Design and Experimental Study on Belt-Tooth Type Collector for Potato Film Residues

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Abstract. At present, collectors for potato film residues in China are mainly used to pick up film residues after the harvest of potatoes, during which the pick-up rate of film residues and the work efficiency are low. Aiming at the above problems, a belt-tooth type collector for potato film residues installed on 4UM-1000 potato harvester was designed. It is mainly composed of a film picking device, a film transport device, a film collecting device and an installation frame. It can realize the harvest of potatoes and pick-up of film residues at the same time. The pick-up rate of film residues and potato damage rate are taken as response indicators. Through single factor test, the optimal combination of structural parameters of film picking teeth was obtained as below: the number in the horizontal direction is 4, the longitudinal space is 300mm, the length is 130mm, and picking teeth are arranged in a non-staggered way. Experiments were designed by using the response surface methodology (RSM). The optimal working parameters of the machine are determined as below: the forward speed is 2.66km/h, the rotation speed of the driving shaft is 89.63r/min and the rotation speed of the conveyor chain shaft is 184.17r/min. Field experiments were carried out to verify the above results, where the verified pick-up rate of film residues and potato damage rate were 90.29% and 4.72% respectively, both of which met design requirements of technical specifications.

1. Introduction

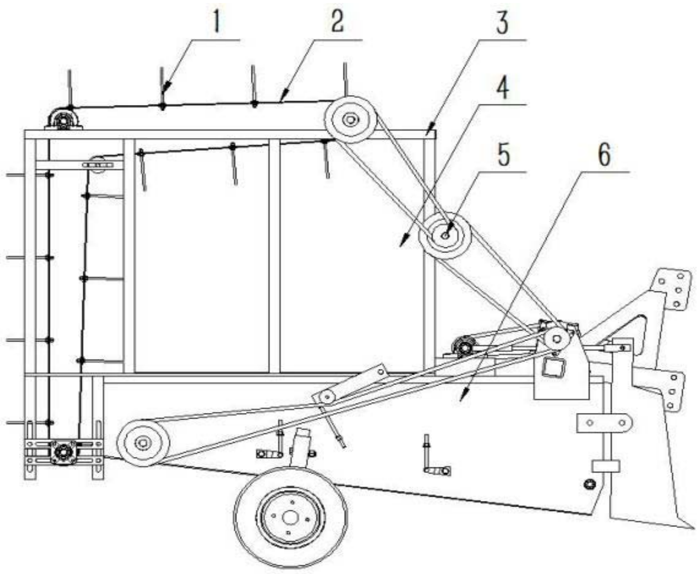
In the 1950s, the plastics industry began to develop and various types of plastic films came into being [1], peasants place films over soil in fields for they can increase and maintain the temperature at the same time prevent and control diseases, insect pests and weeds. In the 1970s, this technology was introduced into China from Japan and was firstly popularized in Jilin Province and local areas. According to the statistics, up to 2014, the usage amount of mulching films throughout the country reached 1.4414 million, and the area covered by films reached 18.1402 million hm^2[2]. Over the past 40 years, the usage amount of agricultural mulching films and film covering area in China have been the first in the world. The significant role played by this technology during agricultural planting in Chinese dry land is rated as a “white revolution” [3-4].

At present, most field mulching films are made of polyethylene (PE) or polyvinyl chloride (PVC) which normally takes 100-300 years to degrade in soil [5-7]. These film residues remaining in the soil for a long time may influence soil structure, reduce soil fertility, influence the growth and development of crop roots and lower the ability of crop roots to absorbing nutrients, thus reducing the output of crops. The “white revolution” has now turned into “white pollution” [8].

Currently, the types of collectors for potato film residues in China are mainly as follows [9-14]: collectors for earth-surface potato film residues, collecting devices for potato mulching film residues, chain-type collectors for potato film residues, and combined machines for potato digging and film residues recovering. But the pick-up rate of film residues realized by them is low, and the harvest of potatoes and recovering of film residues cannot be completed at the same time. Therefore, focusing on the above problems, a belt-tooth type film residues collector was designed. This device can match 4UM-1000 potato harvester, and the combination of the two can realize simultaneous picking of film residues and the harvest of potatoes. During the design process, the structural parameters of the film picking device and working parameters of the entire machine were determined, then, a field test was carried out for the finished model machine, providing test results meeting design requirements. Advantages of this type: easy to disassemble, high working efficiency, high pick-up rate of film residues, low potato damage rate and convenient film unloading.

1.1. Overall Structural Design [15]

The structure diagram of the potato residual film recovery machine is shown in Figure 1. The physical picture is shown in Figure 2. It is mainly composed of the membrane picking device, the film feeding device, the mounting frame, the film collecting device, the power transmission device and the 4UM-1000 potato harvester.



1. Film picking device 2. Film transport device 3. Installation frame
4. UM-1000 potato harvester 5. Film collecting device 6. The 4UM-1000 potato harvester

Figure 1. Structure diagram of belt-teeth type plastic film collector for potato

1. The membrane picking device 2. The film feeding device 3. The mounting frame
4. The 4UM-1000 potato harvester 5. The film collecting device

Figure 2. Picture of a real belt-tooth collector for potato film residues

1.2. Design of Main Parts

(1) Film picking and transport device

The film picking and transport device is mainly composed of film picking teeth and film collecting belts, the length, space and arrangement of film picking teeth are key elements which influence the effect of film residue picking. The structure and installation of film picking teeth are shown in Fig.3.

