Design and field test of a special Chinese herbal medicine harvester

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Abstract: A special Chinese herbal medicine (SCHM) harvester was designed to address the problems such as the highly labor-intensive process, low harvesting efficiency, and lack of suitable machinery. The designed machine was comprised of three main components, including a reciprocating cutter, a clamping chain, and a counter roller. In addition, a mechanical model of a plant stalk during harvester operation is established to analyze the parameters affecting SCHM harvesting: sprocket rotation speed, counter roller gap, and header inclination angle. Considering the operating mode of the harvester, all three parameters were taken as test factors, and the proportion of lost fruit, the proportion of broken capsules, and the length of the retained stem are the test indicators. According to the test results, the fruit lost was 1.14%, the broken fruit was 1.02%, the stalks with an acceptable length was 82.45% at a sprocket rotation speed of 110 r/min, a roller gap of 9 mm, and a header inclination angle of 5°. The research can provide an effective solution to solve the SCHM harvest problem. Further studies need to do for making this machine more automated and intelligent.

Keywords: mechanization, chain, special Chinese herbal medicine, herb harvester
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1 Introduction

Poppy is an annual herb of the poppy family, which is a special Chinese herbal medicine (SCHM)[1-3]. Poppy seeds can be used as a spice in food, and poppy seed oil can lower blood cholesterol, enhance vascular flexibility and permeability, and prevent and treat atherosclerosis, coronary heart disease, and cerebrovascular disease. The main medicinal component of the poppy shell consists of alkaloids, such as morphine, codeine, and papaverine, which have significant analgesic and antitussive effects. Poppy shells are listed in the Chinese Pharmacopeia and are the only Chinese medicine prepared and administered as a narcotic drug. Poppy shells have been given special status in the national Chinese medicine system[4-6]. The state has strict policies and regulations for SCHMs[7,8].

It is required mechanized harvesting techniques and equipment for poppies due to their labor-intensive harvesting procedures, high labor costs, low harvesting efficiency, and potentially hazardous harvesting situations. Except for Luo et al.[9,10], who created a poppy harvester, there have been few investigations on the mechanized harvesting of SCHM. This device rotates by the action of a picking roller on a spiral vertical plate, which essentially fixes the capsules to the roller. The harvested capsules are transferred to a conveying auger, after which the fruit husk is cut by a reciprocating cutter mounted under the picking roller and then transported by the conveying auger to the rear conveying and collecting device. At present, the working principles of crop harvesting machinery apply to maize[11-13], vegetable crops[13-15], fruits[16-20], and drugs such as *Panax notoginseng* and wolfberry[21-23]. The small stem and the location of the capsule at the top of the stem differentiate this SCHM from the other crops. Furthermore, because the capsules must be taken from the end of the stem node and must be as intact as possible, various harvesting approaches are required for this SCHM.

In this research, an SCHM harvester is designed to meet the above harvesting requirements. Through theoretical and experimental analysis, the design and parameters of the harvester are optimized.

2 Harvester and working principle

2.1 Physical properties of the SCHM

The relevant physical properties of the poppy (i.e., the SCHM) are measured to facilitate subsequent mechanical analysis of the stems. The major parameters include the moisture content of the stem, the friction coefficient of the stem, the stress resistance of the shell, and the tensile force at the stem junction (Table 1).

Table 1 Physical properties of the SCHM

Parameter	Value
Stem moisture content/%	50.0±12.3
Stem friction coefficient	0.45±0.04
Husk resistance to pressure/N	61.02±11.62
Stem knot tension/N	220.0±33.1

Note: The stalk friction coefficient herein is the friction coefficient between the stalk and ordinary steel plates.

