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Optimization of Roller-Type Safflower Harvesting Using Computer-Aided Technology

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Abstract

The incorporation of computer information technology has brought about a significant transformation in traditional safflower harvesting methods. This research focuses on exploring the experimental parameters of a roller-type safflower harvesting device by utilizing computer-aided design and optimization techniques. The mechanism of the roller picking device, consisting of essential elements like guide rails, sliders, rubber rollers, and torque sensors, functions by precisely adjusting roller clearances and motor speeds to effectively gather safflower filaments. By conducting systematic experiments and fine-tuning parameters, the optimal combination of roller diameter, gap size, and rotational speed is determined to improve harvesting efficiency. The results of the experiments highlight the effectiveness of the roller-type harvesting device in increasing safflower harvesting rates. This study not only propels advancements in agricultural mechanization but also emphasizes the crucial role of computer information technology in enhancing harvesting processes. The amalgamation of mechanical innovation with computational capabilities signifies a new era in safflower harvesting technology.

Keywords: Safflower harvesting, roller-type device, computer-aided optimization, experimental parameters, experiment, information technology integration.

1. Introduction

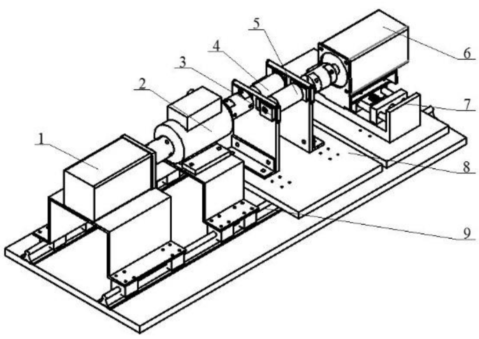
Safflower is China's common food and medicinal annual plants of the Asteraceae family, widely distributed, mainly concentrated in Xinjiang, Qinghai, Sichuan, Henan and other places, has a high medical value, often used to make safflower oil, the treatment of bruises, have blood circulation and blood stasis, sparing the tendons and keys to the bones, dispel dampness and eliminate swelling, and also has a certain therapeutic effect on the cardio-cerebral vascular, it is a kind of collection of edible medicinal plants of the whole book, attracting more and more researchers to pay attention to[1]. According to relevant literature records, in 2015, safflower crops have covered 520 square kilometers of China's territory, accounting for more than 80% of the world's planted area[2]. With the increasing area of safflower planting, the problem of large-scale harvesting work also needs to be solved urgently, however, the current safflower harvesting work mainly relies on manual work to complete, during the harvesting period, the phenomenon of insufficient labor force is becoming more and more prominent, accompanied by the problem of high labor costs. According to the material characteristics of safflower, the flowering period is short, if the harvest is not timely to miss the flowering period will cause a lot of waste of safflower, so the problem of harvesting has become a major obstacle to the development of safflower mechanized production and harvesting[3].