Figure 3. Installation diagram for film picking teeth

Film picking teeth and film collecting belts are connected with bolts. Film picking teeth are fixed on film collecting belts in rows. In order to prevent bolt loosening, large small-hole spacers shall be installed at both sides of round holes. Besides, film residues shall be guaranteed to smoothly slide from film picking teeth down to film collecting tanks; film residues caught by burr shall be prevented, and welding points and the surface of film picking teeth shall be polished smooth.

(2) Operation mode of film collecting belts

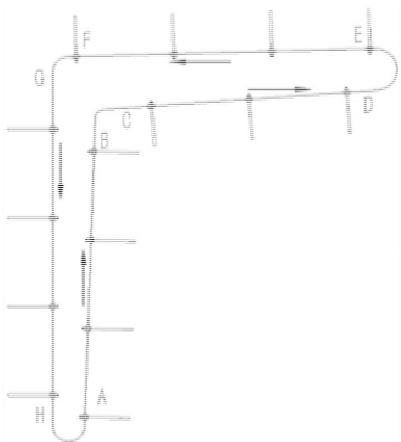


Figure 4. Structure and Operation Mode of Film Collecting Belts

The structure and operation mode of film collecting belts are shown in Fig.4. The overall film collecting belt is in the shape of L and the direction of arrow shows its operation direction. Potatoes, soil block and film residues firstly fall out of the tail of potato harvester to film picking teeth. Since potatoes and soil blocks are relatively large in mass and have an irregular spherical shape, the force supplied by film picking teeth is not enough to support them to continuously move upward, therefore potatoes and soil blocks will fall onto the ground. On the other hand, film residues are relatively light and have a long striped shape, and therefore they will be hung on film picking teeth before continuously moving upward with film picking teeth at AB section. Then, under the action of supporting wheels at BC section, the vertical movement of film picking teeth at AB section will be turned into approximately horizontal movement at CD section; since the surface of film picking teeth is relatively smooth, film residues will fall into film collecting tanks set below CD section under the action of gravity.

During the falling process, some potatoes will inevitably collide with film picking teeth, and therefore suffer surface damage, which generating the potato damage rate. In addition, the structural parameters of film picking teeth will influence the pick-up efficiency of film residues; therefore, in the paper, the effect of all parameters of film picking teeth on potato damage rate and pick-up rate of film residues was researched through single factor test; through analyses and comparisons of the test results, the optimal structural parameters of film picking teeth were determined, in order to obtain the minimum potato damage rate and the maximum pick-up rate of film residues.

(3) Film collecting device

The film collecting device is mainly used to collect film residues; its structure is shown in Fig.2. It can be discovered through observation that among the six planes of film collecting tanks, only the right one is uncovered; therefore, this plane was designed into two doors which can be opened and closed freely, when film collecting tanks are filled up with film residues, the doors can be opened for operation like bagging of film residues, then, the collection of film residues can be continued after closing the doors.

2. Parameter Determination of Main Components

2.1. Determination of Response Indicators

Main functions of collectors for potato film residues are the picking of film residues and the harvest of potatoes; response indicators selected in the Paper are mainly the pick-up rate of film residues and the potato damage rate.

(1) Pick-up rate of film residues

$$C_1 = \frac{M_0}{M} \times 100\%$$

Where, C_1 refers to the pick-up rate of film residues; M_0 refers to the mass of film residues picked, and M refers to the total mass of film residues.

(2) Potato damage rate

$$C_2 = \frac{W_0}{W} \times 100\%$$

Where, C_2 refers to the potato damage rate; W_0 refers to the mass of potatoes with damaged surface in potatoes picked, and W refers to the total mass of potatoes picked by the machine.

2.2. Determination of Test Factors

The structural parameters of film picking teeth determined in the test include the horizontal number, longitudinal space, arrangement mode, and length of film picking teeth. According to previous researches [16-23], it can be discovered that factors influencing the pick-up rate of film residues and potato damage rate include not only the structural parameters but also the working parameters of the machine. Therefore, the working parameters selected this time mainly include the forward speed, the rotation speed of the driving shaft, and the rotation speed of the conveyor chain shaft of the machine. In this test, structural parameters were determined through single factor test firstly, and then experiments were designed by using RSM, and working parameters were determined and optimized.

2.3. Determination of Structural Parameters

The value range of each parameter is shown in Table 1.

Table 1. Value Range of Structural Parameters in Single Factor Test

Factor		Test conditions
Horizontal number	3 4 5	The forward speed of the machine is 3 km/h; the rotation speed of the driving shaft is 90r/min; the rotation speed of the conveyor chain shaft is 180r/min; the longitudinal space is 300mm; the length is 130mm; and the arrangement mode is non-staggered
Longitudinal space (mm)	250 300 350	The forward speed of the machine is 3 km/h; the rotation speed of the driving shaft is 90r/min; the rotation speed of the conveyor chain shaft is 180r/min; the horizontal number is 4; the length is 130mm; and the arrangement mode is non-staggered
Length (mm)	110 130 150	The forward speed of the machine is 3 km/h; the rotation speed of the driving shaft is 90r/min; the rotation speed of the conveyor chain shaft is 180r/min; the horizontal number is 4; the longitudinal space is 300mm; and the arrangement mode is non-staggered
Arrangement	Staggered Non-staggered	The forward speed of the machine is 3 km/h; the rotation speed of the driving shaft is 90r/min; the rotation speed of the conveyor chain shaft is 180r/min; the horizontal number is 4; the longitudinal space is 300mm; and the length is 130mm

In this single factor test, the values of working parameters were temporarily set as: the forward speed of the machine is 3 km/h; the rotation speed of the driving shaft is 90r/min; and the rotation speed of the conveyor chain shaft is 180r/min. Test results are shown in Fig.5, Fig.6, Fig.7 and Fig.8.

