Design and experiment of the double-seed hole seeding precision seed metering device for peanuts

Xiaoshun Zhao*, Wenjing Ran, Jianjun Hao, Wenjie Bai, Xinlei Yang

(*College of Mechanical and Electrical Engineering, Hebei Agricultural University, Baoding 071001, Hebei, China*)

Abstract: A secondary seeding precision double-seed peanut hole seeding seed metering device was designed to improve the performance of the peanut planting equipment and provide a solution for problems on the high seed charge that can cause poor cavitation and uniformity easily. The main structure and operation parameters in terms of groove length, seed charge height, seed-bed belt speed, and rotation speed of the seed metering wheel were determined through theoretical analysis. Single-factor and orthogonal tests were carried out through the JPS-12 seed metering device test bench, and the peanut variety Jinonghua-3 was selected as the test object. The single hole double-seed rate, qualified rate, the variation coefficient of hole spacing, and hole rate were chosen for evaluating the working performance. The results of the single-factor test showed that the seed metering performance is mainly affected by the groove length, the speed of the seed-bed belt and the rotation speed of the seed metering wheel, and the influence of the cavitation rate is minimal. The optimal seeding height is determined to be 40 mm. The results of the orthogonal test showed that the groove length was 27.3 mm, the seed-bed belt speed was 1.51 km/h, and the rotation speed of the seed metering wheel was 14.11 r/min. What's more, a regression model based on the orthogonal test results was established, the qualified rate of the number of holes obtained after optimizing the model was 98.84%, the variation coefficient of hole spacing was 9.74%, and the hole rate was 1.40%. Notably, the working performances of the device can meet the requirement of precision seeding.

Keywords: peanut, precision, seed metering device, orthogonal test, regression method

DOI: 10.25165/j.ijabe.20221503.6608

Citation: Zhao X S, Ran W J, Hao J J, Bai W J, Yang X L. Design and experiment of the double-seed hole seeding precision seed metering device for peanuts. Int J Agric & Biol Eng, 2022; 15(3): 107–114.

1 Introduction

Peanut is one of the most vital oil crops and economic crops in China. The planting area has been increasing year by year, reaching 5.5 million hm^2 at present, accounting for approximately 20% of the total planting area worldwide[1]. At present, peanut-planting in China is limited by the diversification of planting modes and low degree of mechanization, which hamper the development scale and industrialization of peanuts. With the adjusting of the planting structure and the promotion of new technologies, the standardization, mechanization, and scale planting and production of peanuts will surely be the future development trend[2-5]. In recent years, precision seeding has been the main development direction of modern agricultural planting production in China. Precision seeding can achieve cost-saving and efficiency-saving development of peanut planting[6-11], which has a significant effect on peanut production[12]. Therefore, improving peanut precision seeding technology is an important measure to promote the development of eanut industrialization in China[13-16].

Peanut seed is described as a heavy and bulky seed, elliptical shape with soft skin, rich in oil, and easily damaged under low shear force. These properties make it difficult to use the traditional mechanical metering devices to perform precision seeding to meet the agronomic requirements[17]. It was found that existing punching-on film seeders have shortcoming in terms of the seeding uniformity, depth, and precision, resulting in poor operational performance[18].

The seed metering device is a crucial component of planter to ensure planting performance[19]. Sun et al.[20] applied the inner-filled seed metering device to the peanut planter and conducted a single-factor and multi-factors multi-levels test research on the inner-filled seed metering device. Yang et al.[21] proposed an axial cylindrical compound hole structure at the bottom of a chute because of the disadvantage of the poor seed protection of the inner-filled seed metering device. Song et al.[22] designed a fixed cam active pin mechanism, which can adapt to different dimensions and different types of seeds in the process of filling seed, cleaning seed, protecting seed, and seeding. Yang et al.[23] designed a seed metering device with an inclined disc and analyzed the effects of the seed disc rotation speed, dimension radius, and tilt angle on peanut seeding quality. Chen et al.[24] used EDEM software to simulate and analyze the seed metering performance of the inner-filled peanut metering device, and studied the regulation of seed displacement under different rotation speeds and the change of seed cleaning area with rotation speed. He et al.[25] designed a pneumatic peanut precision metering device that used negative pressure to take seeds, an auxiliary clamping device to assist seed carrying, and the seeds rely on self-weight to achieve seeding. Luo et al.[26] invented a combined hole metering device

Received date: 2021-03-22 **Accepted date:** 2022-05-05

Biographies: Wenjing Ran, MS candidate, research interest: agricultural mechanization engineering, Email: wenjingran0321@163.com; **Jianjun Hao**, PhD, Professor, research interest: agricultural production automation technology and equipment, Email: hjjpaper@163.com; **Wenjie Bai**, MS candidate, research interest: agricultural mechanization engineering, Email: 18398263005@163.com; **Xinlei Yang**, PhD, Associate Professor, research interest: peanut genomics and molecular breeding, Email: yangxinlei2500@163.com.

***Corresponding author: Xiaoshun Zhao**, PhD, Associate Professor, research interest: modern agricultural equipment design and control, precision planting technology. College of Mechanical and Electrical Engineering, Hebei Agricultural University, Baoding 071001, Hebei, China. Tel: +86-17330263721, Email: zhao_xsh@126.com.

with adjustable seeding rate, which realized seeding rate adjustment by changing the holes of different dimensions. Chen et al.[27] optimized the peanut seed metering device combined hole structure and designed an inside-filling hole wheel type peanut seed metering device with an adjusting push-piece to control the dimensions of the seed hole, which can adapt to peanut seeds of different dimensions.

