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TECHNICAL PAPER

EXPERIMENT OF A SWING SEPARATING SIEVE ON A POTATO DIGGER

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KEYWORDS

Swing separating sieve, coverage of potato-soil mixture, parameter optimization, experimental studies.

ABSTRACT

For the purpose of achieving the distribution of the potato-soil mixture and the appropriate parameters of the swing separating sieve, we conducted experiments using the 4SW-170 potato digger. The experiments consisted of two parts. In each part, the experimental factors were crank rotational speed, sieve inclination and machine forward speed. The difference is that the first part involved a single factor test, which selected the coverage of the potato-soil mixture as the evaluation indicator. In contrast, the second part involved an orthogonal test, which selected the obvious rate and damage rate as evaluation indexes. In the first part, it was observed that the coverage of the potato-soil mixture on the separating sieve reduced gradually with the increase in crank rotational speed and sieve inclination. Inversely, as the machine forward speed was raised, the coverage of the potato-soil mixture gradually increased. In the second part, when the crank rotational speed was 230 rpm, the sieve inclination became 21.1°, and the machine forward speed was 2.03 $km \cdot h^{-1}$; the optimal parameter combination was obtained. Under such conditions, the obvious rate of potato harvest could reach as high as 99.49%, and the damage rate of potato harvest could reach as low as 0.87%. The reported results may be of help in providing a reference for the design of the swing separating sieve on potato diggers.

INTRODUCTION

Potato diggers have already been equipped with mechanical separating devices in China. These devices generally include a poke finger wheel (Wu et al., 2010), poking roller (Yang et al., 2016), and a swing or vibrating sieve (Lv et al., 2015; Zhao et al., 2007; Zhang et al., 2014), as well as an elevating chain (Liu et al., 2009) and chain-swing sieve (Zhao et al., 2007). Additionally, the chain-swing sieve potato digger is widely used in the midwest area of China. A swing separating sieve is the key component of these diggers used to separate potatoes and soil (Su et al., 2015; Yang, 2009).

The different parameters of the separating sieve lead to its varying performance. The reason is that the changes in parameters of the separating sieve will cause the alteration of potatoes and soil distribution on the separating sieve. Therefore, it is expected that regulation of the distribution of the potato-soil mixture will play a critical role in improving the performance of the separating sieve.

Over the years, the research work on separating sieves has focused on the development of computer simulation and optimization. Jia et al. (2005) used ADAMS motion analysis software to analyse the acceleration, velocity and displacement of the separating sieve and obtained the best parameters of the separating sieve combined with the potato impact pressure characteristics. Shi et al. (2013) and Wei et al. (2015) also used ADAMS software to simulate the kinematical characteristics of the swing-separating sieve and obtained optimal parameters.

Currently, there are few studies about the distribution of the potato-soil mixture on the swing separating sieve. At the same time, the unreasonable parameters of the separating sieve result in a high damage rate and low obvious rate. To date, there have been difficulties in designing a swing separating sieve with an increased obvious rate and a reduced damage rate.

The aim of this study was to determine the potato and soil separating mechanism of the swing separating sieve and obtain the appropriate parameters of the swing separating sieve to promote potato harvest mechanization.

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MATERIAL AND METHODS

The 4SW-170 potato digger is mainly composed of the body frame, digging shovel, elevating chain and swing separating sieve. The main components of the swing separating sieve include the transmission shaft, gearbox, sprocket drive mechanism, rotation shaft, front swing link, rear swing link, sieve inclination adjusting mechanism, slide plate, upper sieve and lower sieve.

When the potato digger works, the potato-soil mixture is dug up by the digging shovel and transported to the swing separating sieve by the elevating chain. The separating sieve is driven by the crank and connecting rod mechanism, causing the soil to break up and fall off. The potatoes are conveyed to the end of the separating sieve and then drop on the ground. The process described above is the working principle of the swing separating sieve (Xie et al., 2017).