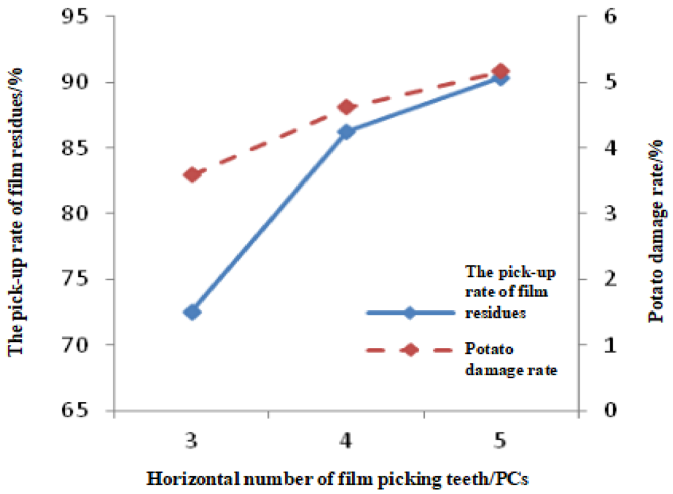


Figure 5. Influence of the Horizontal Number of Film Picking Teeth on Response Indicators

As shown in the above figure, we can see that both the pick-up rate of film residues and potato damage rate increase with the increase of the horizontal number of film picking teeth; according to analysis, the main reason is as follows: when the horizontal number of film picking teeth increases, the density of film picking teeth also increase, and therefore film residues falling out of the tail of potato harvester are more easily to be caught by film picking teeth, thus improving the pick-up rate of film residues. However, with the increase of the number of film picking teeth, the possibility for potatoes to contact with film picking teeth also increase, which means that more potatoes will be impacted by film picking teeth, leading to the increase of potato damage rate at last. According to a comprehensive analysis of the influence on the pick-up rate of film residues and potato damage rate, the horizontal number of film picking teeth was finally selected to be 4.

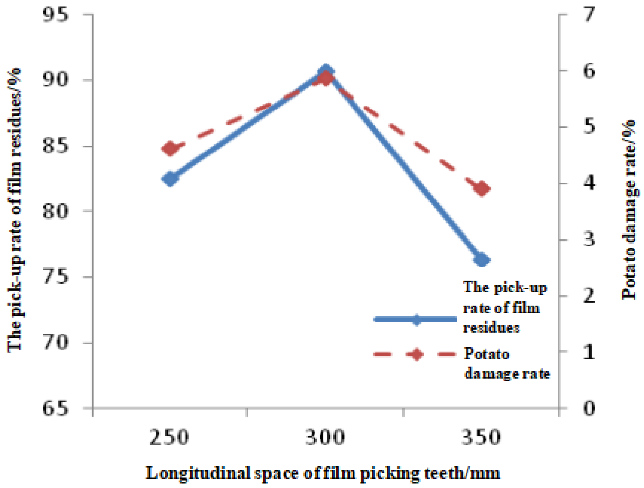


Figure 6. Influence of the Longitudinal Space of Film Picking Teeth on Response Indicators

Through observing the line graph generated from test data, we can find out that with the increase of the longitudinal space of film picking teeth, the pick-up rate of film residues increases firstly and then decreases after reaching a certain value; the potato damage rate shows a similar trend. Main reason to this: when film picking teeth are too dense in the longitudinal direction, film residues may be caught by more than one film picking tooth at the same time, and then fall off during the moving process of film collecting belts, leading to a lower pick-up rate of film residues. When the longitudinal space of film picking teeth is increased to a proper extent, the possibility for film residues to fall on film picking teeth increase, and therefore the pick-up rate of film residues also increase. However, in case the longitudinal space of film picking teeth becomes too large, some film residues will not be caught by the former row of film picking teeth during the movement and then fall off; due to a too large space of film picking teeth, before film residues falling onto the ground, the next row of film picking teeth cannot reach the position for picking film residues, and therefore cannot pick up film residues before they falling onto the ground, leading to the reduction of the pick-up rate of film residues. As for potato damage rate, in case the longitudinal space is too small, some larger potatoes may not fall on film picking teeth, and therefore the potato damage rate is not high. However, when the space is increased, more potatoes will fall on film picking teeth, increasing the potato damage rate. When the space is excessively large, within the gap between the former row of film picking teeth and the later row, many potatoes will fall onto the ground due to no resistance of film picking teeth, thus reducing the potato damage rate. After considering the above reasons and test results, the longitudinal space of film picking teeth was finally selected to be 300mm.