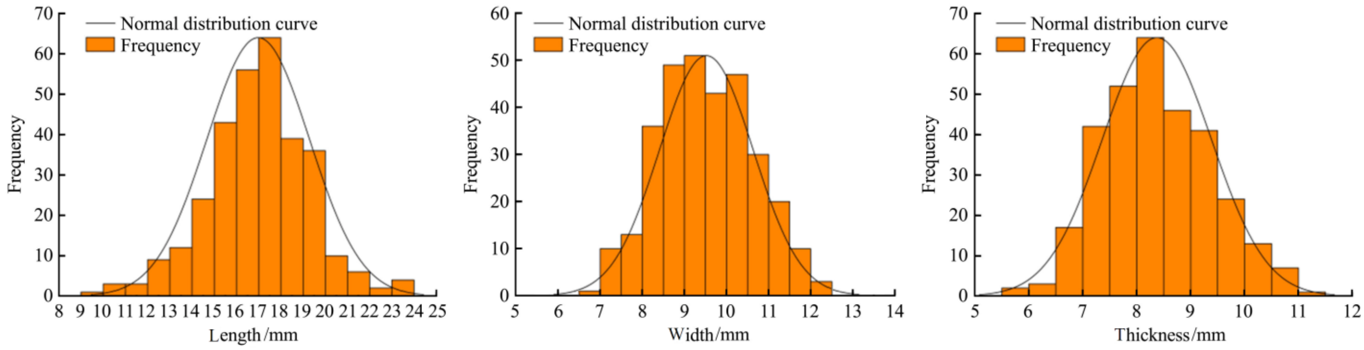
In the current research, a mechanical form was mostly adopted in ordinary peanut seed metering devices. There is a defect that the poor cavitation is caused by the high seed charge height, during the movement process of peanut seeds from the seed metering device to the seed furrow, the collisions or interferences between the seeds or between the seeds and the metering tube results in poor cavitation of the seeds and lower planting quality. However, the pneumatic seed metering device was widely used for precision seeding and is not suitable for peanut seeds with larger specific gravity[28,29].

Based on the mentioned issues above, we designed a hole-wheel type precision double-seed peanut seed metering device with the function of secondary seeding. Compared with other peanut metering devices, a secondary seeding based on the original first seeding was realized in this design. Split pins and seed blocks were designed in the mechanism. Thus, the seeds were completed for the first seeding, after the one will be carried out to the secondary seeding. The original motion mode of the seed was changed to do free-falling movement, which can achieve preciseness seeding. The research results are helpful for the improvement of the peanut precision seed metering device.

2 Materials and methods

2.1 Physical properties of tested peanut seed

The seed’s physical properties are important factors for determining the design and working parameters. The three-axis dimensions of peanut seeds follow a normal distribution as shown in Figure 1. The main dimensions and thousand-peanut weight of peanut seed are listed in Table 1. Six hundred samples were randomly selected for measuring dimensions using an absolute origin digital caliper (111N-101-40) with a sensitivity of 0.01 mm. The 1000-seeds mass was measured using an analytical balance (Xingyun JA203H) with an accuracy of 0.001 g.



a. Length distribution b. Width distribution c. Thickness distribution

Figure 1 Normal distribution diagram of the three-axis dimensions of peanut seeds

Table 1 Three-axis dimensions of Jinonghua-3 peanut seeds

Three-axis dimensions	Maximum value/mm	Minimum value/mm	Average value/mm	Standard deviation	Thousand seed mass/g
Length	23.46	9.04	16.98	2.38	
Width	12.36	6.83	9.52	1.11	794.06
Thickness	11.04	5.50	8.37	1.01	

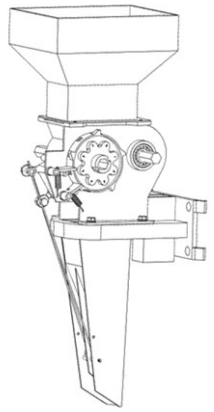
It can be seen from Table 1 that the peanut seeds are oblong. The three-axis dimension parameters of peanut samples were measured as follows: the average length was 16.98 mm, the average width was 9.52 mm, and the average thickness was 8.37 mm. The thousand seed mass of peanut seed is 794.06 g.

2.2 Structural parts and working principle of metering device

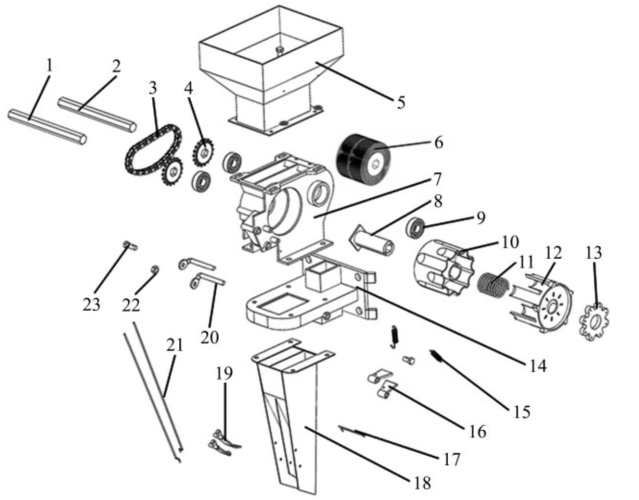
The device is composed of a seed box, mounting seat, seed metering device shell, seed metering wheel, clearing brush, guiding-seed groove, secondary seeding mechanism, transmission shaft, and chain. The whole structure is shown in Figure 2. The whole structure has been authorized by a national patent[30,31].

The seeds in the guiding-seed groove trough are arranged in accordance with two seeds per hole or one flat and one vertical arrangement. The secondary seeding mechanism is composed of split pin and seed block. When the peanut seeds are planted once and planted for the second time, the original movement will be changed mode into free-falling movement to finish precisely planting. According to the movement state of peanut seeds, the seed metering device is divided into three parts: the filling area, the first seeding area, and the second seeding area, as shown in Figure 3. The rotation directions of the seeding wheel and the clearing brush are shown as v_1 and v_2 respectively in Figure 3. The upper and lower limit posts intermittently and asynchronously control the limit baffle to act on the seed metering wheel.

The transmission shaft drives the seed metering wheel to rotate through the sprocket. The peanut seeds enter the seed metering wheel groove from the seed box, the seeds and the seed metering wheel rotate synchronously. The clearing brush removes excess seeds when the seeds are transferred to the clearing area. However, the seeds filled in the groove will enter the seeding area with the rotation of the seed metering wheel and will fall to the second seeding area under its self-weight and centrifugal force. The rotation of the seed metering wheel drives the seed block to open and close intermittently. When the seed block is opened, the seeds fall into the seed groove under its self-weight to complete the seeding. The seed metering device can improve the precision, the double-seed rate, and the cavitation of peanut seeds falling into the seed furrow, thereby ensuring reliable seeding emergence rate and consistency of plant spacing.