The experiments were conducted at the Inner Mongolia Agricultural University planting field in Hohhot in the Inner Mongolia Autonomous Region of China in October of 2016. The planting method employed was flat planting in sandy loam soil. Soil thickness ranged from 0 to 300 mm and the average moisture content was 13.1%. The plant spacing and row spacing were, respectively, 350 mm and 800 mm. The selected variety of potato was Kexin Number 1, which is widely cultivated in the midwest of China. Potato seedlings and weeds were removed before the test.

The test machine was the 4SW-170 potato digger, and the potato digger was driven by a Dongfeng-900 tractor with matching power of 66.18 kW. The equipment was mainly composed of a tape measure, a stopwatch, an EOS1300D single lens reflex camera (Canon, Japan) and a TD2234B rotational speed meter (SAMPO, Taiwan, China).

The experiments included two parts. To obtain coverage of the potato-soil mixture, the first experiment was performed. According to the relevant literature (Su et al., 2015; Yang, 2009) and farmers' experience in harvesting potatoes, the separating effect of potatoes and soil mainly depended on the crank radius, crank rotational speed, sieve inclination and machine forward speed. In selecting the experimental factors and their levels, the following factors were given close attention. First, the crank radius should be reasonable. The longer the crank radius is, the better the separation of potatoes and soil is due to the throwing of the potato-soil mixture from the sieve surface. However, a long crank radius would aggravate potato damage. In contrast, a shorter crank radius would reduce the obvious rate of potato harvest. Based on preliminary results and conclusions in the related literature, a crank radius of 35 mm (Yang, 2009) was selected. Second, the different crank rotational speeds would cause different movement of the potato-soil mixture on the separating sieve, which in turn would produce different separating effects of potatoes and soil. To make the relative motion of the potato-soil mixture obviously different, the crank rotational speed should range from 150 to 230 rpm. Third, the change in sieve inclination would alter the collision impulse and the relative motion time of the potato-soil mixture, thus affecting the separation of potatoes and soil. According to the structural characteristics of the separating sieve, the range of sieve inclination was taken as 0.5-21.1°. Finally, the forward speed of the machine directly affects the quantity of the potato-soil mixture on the separating sieve. According to the instructions (Zhao et al., 2007), the machine forward speed was taken as 1.11-2.78 $\mathrm{km \cdot h^{-1}}$. In short, the crank rotational speed, sieve inclination and machine forward speed were the experimental factors. The factors and their levels are shown in Table 1.

TABLE 1. Factors and levels in experiments on the coverage of the potato-soil mixture.

Levels	Factors		
	Crank rotational speed (rpm)	Machine forward speed ($\mathrm{km \cdot h^{-1}}$)	Sieve inclination (°)
1	150	1.11	0.5
2	161	1.69	7.7
3	180	2.03	14.4
4	205	2.37	21.1
5	230	2.78	

The coverage of the potato-soil mixture on the swing separating sieve was defined as a percentage; that is, the potato-soil mixture area divided by the swing separating sieve area. This was based on the concept of vegetation coverage (Gu et al., 2005). The distribution photograph of the potato-soil mixture on the separating sieve was continuously taken by a camera that was vertical to the swing separating sieve. After the experiment, the photographs were imported into Photoshop CS6 software. The pixel numbers of the potato-soil mixture area and swing separating sieve area were converted by Photoshop CS6 software. The coverage of the potato-soil mixture on the swing separating sieve was then calculated. Specific steps were as follows. First, the photograph resolution ratio and the advanced cache level were set at 72 pixels per inch and 1, respectively. As shown in Figure 1a, the area of the separating sieve was captured using a polygon lasso tool, and then the pixel number (w) was read by histogram. The first area of the potato-soil mixture on the separating sieve was then captured using the polygon lasso tool, and the pixel number of the first area was read by histogram and considered as w_1, as shown in Figure 1b. Similarly, the pixel number of the nth potato-soil mixture area was regarded as w_n. Finally, the coverage of the potato-soil mixture on the swing separating sieve could be calculated by the following formula:

$$\eta = \frac{\sum_{i=1}^{n} w_i}{w} \times 100\% \tag{1}$$

In which:

η is the coverage of the potato-soil mixture on the swing separating sieve (%);

w is the pixel number of the separating sieve area, and

w_i is the pixel number of the ith potato-soil mixture area.

