0 mm, and blade thickness: 0.5 mm.

References

[1] Statistical Bureau of the People's Republic of China, *China statistical yearbook*. Beijing: China Statistics Press, 2022.

[2] R. Pan, X. Q. Zhao, and J. B. Du, "A brief analysis on tea import and export trade in China during 2021," *China Tea*, vol. 44, no. 3, pp. 25-30, 2022.

[3] S. D. Zhou and X. L. Wu, "Analysis on the characteristics and influence of the change of tea production distribution in China," *Tea Newsletter*, vol. 47, no. 3, pp. 496-501, 2020.

[4] X. Peng, "Reflections on the standardized demonstration construction of tea plantation mechanization production," *Hubei Agricultural Mechanization*, vol. 2, pp. 29-31, 2011.

[5] X. Peng, "Thinking about the "tea garden mechanization production technology regulations"," *Agricultural Machinery Science and Technology Promotion*, vol. 6, pp. 41-41, 2011.

[6] D. H. Liu, X. Xiao, and L. Q. Yin, "Research on adaptation of machine picking in Yunnan tea garden," *Shandong Agricultural Science*, vol. 47, no. 4, pp. 49-51, 2015. https://doi.org/10.14083/j.issn.1001-4942.2015.04.013

[7] H. B. Yuan, C. Y. Lu, and Z. F. Mao, "Preliminary study on the grading effect of new fresh leaf sieving machine for famous green tea," *China Tea*, vol. 33, no. 8, pp. 19-21, 2011.

[8] F. X. Cao, Y. Yan, and D. M. Wang, "Comparison of fresh leaves plucked by three reciprocating cutting tea plucking machines," *Tea*, vol. 48, no. 4, pp. 209-213, 2022.

[9] H. J. Hu, "Main factors of affecting mechanization application in tea plucking in Guizhou," *Guizhou Agricultural Science*, vol. 37, no. 7, pp. 191-193, 2009.

[10] W. Y. Yi, F. P. Cheng, and Y. Q. Qiu, "Research status and development trend of single tea-picking machine," *Chinese Journal of Agricultural Machinery Chemistry*, vol. 41, no. 11, pp. 33-38, 2020. https://doi.org/10.13733/j.jcam.issn.2095-5553.2020.11.006

[11] D. L. Wang, "A kind of folding tea picking machine, CN111296066A," Retrieved: https://pss-system.cponline.cnipa.gov.cn/Disclaimer, 2020.

[12] Y. F. Xue and W. C. Cao, "Mechanical properties of tea young shoot under binding," *Journal of Zhejiang Agricultural University*, vol. 20, no. 1, pp. 43-48, 1994.

[13] Z. G. Pan, "Study on the relation of the tenderness and shearing properties of tea shoot," *Tea Science*, vol. 6, pp. 425-428, 2008.

[14] W. C. Cao, "Study on shearing properties of tea shoot," *Journal of Zhejiang University (Agriculture and Life Science Edition)*, vol. 21, no. 1, pp. 11-16, 1995.

[15] G. Y. Zhou, B. L. Liu, and Y. Y. Han, "Minitab complete multiple comparisons and optimal level combination determination for orthogonal experiments with interactions," *Education Teaching Forum*, vol. 10, pp. 271-272, 2018.

[16] K. Liu, *Research on the enzymological characteristics of polyphenol oxidase from tea and the effect of infrared on its activity and conformation.* Wuxi, China: Jiangnan University, 2013.