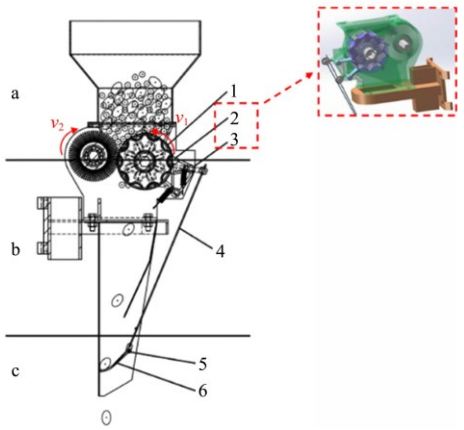
a. Whole structure of the device



1. Seed metering shaft 2. Transmission shaft 3. Chain 4. Sprocket 5. Seed box 6. Clearing brush 7. Seed metering device shell 8. Adjusting shaft 9. Bearing 10. First wheel body 11. Adjusting push-piece 12. Second wheel body 13. Adjusting nut 14. Mounting seat 15. Elastic return piece 16. Limit baffle 17. Split pin 18. Guiding-seed groove 19. Seed block 20. Limit post 21. Transmission rod 22. Limit nut 23. Limit bolt

b. Exploded view of the whole assembly structure

Figure 2 Structure of the seed metering device

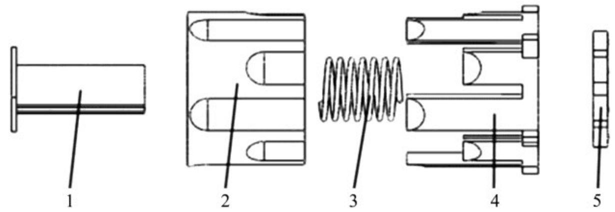


a. Filling area b. First seeding area c. Second seeding area
1. Seed metering wheel 2. Limit baffle 3. Limit post 4. Transmission rod 5. Split pin 6. Seed block

Figure 3 Schematic of seed metering device

2.3 Design of seed metering wheel

The seed metering wheel is a key component of the double-seed hole seeding precision metering device for peanuts, which was mainly composed of the first wheel body, the second wheel body, the adjusting shaft, the adjusting piece, and the adjusting nut, as shown in Figure 4. The seed metering wheel is divided into two parts by the seed block in the shell of the seed metering device, and the grooves are staggered on both sides of the seed metering wheel. The distance of the seed metering wheel is adjusted between the first wheel body and the second wheel body by adjusting nut to adjust the width of the seed trough. The middle adjusting push-piece is a return spring, which provides pushing force when the adjusting nut is twisted. The return spring is forced to receive positive pressure when the adjusting nut rotates counterclockwise, and the seeding amount between the seeding grooves becomes smaller. The return spring provides reverse thrust when the adjusting nut rotates clockwise, the first and second wheel bodies are pushed toward each other, thus, increasing the seeding groove and seeding amount.



1. Adjusting shaft 2. First wheel body 3. Adjusting push-piece 4. Second wheel body 5. Adjusting nut

Figure 4 Schematic of the seed metering wheel structure

A hole wheel type seed metering wheel was adopted by the peanut hole seeding metering device, and an adjustable seeding rate and a combined hole type were adopted by the structure design of the one. Theoretical hole spacing can be determined according to Equation (1)[26].

$$x = \frac{60v_1}{v_2 N} \tag{1}$$

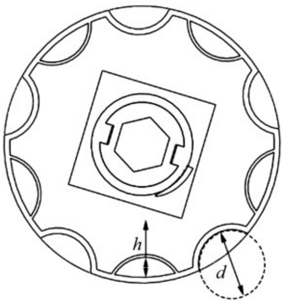
where, N is the number of grooves; v_1 is the planting speed, m/s; x is the theoretical hole spacing, m; v_2 is the rotation speed of the seed metering wheel, r/min.

The operating speed of the peanut planter is about 1.0-3.5 km/h. If the hole spacing is 160 mm and the rotation speed of the seed metering wheel is about 10-40 r/min, the value range of the number of grooves N is calculated about 9.1-10.4. This design takes N=10. The diameter of the common special-hole type seed metering device is about 80-200 mm, referring to the dimensions of peanut seeds, the diameter of the seed metering wheel was determined as 98 mm, respectively. The groove shape of the seed metering wheel is a semicircular cross-section, and the structure is shown in Figure 5. When the first wheel body and the second wheel body of the seed metering wheel are fully fitted, the planting amount is the smallest. At this time, the groove shape is two hemispheres, and the horizontal length is l_1. In this test, the planting amount is generally 2 seeds per hole, and the seed arrangement is mostly two seeds lying flat or one lying flat and one standing, then the section diameter, section height, and adjustment shaft stroke meet the Equation (2).

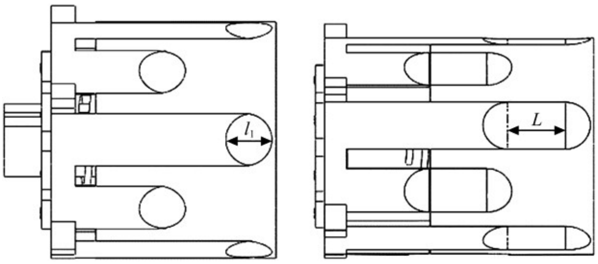
$$\begin{cases} d \geq l + b \\ b \leq h \leq l \\ l + b \leq l_1 + L \leq 2l \end{cases} \tag{2}$$

where, d is the section diameter, mm; h is the section height, mm; L is the adjustment shaft stroke, mm; l_1 is the length of the groove hemisphere, mm; l is the average seed length, mm; b is the average seed width, mm.

The average seed length and the average width of peanut variety Jinonghua-3 were substituted into Equation (2), the diameter of groove semicircle section d, the section height h, and the adjustment shaft stroke L can be determined: d≥29.78 mm, 10.42 mm≤h≤19.36 mm, 14.78 mm≤L≤23.72 mm, therefore, the diameter of groove semicircle section d is 30 mm, the section height h is 20 mm, and the adjustment shaft stroke L is 24 mm.



a. Seed metering wheel section



b. Working parameters of seed metering wheel

Figure 5 Structure and main parameters of the first wheel body of the seed metering wheel