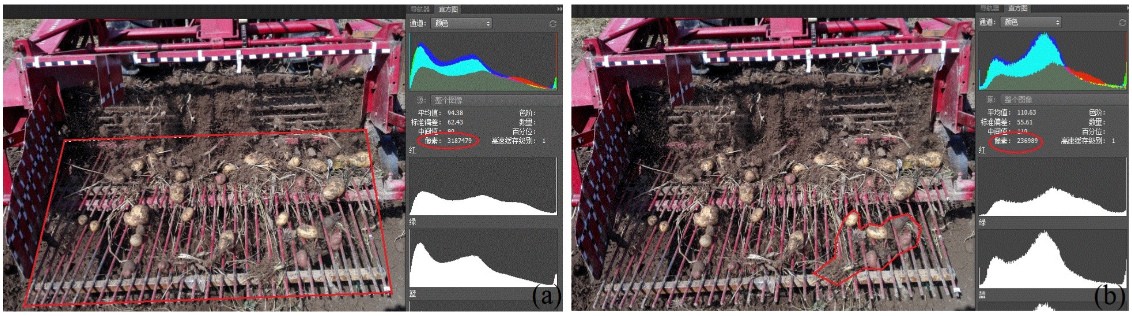

FIGURE 1. The area and pixel number of the separating sieve (a) and the area and pixel number of the potato-soil mixture (b)

The camera shooting angle was adjusted so that it was perpendicular to the separating sieve following the potato digger at the machine forward speed. The distribution photograph of the potato-soil mixture on the separating sieve was captured continuously when the swing separating sieve worked steadily. Each group test was repeated three times, and 20 photographs were taken each time. To overcome human interference during the test process, 5 photographs were equidistantly selected from 20 consecutive photographs and were imported into the Photoshop CS6 software for collecting the pixel number. Subsequently, the coverage of the potato-soil mixture on the separating sieve was obtained from each photograph. The average coverage of the potato-soil mixture from the 5 photographs was the result of each replicate. Therefore, the final result in each group depended on the average value of 3 replicates.

The second experiment was the orthogonal test. To obtain the optimum parameter combination of the swing separation sieve, the orthogonal test was conducted according to “NY/T 648 - 2015 Technical specifications of quality evaluation for potato harvesters” in China. The evaluation indexes were the obvious rate and damage rate. The calculated equations are:

$$Y_1 = \frac{q_1}{Q} \times 100\% \tag{2}$$

$$Y_2 = \frac{q_2}{Q} \times 100\% \tag{3}$$

In which,

Y_1 is the obvious rate (%);

Y_2 is the damage rate (%);

q_1 is the mass of potatoes exposed to the ground surface after machine operation (kg);

q_2 is the mass of damaged potatoes after machine operation (kg), and

Q is the total mass of potatoes after machine operation (kg).

The crank rotational speed (A), sieve inclination (B) and machine forward speed (C) with three levels were selected as the experiment factors, namely, the $L_9(3^4)$ orthogonal experiment in Table 2. Each group was repeated three times. The statistical analysis of the obvious rate and damage rate were carried out to find the best combination of factors and levels.

TABLE 2. Factors and levels of orthogonal experiments.

Levels	Factors		
	Crank rotational speed A (rpm)	Sieve inclination B (°)	Machine forward speed C ($km \cdot h^{-1}$)
1	180	7.7	1.69
2	205	14.4	2.03
3	230	21.1	2.37

Both the first and second experimental results were inputted into SPSS19.0 software. We then calculated the responding average value, standard deviation, linear regression model and range.

RESULTS AND DISCUSSION

The separating process of potatoes and soil mainly includes 2 stages. In the first stage, the potato-soil mixture falls to the separating sieve from the elevating chain; this mixture collides with the separating sieve to achieve the separating effect. In the second stage, the potato-soil mixture moves relative to the separating sieve. The separated potato-soil mixture is influenced by dispersion and shear from the separating sieve; this achieves the separation of potatoes and soil.

