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Design of Cabbage Pulling-out Test Bed and Parameter Optimization Test

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The development of cabbage harvester is mature aboard while related research and applications in China are still in its early stage. At present, nearly all harvests of cabbage are manually completed in China. Therefore, the mechanization of cabbage harvest has become a matter of great urgency. In order to realize the cabbage harvester obtaining the cabbages successfully during the harvesting process, a cabbage pulling-out test bed was designed. By analyzing the working principle of the test bed and the force-bearing status at the time of pulling, the key parts structure of the test bed was determined. The author investigated the optimization test of the working parameters of a cabbage pulling-out harvester through the following procedures: selecting the rotational speed of screw pole, spacing between two screw poles, analyzjng the angle between the screw pole and the ground as influencing factors, determining the pulling-out percentage as the objective function, and adopting the quadratic orthogonal regressive rotation test as the method. The pulling-out percentage of cabbage reached 95% or higher when the angle between the screw pole and the ground is 15°, and the spacing between two screw poles was 50–70 mm while the rotational speed of screw pole was 180 r/min. The research findings provide a theoretical basis for the modified design of the cabbage harvester.

1. Introduction

China is a big producer in terms of vegetable yield, but the mechanization development of vegetable harvest lags behind (Xu et al., 2015). The harvest operation accounts for 40% of the total workload; therefore, developing the machinery for vegetable harvest and realizing the mechanization of vegetable production can greatly improve China's agricultural productivity (Wang et al., 2014).
Cabbage is one of the major vegetable varieties in China as it ranks third among all vegetables in terms of sown area and yield (Du et al., 2014). However, so far nearly all harvests of cabbage are manually completed. Therefore, the mechanization of cabbage harvest has become a matter of great urgency.
A relatively stable mechanized production system and auxiliary tools have already been developed by Europe, the United States, and other developed countries (Gao et al., 2015). In 1931, the former Soviet Union successfully created the first cabbage harvester in the world (Murakami et al., 1994; Kanamitsu and Yamamoto, 1996), thereby forming the basic structure of a cabbage harvester. Europe, the United States, and Japan are the countries where research on cabbage harvester have been developed at the highest level. The cabbage harvester has previously been merchandized in Europe and the United States, where the major products are either trail-type or suspension type. Some are provided with a cabbage head conveyor, by which they could work together with a transport vehicle. In Asia, Japan spearheaded the research, and their products are mainly small self-propelled harvesters (Abe et al., 1999).
Chinese Scholars have started the research and application of a mechanized cabbage harvester in recent years (Gu and Jiang, 2007; Geng et al., 2004). Apart from Taiwan, Gansu Agricultural University of China by analyzing the influencing factors of cabbage root-cutting force, designed a 4YB-I cabbage harvester and created a three-dimensional model as well. However, they have not yet created the prototype. Zhejiang

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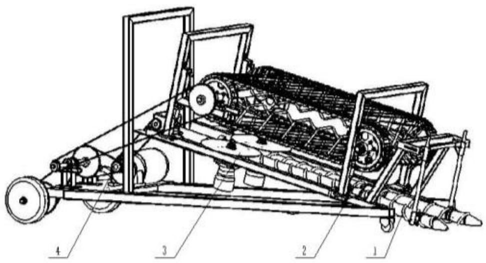
University also designed a self-propelled cabbage harvester suitable for field operations in Southern China, with a preliminary mechanized harvest capacity (Du et al., 2015). The Tai'an Research Institute of Farm Machinery Science in Shandong Province also designed a self-propelled all-hydraulic cabbage harvester, but they failed to provide a detailed description of the trial test (Wu et al., 2016).
The pulling-out device is the key part of the cabbage harvester. The design rationality and working performance of the part determines the working performance of the harvester. Accordingly, this paper investigated how the cabbage pulling-out device can improve the harvesting results of cabbage harvester.