2.2 Harvester

The SCHM harvester is composed of a frame, a clamping chain, a pair of rollers, a reciprocating cutter, and a disc cutter, as shown in Figure 1. The frame includes a side plate, a support

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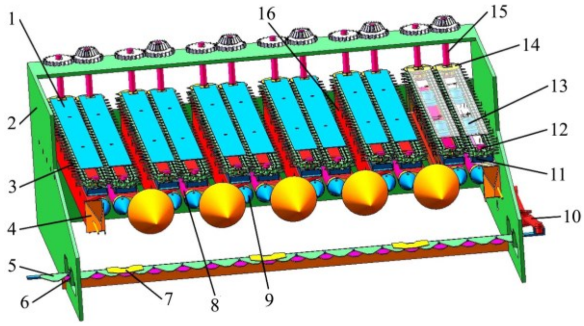
plate, a divider, and a protective limit plate. A clamping chain, a clamping sprocket, a sprocket shaft, and a carrier roller make up the clamping chain. A pair of rollers, a front tip, and a front-end pitch adjuster make up the counter roller. The front-end pitch adjuster is bolted to the inner side of support plate, and a spacer is used to adjust the roller spacing. The reciprocating cutter is made up of a moving blade, a stationary blade, another blade, and other similar pieces and has a pendulum ring construction. The disc cutter assembly is made up of a disc cutter and a driveshaft, and the disc cutter and clamping sprocket share the same driveshaft.



1. Protective limit plate 2. Side plate 3. Clamping chain 4. Separator 5. Moving blade 6. Fixed blade 7. Edge guard 8. Pair of rollers 9. Front tip 10. Pendulum ring mechanism 11. Front end spacing adjuster 12. Clamping sprocket 13. Carrier sprocket 14. Disc cutter 15. Sprocket shaft 16. Support plate

Figure 1 Structure of the SCHM harvester

2.3 Working principle

The SCHM harvester travels at a steady speed during operation. The stalk is fed into the clamping chain through the divider, and the clamping chain holds the stalk and feeds it into the pair of rollers so that the pair of rollers can hold the stalk. Meanwhile, the reciprocating cutter cuts the stems at the same height. The stalk carrying the capsule is then transported to the disc cutter under the action of the clamping chain and the counter roller. When the excess stalk is cut off by the disc cutter, it drops under the harvester, and the capsule is sent to the tank behind the harvester.

3 Key design components

3.1 Reciprocation cutter

A diagram of the initial cutting of the stalk by the reciprocating cutter, in which the ground is the *X*-axis, is shown in Figure 2. The cut stems are transported to the disc cutter by the clamping chain and the counter roller.

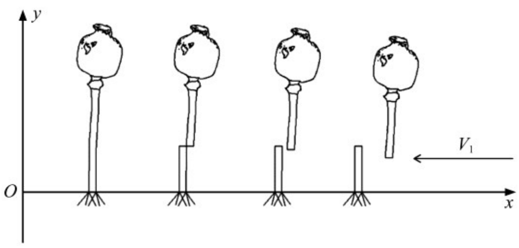
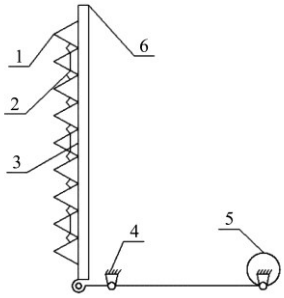


Figure 2 Schematic diagram of cutting the stem

The initial cutting of the stem is done by the reciprocating cutter, which has a pendulum ring mechanism as shown in Figure 3. The stalk is cut at a uniform height and then transported to the disc knife location by the action of the roller and the clamping chain. The disc cutter performs the second cut, completing the harvest of the SCHM.

The reciprocating cutter is fixed in place by the frame, and the eccentric wheel 5 generates force by rotating eccentrically to enable the moving blade 3 to move back and forth. The clamping and cutting of the stalk are completed at the same time by the moving and static blades, completing the separating process.



1. Moving blade 2. Fixed blade 3. Blade guard 4. Harvesting device frame 5. Eccentric wheel 6. Knife holder

Note: V_1 is the reciprocating cutter cutting the stem running direction.

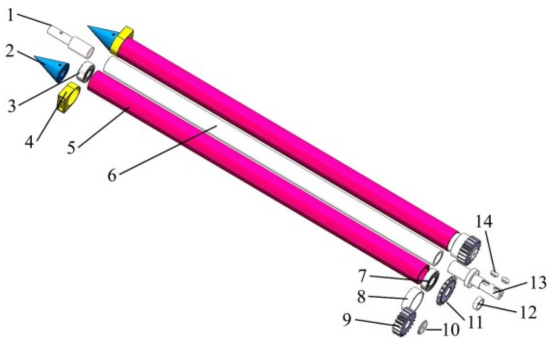
Figure 3 Schematic diagram of the structure

3.2 Counter roller

The stalk is subjected to friction generated by the rollers after being fed into the pair of rollers. Under the action of friction, the stalk maintains axial movement until its stem knot rests on the protective limit plate.