The integration of computer information technology has brought about a paradigm shift in the field of safflower harvesting, revolutionizing traditional practices and paving the way for enhanced efficiency and precision[4]. The Indian Agricultural Research Institute (IARI) spearheaded the development of saffron harvesters in 2003 and 2004, introducing both backpack and hand-push variants. These mechanisms rely on cyclone separators and negative-pressure suction via a fan to extract and gather saffron filaments. Despite their operational simplicity and efficiency, these devices are characterized by high energy consumption and notable noise emissions[5]. In 2012, Siavash Azimi of Tehran Black University devised a saffron filament harvester predicated upon negative airflow adsorption principles. While this innovation yielded a notable augmentation in harvesting volume relative to manual techniques, it concurrently exhibited drawbacks such as diminished suction capability, heightened noise emissions, and increased filament loss ratios[6]. Subsequently, in 2018, Cao Weibin et al. of Shihezi University engineered a comb-clamping saffron filament harvesting apparatus, leveraging cam-driven mechanisms to enact filament clamping prior to suction-driven collection within a dedicated receptacle[7]. In a parallel development, Zhang Guozhen et al. of Xinjiang Agricultural University introduced a rotary oblique-cut saffron filament picking head in 2019. This design integrates eccentric flower inlet mechanisms to shape filaments before effectuating cutting actions via motor-driven oblique cutters. Subsequent to cutting, filaments are channeled into a storage unit via negative pressure airflow within a dedicated flower delivery conduit[8]. While multiple safflower harvesting machines with diverse end-effectors have been cultivated, their efficaciousness remains constrained despite significant resource allocations and reliance upon manual labor inputs[9]. Against this backdrop, we propose an innovative roller-type harvesting apparatus characterized by its parsimonious structural configuration, cost-effectiveness, and facile deployment. By harnessing the principle of high-speed relative rotation between rollers and judiciously modulating airflow dynamics and roller frictional characteristics, this device is proficient in the separation of safflower from fruit clusters, thereby enhancing harvesting efficiency. Empirical validations of this design evince its efficacy and furnish seminal theoretical and technical contributions for subsequent advancements in safflower harvesting machine engineering.

2. Devive Structure and Working Principles

2.1 Structure

Adopting roller picking device as the research carrier, the main working parts are guide rail, slider, rubber roller, parallel guide rail, multifunctional turn out data display table, torque sensor, motor, bearing and different types of support plate, etc. The structure is shown in Figure 1.

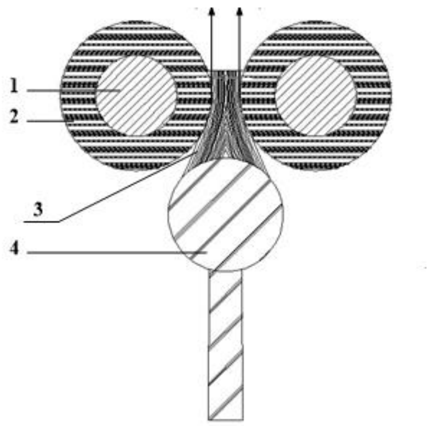


1.Motor 1 2.Sensor 3.Slider 4.Rubber Roller 1 5.Rubber Roller 2 6.Motor 2 7.Screw Guide 8.Base Plate 9.Sliding Guide

Figure 1 Pair-roller saffron harvesting test bed

2.2 Principle of operation

The working principle of rubber roller picking is shown in Figure 2. When the test device works, first control a certain pair of roller gap and motor speed size, so that the pair of rollers in the same type of two motors rotate in opposite directions, slowly feed the filament so that it enters the two rotating rubber rollers, so that the filament in the role of a strong airflow field adsorption, friction, pulling the filament, to complete the work of the filament picking, and carry out a number of picking test, change the rollers gap, rotational speed, and other factors for the experimental study[10]. Among them, the replacement of rubber rollers can be realized by moving the parallel guide rail to make it open and close so as to change down, the size of the roller gap can be controlled through the parallel movement of the screw guide rail, and the speed of the rollers can be realized by controlling the motor, and by controlling the various variable factors in many trials so as to find out the parameter combination that makes the highest picking net rate and the best harvesting effect in order to complete the optimization work.



1.drive shaft 2.rubber roller 3.filament 4.fruit ball

Figure 2 Working principle diagram of rubber roller

2.3 Test materials

This experiment selected Xinjiang Yumin thornless safflower as the object of harvesting, this safflower was planted in the experimental field in April, the height of the plant was greater than 75cm and less than 105cm, the number of filaments on a single safflower bulb ranged from 35-100, the filament moisture content of the selected experimental flowers were different, and there were large morphological differences in the morphology of the flowers on different days after blooming. The first two days of the flower filament morphology, water content is higher, three to five days for semi-dry morphology, water content is slightly lower, six or seven days show dry flower morphology, water content is very low, this test is used in fresh or semi-dry morphology flowers for the test to ensure that the test is effective. The flower morphology is shown in Figure 3[11].