2.4 Theory analysis of seeding process

According to the working process and principle of the seed metering device, the working process of the seed metering device can be divided into the filling stage, the clearing stage, the carrying stage, the first seeding stage, and the secondary seeding stage. In the first seeding stage, the seeds were separated from the seed metering wheel under the multiple actions of their self-weight and inertial force to complete the first seeding. Meanwhile, the peanut seeds fall onto the seed block. The kinematics and dynamics modeling analysis was performed when the seed just left the seed metering device. The center of the seed metering wheel was used as the coordinate origin, the machine forward speed is the X-axis, the vertical direction is the Y-axis, and the coordinate system was established (Figure 6). According to the kinematic analysis, the force of the seed along the normal and tangential directions of the seed metering wheel is as:

$$\begin{cases} F_x = G + f_t \cos\theta \\ F_y = f_t \sin\theta - f_g \end{cases} \tag{3}$$

The trajectory of the seed can be defined as Equation (4):

$$\begin{cases} X_1 = \omega rt\cos\theta \\ Y_1 = \omega rt\sin\theta + \dfrac{1}{2}gt_1^2 \end{cases} \tag{4}$$

where, ω is the angular velocity of the seeding wheel, rad/s; r is the distance from the center of the seed to the center of the seed metering wheel, mm; θ is the rotation angle of the second wheel body, rad; V_X is the sub-velocity of the seed in the X-axis direction, m/s; V_Y is the sub-velocity of the seed in the Y-axis direction, m/s; X_1 is the displacement of the seed in the X-axis direction, m; Y_1 is the displacement of the seed in the Y-axis direction, m; g is the acceleration of gravity, 9.8 m/s^2; t_1 is the seed movement time, s.

The secondary seeding mechanism was mainly composed of an elastic return piece, a limit baffle, a split pin, a seed block, a transmission rod, a limit nut, and a limit bolt. It can be seen from the schematic diagram of secondary seeding (Figure 7) that the seed metering wheel drove the movement of the secondary seeding mechanism. Toggle teeth are distributed every two seed metering grooves on the seed metering wheel to ensure that there are two seeds on the seed block each time the limit baffle is toggled. The toggle teeth shift the limit baffle, which drives the transmission rod to move upward, and the transmission rod drives the seed block to move down. That is, the seed block is opened, so that the two seeds staying on the seed block fall at the same time, and the second seeding is completed. When the seed metering wheel rotated for one circle, the two limit baffles moved 5 times each.

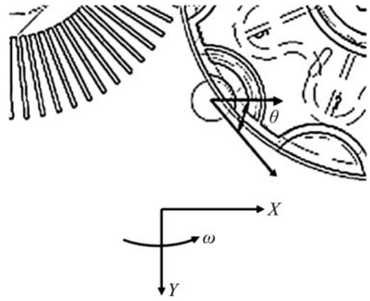
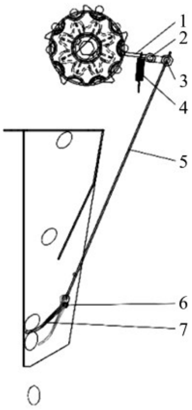


Figure 6 Analysis of seed movement during the first seeding stage



1. Limit baffle 2. Limit post 3. Limit bolts and nuts 4. Elastic return piece 5. Transmission rod 6. Split pin 7. Seed block

Figure 7 Schematic of the secondary seeding

Assuming that after the seed is in contact with the limiting baffle, the velocity in the vertical ground direction is 0, then the seed will make a free-falling movement after the secondary seeding. To make the seed fall smoothly, combine Equation (4) with Equation (5):

$$\begin{cases} Y_1 = \dfrac{1}{2}gt_1^2 \\ l \leq 1000Y_1 \\ t_2 = \dfrac{12}{v_2} \end{cases} \tag{5}$$

where, Y_1 is the displacement of the seed in the Y-axis direction, m; t_2 is the time for the limit baffle to move for one cycle, s.

2.5 Working performance test

In order to clarify the effect of influencing factors on working performance, a test-bed test was built according to the standard on operating quality grain film-covering hill-drop dill[32]. A transportation belt was used to simulate the seed-bed run situation. The equipment was fixed above the belt, and the forward speed of the belt was the same as the seeder operating speed. 100 consecutive actual seed spacings were recorded when the equipment rotated uniformly. Data were processed to obtain the values of the evaluation indexes.

According to the industry standard[32], the hole spacing was qualified as the theoretical hole spacing ±15 mm. If it was greater than 1.5 times the theoretical hole spacing, it was an empty hole.

According to local agronomic requirements, n±1 peanut seeds were qualified (when $n=1$, take one or two seeds as qualified seed). Through the following test, it was found that the qualified rate of the number of the hole was almost above 90%, which satisfied the requirements in the standard (≥85%). Therefore, this test adopts an index that was higher than the qualified rate of the number of a hole in the literature was the single hole double-seed rate[31]. The single hole double-seed seeding effect of the seed metering device was measured, and 2 peanut seeds per hole were regarded as qualified, and the rest parts were unqualified.

The groove length, seed charge height, seed-bed belt speed, and rotation speed of the seed metering wheel were selected as the test factors. The evaluation indexes were single hole double-seed rate, qualified rate of hole spacing, variation coefficient of hole spacing, and hole rate. No less than 30 points are measured in each row, and the number of measured hole is determined to be f=36. The calculated equations are

Single hole double-seed rate:

$$H_l = \frac{l_h}{f} \times 100\% \tag{6}$$

Qualified rate of hole spacing:

$$H_x = \frac{x_h}{f} \times 100\% \tag{7}$$

Variation coefficient of hole spacing:

$$C_v = \sqrt{\frac{\Sigma(L_s - \bar{L}_s)^2}{(f-1)\bar{L}_s^2}} \times 100\% \tag{8}$$

Hole rate:

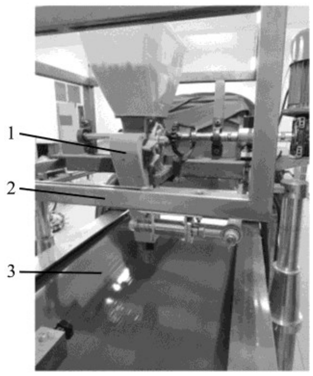
$$H_k = \frac{k_h}{f} \times 100\% \tag{9}$$

where, l_h is the number of seed holes in which two seeds fall into the sample seed hole; x_h is the qualified number of hole spacing; L_s is sample hole spacing; $\bar{L}_s$ is the average value of sample hole spacing; k_h is the number of hole.

Peanut variety Jinonghua-3 was selected as the single-factor and orthogonal tests material of the JPS-12 seed metering device test bench. The experimental factors and levels are listed in Table 2, the actual operation is shown in Figure 8.