The roller structure is shown in Figure 4, and the pair of rollers consists of a left and a right roller. The left roller is composed of a short shaft, a front tip, a front-end adjustment bearing, a front-end spacing adjuster, a piece of rubber, a hollow shaft, a tail bearing, a bearing seat, a transmission gear, an end cover, a transmission sprocket, a bushing, a tail axis, and keys.

The roller shaft has a diameter of 50 mm and a length of 910 mm. The roller gap can be adjusted from 0 mm (minimum) to 14 mm (maximum).



a. Exploded view

b. Axonometric projection

1. Short shaft 2. Front tip 3. Front end adjustment bearing 4. Front end spacing adjuster 5. Piece of rubber 6. Hollow shaft 7. Tail bearing 8. Bearing housing 9. Transmission gear 10. End cover 11. Drive sprocket 12. Bushing 13. Tail shaft 14. Key 15. Right counter roller 16. Left counter roller

Figure 4 Structure of the picking roller

Both the movement of the stalk in the roller and the mechanical state during harvesting were analyzed to determine the optimal working parameters of the roller in the SCHM harvester. The structural parameters of the roller directly affect the movement of the stalk in the harvester, which affects the harvesting efficiency. If the roller is excessively long, the stem moves radially under the action of the roller and is dropped in the middle of the protection limit plate, resulting in decreased harvesting efficiency. In contrast, if the roller is excessively short, the stem moves radially under the action of the roller, and the stem knot does not fall on the protective limit plate, which fails to meet the harvesting standard for a stalk with an excessively long stem. Therefore, it is vital to study and determine the stalk structure and working parameters.

As shown in Figure 5, a physical model was established of a stalk within the rollers, and the stalk was subjected to mechanical analysis. The roller assembly moves synchronously with the harvester and has an adjustable inclination angle to the ground. The header serves as the horizontal plane in the model.

The stem experiences pressure from the roller and moves continuously. The displacement equation is

$$y = \pi d_y \frac{w_y t_y}{2\pi} = d_y \frac{w_y t_y}{2} \tag{1}$$

The velocity equation is derived from Equation (1) as,

$$v_y = \frac{\mathrm{d}y}{\mathrm{d}t} = d_y \frac{w_y}{2} \tag{2}$$

where, y is the length from the bottom to the top of the stem after the reciprocating cutter cuts the stem, mm; d_y is the diameter of the rollers, mm; w_y is the angular velocity of the roller, rad/s; and t_y is the time it takes for the stalk to fall on the protective limit plate, s. By analyzing the motion of the stem under the action of the roller, t_y is obtained.

Next, a mechanical analysis of the stems is performed, and the vertical movement of the protection limit plate is described as follows:

$$m\frac{\mathrm{d}^2 y}{\mathrm{d}t^2} = m\frac{\mathrm{d}v_y}{\mathrm{d}t} = F_y = mg\cos\alpha - \mu F_N \tag{3}$$

$$F_N = F_n = mv_y^2 r_y = mv_y^2 \frac{d_y}{2} \tag{4}$$

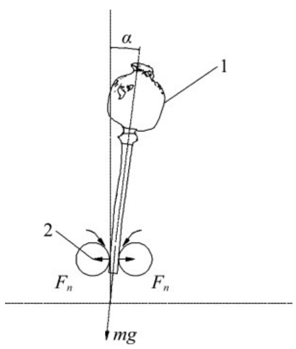
where, g is the acceleration due to gravity, mm/s^2; α is the header inclination angle, (°); μ is the coefficient of friction between the stalk and counter roller; F_N is the pressure applied to the stalk by the roller, N; and F_n is the centripetal force of the roller, N.

According to the force analysis, if the stem knot falls directly in the middle of the protective limit plate, then the force in the direction of the vertical protective limit plate that can break the stem knot is avoided.

$$F_{f\ stem\ knot} > mg\cos\alpha - \mu mv_y^2 \frac{d_y}{2} \tag{5}$$

where, $F_{f\,stem\,knot}$ is the tension at the stem, N.

