Design and Cutting Test Analysis of Chinese Cabbage Harvester

Liwen Cao¹*, Shuaitong Miao¹ and Lizhi Gu²

¹School of Mechanical and Electrical Engineering, Heilongjiang University, Harbin, Heilongjiang Province, China.
²School of Mechanical and Electrical Engineering, Quanzhou University of Information Engineering, Quanzhou, Fujian Province, China.
*Email: caoliwen68@163.com

Abstract. Chinese cabbage is a major vegetable widely planted in most areas of my country. With the increase in market demand and the growth of Chinese cabbage planting area, traditional manual harvesting can no longer meet the development needs of the times, and agricultural mechanization has become a trend. In view of the actual production situation of Chinese cabbage in China, the important parts of the Chinese cabbage harvester are designed based on the TRIZ theory, and the working principle of the Chinese cabbage harvester is clarified. The designed Chinese cabbage harvester includes the functions of pulling, transporting and cutting roots, and completes most of the work required for manual harvesting. Carrying out cutting experiments to explore the best cutting parameters in the root cutting process is conducive to the subsequent design and research of the Chinese cabbage harvester.

1. Introduction

At present, various types of Chinese cabbage harvesters have been introduced in China, and the side-hung single-ridge harvester is the main research direction of domestic agricultural machinery research institutes and universities [1-3]. The side-hanging trial single-ridge harvester can only harvest along one side of the vegetable field. After harvesting from one end of the vegetable field to the other, you need to return to the starting place to harvest again, or turn around to harvest along the other side of the vegetable field. The harvesting efficiency is Low. It is urgent to realize the harvester under the existing Chinese cabbage planting conditions in a real sense to improve the efficiency of automatic cabbage harvesting [4].

So far, there have been few researches on Chinese cabbage harvesters at home and abroad. Among them, Yao Huiling from China Agricultural University determined the mechanical properties of cabbage rhizomes for the first time and gave the best cutting tool style in the Chinese cabbage rhizome shear test [5]. The parameter design of the disc cutter, but the related principle prototype has not been manufactured. In terms of cutting test, there are many reports on cabbage rhizome cutting test. Among them, Li Xiaoqiang, Du Dongdong and others studied the influence of cutting root position, cutting speed, cutting position, cutting tool style, and cutting method on the cutting force of cabbage rhizome [6-7]. The above test stays on the theoretical research of cutting force carried out on the universal testing machine, and lacks the research on the overall effect of the root cutting device. Meng Zhiwei designed a complete cabbage root cutting device and conducted a root cutting experiment on it, but he used a disc cutter by default, and did not discuss the influence of the cutter on the cutting effect [8].

At present, the research of Chinese cabbage harvester in China is still in the preliminary stage of...
research and development, and there is a lack of theoretical research on key parts.

2. Chinese Cabbage Harvester Design

2.1. Design of Extraction Device Based on TRIZ Theory

According to the TRIZ theory, the "object-field" model of the cabbage extraction process is constructed. S1 is the growing cabbage, S2 is the extracted Chinese cabbage, and F1 is the combined force of the adhesion of the Chinese cabbage rhizome to the soil and the Chinese cabbage's own gravity. During the transition from S1 to S2, the "field" between the two is F1, and the key to successfully extracting Chinese cabbage is to destroy the adhesion of the cabbage rhizome to the soil and the resultant force F1 of the cabbage's own gravity, so the extraction device S3 is introduced. The resultant force F1 is destroyed by applying the pulling force F2 to the growing Chinese cabbage S1. The "object-field" model diagram of the extraction process is shown in figure 1.

![Figure 1. The "object-field" model diagram of the extraction process.](image1)

Figure 1. The "object-field" model diagram of the extraction process.

Through the above analysis, a schematic diagram of the extraction method is designed as shown in figure 2. The basic extraction process is to advance forward through the extraction shovel with a certain inclination angle. The support force of the extraction shovel to the cabbage and the adhesion force of the cabbage rhizome and soil form a vertical upward force, and the cabbage is extracted by this combined force.