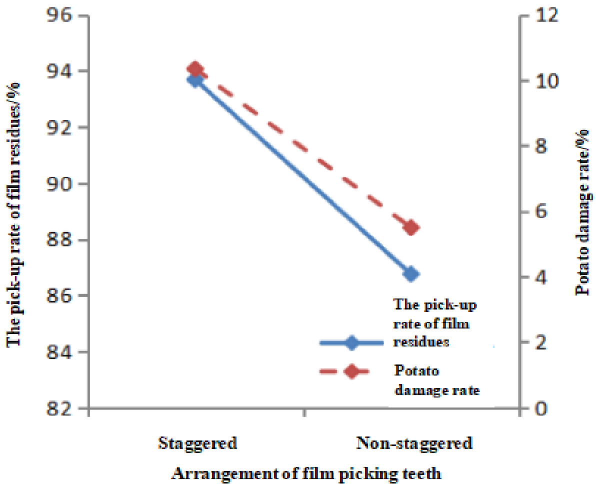


Figure 7. Influence of the Arrangement of Film Picking Teeth on Response Indicators

According to the line graph generated from test data, we can see that the pick-up rate of film residues is higher with staggered film picking teeth compared to the rate under non-staggered film picking teeth, which is mainly because that the dense of film picking teeth is larger under non-staggered mode and is nearly two times of the dense of single-row arrangement, suggesting that film residues not picked up by the first row of film picking teeth will be picked up by the second row of staggered film picking teeth; therefore, the pick-up rate of film residues will become relatively high. However, with the increase of the arrangement dense, the possibility for potatoes to contact with film picking teeth will increase, which means more potatoes will fall on film picking teeth, thus increasing the potato damage rate; for these reasons, it is required to find a best balance point between the pick-up rate of film residues and potato damage rate; after many comparisons, the arrangement mode of film picking teeth was finally selected as non-staggered mode.

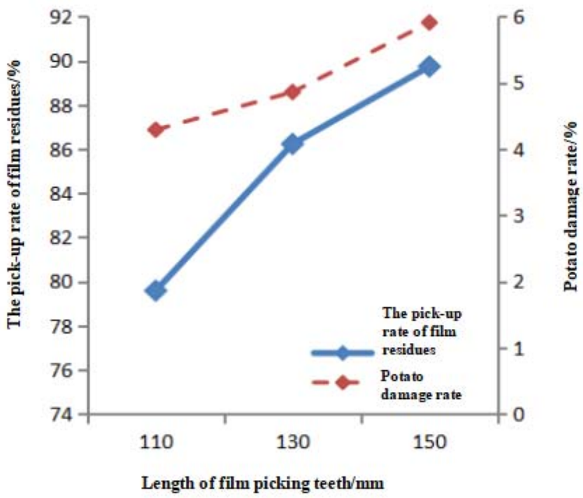


Figure 8. Influence of the Length of Film Picking Teeth on Response Indicators

We can see from the line graph that both the pick-up rate of film residues and potato damage rate increase with the increase of the length of film picking teeth; according to analyses, the reason may be that during the rising process of film residues after being picked up, film residues may slide up and down along film picking teeth; in case film picking teeth are short, due to the vibration generated during the movement of film collecting belt, some film residues picked will fall off during the rising process, thus reducing the pick-up rate of film residues. However, with the lengthening of film picking teeth, some film residues will not fall off completely during the slide-sown process, and the pick-up rate of film residues will not be influenced; therefore, the trend shown in the above line graph will occur. As for potatoes, with the increase of the length of film picking teeth, the contact area between potatoes and film picking teeth during the rising process will increase, thus increasing the potato damaging rate, as shown in the above graph. After many comparisons and analyses, the length of film picking teeth was selected as 130mm.

2.4. Determination of Working Parameters

Software Design Expert8.0 was used to design the test; the principle adopted is BBD (Box-Behnken Design); the test designed is three-factor and three-level test [24-25]. After the test was completed, the response surface methodology was used to analyze and optimize, so as to obtain the optimal combination of working parameters.

2.4.1. Table for test factors and levels

Table 2. Table for Test Factors and Levels

Factor	Level		
	-1	0	1
A: Forward speed of the machine (km/h)	2.5	3	3.5
B: Rotation speed of the driving shaft (r/min)	80	90	100
C: Rotation speed of the conveyor chain shaft (r/min)	150	180	210

2.4.2. Test results. The BBD method is used to design the test, 17 groups of test were carried out in total, each group had been repeated for 3 times, test results were shown in mean values; errors were minimized. Test results are shown in Table

Table 3. Scheme and Results of Response Surface Test

Test No.	Forward speed of the machine (km/h)	Rotation speed of the driving shaft (r/min)	Rotation speed of the conveyor chain shaft (r/min)	Pick-up rate of film residues (%)	Potato damage rate (%)	Z value
1	2.50	80.00	180.00	88.21	3.81	84.4
2	3.00	80.00	150.00	85.25	3.87	81.38
3	3.50	100.00	180.00	81.73	4.54	77.19
4	3.50	80.00	180.00	86.59	5.14	81.45
5	3.50	90.00	210.00	85.43	5.13	80.3
6	3.00	80.00	210.00	87.28	5.22	82.06
7	2.50	90.00	210.00	90.12	3.26	86.86
8	2.50	100.00	180.00	88.24	3.52	84.72
9	3.00	90.00	180.00	91.92	5.37	86.55
10	3.00	100.00	150.00	82.51	4.03	78.48
11	3.00	90.00	180.00	94.21	5.22	88.99
12	3.00	90.00	180.00	95.17	5.52	89.65
13	3.50	90.00	150.00	81.05	4.87	76.18
14	2.50	90.00	150.00	87.14	3.23	83.91
15	3.00	90.00	180.00	92.08	5.15	86.93
16	3.00	90.00	180.00	93.24	5.17	88.07
17	3.00	100.00	210.00	84.59	4.22	80.37

2.4.3. Analysis of test results. The objective functions designed in the test are 2, namely the pick-up rate of film residues and potato damage rate; the optimal result of this test is to be a set of parameters which guarantee a pick-up rate of film residues as large as possible and a potato damage rate as small as possible at the same time. In order to make the optimization results more visualized and reliable, through weighted assignment, the two objective functions were turned into single-objective dimensionless functions. According to empirical analysis, the pick-up rate of film residues and potato damage rate were of similar importance, and therefore the weights of the two were 1, set Z value to make $Z=C_1-C_2$, measure the test results as per the value of Z, and then the group of data obtained when Z is the largest will be the optimal results.