Mechanical analysis of the stem reveals that the factors affecting the transport of the knot to the tail of the protective limit plate are the chain speed, the angle of the header, the pressure applied to the stem by the roller, and the angular velocity of the roller.



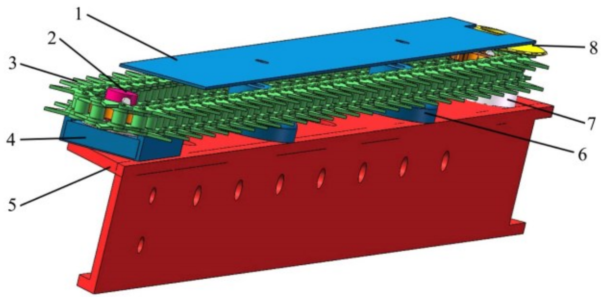
1. Plant stem 2. Pair of rollers

Figure 5 Analysis of the stress on the stem from the action of the rollers

3.3 Clamping chain

The clamping chain uses the gap between the sprockets to hold the stem and axially transports the stalk to the tail of the clamping chain, where the stalk is cut by a disc cutter to complete the harvesting process.

The clamping chain structure, which consists of two parts, is shown in Figure 6. The left clamping chain is mainly composed of the following parts: a protection limit plate, a clamping chain shaft, a clamping chain, a front-end spacing adjuster, a support plate, a drag chain wheel, a bearing seat, and a circle plate cutter.



1. Protection limit plate 2. Clamping chain shaft 3. Clamping chain 4. Front end spacing adjuster 5. Support plate 6. Drag sprocket 7. Bearing seat 8. Disc knife

Figure 6 Structural diagram of the clamping chain

In this study, the distance between the centers of the clamping sprockets is 940 mm, the pitch of the clamping chain is 15.875 mm, and the clearance of the protective limit plate is 20 mm.

To determine the optimal working parameters of the clamping chain in the SCHM harvester, the movement of the stem in the clamping chain is analyzed, and mechanical analysis of the stem during harvesting is carried out. The structural parameters of the clamping chain directly affect the movement of the stalk in the harvester, thereby affecting the harvesting efficiency. If the clamping chain moves too fast, then the stem knot does not consistently fall onto the protective limit plate, resulting in a long stem length after harvest. In contrast, if the clamping chain moves too slowly, then the harvesting efficiency is low.

A physical model of the stalk and the mechanical analysis of the stalk are depicted in Figure 7. The clamping chain moves synchronously with the harvester. The harvester has an adjustable inclination angle to the ground. The model is built with the header as the horizontal plane.

The stem is subjected to the pulling force of the clamping chain and moves continuously. The displacement equation is,

$$x = \pi d_x \frac{w_x t_x}{2\pi} + v_1 t_x = d_x \frac{w_x t_x}{2} + v_1 t_x \tag{6}$$

The velocity equation is derived from Equation (6) as

$$v_x = \frac{\mathrm{d}x}{\mathrm{d}t} = d_x \frac{w_x}{2} + v_1 \tag{7}$$

$$v_{x1} = d_x \frac{w_x}{2} \tag{8}$$

where, x is the protection limit plate length, mm; d_x is the indexing sprocket diameter, mm; w_x is the sprocket angular velocity, rad/s; t_x is the time required for the stem to move to the tail of the protective limit plate, s; v_1 is the forward harvester speed, m/s; and v_{x1} is the clamping sprocket linear velocity, m/s.

By analyzing the motion of the stem under the clamping chain, the time required for the stalk to be transported to the tail of the protective limit plate, t_x, is obtained.