2.2. Design of Root Cutting Device Based on TRIZ Theory

According to the TRIZ theory, a "thing-field" model of the Chinese cabbage root cutting process is constructed. S2 is the Chinese cabbage after plucking, S4 is the Chinese cabbage after cutting the roots, and F3 is the cutting resistance caused by the rhizome fiber during the root cutting process. During the transition from S2 to S4, the "field" between the two is F3, and the key to perfect root cutting is to cut the Chinese cabbage rhizome fiber to destroy the cutting resistance F3, so the root cutting device S5 is introduced. Provides cutting force F4 to destroy Chinese cabbage fibers. In this process, the cutting force should be fast enough to destroy the Chinese cabbage rhizome fibers while ensuring that the cutting surface is flat and the cutting position is accurate. The "object-field" model diagram of the Chinese cabbage root cutting process is shown in figure 3.

![Figure 3. The "object-field" model diagram of the root cutting process of Chinese cabbage.](image3)
Through the above analysis, the cutting device must ensure sufficient cutting speed while ensuring sufficient cutting force. Therefore, a disc root cutting device is designed. The device can cut the Chinese cabbage rhizome fiber while maintaining the continuity of the cutting process and ensure the flatness of the cutting surface.

2.3. Design of Transmission Device Based on TRIZ Theory
According to the TRIZ theory, a "object-field" model of the Chinese cabbage cutting process was constructed. S2 is the Chinese cabbage that has been plucked, and S6 is the Chinese cabbage that has been harvested. During the conveying process, the clamping force F5 for fixing the Chinese cabbage and the pushing force F6 for conveying the cabbage backward are required to act on the cabbage together to complete the backward conveying of the cabbage. The "object-field" model diagram of the Chinese cabbage transmission process is shown in figure 4.

![Figure 4](image)

**Figure 4.** The "object-field" model diagram of the cabbage transmission process.

1 Leather belt; 2 Chinese cabbage

![Figure 5](image)

**Figure 5.** Schematic diagram of Chinese cabbage clamping.

Through the above analysis, the belt is selected as the clamping part of the clamping transmission device, and the design of the upper and lower double belts on both sides is adopted. The Chinese cabbage is clamped tightly under the action of friction with the belt, providing a clamping force of F5. At the same time, the belt is driven by the pulley to move backwards, and the belt gives the Chinese cabbage a backward force F6 to transport the Chinese cabbage backwards. The clamping diagram of Chinese cabbage is shown in figure 5. This design adopts a double belt design, so that the center of gravity of the Chinese cabbage is between the upper and lower belts.

2.4. The Frame Structure Design of Chinese Cabbage Harvester
The design of this research is a front-mounted Chinese cabbage harvester, which is different from the side hanging style and has different requirements for its structure. The whole rack adopts a frame type, and the Chinese cabbage is transported from the middle position of the frame. In order to adjust the spacing between the two sides of the rack to adapt to the reliable clamping of different varieties and sizes of cabbage, the whole is a split structure, consisting of a split rack on the left and right sides and a middle connecting pipe, and the split rack and the connecting pipe pass through. The bolts are tightened, and the frame is shown in figure 6.

![Figure 6](image)

**Figure 6.** Rack structure diagram.

1 Front swing head; 2 V-shaped with adjusting bracket; 3 V-shaped with adjusting bolt; 4 Bracket connecting pipe; 5 Rear swing head; 6 Two-sided split frame
2.5. The Overall Structure and Working Principle of the Cabbage Harvester

2.5.1. The overall structure of the Chinese Cabbage Harvester. The overall structure is shown in figure 7. In terms of power, the cut-root DC motor is powered by a battery, which can provide sufficient torque and high speed; the wheel-driven hydraulic motor is provided by the tractor’s own hydraulic system, and the hydraulic motor can be used to drive the running parts. The stepless adjustment of the speed and the circuit design of various hydraulic valves can realize the speed stability of the operating parts driven by the hydraulic motor under different operating conditions of the engine.