Table 3 lists the coverage percentage values of the potato-soil mixture on the separating sieve at different crank rotational speeds when the machine forward speed and the sieve inclination reach 1.69 $\mathrm{km \cdot h^{-1}}$ and 7.7°, respectively.

TABLE 3. Coverage of the potato-soil mixture at different crank rotational speeds.

Crank rotational speed (rpm)	Test number	Coverage of potato-soil mixture (%)	Average value (%)	Standard deviation (%)
150	1	75.14	75.34	0.20
	2	75.93		0.59
	3	74.94		0.60
161	1	69.23	70.21	0.98
	2	69.24		0.97
	3	72.17		1.96
180	1	62.77	63.97	1.20
	2	62.54		1.43
	3	66.60		2.63
205	1	53.69	52.15	1.54
	2	51.23		0.92
	3	51.54		0.61
230	1	35.44	36.13	0.69
	2	36.30		0.17
	3	36.65		0.52

Table 3 shows that the coverage of the potato-soil mixture on the separating sieve reduced gradually with the increase in crank rotational speed. The main reasons for this are as follows. At the first stage, the collision impulse between the soil blocks and the separating sieve increased with the increase in the crank rotational speed. This eventually leads to an increase in the rate at which soil blocks are broken. During the movement of the potato-soil mixture relative to the separating sieve, the motion state transferred into a slight jump from the reciprocating slide and further transferred into a violent jump with the increase in the crank rotational speed. The changed motion state strengthened the dispersion and shear of the separating sieve on the soil. The enhanced dispersion and shear made the potato-soil mixture layer thin. This increased the breaking up of soil blocks.

Table 4 lists the coverage percentages of the potato-soil mixture on the separating sieve at different sieve inclinations when the machine forward speed and the crank rotational speed reach 1.69 $\mathrm{km \cdot h^{-1}}$ and 205 rpm, respectively.

TABLE 4. Coverage of the potato-soil mixture at different sieve inclinations.

Sieve inclination (°)	Test number	Coverage of the mixture of potatoes and soil (%)	Average value (%)	Standard deviation (%)
0.5	1	66.49	64.48	2.01
	2	62.52		1.96
	3	64.44		0.04
7.7	1	53.69	52.15	1.54
	2	51.23		0.92
	3	51.54		0.61
14.4	1	27.06	26.98	0.08
	2	27.46		0.48
	3	26.43		0.55
21.1	1	21.02	22.82	1.80
	2	24.86		2.04
	3	22.57		0.25

Table 4 shows that the coverage of the potato-soil mixture on the separating sieve gradually reduces as the sieve inclination increases. The reasons are briefly summarized as follows. At the first stage, the fall distance of the potato-soil mixture from the elevating chain to the separating sieve increased with the increase in the sieve inclination, which eventually increased the rate at which soil blocks were broken. As a result, most of the soil dropped to the ground at the front of the separating sieve. At the second stage, the acceleration component, which was perpendicular to the separating sieve, was directly proportional to the sieve inclination. Therefore, when the potato-soil mixture moved relative to the separating sieve, the increased acceleration component enhanced the separating effect of potatoes and soil.

There was little difference in the coverage of the potato-soil mixture when the values of sieve inclination were 0.5° and 7.7°. Similarly, there was no perceptible difference on the separating sieve when the sieve inclination was 14.4° and 21.1°. In contrast, the difference in the coverage of the potato-soil mixture on the separating sieve was visible when the sieve inclination was 7.7° and 14.4°. This result was attributed to the fact that both the separating and conveying capacity of the separating sieve improved with increasing sieve inclination. Therefore, the larger sieve inclination was not only conducive to the separation of potatoes and soil but also had better transport performance.

Table 5 lists the coverage values of the potato-soil mixture on the separating sieve at different machine forward speeds when the sieve inclination and the crank rotational speed, respectively, are 7.7° and 205 rpm.