At the same time, mechanical analysis of the stem is carried out along the direction of the protective limit plate.

$$m\frac{\mathrm{d}^2x}{\mathrm{d}t^2}=m\frac{\mathrm{d}v_x}{\mathrm{d}t}=F_x=F_c+F_f \tag{9}$$

$$F_c=qv^2 \tag{10}$$

$$F_f=K_f qga \tag{11}$$

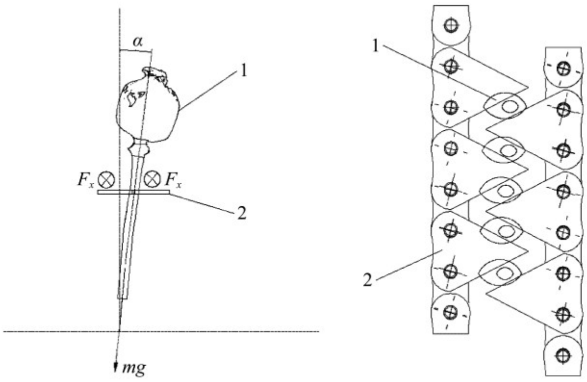
where, m is the stalk mass, g; F_c is the centrifugal tension, N; q is the chain mass per unit length, kg/m; v is the chain speed, m/s; F_f is the dip tension, N; K_f is the sag coefficient; g is the acceleration due to gravity, mm/s^2; and a is the chain drive center distance, mm.

According to the force analysis, if the stem knot falls directly on the protection limit plate and moves to the middle of the plate without being cut by the shearing force along the direction of the protection limit plate, the following correlation needs to be satisfied.

$$F_{\tau\ stem\ knot}>qv^2+K_f qga \tag{12}$$

where, $F_{\tau\ stem\ knot}$ is the shearing force at the stem junction, N.

According to the kinetic analysis of the stem, the factors affecting the landing of the stem on the protective limit plate are the sprocket angular velocity and the counter roller angular velocity.



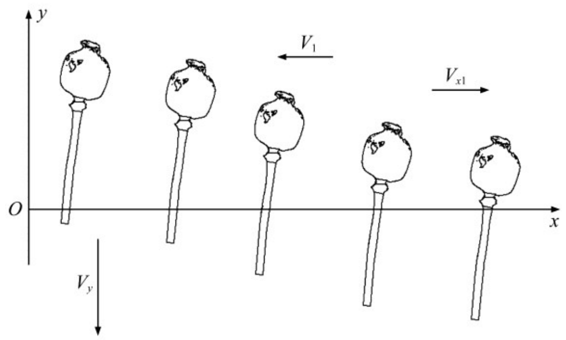
a. Schematic diagram b. Top view

1. Plant stem 2. Clamping chain

Figure 7 Analysis of stress on a stem from the action of the clamping chain

4 Analysis of stalk movement characteristics

Take the front-end of the protective limit plate as the origin (O), the direction of the protection limit plate as the X-axis, and the direction perpendicular to the limit guard as the Y-axis. The stalk has a certain inclination angle to the protection limit plate, and the inclination angle is the header inclination angle. A kinetic analysis model is established for the stalk, as shown in Figure 8. The stalk continuously moves under the tension of the clamping chain and the pressure from the roller.



Note: V_1 is the harvester working direction, V_{x1} is the clamping chain running direction, and V_y is the direction of roller rotation.

Figure 8 Analysis of stem movement

According to the analysis of the motion characteristics, if the stem moves to the tail of the harvester, the stem is located on the protective limit plate, and its correlation needs to satisfy $t_y>t_x$.

The stem knot is located on the protective limit plate, which enables the disc cutter to cut the stem at a position close to the stem knot and harvest the capsule while meeting the harvesting requirements for the capsule.

The analysis of stalk movement revealed that the factors affecting the stems falling onto the protective limit plate are the sprocket angular velocity and the counter roller angular velocity, whereas the factors affecting the transport of the stems to the tail of the protective limit plate are the chain speed, the inclination of the header, the pressure applied to the stalk by the roller, and the angular velocity of the roller. Therefore, the sprocket rotation speed, header inclination angle, and roller gap are important factors in the harvesting of this SCHM.

5 Field trials

5.1 Test conditions and methods

This study was conducted in the planting base of special medicinal materials. The test time was from July 11 to July 22, 2021. The test object was SCHM.

Test device: the SCHM harvester is shown in Figure 9. The field operation is shown in Figure 10.

Figure 9 Chain harvester for SCHMs

a. Field test

b. Harvest yield

c. Postharvest residual stems

Figure 10 Harvesting experiment

The plant variety used in the field trial is Baihua No. 1, selected by the 5-point sampling method, and 5 plants are taken for measurement at each sampling point. The main physical parameters of the collected plants are shown in Table 2.