Table 2 Test factors and levels setting

Factors	Levels setting				
Groove length/mm	20.00	25.00	30.00	35.00	40.00
Seed charge height/mm	20.00	40.00	60.00	80.00	100.00
Seed-bed belt speed/km·h^{-1}	1.04	1.68	2.05	2.46	3.02
Rotation speed of the seed metering wheel/r·min^{-1}	11.80	15.00	17.90	21.10	23.80



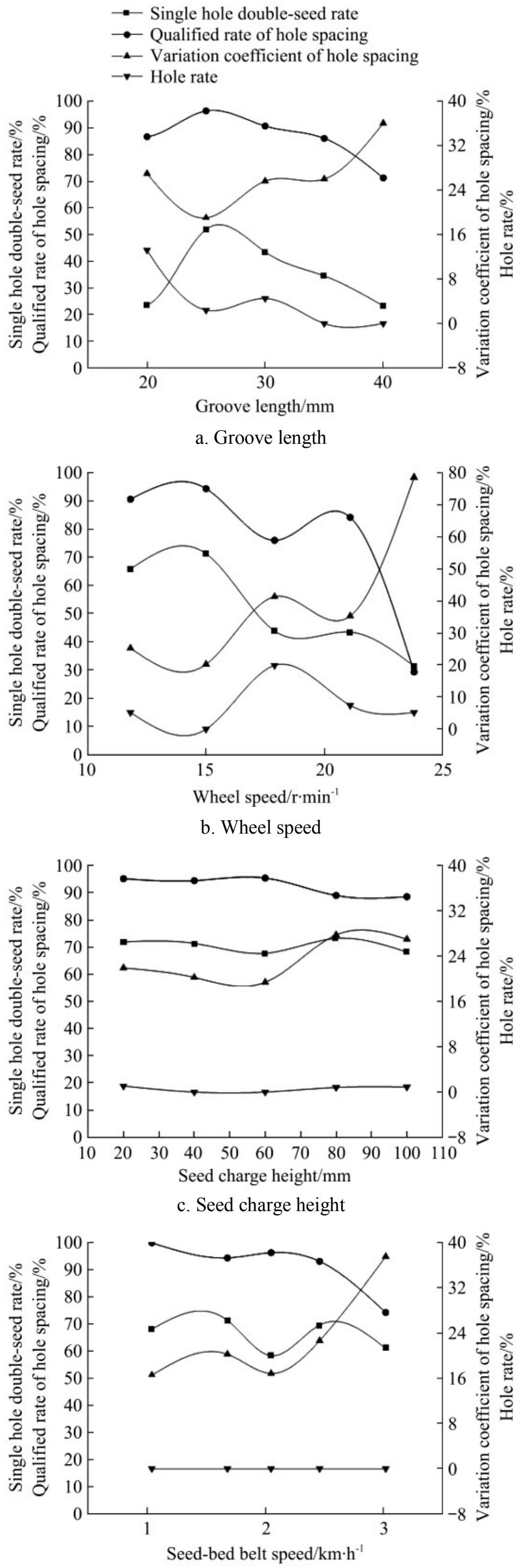
1. Seed metering device 2. Fixed frame of seed metering device
3. Seed-bed belt

Figure 8 Test device of seed metering process

3 Results and discussion

3.1 Influence of different factors

The test results of the effects of different factor levels on the performances of the seed metering device are shown in Figure 9. The horizontal coordinate in the figure is the level of each factor, and the vertical coordinate is the test evaluation index.



a. Groove length

b. Wheel speed

c. Seed charge height

d. Seed-bed belt speed

Figure 9 Effects of different factors (groove length, wheel speed, seed charge height, and seed-bed belt speed) on the performances of the seed metering device

It can be seen from Figure 9a that the overall trend of the hole rate is to decrease with the increase of the groove length, which shows that when the groove length is larger than 25 mm, the effect on the hole rate is small; the variation coefficient of the hole spacing first decreases and then increases with the increase of the groove length. The qualified rate of hole spacing and the single hole double-seed rate first increase and then decrease with the increase of the groove length, indicating that when the groove length is larger than 25 mm, the number of seeding increases, and poor cavitation rate decreases.

It can be seen from Figure 9b that the seed charge height has little effect on the cavitation rate; with the increase of the sending height, single hole double-seed rate, the qualified rate of hole spacing, and variation coefficient of hole spacing are all within 10%. The four indexes have little overall change, indicating that the seed metering device can effectively reduce the seed-falling speed, and the difference in the falling speed of various seeds is small. In the next multi-factor orthogonal experiment, the seed charge height was set to 40 mm.

It can be seen from Figure 9c that the seed-bed belt speed has a small effect on the hole rate; as the seed-bed belt speed increases, the single hole double-seed rate and the qualified rate of hole spacing show a downward trend, and the variation coefficient of the hole spacing shows an upward trend. It shows that when the seed-bed belt speed increases, the seed spacing will be increased and the cavitation rate will be reduced.

It can be seen from Figure 9d that as the rotation speed of seed metering wheel increases, the hole rate returns to the previous level after reaching the peak; the single hole double-seed rate shows a linear downward trend with the rotation speed of seed metering wheel; the qualified rate of hole spacing and the variation coefficient of hole spacing. The change in the rotation speed of the seed metering wheel is gradually obvious, especially when the rotation speed of the seed metering wheel is 23.8 r/min, the qualified rate of the hole spacing shows an approximately linear downward trend, and the variation coefficient of hole spacing rises sharply. It shows that when the rotation speed of the seed metering wheel is too fast, the quality of the filling seed will decrease; when the rotation speed of the seed metering wheel is 11.8-21.1 r/min, the effect of the secondary seeding mechanism of the seed metering device is obvious, which can effectively reduce the speed of seed-falling speed and the difference in seed-falling; when the rotation speed of the seed metering wheel is greater than 21.1 r/min, the residence time of peanut seeds in the secondary seeding area is too short, and the effect of the secondary seeding mechanism of the seed metering device is not obvious.

3.2 Orthogonal test

Through the single factor test, it can be known that the seed metering performance of the seed metering device is affected by the groove length, the seed-bed belt speed, and the rotation speed of the seed metering wheel. However, the effect on the hole rate is not significant, and the performance is irrelevant. Design-Expert 8.0.6 software Box-Behnken response method was used to design the orthogonal test, and the optimal parameter combination under the optimal seeding performance was determined. The test program includes 17 test points, including 12 analysis factor points and 5 zero-point estimation errors. The coding of test factors and levels are listed in Table 3.