TABLE 5. Coverage of the potato-soil mixture at different machine forward speeds.

Machine forward speed ($km \cdot h^{-1}$)	Test number	Coverage of the potato-soil mixture (%)	Average value (%)	Standard deviation (%)
1.11	1	35.02	36.15	1.13
	2	36.20		0.05
	3	37.22		1.07
1.69	1	53.69	52.15	1.54
	2	51.23		0.92
	3	51.54		0.61
2.03	1	59.92	60.43	0.51
	2	60.00		0.43
	3	61.38		0.95
2.37	1	65.76	65.06	0.70
	2	64.59		0.47
	3	64.82		0.24
2.78	1	73.22	73.40	0.18
	2	74.69		1.29
	3	72.30		1.10

Table 5 shows that the coverage of the potato-soil mixture on the separating sieve gradually increased with an increase in the machine forward speed. This is due to the increased quantity of the potato-soil mixture on the separating sieve with the increasing machine forward speed.

Tables 3-5 show that the maximum standard deviation between the experimental value and the average value of the coverage reached 2.63%, while the minimum is merely 0.04%. These results indicate that it is feasible and reliable to calculate the coverage of the potato-soil mixture by converting the pixel number of the photograph.

To establish the relationship between the separating sieve parameter and the coverage of the potato-soil mixture, the average value of the coverage and the corresponding parameter of the separating sieve were input into SPSS19.0 software. The linear regression analysis was then carried out. The regression equations and the correlation coefficients are shown in Table 6.

TABLE 6. Regression equation between the coverage of the potato-soil mixture and separating sieve parameter.

Factors	Linear regression equation	Correlation coefficient
Crank rotational speed, A (rpm)	$\eta = -0.4781A + 148.11$	0.9859
Machine forward speed, B ($km \cdot h^{-1}$)	$\eta = -2.192B + 65.555$	0.9388
Sieve inclination, C (°)	$\eta = 21.994C + 13.537$	0.9846

As shown in Table 6, the fitting relationship between the coverage and parameters of separating sieves is good. The coverage of the potato-soil mixture is sensitive to the change in the crank rotational speed, sieve inclination and machine forward speed.

The test procedure and results of the orthogonal test are shown in Table 7, and the results of the range analysis are given in Table 8. The data in Table 8 indicate that the effect intensity of factors on the obvious rate is A>C>B, and the same results were found with respect to the damage rate.

TABLE 7. Program and results of the orthogonal test.

No.	Crank rotational speed A (rpm)	Sieve inclination B (°)	Machine forward speed C ($km \cdot h^{-1}$)	Obvious rate (%)	Damage rate (%)
1	1 (180)	1 (7.7)	1 (1.69)	96.85	8.57
2	1	2 (14.4)	2 (2.03)	98.80	6.89
3	1	3 (21.1)	3 (2.37)	97.37	8.01
4	2 (205)	1	2	99.07	6.41
5	2	2	3	99.08	10.34
6	2	3	1	99.03	10.71
7	3 (230)	1	3	99.01	7.51
8	3	2	1	99.10	4.82
9	3	3	2	99.49	0.87

According to the results of the range analysis, when the crank rotational speed was 230 rpm, the sieve inclination reached 21.1° and the machine forward speed reached 2.03 $km \cdot h^{-1}$ (A3B3C2), the optimum operating parameters were obtained. Under this condition, the obvious rate accounted for the highest value of 99.49% in nine group tests, and the damage rate had the lowest value of 0.87%. Since the optimal parameters appear in the orthogonal test, there is no need for experimental verification.

TABLE 8. Range analysis results of the orthogonal test.