1st day 2nd day 3rd day 4th day 5th day 6th day

Figure 3 Morphology of safflower flowers at different maturity levels

3. Design of Orthogonal Tests Using Minitab

3.1 Picking influencing factors and level selection

According to the pre-test harvesting test, it is concluded that the rubber roller diameter, roller gap, roller speed three parameters have a greater impact on the harvesting effect, this harvesting test selected roller diameter of 20 , 30 , 40 three parameters; roller gap selection of 0.3 , 0.5 , 0.7 three parameters; consider the economic cost and test stability and other factors affecting the roller speed should be in the range of 600-1400 , the test In the test, 600 , 1000 , 1400 are selected as the three rotational speeds[12].

By selecting three levels for each of the picking influences, this three-factor, three-level table is shown in Table 1 below.

Table 1 Factor level for safflower picking test.

level			considerations	
		Roller diameter mm	Roller gap mm	Roller rotation speed $r/\min$
1		20	0.3	600
2		30	0.5	1000

3		40	0.7	1400

According to the harvesting performance requirements of the safflower harvesting device, two indexes, the net harvesting rate and the crushing rate, were used to measure its harvesting effect. In order to make the experimental data precise, the calculation of the harvesting rate[13] was carried out after testing 10 saffron fruit balls separately.

3.1.1 Net harvesting rate

The filaments separated from the saffron fruiting bulb and all the filaments on the saffron fruiting bulb were weighed separately, and the ratio of the total mass of the two was the net harvesting rate. Its calculation formula is:

$$y_1 = \frac{m_1 + m_2}{m_1 + m_2 + m_3} \times 100\% \tag{1}$$

m_1 refers to the weight of 10 filaments picked by the roller picking device in g ; m_2 refers to the mass of 10 test specimens of filaments scattered outside the collection box after the separation of the saffron fruit bulb from the filaments in g ; m_3 refers to the weight of the filaments on the 10 saffron fruit bulbs that were not picked after the separation action was completed in g .

3.1.2 Drop rate

The percentage of the total mass of filaments in 10 saffron fruit bulbs that have been picked and dropped outside the confines of the collection box to the total mass of filaments growing on the saffron fruit bulb is called the drop rate, which is calculated by the formula:

$$y_2 = \frac{m_2}{m_1 + m_2 + m_3} \times 100\% \tag{2}$$

3.1.3 Breakage rate

After picking 10 saffron fruit balls, the percentage of total mass of broken filaments to the total mass of filaments picked by the test device is called the breakage rate, which was calculated by the formula:

$$y_3 = \frac{m_4}{m_1 + m_2} \times 100\% \tag{3}$$

where m_4 is the total mass of 10 broken saffron filaments in g .

3.2 Experimental design

This test adopts three-factor three-level orthogonal test method[14], there are three factors of rubber roller diameter, roller gap, roller rotation speed and three levels of picking rate, drop rate, breakage rate, if the factors and levels are paired with each other to carry out the cross-test, it is necessary to carry out 33 i.e., 27 times of the test, the test process is too complex, and it should be appropriately simplified. Considering the representative factors and levels combined with each other, redistributed after the test, the number of tests can be appropriately reduced on the basis of not affecting the results. Therefore, $L9(34)$ orthogonal method was chosen to correspond the level factors in each column, and the test was simplified into 9 groups according to the different combinations of factors and levels, and the results of the corresponding test indexes were obtained, and then the indicators were analyzed and studied by the comprehensive balance method, analysis of variance (ANOVA) method, and the main effect curve diagrams of each factor[15].

The test was divided into 9 groups, and each group was repeated 5 times, and the average of the 5 tests was selected as the result of the test.

3.3 Experimental results and analysis of variance at significance level

After determining the factors, levels and experimental program selected for the test, the picking test was conducted for each factor indicator, and the data and results obtained from the test are shown in Table 2.