In the test index, y_1 is the single hole double-seed rate, y_2 is the qualified rate of hole spacing and y_3 is the variation coefficient of hole spacing. Test factors x_1, x_2, and x_3 are the groove length, the seed-bed belt speed, and the rotation speed of the seed metering wheel. The test results are listed in Table 4.

Table 3 Coding of test factors and levels

Levels	Groove length x_1/mm	Seed-bed belt speed x_2/km·h^{-1}	Rotation speed of the seed metering wheel x_3/r·min^{-1}
–1	22	1.0	12
0	25	1.8	14
1	28	2.6	16

Table 4 Test arrangement and test results

No.	Test factors			Test indicators		
	x_1	x_2	x_3	y_1/%	y_2/%	y_3/%
1	0	1	1	58.85	90.88	8.35
2	0	−1	−1	71.64	98.13	11.74
3	0	0	0	70.62	98.66	18.96
4	1	0	1	66.45	97.17	20.71
5	0	−1	1	65.52	96.25	13.63
6	0	1	−1	61.95	91.94	7.04
7	0	0	0	66.12	96.33	13.64
8	−1	1	0	40.26	92.58	16.75
9	1	0	−1	69.27	95.62	11.74
10	0	0	0	66.36	96.33	13.76
11	−1	0	1	42.87	93.83	11.88
12	0	0	0	66.11	96.12	13.89
13	−1	0	−1	44.65	94.01	11.69
14	−1	−1	0	50.84	99.26	10.42
15	1	−1	0	71.81	99.61	14.36
16	1	1	0	68.13	87.80	12.08
17	0	0	0	66.28	96.56	12.98

3.3 Regression model and analysis

According to the test results in Table 4, the test results are subjected to multiple regression fitting analysis and variance analysis. The results of the variance analysis are listed in Table 5. The single hole double-seed rate y_1, the qualified rate of hole spacing y_2, the variation coefficient of hole spacing y_3, and the regression equation of the coded value of the test factor can be finally obtained:

$$y_1=67.10+12.13x_1-3.83x_2-1.73x_3+1.72x_1x_2-0.26x_1x_3+0.76x_2x_3-9.01x_1^2-0.33x_2^2-2.28x_3^2 \quad (10)$$

$$y_2=96.80+0.065x_1-3.76x_2-0.20x_3-1.28x_1x_2+0.43x_1x_3+0.20x_2x_3-0.56x_1^2-1.42x_2^2-1.08x_3^2 \quad (11)$$

$$y_3=14.65+1.02x_1-0.74x_2+1.55x_3-2.15x_1x_2+2.19x_1x_3-0.15x_2x_3+1.29x_1^2-2.53x_2^2-1.93x_3^2 \quad (12)$$

Using Design Expert 11 software, based on the Box-Behnken test principle, the predicted vs. measured values of all test index was drawn in Figure 10.

It can be seen from Table 5 that the single hole double-seed rate y_1 model $p<0.01$, as can be seen from Figure 10a, the relationship between predicted vs. measured value is linear, indicating that the regression equation is significant within the confidence interval of 99%, and the regression coefficients X_1, X_2, and X_1^2 have a very significant effect on the single hole double-seed rate ($p<0.01$), The regression coefficients X_3 and X_3^2 have significant effects on the single hole double-seed rate ($p<0.05$). The order of the single hole double-seed rate is as follows: groove length, seed-bed belt speed, and rotation speed of the seed metering wheel. The qualified rate of hole spacing y_2 model $p<0.05$, as can be seen from Figure 10b, the relationship between predicted vs. measured value is linear, indicating that the regression equation is significant within the 95% confidence interval, the regression coefficient X_2 has a very significant influence on the qualified rate of hole spacing (p<0.01), and the main factor affecting the qualified rate of hole spacing is the seed-bed belt speed. The variation coefficient of hole spacing y_3 model p>0.05, while there is no linear relationship between predicted vs. measured value in Figure 10c, indicating that the regression equation is not significant within the 95% confidence interval, and each regression coefficient has no significant influence on the variation coefficient of hole spacing (p>0.05). Therefore, the predicted value of the regression equation and the actual value are not significant. Based on ensuring that the model is significant, the insignificant regression terms are eliminated, and the three models are optimized. The result is the single hole double-seed rate y_1 and the qualified rate of hole spacing y_2 can be determined:

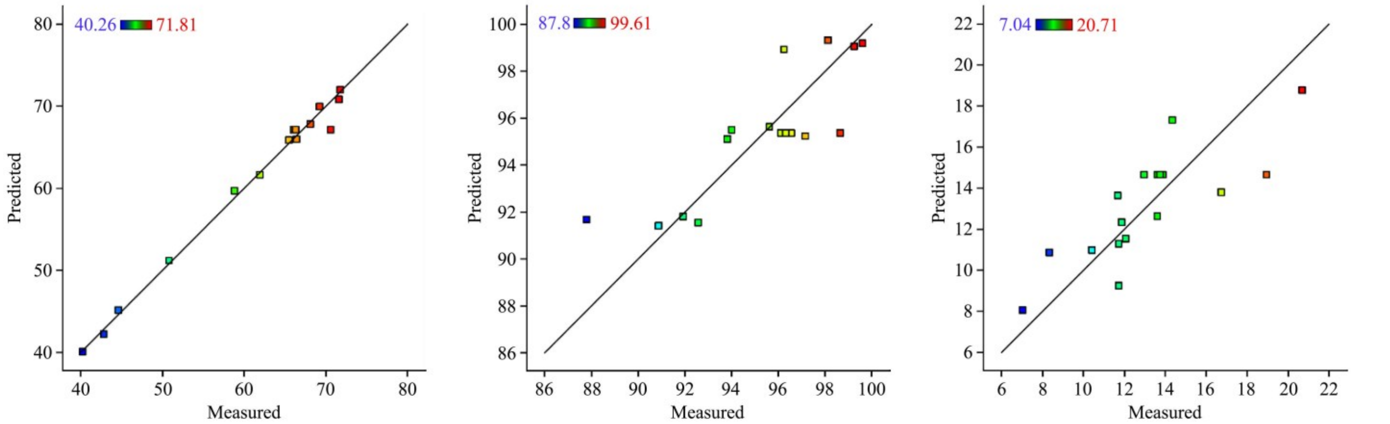
$$y_1=67.10+12.13x_1-3.83x_2-1.73x_3-9.01x_1^2-2.28x_3^2 \quad (13)$$