![Figure 7. Chinese cabbage harvester.](image)

2.5.2. The Working Principle of the CHINESE CABBAGE HARVESTER. During the working process, the Chinese cabbage harvester moves forward and uses the pulling shovel to pull up the Chinese cabbage and guide it. With the inertia of the Chinese cabbage and the pushing force of the undrawn Chinese cabbage on the pulled Chinese cabbage, the pulled Chinese cabbage is routed. Pull the shovel into the feed inlet of the conveyor. The clamping belt of the transmission device clamps the Chinese cabbage and transports it backwards. When the Chinese cabbage is transported to the position of the disc cutter, the disc cutter will cut off the roots of the Chinese cabbage, and then continue to transport it backwards. Complete the harvest. The entire harvesting process of extraction, root cutting and transmission is fully mechanized, which greatly improves harvesting efficiency and saves labor costs.

3. Cutting Test and Analysis of Chinese Cabbage Harvester

3.1. Test Equipment and Materials

3.1.1. Test Equipment. The test equipment includes a Chinese cabbage harvester prototype, a wheel speed sensor, a DC power supply, a speed sensor and a hydraulic test bench. In the working process, the hydraulic motor is driven by the pressure provided by the hydraulic test bench in the laboratory to drive the belt. The sensor is fixed on the upper side of the pulley, and the transmission speed of the belt is calculated by detecting the rotation speed of the pulley; The DC power supply provides electric energy, and the motor speed is controlled by adjusting the output voltage of the DC power supply. A sensor is fixed next to the motor shaft to detect the speed of the motor. The test equipment diagram is shown in figure 8.
3.1.2. **Test Tool.** In the experiment, in order to explore the influence of different tool edge curves, tool edge forms, and the number of cuts during one revolution of the tool on the cutting effect, six-bladed smooth knives, six-bladed serrated knives, three-bladed arc-toothed knives and 80-tooth discs were prepared. There are four different types of cutters for tooth cutters. Among them, the six-blade smooth knife and the six-blade serrated knife are designed to explore the cutting effect of the non-serrated and serrated blades in the same situation; the arc direction of the three-edged arc-toothed knife is opposite to that of the six-edged knife, and the purpose is to explore different blades The cutting effect in the arc direction; 80-tooth disc cutter, the purpose is to explore the influence of cutting frequency on the cutting effect.

3.1.3. **Experiment Material.** The test material was Chinese cabbage grown in the suburbs of Harbin City, Heilongjiang Province. The collection time was October 8, 2020, which coincided with the harvest time of local Chinese cabbage. The cabbage was sent to the laboratory on the same day after it was uprooted. In the experiment, the junction between the main root and the main stem of Chinese cabbage was selected as the root cutting position. The ratio of the rhizome fiber layer to the matrix in this part was moderate, and the Chinese cabbage after cutting sold well. Based on various factors, the Chinese cabbage with a diameter of about 50mm at this location was finally determined as the test material.

3.2. **Experiment Method**

3.2.1. **Choice of Test Method.** Orthogonal experimental design is an important mathematical method for studying multi-factor experiments. It is also a reasonable and effective arrangement of experimental factors to minimize test errors and achieve high-efficiency, rapid, and economical purposes. Therefore, here we use a multi-factor orthogonal test to carry out the cutting test.

3.2.2. **Choice of Test Factors.** In the working process of the harvester, different tool shapes and cutting edge forms will affect the cutting force of the root cutting device. The pair of tool speed and belt feed speed and their interaction will affect the quality of cutting roots and impact load.

   Based on the above conditions, determine the three factors of tool shape, tool speed and belt feed speed as experimental factors.

3.2.3. **Establishment of Cutting Performance Evaluation Index.** For the root cutting device of the harvester, the quality of root cutting is the first element. Root cutting quality can be reflected by the flatness of the cross-section of the cutting root. In order to digitize the cutting quality, this article introduces the cutting ratio (the ratio of the diameter of the cutting surface of the tool to the total diameter). The larger the cutting ratio, the smoother the cutting surface.

3.2.4. **Determination of Factor Level Table and Orthogonal Table.** By consulting the data, in the simulation test, when the cutter speed is 275r/min and the belt feed speed is 0.9m/s, the cutting force is
the smallest [9]. Taking into account the fact that the Chinese cabbage slides with the belt after being stressed and the vibration phenomenon in the cutting process of the tool, the tool speed and belt feed speed are centered on the above values, and four factors are set to explore the actual situation. The influence of factors. The factor level table is shown in table 1.

| Factor | Tool shape A       | Tool speed B r/min | Belt feed speed C m/s |
|--------|--------------------|--------------------|-----------------------|
| 1      | Six-bladed light knife | 250               | 0.6                   |
| 2      | Six-blade serrated knife | 300            | 0.8                   |
| 3      | Three-edged arc tooth knife | 350         | 1.0                   |
| 4      | Disk tooth knife     | 400               | 1.2                   |

Table 1. The factor level table.