2. Structure and working principle of test bed

The design for a pulling-out test bed for cabbage mainly comprised by a double helix pulling-out mechanism, a reticular capping mechanism, a double-disk root-cutting mechanism, and a drive system, as shown in Fig. 1.



Note: 1. Double helix pulling-out mechanism 2. Reticular capping mechanism 3. Double-disk root-cutting mechanism 4. Drive system

Figure 1: Cabbage Pulling-out Test Bed

The double helix pulling-out mechanism feeds the head cabbage in and then pulls it out, after which the mechanism conveys it to the root-cutting mechanism. The double helix pulling-out mechanism is installed above the capping mechanism, which is composed of highly resilient mesh rubber belt that covers the top of cabbage head. As the two screw poles rotate in the opposite direction, the cabbage root remains in the soil when the screw poles fail to make a complete contact with the cabbage head. Given that the screw poles are tilted at a certain angle in the ground, the cabbage root may come in contact with the screw poles as the vehicle moves forward. When the screw poles completely contact the cabbage root and cabbage head wrapper, the screw poles may generate an upward pulling force on the cabbage. As the vehicle continues moving, the cabbage is raised continuously. The cabbage is then gradually pulled out of the soil. Simultaneously, the capping mesh belt contacts with and then wraps the cabbage. With the joint effect of screw poles and capping mesh belt, the cabbage is conveyed to the root-cutting mechanism. Figure 2 shows the pulling-out principle.

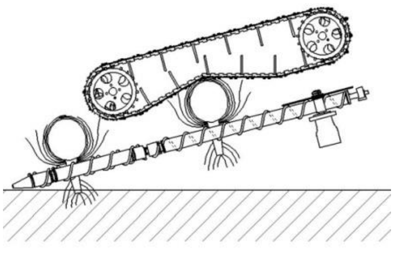


Figure 2: Cabbage pulling-out principle

The double helix pulling-out mechanism is mainly composed of two screw poles. The thread pitch and directions are the same in each set of the screw poles which are connected with the cardan joint. The two screw poles rotate in the opposite direction and they are fixed at the rack, with the screw pole with a certain opening angle playing the guiding role. The capping belt is immediately above the double helix pulling-out mechanism and it helps convey the cabbages, during which process the linear velocity of the capping mesh belt shall be kept same with the conveying speed of screw poles. During the pulling-out process of cabbage, a jam may occur in the test bed if the conveying speed of screw poles is less than the moving speed of the test bed. And a difference is expected between the top and root of cabbage during the conveying process, while the upright position of the cabbage is not maintained if the speed between the top and root is not the same. When the tilt angle is extremely large, the cabbage root may slip out of the screw poles, thereby resulting in a jam and affecting the root-cutting effect.

3. Determination of experimental factors

The force analysis of cabbages for the pulling-out process is shown in Figure 3a. Taking the symmetrical screw poles into consideration, the mutual effect of both screw poles upon the cabbage is ignored during the analysis. First, the cabbage is subject to the gravitational force *mg* and the vertical grasping force of soil F_z. When the cabbage is carried upward by the screw poles, the cabbage is subject to the supporting force of screw poles N_1 and the thrust force of screw poles *F,* in which process its direction is perpendicular to the helix and the friction of screw poles *f*. Simultaneously, the capping mesh belt covers the top part of the cabbage and carries the cabbage to move upward, along with the direction of the screw poles. At this moment, the cabbage is subject to the downward pushing force of the capping mesh belt N_2. The coordinate system with the screw pole direction as the *x*-axis is established. Given that the magnitude and direction of the friction force *f* cannot be determined, it is decomposed into two respective component forces along the x-axis and y-axis, i.e., f_x, f_y. To simplify the rigid system, the author does not consider the position of mass point or mass center during the analysis. Figure 3b presents the simplified force analysis.
Based on Newton's second law, $\mathrm{m}a_{\mathrm{y}} = \sum F$, the following equation along the y-axis is obtained:

$$\mathrm{ma_y} = N_1 + F\sin\alpha - N_2 - f_y - (mg + F_z)\cos\beta \tag{1}$$

Considering that the cabbage will no longer remain still and will begin to move once it is pulled out, an accelerated speed must exist as follows:

$$\mathrm{a_y} > 0 \tag{2}$$

From foresaid equations (3), we have the following:

$$\frac{N_1 - N_2 - f_y + F\sin\alpha}{\cos\beta} > F_z + mg \tag{3}$$

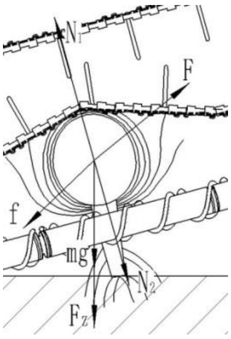


Figure 3a: Force Analysis

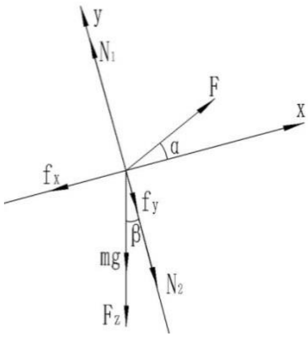


Figure 3b: Simplified Force Analysis

From the above-mentioned equations, the helix angle of screw poles α, the angle between the screw pole and the ground β, the spiral thrust force F, and the friction born by the cabbage *f* will all directly affect the pulling-out of cabbages, among which the helix angle is positively correlated with thread pitch. During the test, the double helix screw poles with different thread pitch shall be manufactured and used in the test if people want to change the helix angle. Nonetheless, a huge workload is necessary. Based on previous tests and studies, a proper parameter is selected and will no longer be changed. The friction born by the cabbage *f* is positively correlated with the extrusion force born by the cabbage root. The spacing between two screw poles directly affect the extrusion force born by the cabbage root. Thus, the space between two screw poles is treated as an influencing factor. During the work, the rotating speed of screw poles may affect the spiral thrust *F.* Consequently, the rotating speed of screw poles, the spacing between screw poles, and the angle between the screw pole and the ground are selected as the influencing factors during the analysis.

4. Parameter optimization test

4.1 Test object and equipment

The cabbage used in this test is the early maturing variety of Northern China (Beilv 60) and its physical parameters are shown in Figure 4 and Table 1.

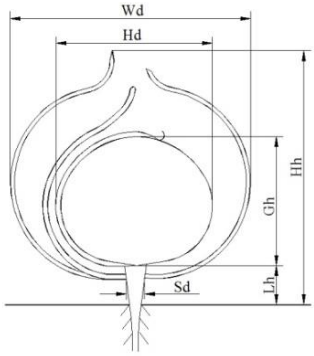


Figure 4: Dimension of Cabbage

Table 1: Basic Physical Property Parameters of Cabbage

Statistical index	Longitudinal diameter Hh/mm	Transverse diameter Wd/mm	Total mass /kg	Head mass /kg	Expansion /mm
Mean	Figure 4.0	154.2	2.81	1.60	545
Max	192.2	Figure 8.3	3.24	1.83	590
Min	15.8	32.1	2.41	1.25	480
Standard deviation	12.6	10.3	0.21	0.14	27.1
Variation coefficient	0.07	0.07	0.07	0.09	0.0

The self-made pulling-out test bed, frequency converter and digital camera are the major instruments used in this test.