Table 2 Parameters of the SCHM

Parameter	Value
Ridge height/cm	4.70
Ridge distance/cm	156.20
Plant spacing/cm	13.40
Line spacing/cm	20.82
Capsule weight/g	7.00
Stem height/mm	8.60
Stem diameter/mm	4.85-9.80
Height of plant/cm	107.24-113.20
Height of the fork/cm	40.12-44.48
Height from the ground/cm	102.74-108.70
Number of capsules per plant	2.36
Capsule (approximate ellipsoid) radius/mm	40.06
Distance of the side of the fruit from the stalk/cm	3.09-4.73
Capsule (approximate ellipsoid) center distance/mm	41.94

In the test, the proportion of lost fruit, the proportion of damaged capsules, and the length of the retained stem are taken as the test indexes. The proportion of lost fruit is expressed as:

$$S_L = \frac{W_L}{W_K} \times 100\% \tag{13}$$

where, S_L is the proportion of lost fruit, %; W_L is the number of unharvested capsules; and W_K is the total number of capsules in the measurement area.

The proportion of broken fruit is expressed as:

$$Z_S = \frac{W_S}{W_Z} \times 100\% \tag{14}$$

where, Z_S is the proportion of broken capsules, %; W_S is the number of damaged fruits; and W_Z is the number of harvested fruits.

The proportion of stalks with an acceptable length is expressed as

$$Q_I = \frac{W_B}{W_Z} \times 100\% \tag{15}$$

where, Q_I is the proportion of stalks with an acceptable length, %, and W_B is the number of stems less than 2 cm in length.

5.2 Test plan and results

Analysis of the kinetic characteristics of the stalk revealed that if the clamping chain moves too fast, then the stem knot does not consistently fall onto the protective limit plate, resulting in a long stem length after harvesting. In contrast, if the clamping chain moves too slowly, then the stem is unlikely to be captured. If the angle of the header is too large, then the harvested stalks may be too long. If the angle of the header is too small, then the capsule may be damaged. If the gap between the rollers is too large, then stem clamping may fail. If the gap between the rollers is too small, then the axial movement of the stem (*X*-axis) may be hindered.

Therefore, the sprocket rotation speed, roller gap, and header inclination angle are selected as experimental factors, and the effects on the proportions of lost fruit, broken capsules, and retained stems with an acceptable length are analyzed. According to the speed of the critical clamping sprocket for successful grasping of the stalk, the sprocket rotation speed interval is set to 90-130 r/min during the test. Taking the minimum diameter of the stalk in the test area as 4.85 mm and the maximum diameter of the stalk as 9.8 mm, the space between the rollers is set to 7-9 mm during the test. Considering the minimum plant height of 107.24 cm and the maximum plant height of 113.2 cm in the test area, the inclination angle of the header is set to 5°-15°. To find the optimal combination of parameters for the SCHM harvester, three levels of values are considered for the sprocket rotation speed, the roller gap, and the header inclination angle. The factors and levels are shown in Table 2. An orthogonal test is carried out by referring to the L9 (3^3) table[24,25]; the number of test groups N=9, and each group of experiments is repeated 3 times. The average of 3 tests is considered the test result for each group. Therefore, the proportion of lost fruit, the proportion of broken capsules, and the proportion of retained stems with an acceptable length are obtained for each group. The test results are shown in Table 3, where A, B, and C are the factor levels.

Table 3 Factors and levels

Level	Sprocket speed A /r·min^{-1}	Roller gap B /mm	Header inclination angle C/(°)
1	90	7	5
2	110	8	10
3	130	9	15

5.3 Test results and analysis

5.3.1 Range analysis

To obtain the best combination of parameters, the experimental results are subjected to a range analysis, the results of which are shown in Table 4. The effect of the sprocket rotation speed, roller gap, and header inclination angle on the harvesting efficiency is shown in Figure 11. The greater the difference between the tested factors is, the greater the influence of those factors on the test indicators.