There are three factors, A, B, and C, and there is an interaction between B and C. Therefore, the sum of the three factors and the degrees of freedom of interaction is:

\[ f_A + f_B + f_C + 3f_{A\,B} = 1 + 1 + 1 + 3 = 6 \] (1)

With additional empty columns, the number of columns in the orthogonal table should be: \( n \geq 6 + 1 = 7 \), Orthogonal table selection L_{32} (4^3).

3.3. Results and Analysis

After completing each group of orthogonal experiments in turn and obtaining the corresponding data, the experimental data is analyzed through MATLAB software. See figure 9 for the effect of cutting roots of Chinese cabbage, see table 2 for the calculation analysis of the results of cutting roots.

Figure 9. Chinese cabbage cut root effect picture.

| Factor | A     | B     | C     | B\times C | Empty column | Cut-off ratio |
|--------|-------|-------|-------|-----------|---------------|---------------|
| 1      | 1     | 1     | 1     | 1         | 1             | 1             | 0.2           |
| 2      | 1     | 2     | 2     | 2         | 2             | 2             | 2             | 2             | 2             | 0.34          |
| 3      | 1     | 3     | 3     | 3         | 3             | 3             | 3             | 3             | 0.6           |
| 4      | 1     | 4     | 4     | 4         | 4             | 4             | 4             | 4             | 0.58          |
| 5      | 2     | 1     | 1     | 3         | 2             | 3             | 3             | 4             | 0.18          |
| 6      | 2     | 2     | 2     | 1         | 4             | 4             | 3             | 3             | 0.34          |
| 7      | 2     | 3     | 3     | 4         | 1             | 1             | 2             | 2             | 0.58          |
| 8      | 2     | 4     | 4     | 1         | 2             | 2             | 1             | 1             | 0.56          |
| 9      | 3     | 1     | 2     | 3         | 4             | 1             | 2             | 3             | 4             | 0.3           |
| 10     | 3     | 2     | 1     | 4         | 3             | 2             | 1             | 4             | 3             | 0.26          |
| 11     | 3     | 3     | 4     | 1         | 2             | 3             | 4             | 1             | 2             | 0.64          |
| 12     | 3     | 4     | 3     | 2         | 1             | 4             | 3             | 2             | 1             | 0.72          |
| 13     | 4     | 1     | 2     | 4         | 3             | 3             | 4             | 2             | 1             | 0.6           |
| 14     | 4     | 2     | 1     | 3         | 4             | 4             | 3             | 1             | 2             | 0.64          |
| 15     | 4     | 3     | 4     | 2         | 1             | 2             | 4             | 3             | 1             |               |

Table 2. Root cutting effect test results calculation analysis table.
The results in table 2 show that the primary and secondary order of the influence of each factor is A, B, C, B×C, indicating that the shape of the tool has the greatest influence, followed by the tool speed and belt feed speed, and finally the tool speed and belt feed speed. Interaction. The level priority in table 2 indicates the optimal level of each factor. The best choice in the shape of the tool is the 80-tooth disc cutter, the best tool speed is 400r/min, and the best belt feed speed is 1.0m/s.

4. Conclusion
Based on the TRIZ theory, the overall structure of the Chinese cabbage harvester is designed. The Chinese cabbage harvester can realize the automatic harvesting process of cabbage extraction, root cutting and transportation.

In the multi-factor orthogonal experiment, through the analysis of the root cutting effect, among the six-blade smooth knife, six-blade serrated knife, three-blade arc-tooth knife and 80-tooth disc knife, the 80 with the best root cutting effect Tooth disc cutter.

Among the four levels given, the best tool speed is 400r/min, and the best belt feed speed is 1.0m/s. In this case, the cutting quality is the best.

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