Where, C_1 refers to the pick-up rate of film residues and C_2 refers to the potato damage rate.

(1) Regression analysis of the pick-up rate of film residues

Through multiple regression fitting of the above results by using software, the regression equation of the pick-up rate of film residues with respect to the forward speed of the machine, the rotation speed of the driving shaft and the rotation speed of the conveyor chain shaft was obtained, as shown in equation 1.

$$C_1=-538.74+86.33A+7.94B+1.71C-0.245AB+0.023AC-0.000042BC-12.21A^2-0.041B^2-0.0048C^2 \quad (1)$$

Where, C_1 refers to the pick-up rate of film residues; A refers to the forward speed of the machine; B refers to the rotation speed of the driving shaft; and C refers to the rotation speed of the conveyor chain shaft.

A variance analysis was carried out for the above mentioned regression equation, as shown in Table 4, so as to determine whether the influence of each factor on the test results is significant or not and then to obtain a new fitting equation.

Table 4. Variance Analysis on the Regression Equation of the Pick-up Rate of Film Residues

Variance source	Quadratic sum S	Degree of freedom f	Mean sum of square S	F value	p value	Significance
Factor influence	290.78	9	32.31	22.70	0.0002	Extremely significant
A	44.70	1	44.70	31.41	0.0008	Extremely significant
B	13.16	1	13.16	9.25	0.0188	Significant
C	16.45	1	16.45	11.56	0.0115	Significant
AB	5.98	1	5.98	4.20	0.0796	Non-significant
AC	0.49	1	0.49	0.34	0.5758	Non-significant
BC	6.25×10-4	1	6.25×10-4	4.39×10-4	0.9839	Non-significant
A2	39.22	1	39.22	27.56	0.0012	Extremely significant
B2	70.07	1	70.07	49.24	0.0002	Extremely significant
C2	79.20	1	79.20	55.65	0.0001	Extremely significant
Residual	9.96	7	1.42			
Lack of fit	2.24	3	0.75	0.39	0.7690	Non-significant
Pure error	7.72	4	1.93			
Sum	300.75	16				

(Remark: $p<0.01$ refers to extremely significant; $0.01<p<0.05$ refers to significant; $p>0.05$ refers to non-significant)

As can be seen from the above table, items that have significant influence on the pick-up rate of film residues are A, B, C, A^2, B^2, and C^2 respectively; items that have non-significant influence are AB, AC, and BC. Therefore, the regression equation was obtained after excluding non-significant items, as shown in equation 2.

$$C1=-485.99+68.52A+7.21B+1.78C-12.21A^2-0.041B^2-0.0048C^2 \quad (2)$$

The equation determination coefficient R^2 after re-fitting is 0.9454, and the variation coefficient C.V. is 1.46%, which indicates only 5.46% variations do not fit the equation, suggesting the overall fitting of the equation is good and this equation can be used to optimize response surface models.

(2) Response surface analysis of the pick-up rate of film residues

The response surface models between the pick-up rate of film residues and three working parameters were established by using software, as shown in Fig.9, Fig.10 and Fig.11. Then, we can obtain the relationship between the pick-up rate of film residues and three working parameters through analysis.

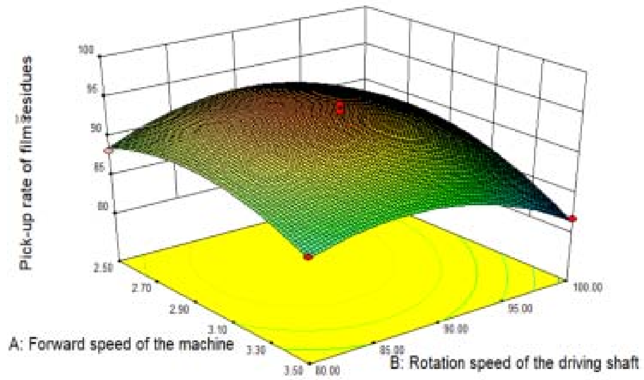


Figure 9. Response Surface Graph for the Influence of the Forward Speed of the Machine and the Rotation Speed of the Driving Shaft on the Pick-up rate Film Residues

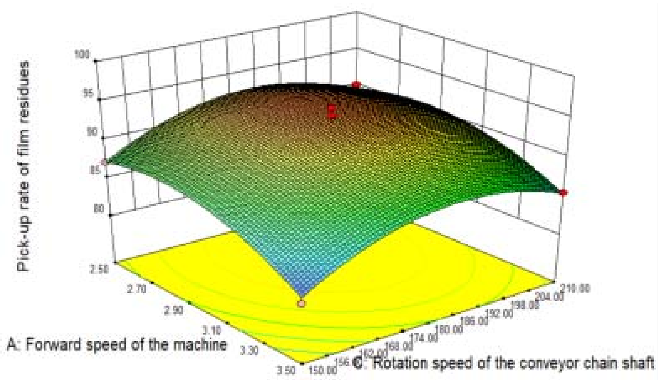


Figure 10. Response Surface Graph for the Influence of the Forward Speed of the Machine and the Rotation Speed of the Conveyor Chain Shaft on the Pick-up rate Film Residues