Table 2 Test results.

test number		considerations		Test results for each indicator /%		
	Diameter of rubber roller mm	Roller gap mm	Motor speed r / min	recovery rate	drop rate	breakage rate
1	20	0.3	600	84.6	3.68	4.72
2	20	0.5	1000	87.7	3.40	4.16
3	20	0.7	1400	88.5	2.84	2.82
4	30	0.3	1000	86.6	3.24	4.53
5	30	0.5	1400	89.1	2.91	3.35
6	30	0.7	600	87.4	3.56	3.24
7	40	0.3	1400	91.5	2.70	2.96
8	40	0.5	600	89.4	3.65	3.25
9	40	0.7	1000	90.2	3.14	2.86

The results of the tests were analyzed by ANOVA to find out the significant degree of each factor. The larger the F value test, the more significantly the factor can affect the picking effect significantly, and the more obvious the effect on the test results. In the analysis of variance, it is assumed that each test is independent and the indicators under each test condition obey normal distribution[16]. The ANOVA of the picking clean rate, dropping rate grade breakage rate of this test is shown in Table 3, Table 4 and Table 5.

Table 3 Analysis of variance (ANOVA) of net harvesting rate.

Source of variation	degrees of freedom	*Seq SS*	*Adj SS*	*Adj MS*	*F*	*P*
Diameter of rubber roller	2	22.8356	22.8356	11.4178	16.76	0.046
Roller gap	2	2.5756	2.5756	1.2878	1.89	0.346
Roller rotation speed	2	10.0822	10.0822	5.0411	7.40	0.109
inaccuracies	2	1.3622	1.3622	0.6811		
add up the total	8	36.8556				
$S = 0.8259 \quad R - Sq = 96.3\% \quad R - Sq$(adjusted） $= 93.22\%$						

Through the analysis in Table 3, it can be obtained that the three parameters of rubber roller diameter, roller clearance and rotational speed significantly affected the harvesting effect of saffron. From the data in Table 3, it can be obtained that the F-value of roll gap is significantly smaller than the F-value of rubber roller diameter and roller speed. It indicates that for the net harvesting rate, the effect of roll clearance on the harvesting effect is much smaller than that of rubber roller diameter and roller speed. At the same time, the P value corresponding to the diameter of the rubber roller is much smaller than the gap of the rubber roller and the speed of the rubber roller, which proves that the effect of the diameter of the roller on the net picking rate is more significant than the gap and speed of the roller. Through the above analysis, it can be obtained that the order of the three influencing factors on the net picking rate is rubber roll diameter＞roll rotation speed＞roll gap. The increase of rubber roll diameter makes the contact area between filament and rubber roll larger, and improves the filament feeding capacity, so the rubber roll diameter has the greatest influence on the net picking rate[17].

Table 4 ANOVA table for drop rate.

Variation source (of information etc)	Degrees of freedom	*Seq SS*	*Adj SS*	*Adj MS*	*F*	*P*
Diameter of rubber roller	2	0.04096	0.04096	0.02048	14.51	0.064
Roller gap	2	0.03982	0.03982	0.01991	14.11	0.066
Roller rotation speed	2	0.94516	0.94516	0.047258	334.9	0.003
inaccuracies	2	0.00282	0.00282	0.00141		
add up the total	8	1.02876	1.02876			
$S = 0.0375648 \quad R - Sq = 99.73\% \quad R - Sq(\text{adjusted}) = 98.9\%$						

ANOVA on the drop rate in Table 4, the F-value of the roll diameter and roll gap is much smaller than the roll rotation speed, and the P-value of the roll rotation speed is also much smaller than the roll diameter and roll rotation speed. This indicates that the roll speed has a greater influence on the drop rate than the other two parameters, the influence of the roll diameter is the second largest, and the influence of the roll gap is the smallest. That is, the order of influencing factors for the roll speed > roll diameter > roll gap. Because the increase of the roller speed makes the experimental equipment on the filament adsorption capacity increases, and by the analysis of the above paragraph can be obtained from the increase in the diameter of the rubber rollers can improve the picking rate, so the drop rate with the increase in the diameter of the rubber rollers and decline.