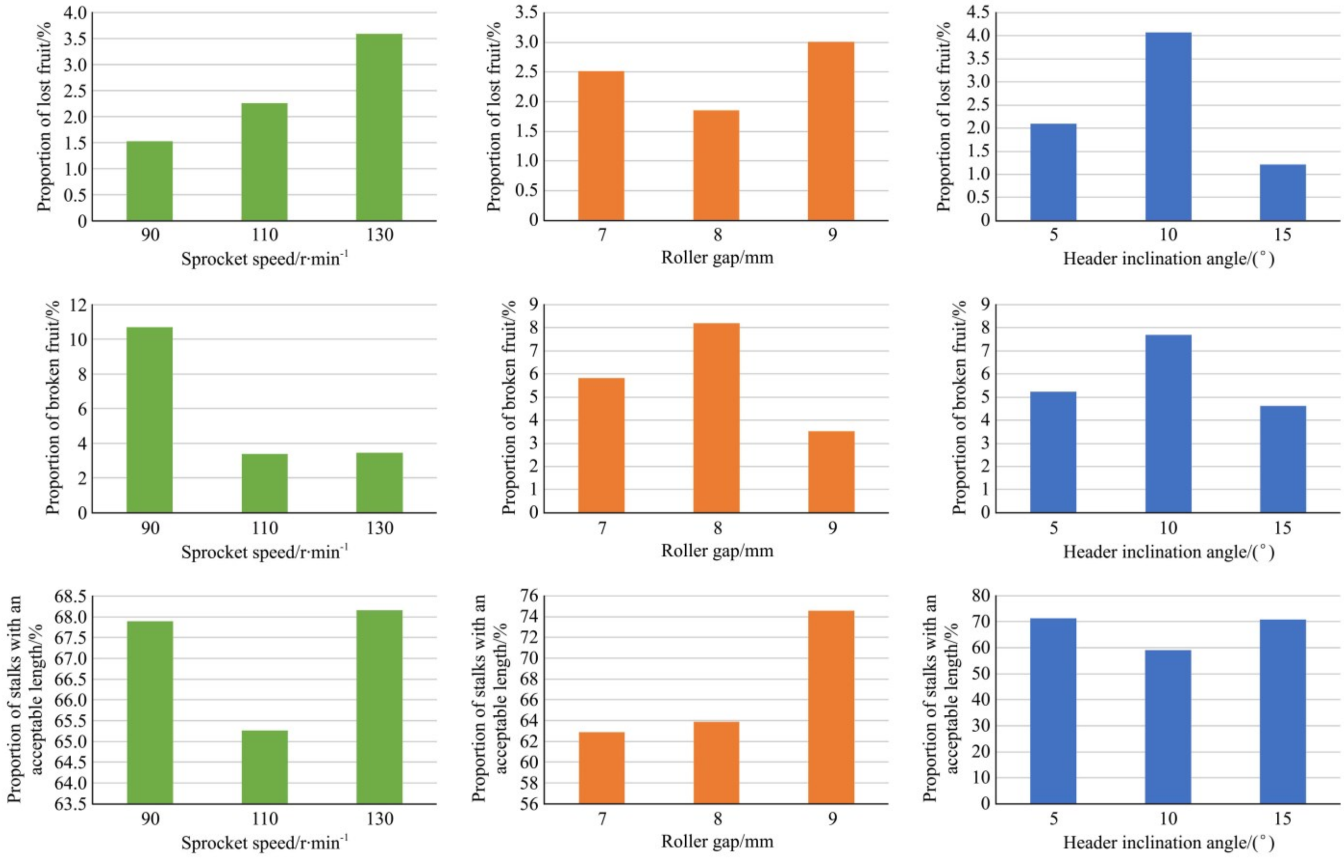
Table 4 Test plans and results

No.	A	B	C	Proportion of lost fruit/%	Proportion of broken fruit /%	Proportion of stalks with an acceptable length/%
1	1	1	1	2.14	9.46	61.20
2	1	2	2	1.21	15.42	62.08
3	1	3	3	1.23	7.17	80.40
4	2	1	2	4.32	5.23	54.24
5	2	2	3	1.32	3.92	59.12
6	2	3	1	1.14	1.02	82.45
7	3	1	3	1.07	2.78	73.15
8	3	2	1	3.03	5.22	70.43
9	3	3	2	6.67	2.38	60.90

5.3.2 Analysis of variance

The variance in the test results is analyzed, and the results are shown in Table 5. The sprocket rotation speed, roller gap, and header inclination have different effects on the harvesting efficiency. The sprocket rotation speed has a significant effect on the proportion of broken capsules but little effect on the proportion of lost fruit and the proportion of stalks with an acceptable length. The roller gap has a significant effect on the proportion of broken capsules but little effect on the proportion of lost fruit and the proportion of stalks with an acceptable length. The header inclination angle has a significant effect on the proportion of broken capsules but little effect on the proportion of lost fruit and the proportion of stalks with an acceptable length.