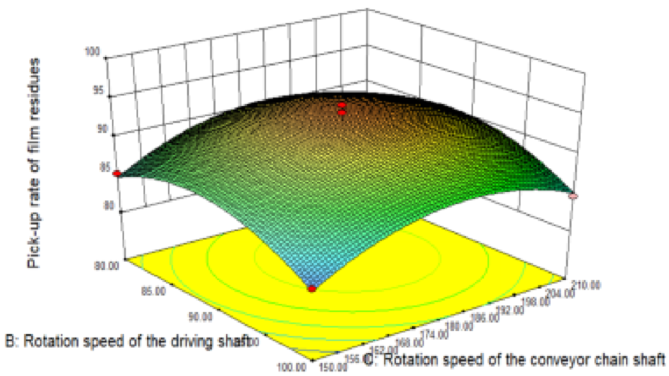


Figure 11. Response Surface Graph for the Influence of the Rotation Speed of the Driving Shaft and the Rotation Speed of the Conveyor Chain Shaft on the Pick-up rate Film Residues

It can be seen from the response surface graphs that when the forward speed of the machine, the rotation speed of the driving shaft, and the rotation speed of the conveyor chain shaft is increasing, the pick-up rate of film residues increases firstly and then reduces. The main reason is that when the rotation speed of the driving shaft increases, the moving speed of film transport belts will also increase correspondingly, which may lead to puncture or tearing of some film residues and picking failure at last. When the rotation speed of the conveyor chain shaft is too high, some film residues may pile up at the tail of harvesters and therefore cannot be picked up, thus reducing the pick-up rate of film residues.

(3) Regression analysis of the potato damage rate

The regression analysis method for the potato damage rate is the same as the analysis method for the pick-up rate of film residues; the regression equation of the potato damage rate was obtained via software analysis, as show in equation 3.

$$C_2=-91.45+17.12A+0.94B+0.30C-0.0155AB+0.0038AC-0.000967BC-2.49A^2-0.00411B^2-0.0006C^2 \quad (3)$$

After influence significance analyses on all influence factors and the excluding of non-significant influence items, the regression equation was finally obtained, as shown in equation 4.

$$C_2=-73.67+16.42A+0.72B+0.22C-2.49A^2-0.00411B^2-0.0006C^2 \quad (4)$$

Through calculation, the determination coefficient R2 of the new regression equation is 0.9156, and the variation coefficient C.V. is 6.36%, which indicates only 8.44% variations do not fit this equation, suggesting the overall fitting of the equation is good and this equation can be used to optimize response surface models.

(4) Response surface analysis of the potato damage rate

The response surface models between the potato damage rate and three working parameters were established by using software, as shown in Fig.12, Fig.13 and Fig.14.

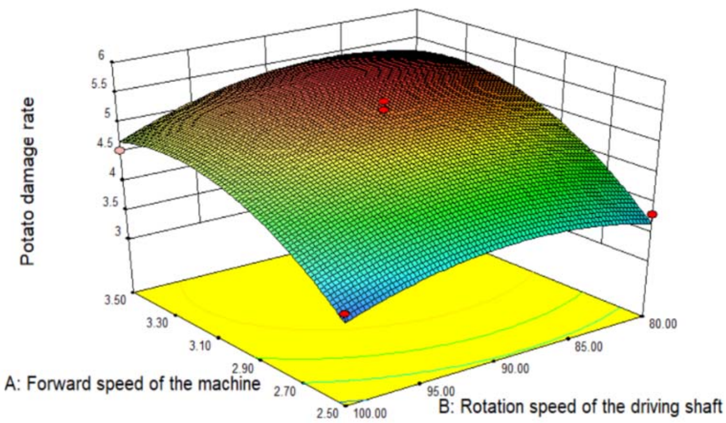


Figure 12. Response Surface Graph for the Influence of the Forward Speed of the Machine and the Rotation Speed of the Driving Shaft on the Potato Damage Rate

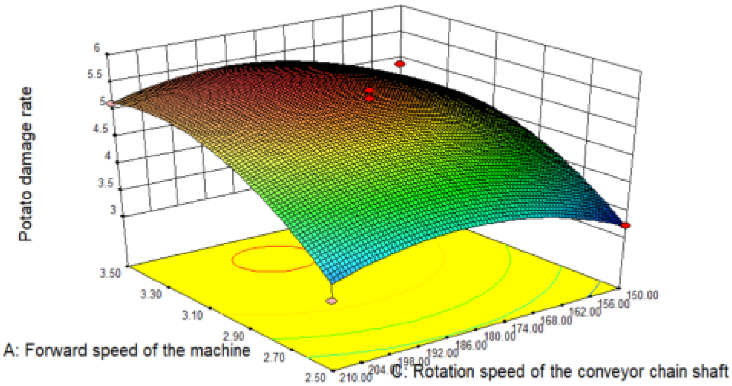


Figure 13. Response Surface Graph for the Influence of the Forward Speed of the Machine and the Rotation Speed of the Conveyor Chain Shaft on the Potato Damage Rate

