SIMULATION OF SOYBEAN SEED PHYSICAL PROPERTIES ON FILLING PERFORMANCE
/
大豆种子物理特性对充种性能影响的仿真研究

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ABSTRACT
Soybean seed physical properties is important on filling performance during planting. To evaluate the effect of sphericity and variation coefficient of mean diameter on seeding performance in seed metering device, seven soybean genotypes [The Ken Dou 40, Ken Feng 17, Qing Ren Black Soybean, Black Soybean, Hei He 44, Bei Jiang 91 and Dong Nong 52] were tested to measure the length, width, thickness, and calculate these sphericities, mean diameter and variation coefficient of mean diameter, respectively. The model of soybean seed with equal mean diameter was developed and the discrete element method was used to set the different sphericity and variation coefficient of mean diameter. A simulation study was performed in the model of the cell wheel feed followed by mathematical modeling of the experimental data, and the data with response to the surface methodology was analyzed. Results showed that while the sphericity had a significant effect on both single- and empty -seed rates, the variation coefficient of mean diameter had a significant effect on the multi -seed rate. With the increase of sphericity, the single-seed rate increases but empty-seed rate decreases. With the increase of variation coefficient of mean diameter, the multi-seed rate increases. Based on our results, the Ken Feng17, Ken Dou 40, Black Soybean and Qing Ren Black soybeans were only selected for bench test. The relative error between the experimental results and the theoretical values of the regression analysis was small; however, the respond trend of factor index was same. Our study suggested that the effect of sphericity and variation coefficient of mean diameter on seeding performance can be used by using simulation experiment.

摘要
大豆种子的物理特性对充种过程中的充填性能影响非常重要，为了探究球度与均径变异系数对种子在排种器中充填性能的影响，选取 7 种不同品种的大豆种子[垦豆 40, 垦丰 17, 青仁黑豆, 黑豆, 黑河 44, 北疆 91 和东农 52]为试验对象，分别测量种子的长度、宽度、厚度，并计算种子的球度、均径变异系数，建立相同均径的大豆种子模型，并采用离散元法设置不同的球度和均径变异系数，并在窝眼轮式排种器模型中进行仿真试验。构造试验数据的数学模型，并进行响应曲面分析，结果表明：球度对单粒率和空粒率影响显著，均径变异系数对多粒率影响显著；随着球度的增加，单粒率升高，空粒率减小；随着均径变异系数的增加，多粒率升高。依据结果，选择垦丰 17、垦豆 40、黑豆和青仁黑豆进行台架试验，其试验值与回归方程输出理论值的相对误差较小，且具有相同的因素指标响应趋势，即利用仿真试验研究球度及均径变异系数对排种性能的影响具有可行性。

INTRODUCTION
Soybean is one of the most important legume grain crops associated with global food security. Soybeans as a crop is grown on an estimated 6% of the world’s arable lands (*Hartman et al., 2011*). Global soybean production in the 2017-2018 market year was 346 million metric tons which represents 61% of the world’s oilseeds production. Out of 12 major soybean producing countries, Brazil, Argentina and the U.S. produced over 82% of the world’s soybeans. The U.S. was first in world soybean production with 119.5 million tons followed by Brazil at 112 million tons, and Argentina 54 million tons (*USDA/NASS., 2017*). China accounts for 4% of soybean production in the world, covering over 235 million hectares farmland. China accounts for 60% of worldwide soybean imports to meet the domestic demand. World growth of soybeans has been impressive as the growth has increased by about 350% since 1987 in response to the commercial growth of livestock and poultry industries.

While soybean is an important protein and oil source, the potential of greater benefits will achieve both economically and socially if soybeans can be sustainably and continuously grown with precision technology. Sustainable agricultural practices have the potential to maximize soybean production in response to increasing global demand; however, a systematic approach is needed to equilibrate soybean seeding techniques.