The influences of the three factors on the proportion of lost fruit were in descending order as C, B, and A. The proportion of lost fruit is positively correlated with the sprocket speed. The faster the sprocket rotates, the less likely it is for the stalk to be clamped in time. In this case, the stalk is pushed down during the forward movement of the header, and the stalk fails to enter the cutting header. Consequently, the capsule is not harvested. The test results reveal that the optimal parameter combination to minimize the proportion of lost fruit is C3A1B2.



a. Sprocket speed b. Roller gap c. Header inclination angle

Figure 11 Effects of different test indicators on harvesting performance

Table 5 Analysis of the range of each test indicator

Performance		Factor		
		A	B	C
Proportion of lost fruit	K1	1.53	2.51	2.10
	K2	2.26	1.85	4.07
	K3	3.59	3.01	1.21
	Rj	2.063	1.16	2.86
Proportion of broken fruit	K1	10.68	5.82	5.23
	K2	3.39	8.19	7.68
	K3	3.46	3.52	4.62
	Rj	7.29	4.66	3.05
Proportion of stalks with an acceptable length	K1	67.89	62.86	71.36
	K2	65.27	63.88	59.07
	K3	68.16	74.58	70.89
	Rj	2.89	11.72	12.28

The influences of the three factors on the proportion of broken capsules were in descending order of A, B, and C. The test results reveal that the optimal parameter combination to minimize the proportion of damaged capsules is A2B3C3.

The influences of the three factors on the proportion of stalks with an acceptable length were in descending order of C, B, and A. The proportion of stalks with an acceptable length is positively correlated with the roller gap. The roller gap can directly affect the movement of the stalk. If the gap between the rollers is too small, then the stem does not easily enter the roller pair. If the gap between the rollers is too large, then the stems enter the pair of rollers, but the effect of the rollers on the stems is reduced. The test results reveal that the optimal parameter combination for stem retention is C1B3A3.

The influence of each test factor on the harvesting efficiency and the optimal parameter combination is determined based on the analysis of the test data ranges and variance and by comprehensive consideration of the influences of the three factors on the primary and secondary influences. For a low proportion of damaged capsules, a low proportion of lost fruit, and a high retained stem length, A2B3C1 is determined as the optimal combination, which corresponds to a sprocket rotation speed of 110 r/min, a counter roller gap of 9 mm, and a header inclination angle of 5°. With these settings, the proportion of lost fruit was 1.14%, the proportion of broken fruit was 1.02%, and the proportion of stalks with an acceptable length was 82.45%, which can meet the design requirements.

Table 6 Variance analysis results

Test indicator	Source of variance	Squared sum of dispersion	Degrees of freedom	F	Significance
Proportion of lost fruit	A	6.56	2	0.798	
	B	2.03	2	0.247	
	C	12.84	2	1.560	
	Error column	8.23	2		
Proportion of broken fruit	A	110.61	2	52.713	**
	B	37.59	2	16.319	*
	C	17.14	2	7.836	*
	Error column	1.08	2		
Proportion of stalks with an acceptable length	A	15.31	2	0.067	
	B	253.02	2	1.107	
	C	290.82	2	1.272	
	Error column	228.57	2		

Note: * indicates that the impact is significant and ** indicates that the impact is extremely significant.

6 Conclusions

This study presents a design for a special Chinese herbal medicine harvester. A dynamic model of the stalk was established under the condition of the harvester's operation. Harvesting was primarily influenced by sprocket rotation speed, header inclination angle, and roller gap. Based on orthogonal testing with the harvester, the optimal parameter combination was obtained as the sprocket rotation speed of 110 r/min, roller gap of 9 mm, and header inclination angle of 5°. With these settings, the proportion of lost fruit was 1.14%, the proportion of broken capsules was 1.02%, and the proportion of stalks with an acceptable length was 82.45%, which could satisfy the design requirements.

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