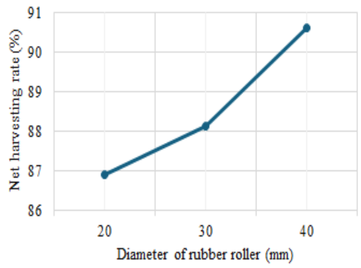
Table 5 ANOVA table of breakage rate.

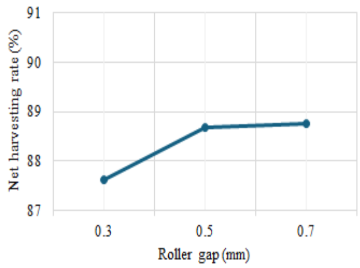
variation source (of information etc)	degrees of freedom	*Seq SS*	*Adj SS*	*Adj MS*	*F*	*P*
Diameter of rubber roller	2	1.32207	1.32207	0.66103	20.51	0.046
Roller gap	2	1.75940	1.75940	0.87970	27.29	0.035
Roller rotation speed	2	1.14427	1.14427	0.57213	17.75	0.053
inaccuracies	2	0.06447	0.06447	0.03223		
add up the total	8	4.29020				
$S = 0.179536 \quad R - Sq = 98.5\% \quad R - Sq(\text{adjusted}) = 93.99\%$						

In accordance with the same method of analysis of Table 5, it can be obtained that the roll speed than the roll gap and roll diameter on the impact of the breakage rate is small, the three factors affecting the main order of roll gap > roll diameter > roll speed.

3.4 Research on the influence law of experimental factors and determination of optimal parameter combinations

In order to facilitate the comprehensive analysis of the test of the impact of the parameters on the results, more clearly derived picking performance by the change law of the various experimental influencing factors, and to find out the optimal picking parameters, that is, the highest rate of picking clean, the lowest rate of breakage, the lowest rate of falling out of the parameter combinations are also the lowest. Each parameter index with the factor level change with the mean main effect curve expressed[18], as shown in Figure 4, Figure 5, Figure 6, through the analysis of the curve graph can be derived from the influence of the factor level change.





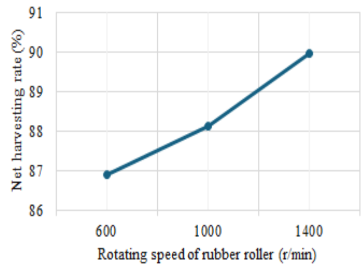


Figure 4 Plot of main effect of net harvesting rate

Analyze the main effect curve of the picking rate, it can be obtained that the picking rate, roller speed, roller diameter are positively correlated, i.e., when the roller speed and roller diameter respectively increase, the picking rate increases, and in the roller speed and roller diameter have reached the extreme value of the picking rate also reaches the extreme value, at this time, the best effect of the picking. Roller gap is less than 0.5mm, gap increase can significantly improve the net picking rate, when the gap is greater than 0.5mm on the net picking rate is limited.