The effects of physical properties of soybean seeds on seeding performance is one of the key problems in current research on soybean breeding (*Liu et al., 2015; Horabik and Molenda, 2016*; *An et al., 2017; Shi et al., 2020*). It's often problematic for the commercially available current metering devices to meet the seed filling requirements due to the differences of the geometric characteristics of the soybean seeds. The variable geometric characteristics of soybean seeds with internal friction among themselves resulted in irregular seeding of soybeans, therefore improving seeding performance has always been a research focus of the precision seed metering device. Use of planting equipment with adaptive seed metering devices can improve the efficiency of precision planting of seeds and reduce the cost of soybean production. While several studies have researched the relationship between soybean seeds filling and parameters of type hole, there are very limited research information available on filling performance of different sphericity and variation coefficient of mean diameter of soybean seeds in seed metering devices (*Dun et al., 2016; Coetzee, 2019; Zhao et al., 2019*).

With the development of computer technology, numerical simulation has been used in the design, analysis, and optimization of agricultural machinery. The discrete element method is a new numerical method for analyzing and solving the dynamics of discrete systems *(Yang et al., 2018; Zeng et al., 2018; Han et al., 2019*). A recent study reported the influence factors of seed filling problem of corn seed distributor by using the discrete element method (*Lu et al., 2018*). Similarly, another one proposed a method of seed discrete element modeling based on granular assembly by measuring and analyzing the parameter of soybean seeds (*Wang et al., 2018*). Other studies have also dynamically simulated the working processes of seed metering device with discrete element method (*Qian et al., 2023*). Based on the results of previous studies, the discrete element method has a great potential and space to optimize the performance of seed metering devices.

Based on the discrete element method, the soybean seeds with different sphericity and variation coefficient of mean diameter were simulated by using the model of Shuang Fu cell wheel feed. The effect of sphericity and variation coefficient of mean diameter on filling performance was evaluated to provide a theoretical basis on designing the seed meter device for soybean seeds. The simulation analysis on the seed metering device by discrete element numerical simulation will save costs, minimize test cycle, and provide references and calibration for the improvement of the precision planters.

MATERIALS AND METHODS

Measurement and calculation of physical characteristics of soybean seeds

The Ken Dou 40, Ken Feng 17, Qing Ren Black Soybean, Black Soybean, Hei He 44, Bei Jiang 91 and Dong Nong 52 were selected as test objects to study the effect of sphericity and variation coefficient of mean diameter on filling performance.

The parameters (length L, width W, and thickness T) of 100 seeds randomly selected from each variety were measured with SANTO 8014 digital caliper (measuring range 1~150 mm, accuracy 0.01 mm) as shown in Fig.1. The mean diameter, sphericity, and variation coefficient of soybean seeds were also calculated (*Lu et al., 2017; Xu et al., 2017*).

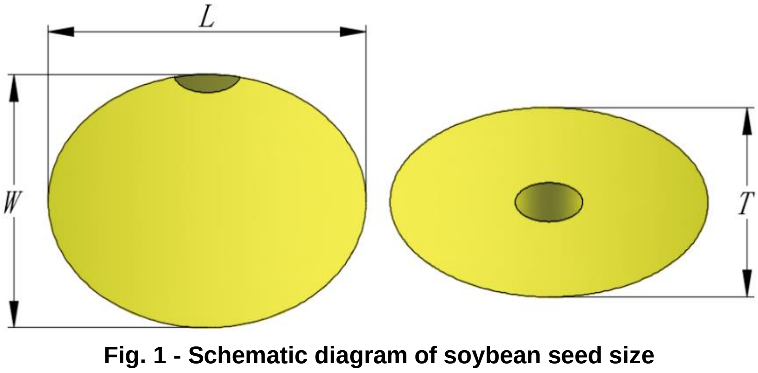

Fig. 1 - Schematic diagram of soybean seed size

Note: L seed length, mm, W seed width, mm, T seed thickness, mm.