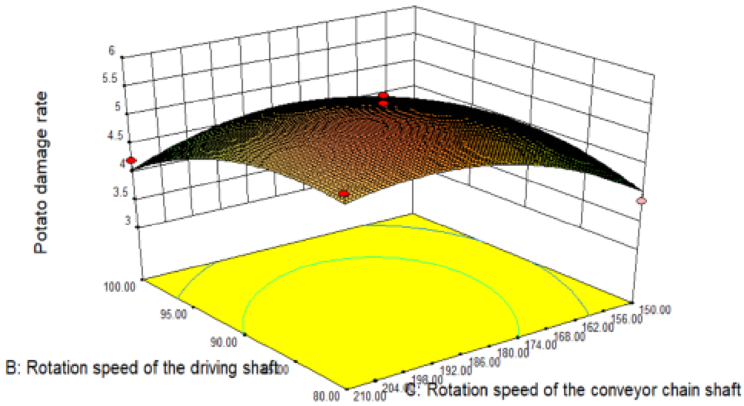


Figure 14. Response Surface Graph for the Influence of the Rotation Speed of the Driving Shaft and the Rotation Speed of the Conveyor Chain Shaft on the Potato Damage Rate

As can be obtained from the response surface graphs, with the increase of the forward speed of the machine, the rotation speed of the driving shaft, and the rotation speed of the conveyor chain shaft, the potato damage rate increases firstly and then reduces, the main reason to which is that when the rotation speed of the driving shaft increases, the speed of film picking teeth also increases, which enlarges the interaction force between teeth and potatoes, thus increasing the potato damaging rate.

(5) Regression analysis of Z value

The regression analysis method for Z value is the same as the analysis method for the pick-up rate of film residues; the regression equation of Z value was obtained via software analysis, as show in equation 5.

$$Z=-417.09+64.40A+6.64B+1.33C-0.23AB+0.02AC+0.001BC-8.92A^2-0.03B^2-0.004C^2 \quad (5)$$

After influence significance analyses on all influence factors and the excluding of non-significant influence items, the regression equation was finally obtained, as shown in equation 6.

$$Z=-382.13+47.30A+6.14B+1.48C-8.92A^2-0.03B^2-0.004C^2 \quad (6)$$

Through calculation, the determination coefficient R2 of the new regression equation is 0.9223, and the variation coefficient C.V. is 2.06, which indicates only 7.77% variations do not fit this equation, suggesting the overall fitting of the equation is good and this equation can be used to optimize response surface models.

(6) Response surface analysis of Z value

The response surface models between the pick-up rate of film residues and three working parameters were established by using software, as shown in Fig.15, Fig.16 and Fig.17.

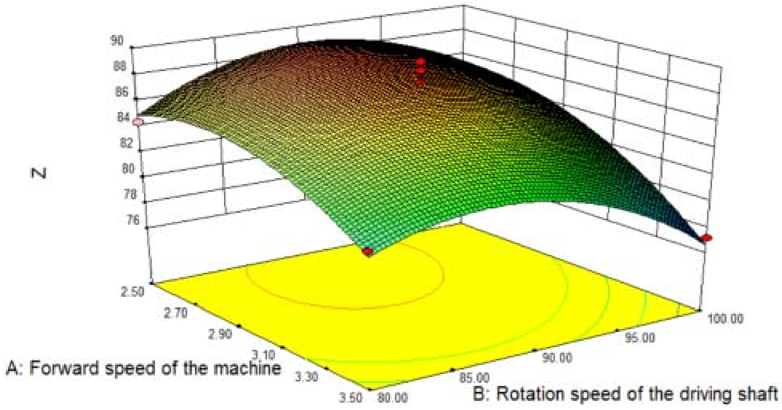


Figure 15. Response Surface Graph for the Influence of the Forward Speed of the Machine and the Rotation Speed of the Driving Shaft on Z Value

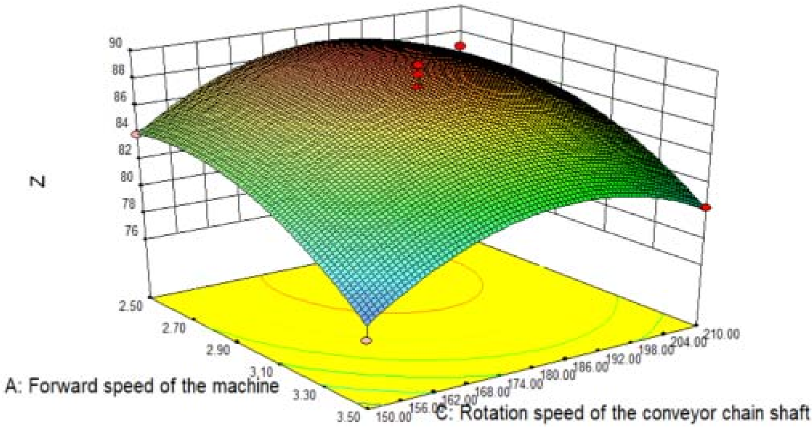


Figure 16. Response Surface Graph for the Influence of the Forward Speed of the Machine and the Rotation Speed of the Conveyor Chain Shaft on Z Value