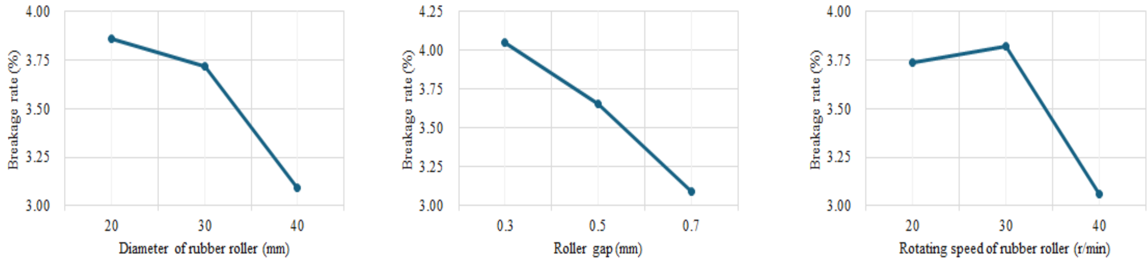


Figure 5 Main effect plot of breakage rate

The analysis of Figure 5 shows that the roll gap and the three parameters of roll speed and roll diameter can significantly affect the breakage rate. Specifically, with the increase of roller diameter, breakage rate monotonically decreases, the two are inversely proportional to the law, and when the diameter of the rubber rollers increased to 40mm , the breakage rate is reduced to the minimum; rubber rollers rotational speed in the speed interval of 600-1000 r/min , the breakage rate increases slowly, increasing the speed of the rollers to the 1000-1400 r/min area, the breakage rate with the increase in speed decreases significantly when the rotational speed reaches 1400 r/min, breakage rate is the smallest. When the speed reaches 1400, the breakage rate is minimized. The breakage rate with the increase of the roll gap sharply monotonous decline, this is because with the increase of the roll gap, reduces the roll on the filament extrusion, pulling force.

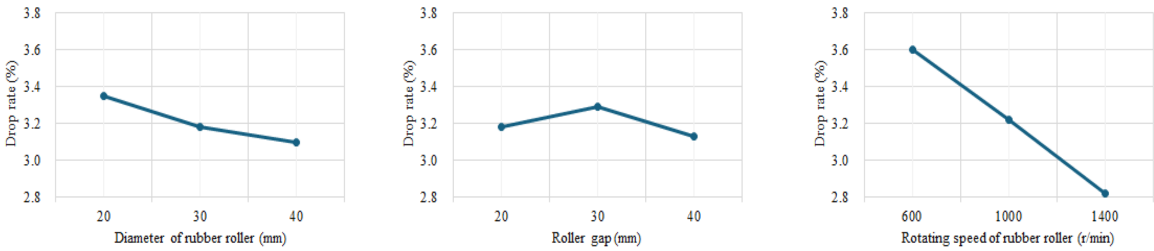


Figure 6 Plot of main effect of drop rate

Analysis of Figure 6 shows that the dropout rate decreases with the increase of roll diameter and roll speed, and the roll speed has a deeper influence than the roll diameter. And in the roller speed of 1400 r/min, diameter of 40 mm , the dropout rate is reduced to the lowest. The dropout rate is not sensitive to the change of roll gap.

After comprehensive analysis of the three main effect curve graphs, the highest picking efficiency, i.e., the highest picking clean rate, and the lowest drop rate and breakage rate, was achieved when the rubber roller diameter was 40 mm , the pair of rollers gap was 0.5 mm, and the rubber roller speed was 1400 r/min. This set of data is the best combination of parameters.

4. Conclusion

This study presents an empirical investigation into the efficacy of a roller-type safflower harvesting device through controlled experimental trials. By integrating computational techniques into the traditional mechanical framework, this study has demonstrated the immense potential of leveraging technology to overcome challenges in agricultural mechanization. Utilizing Minitab software for rigorous orthogonal test analysis, we systematically explored the dynamics of influencing factors to ascertain optimal parameter combinations for enhancing picking performance. Our analysis reveals that pivotal variables including rubber roller diameter, roller gap, and rubber roller speed exert significant influence on the safflower picking performance of the experimental apparatus. Through comprehensive examination of main effect curves, we dissected the impact of each factor on key performance metrics such as clean rate, drop rate, and breakage rate, elucidating discernible patterns and trends of variation.

However, while the designed safflower harvesting test device adeptly addresses prescribed regulatory and test parameters, it regrettably overlooks the intricate influence of airflow dynamics on filament collection efficacy during experimentation. This limitation impedes a comprehensive analysis of filament picking quality and efficacy. Thus, future endeavors must prioritize the fabrication of a prototype safflower picker, coupled with extensive field trials, to rigorously validate the accuracy and comprehensiveness of our device's performance evaluations. Such endeavors are imperative for advancing the efficacy and applicability of safflower harvesting technologies.

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