$$y_2=96.80-3.76x_2 \quad (14)$$

Table 5 Variance analysis of the results of seed metering performance test

Source	Single hole double-seed rate				Qualified rate of hole spacing				Variation coefficient of hole spacing			
	Sum of squares	Degree of freedom	F	p	Sum of squares	Degree of freedom	F	p	Sum of squares	Degree of freedom	F	p
Model	1710.23	9	70.67	<0.0001	136.94	9	4.49	0.030	119.10	9	1.44	0.3226
X_1	1177.10	1	437.78	<0.0001	0.03	1	0.01	0.923	8.30	1	0.90	0.3736
X_2	117.20	1	43.59	0.0003	112.88	1	33.28	0.001	4.40	1	0.48	0.5115
X_3	23.87	1	8.88	0.0205	0.31	1	0.09	0.772	19.10	1	2.08	0.1927
X_1X_2	11.90	1	4.43	0.0734	6.58	1	1.94	0.206	18.53	1	2.02	0.1986
X_1X_3	0.27	1	0.10	0.7604	0.75	1	0.22	0.652	19.27	1	2.10	0.1909
X_2X_3	2.28	1	0.85	0.3878	0.17	1	0.05	0.830	0.08	1	0.01	0.9265
X_1^2	341.74	1	127.10	<0.0001	1.34	1	0.40	0.549	6.96	1	0.76	0.4130
X_2^2	0.46	1	0.17	0.6929	8.52	1	2.51	0.157	26.94	1	2.93	0.1307
X_3^2	21.87	1	8.13	0.0246	4.89	1	1.44	0.269	15.63	1	1.70	0.2335
Residue	18.82	7			23.74	7			64.34	7		
Lack of fit	3.27	3	0.28	0.8378	19.32	3	5.83	0.0608	40.59	3	2.28	0.2215
Error	15.55	4			4.42	4			23.75	4		
Sum	1729.05	16			160.68	16			183.44	16		

Note: p<0.01 (highly significant), p<0.05 (significant).



a. The single hole double-seed rate y_1 b. The qualified rate of hole spacing y_2 c. The variation coefficient of hole spacing y_3

Figure 10 Predicted vs. measured values of y_1, y_2, y_3

3.4 Analysis of all factors on performance

To find the optimal combination of various factors, the single hole double-seed rate of the seed metering device and the maximum qualified rate of the hole spacing were used as evaluation indicators. In the multi-objective optimization solution to the seeding performance index regression model, the constraint conditions can be obtained:

$$\begin{cases} \max y_1(x_1,x_2,x_3) \\ \max y_2(x_2) \\ 22\text{ mm} \le x_1 \le 28\text{ mm} \\ 1.0\text{ km/h} \le x_2 \le 2.6\text{ km/h} \\ 12\text{ r/min} \le x_3 \le 16\text{ r/min} \end{cases} \quad (15)$$

Bringing the data into the Design-Expert software, the optimal working parameters were obtained as follows: the groove length is 27.3 mm, the seed-bed belt speed is 1.51 km/h, and the rotation speed of the seed metering device is 14.11 r/min.

3.5 Test of the optimized seed metering device

The optimized parameters are as follows: the groove length is 27.3 mm, the seed-bed belt speed is 1.51 km/h, and the rotation speed of the seed metering wheel is 14.11 r/min. The seed charge height in the experiment was 40 mm, the test was repeated three times, and the average of measured values was processed as the final results. The results showed that the qualified rate of the seeds number per hole was 98.84%, the single hole double-seed was 72.32%, the qualified rate of hole spacing was 97.17%, and the variation coefficient of hole spacing was 9.74%, and the hole rate was 1.40%. These indexes can meet the peanut single hole double-seed agronomic requirements of the standard on the operating quality of plastic film mulch hole seeding drill in China.

4 Conclusions

1) In this study, a precision double-seed peanut seed metering

device with the function of secondary seeding was designed, and the key components of the seed metering device were theoretically analyzed and calculated to meet the expected peanut double-seed hole seeding requirements.

2) Analysis by regression model showed that the influence of groove length, seed-bed belt speed, and rotation speed of seed metering wheel on the single hole double-seed rate was successively reduced; the main factor influencing the qualified rate of hole spacing is seed-bed belt speed and various factors have no significant influence on the variation coefficient of hole spacing.

3) The optimal parameter combination of the optimized seed metering device was obtained through Design-Expert software: the groove length was 27.3 mm, the seed-bed belt speed was 1.51 km/h, and the rotation speed of the seed metering wheel was 14.11 r/min. The performance test result of the optimized seed metering device was: the qualified rate of seeds number per hole was 98.84%, the single hole double-seed rate was 72.32%, the qualified rate of the hole spacing was 97.17%, the variation coefficient of hole spacing was 9.74%, and the hole rate was 1.40%. Compared with the indexes of the standard on operating quality grain film-covering hill-drop dill, the parameters have been greatly improved, especially the quality of peanut double-seed hole seeding, which fully meets the agronomic requirements of peanut double-seed hole seeding.

Acknowledgements

This work was financially supported by the Modern Agricultural Industrial Technology System Oil Industry Innovation Team Building Project of Hebei Province (Grant No. HBCT2018090206), the Hebei Province Youth Top Talent Funding Project.

[References]

[1] Kang J M, Peng Q J, Zhang C Y, Zhang N N, Fang H M. Design and testing of a punching-on-film precision hole seeder for peanuts. Transactions of the ASABE, 2020; 63(6): 1685–1696.

[2] Zhao Y F, Zhang C J, Meng Y, Wang M L, Wang Y F, Zhang X J, et al. Effects of calcium application on agronomic characters of peanut pods at development stage. Journal of peanut science, 2019; 48(1): 27–33, 57. (in Chinese)

[3] Yazgi A, Degirmencioglu A. Measurement of seed spacing uniformity performance of a precision metering unit as function of the number of holes on vacuum plate. Measurement, 2014; 56: 128–135.

[4] Yang L, Yan B X, Cui T, Yu Y M, He X T, Liu Q W. Global overview of research progress and development of precision maize planters. Int J Agric & Biol Eng, 2016; 9(1): 9–26.