Evaluation index	Factors	K1	K2	K3	R	Optimum level	Optimal parameter combination
Obvious rate	A	97.673	99.06	99.2	1.527	A3	A3B3C2
	B	98.31	98.993	99.12	0.683	B3	
	C	98.327	99.12	98.487	0.793	C2	
Damage rate	A	7.823	9.153	4.4	4.753	A3	A3B3C2
	B	7.497	7.35	6.35	0.967	B3	
	C	8.033	4.723	8.62	3.897	C2	

The optimized results showed that a moderate machine forward speed, higher crank rotational speed and larger sieve inclination not only improved the obvious rate but also reduced the damage rate. In comparing the test results with the predetermined values (obvious rate ≥ 96%, damage rate ≤ 2%) in "NY/T 648 - 2015 Technical specifications of quality evaluation for potato harvesters", it can be found that the working performance of this separation sieve was significantly better than that of national standards.

CONCLUSIONS

1. The investigation selected the crank rotational speed, sieve inclination and machine forward speed as factors and determined the influence of a single factor on potato-soil mixture coverage. There was a linear relationship between the coverage of the potato-soil mixture and the relevant parameters of separating sieves (crank rotational speed, sieve inclination and machine forward speed). The correlation coefficients of the coverage and three parameters, respectively, were 0.9859, 0.9388 and 0.9846.

2. The orthogonal experiment was carried out in the field. The optimal operation parameter group of both the obvious rate and damage rate is a crank rotational speed of 230 rpm, sieve inclination of 21.1°, and machine forward speed of 2.03 $km \cdot h^{-1}$. Under the above conditions, the obvious rate and damage rate, respectively, reach 99.49% and 0.87%. Test results implied that the swing separation sieve performance was better than that in the national standard.

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REFERENCES

Gu ZJ (2005) Study on the measurement of photography method for vegetation coverage and its relationship with vegetation index. Master Thesis, Nanjing Normal University.

Jia JX, Zhang DX, Hao XM, Liu HW (2005) Parametric modelling and computer simulation of potato harvester parts. Transactions of the Chinese Society for Agricultural Machinery 36:64-67.

Liu B, Zhang DX, LI J (2009) Design on MZPH-820 single-row potato harvester. Transactions of the Chinese Society for Agricultural Machinery 40:81-86.

Lv JQ, Tian ZE, Wu JE, Yang Y, Shang QQ, Wang YB, Liu ZX (2015) Design and experiment on 4U1Z vibrating potato digger. Transactions of the CSAE 31:39-47.

Ministry of Agriculture of the PRC (2015) NY/T 648 – 2015. Technical specifications of quality evaluation for potato harvesters. Ministry of Agriculture of the PRC, 3p.

Shi ZL, Zhang XJ, Zhao WY, Yang JS, Wei LJ (2013) Analysis of kinetic characteristics and simulation of vibrating sieve of 4UX-550 potato harvester. Journal of Gansu Agricultural University 48:156-160.

Su JD (2015) Study on the movement characteristics of potato during separating based on high speed photography technology. Master Thesis, Inner Mongolia Agricultural University.

Wei LJ, Zhao WY, Niu HH (2015) Optimal design of the vibrational structure of 4UD-600 potato digger based on ADAMS. Agricultural Research in the Arid Areas 33:278-282.

Wu JM, Li H, Sun W, Huang XP, Sun BG (2010) Design of potato digger in poke finger's wheel type. Transactions of the Chinese Society for Agricultural Machinery 41:76-79.

Xie SS, Wang CG, Meng JG, Deng WG, Wang HC, Yan JG (2017) Velocity analysis and experiment of potato on swing separation sieve. Journal of China Agricultural University 22:101-108.

Yang RB, Yang HG, Shang SQ, Xu PX, Cui GP, Liu LH (2016) Design and test of poking roller shoving type potato harvester. Transactions of the Chinese Society for Agricultural Machinery 47:119-126.

Yang L (2009) Simulation and optimization on parameters of separating of potato digger. Master Thesis, Inner Mongolia Agricultural University.

Zhang H, Wu JM, Sun W, Luo TE, Wang D, Zhang JL (2014) The design and experiment of 4UM-640 vibration potato digger. Agricultural Research in the Arid Areas 32：264-268.

Zhao MQ, Zhao SJ, She DQ, Liu HT, Liu WZ, Wang Z (2007) Combined separating type potato digger. Journal of Agricultural Mechanization Research 29:69-72.