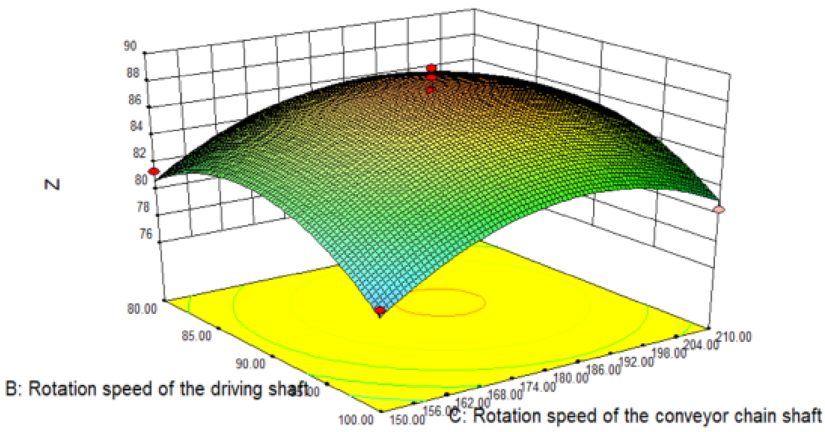


Figure 17. Response Surface Graph for the Influence of the Rotation Speed of the Driving Shaft and the Rotation Speed of the Conveyor Chain Shaft on Z Value

As can be obtained from the response surface graphs, with the increase of the forward speed of the machine, the rotation speed of the driving shaft, and the rotation speed of the conveyor chain shaft, the value of Z increases firstly and then reduces.

2.5. Optimization of Working Parameters

The value range of all parameters was set via software, where the value range of the forward speed of the machine is 2.5-3.5 km/h, that of the rotation speed of the driving shaft is 80-100r/min, and that of the rotation speed of the conveyor chain shaft is 150-210r/min; the maximum value of Z was set as 100%. After the setting of the above parameters, a comprehensive analysis was carried out on the regression equation of Z, and then the equation was solved; test results are shown in Table 5.

Table 5. Test Optimization Results

Parameters and indicators	Forward speed of the machine (km/h)	Rotation speed of the driving shaft (r/min)	Rotation speed of the conveyor chain shaft (r/min)	Z value
Optimization results	2.66	89.63	184.17	88.7875

Working parameters of the machine were set in accordance with parameter optimization results shown in Table 5 so as to carry out filed test.

3. Field Test

3.1. Test Conditions and Methods

The experimental base of Gu’an Jingquan Spring Factory in Xishi Village, Gu’an County, Hebei Province was selected as the site of the test, two-row planting with mulching films method was adopted, the row space is 450mm, and the plant space is 250mm. White mulching films which are 1200mm wide and 0.008mm thick were used in the test, the film covering time is about 120d. Soil is clay soil with a moisture content of about 18%. At the time of conducting the field test, Dongfanghong 404 tractors were used for power.

Within the test land, 10 square pieces with a length of 50m were randomly selected as test areas; after the test of each test area was completed, the 2 indicators [26-27], namely the pick-up rate of film residues and the potato damage rate, were calculated respectively. After the calculation of all 10 test areas were completed, the mean pick-up rate of film residues and the mean potato damage rate of the 10 groups were taken as the final pick-up rate of film residues and potato damage rate.

3.2. Test Results

Table 6. Field Test Results of the Collector for Film Residues

No.	Mass of picked film residues /g	Mass of non-picked film residues /g	Pick-up rate of film residues/%	Mass of potatoes with damaged surface/kg	Mass of potatoes with undamaged surface/kg	Potato damage rate/%
1	779.9	72.2	91.53	152.4	6.8	4.27
2	792.7	62.7	92.67	148.6	7.5	4.80
3	769.8	78.7	90.72	162.3	8.1	4.75
4	759.3	75.9	90.91	145.6	9.1	5.88
5	724.9	113.4	86.47	151.9	7.1	4.47
6	771.4	82.8	90.31	135.9	6.7	4.70
7	746.2	95.6	88.64	156.7	6.3	3.87
8	742.8	101.5	87.98	149.8	7.8	4.95
9	769.7	82.1	90.36	139.9	8.2	5.54
10	786.5	56.2	93.33	153.6	6.4	4
Mean			90.29			4.72

The pick-up rate of film residues and potato damage rate of the collector for potato film residues obtained in the field test are shown in Table 6.

Test results show that, the mean pick-up rate of film residues of the collector for potato film residues is 90.29% and the mean potato damage rate is 4.72%, both meeting the test design requirements.

4. Conclusion

(1) The structural parameters of the machine were determined through single-factor test, and they are as follows: the horizontal number of film picking teeth is 4, the longitudinal space of film picking teeth is 300mm, film picking teeth were arranged in the non-staggered mode; and the length of film picking teeth is 130mm. The response surface methodology was used to design tests for further analysis and optimization, and the forward speed of the machine obtained is 3.08km/h, the rotation speed of the driving shaft is 87.57r/min, and the rotation speed of the conveyor chain shaft is 186.54r/min.

(2) The main influence element of the pick-up rate of film residues is as follows: in case the damage degree of film residues is relatively high or a relatively large amount of soil is on film residues, the effect of separation between soil and film residues will not be good, and therefore film residues will fall off together with potatoes at the tail of harvesters and cannot be picked up by film picking teeth. The main influence factors of the potato damage rate are the forward speed of the machine and the line speed of film picking teeth. During field work, the machine cannot maintain a highly accurate forward motion at constant speed; when its speed is high, the line speed of corresponding film picking teeth will increase, thus increasing the potato damage rate. Therefore, at the time of harvesting potatoes and collecting film residues, great efforts shall be made to loosen the soil in fields, so that there are not too many soil blocks. In addition, the machine shall be maintained at a proper forward speed, so as to realize the optimal field working performance.

(3) The machine has a relatively good recovery effect on film residues which are relatively complete, but its recovery effect on fragmentary film residues at ridge edges and in deeper soil layers is not very good, which requires further improvement and optimization of its film collecting function.

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