[5] Zhang K F, Zhang Z, Wang S, Yang C, Yu Y C, Li H. Design and experiment of electronic seeding system based on response surface method. International Journal of Computer Integrated Manufacturing, 2020; 33(10-11): 982–990.

[6] Jin X Y, Sun S M, Zhang H B, Liang Y C, Yu X B. Design and research of 2BJZ-2 type corn single-grain precision seeder. Journal of Agricultural Mechanization Research, 2019; 41(3): 51–57. (in Chinese)

[7] Ding Y, Wang L, Li Y W, Li D L. Model predictive control and its application in agricultural: A review. Computers and Electronics in Agriculture, 2018; 151: 104–117.

[8] Jin X, Li Q W, Zhao K X, Zhao B, He Z T, Qiu Z M. Development and test an electric precision seeder for small-size vegetable seeds. Int J Agric & Biol Eng, 2019; 12(2): 75–81.

[9] He X K, Bonds J, Langenakens J. Recent development of unmanned aerial vehicle for plant protection in East Asia. Int J Agric & Biol Eng, 2017; 10(3): 18–30.

[10] Zhu T, Cong J L, Qi B B, Wu M C, Peng X Y, Wang Y S. Design and tests of mechanical-pneumatic combined peanut precision seed-metering devices. China Mechanical Engineering, 2020; 31(21): 2592–2600. (in Chinese)

[11] Singh R C, Singh G, Saraswat D C. Optimisation of design and operational parameters of a pneumatic seed metering device for planting cottonseeds. Biosystems Engineering, 2005; 92(4): 429–438.

[12] Zhang J L, Guo F, Yang D Q, Meng J J, Yang S, Wang X Y, et al. Effects of single-seed precision planting on population structure and yield of peanuts with super-high yield cultivation. Scientia Agricultura Sinica, 2015; 48(18): 3757–3766. (in Chinese)

[13] Zhang Z M, Dai L X, Ci D W, Yang J S, Ding H, Qin F F, et al. Effects of planting density and planting method on growth, development, yield, and quality of peanut in saline-alkali land. Chinese Journal of Eco-Agriculture, 2016; 24(10): 1328–1338. (in Chinese)

[14] Liao Y T, Wang L, Liao Q X. Design and test of an inside-filling pneumatic precision centralized seed-metering device for rapeseed. Int J Agric & Biol Eng, 2017; 10(2): 56–62.

[15] Liao Q X, Lei X L, Liao Y T, Ding Y C, Zhang Q S, Wang L. Research progress of precision seeding for rapeseed. Transactions of the CSAM, 2017; 48(9): 1–16. (in Chinese)

[16] Zhang T T, He X N, Wang Y Y, Shang S Q, Wang D W, Tong Q T. Study on air suction precision seeder for peanut. Journal of Agricultural Mechanization Research, 2017; 39(5): 68–74. (in Chinese)

[17] Elebaid J I, Liao Q X, Wang L, Liao Y T, Yao L. Design and experiment of multi-row pneumatic precision metering device for rapeseed. Int J Agric & Biol Eng, 2018; 11(5): 116–123.

[18] Yu J J, Liao Y T, Cong J L, Yang S, Liao Q X. Simulation analysis and match experiment on negative and positive pressures of pneumatic precision metering device for rapeseed. Int J Agric & Biol Eng, 2014; 7(3): 1–12.

[19] Yang L, Yan B X, Cui T, Yu Y M, He X T, Liu Q W, et al. Global overview of research progress and development of precision maize planters. Int J Agric & Biol Eng, 2016; 9(1): 9–26.

[20] Sun Y T, Tian L Z, Shang S Q, Yang R B, Wang Y Y, Zhao J L. Experimental research on inside-filling metering device for peanut seeder. Transactions of the CSAE, 2012; 28(S2): 84–89. (in Chinese)

[21] Yang Y G, Yang X M, Li C H. The improvement and motion simulation research of filling type vertical plate seed-metering device. Journal of Agricultural Mechanization Research, 2014; 36(4): 16–20. (in Chinese)

[22] Song J L, Yang Z D, Yang S D, Zhang G H, Li H W. A novel inside-filling seed metering device. Journal of Agricultural Mechanization Research, 2013; 35(6): 90–93. (in Chinese)

[23] Yang R B, Chai H H, Shang S Q. Performance of metering device with declined discon peanut seeder. Transactions of the CSAM, 2014; 45(6): 79–84. (in Chinese)

[24] Chen T, Zhai C N, Xing Z Z, Guo X J, Zhang H D. Discrete element simulation study of seed metering process of inside-filling meter based on EDEM. Journal of Anhui Agricultural Sciences, 2016; 44(16): 250–253, 278. (in Chinese)

[25] He Y H, Cong J L, Kan Z, Liu X Y. Design and simulation of cam contour curve of pneumatic precision metering device. Journal of Shihezi University (Natural Science), 2016; 34(3): 391–396. (in Chinese)

[26] Luo X W, Zhang M H, Wang Z M, Zeng S, Zhou Z Y, Zang Y, et al. Combined hole seed metering device with adjustable seeding rate, 2012; Chinese Patent: CN102612904A. (in Chinese)

[27] Chen X, Chen G L, Wang X D. Optimization design and test of the pore structure of peanut seed metering device. Journal of Zhongkai University of Agricultural Engineering, 2019; 32(1): 28–34. (in Chinese)

[28] Wang B L, Wang Z M, Luo X W, Zhang M H, Fang L Y, Liu S C, et al. Design and experiment of wedge churning device for pneumatic cylinder-type seed metering device for hybrid rice. Transactions of the CSAE, 2019; 35(23): 1–8. (in Chinese)

[29] Hebei Agricultural University. Seed metering devise with secondary seeding function, 2020; Chinese Patent: ZL201921327152.7. (in Chinese)

[30] Hebei Agricultural University. Seed metering devise with secondary seeding function, 2019; Chinese Patent: CN201910755084.2. (in Chinese)

[31] Lei X L, Zhang L, Yang H, Liu Y L, Li Y H, Luo M L. Design and experiment of the electric drive control system of precision centralized metering device for rapeseed. Journal of Anhui Agricultural University, 2020; 47(3): 472–479. (in Chinese)

[32] NY/T987-2006. Operating quality grain film-covering hill-drop dill. Ministry of Agriculture, the People's Republic of China, 2006. (in Chinese)