4.2 Test methods

The test was conducted in the greenhouse of Heilongjiang Academy of Land Reclamation Science from 2 November 2016 to 10 November 2016. The quadratic orthogonal regressive rotation test with three factors and five levels was carried out there. Based on the preliminary test and practices, the rotating speed of screw poles (x_1), spacing between screw poles (x_2), and the angle between the screw pole and the ground (x_3) are selected as the influencing factors. The pulling-out percentage (y) is chosen as the objective function. A total of 20 tests were conducted, during which process the cabbages were deemed successfully pulled out if they were pulled out and conveyed to the disk cutter. The vehicle were suspended for clearing if any cabbage was not pulled out or conveyed successfully. The vehicle proceeded after the clearing was completed and a total of 30 cabbages were harvested in each test. During the pulling-out process, the wrapper of some cabbages might be damaged, but the injured wrappers were peeled off in the following root-cutting and wrapper-peeling process. Consequently, the cabbage head were not be affected. The damage to cabbage head mainly occurred during the root-cutting process, where the analysis of cabbage injury had put more emphasis. Thus, the pulling-out and conveying processes were not be considered. The Design-Expert software has been used for data processing and Tables 2 and 3 present the coded value as well as test scheme for each factor, while Figure 5 presents the status of the tests.

Figure 5: Test Status

Table 2: Coded Value of Each Test Factor

Coded value	Rotational speed (r·min^{-1}) of the screw pole x_1	Spacing (mm) between two screw poles x_2	Angle (°) between the screw pole and the ground x_3
Upper asterisk +2	294	70	25
Upper level +2	252	60	20
Zero 0	210	50	15
Lower level -1	168	40	10
Lower asterisk -2	126	30	5

5. Test results and analysis

5.1 Test results

The test scheme and results are shown in Table 3.

Table 3: Test Scheme and Results

No.	x_1(r/min)	x_2(mm)	x_3 (°)	y(%)	No.	x_1(r/min)	x_2(mm)	x_3 (°)	y(%)
1	210	50	20	93.33	11	168	60	25	80
2	210	50	20	86.66	12	210	70	20	83.33
3	210	30	20	96.66	13	210	50	20	83.33
4	210	50	10	93.33	14	210	50	20	83.33
5	252	60	15	90	15	210	50	20	93.33
6	210	50	20	90	16	168	60	15	76.66
7	210	50	30	90	Figure	126	50	20	83.33
8	252	40	15	90	18	168	40	15	86.66
9	168	40	25	96.67	19	252	40	25	93.33
10	252	60	25	90	20	294	50	20	73.33

5.2 Data processing

(1) Regression equation and significance analysis

The Design-Expert software was used for data processing and analysis. The variance analysis of the pulling-out percentage (y) is shown in Table 4.

Table 4: Variance Analysis

	Source	Square sum	Df	Mean square	F value	Pro>F	Significant
	Model	657.00	9	73.00	5.93	0.005	Significant
	Residual	123.Figure	10	12.32			
y	Fitting	62.09	5	12.42	1.02	0.4931	non-significant
	Error	61.09	5	12.22			
	Sum	780.Figure	19				

(2) Determination of regression equation

The *F* test was conducted over the regression coefficient of the pulling-out percentage regression equation at the confidence coefficient of 0.05. After deleting the non-significant items, the simplified regression equation was obtained, as shown in Equation (4):

$$y = 91.82 - 2.29x_1 - 4.79x_3 - 1.59x_1^2 - 1.59x_2^2 - 2.01x_3^2 \quad (4)$$

(3) Factors contribution
Through the analytical computation, the contribution of each factor to pulling-out percentage have been ranked from the smallest to the largest, i.e., the angle between the screw pole and the ground of 1.85, the rotating speed of screw poles of 1.10, and the spacing between screw poles of 1.67.

6. Conclusions

(1) The feasible combination of optimized parameters for the pulling-out test bed is as follows: the angle between the screw pole and the ground of 15°, the spacing between screw poles of 50–70 mm, and the rotating speed of screw poles of 180 r/min. Based on these values, the pulling-out percentage of cabbage is higher than 95%.
(2) The influence of the three factors upon pulling-out and conveying processes of cabbage is ranked from the largest to the smallest as follows: the angle between the screw pole and the ground, the spacing between screw poles, and the rotating speed of screw poles.
(3) The test results involved in the cabbage pulling-out test bed analysis have proven that the designed structure can effectively pull out the cabbages.

Acknowledgments

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