The soybean seed was supposed to be a three-dimensional ellipsoid, according to the related researchers (*Yuan et al., 2022; Rorato et al., 2019*), the calculation formula of sphericity was as follows:

$$S_P = \frac{\sqrt[3]{LWT}}{L} \quad (1)$$

where: L is length of the seed, mm; W is width of the seed, mm; T is thickness of the seed, mm.

The variation coefficient can reflect the discrete degree of soybean mean diameter, and the calculation formula of variation coefficient was as follows:

$$C = \frac{S_d}{N} \times 100\% \quad (2)$$

where:

C is the variation coefficient of mean diameter, %; S_d is the standard deviation, mm; N is the average value, mm.

According to the measurement and calculation of the physical characteristics of the above seeds, mean diameter, range of sphericity, mean sphericity and variation coefficient of mean diameter were calculated as shown in Table 1.

Table 1

The data of soybean seed with descriptive statistics Table

Soybean variety	Mean diameter (mm)	The range of sphericity (%)	Mean sphericity (%)	Variation coefficient of mean diameter
Ken Dou 40	6.13	93.2 - 99.8	96	0.046
Ken Feng 17	6.66	88.7 - 99.8	96.4	0.041
Qing Ren Black Soybean	6.65	75.5 - 94.4	87.1	0.068
Black Soybean	7.52	81.3 - 95.2	89.9	0.057
Hei He 44	5.98	78.1 - 95.8	88.8	0.050
Bei Jiang 91	6.88	84.6 - 98.4	95.1	0.062
Dong Nong 52	6.69	90.8 - 98.4	95.5	0.043

Mean diameter of soybean seeds was supposed to be a constant value for studying the effect of sphericity and variation coefficient of mean diameter on seed filling performance. Because in the context of definite type hole, the smaller the mean diameter of soybean seeds is, the easier it is to fill the seeds. It was selected as the model of test that the smallest integer of mean diameter range is 6 mm and range of the sphericity is 70 - 100%, and range of variation coefficient of mean diameter is 0.041 - 0.068. Based on the information, our discrete element simulation test was developed.

The establishment of discrete element model

The contact parameters in EDEM

The material of the seed metering device was set as steel and the brush was nylon origin. Related research (*Zhang et al., 2018; Zhang et al., 2017*) have shown that the Poisson's ratio, shear modulus, and density of the soybean seed, steel surface and brush were supposed to be constant values. So, the coefficient of restitution, coefficient of static friction, and coefficient of rolling friction of the seed-seed, seed-brush, and seed-steel surface were calculated, as shown in Table 2.

Table 2

Basic parameters of soybean seed

Material	Parameters	Value
Soybean seed	Poisson's ratio	0.23
	Shear modulus (MPa)	63
	Density (kg/m^3)	1290
Brush	Poisson's ratio	0.40
	Shear modulus (MPa)	100
	Density (kg/m^3)	1150
Steel surface of seed metering device	Poisson's Ratio	0.30
	Shear modulus (MPa)	70000
	Density (kg/m^3)	7800
Seed-seed	Coefficient of restitution	0.30
	Coefficient of static friction	0.39
	Coefficient of rolling friction	0.17
Seed-brush	Coefficient of restitution	0.45
	Coefficient of static friction	0.50
	Coefficient of rolling friction	0.01
Seed-steel surface	Coefficient of restitution	0.52
	Coefficient of static friction	0.15
	Coefficient of rolling friction	0.09

Soybean seed model, establishment of seed metering device model and parameter setting

According to parameters in Table 1 and 2, the model of soybean seeds (mean diameter, 6 mm) was built with the granular assembly method. The relationship between seeds length, width and thickness and seeds sphericity was as follows:

$$\begin{cases} \dfrac{L+W+T}{3}=N \\ \dfrac{\sqrt[3]{L\times W\times T}}{L}\times 100\%=S_P \\ L=S+D \\ T=D \end{cases} \tag{3}$$

where: L is length, [mm]; W is width, [mm]; T is thickness, [mm]; N is mean diameter, [mm]; S_p is sphericity, [%]; S is the distance between the outside two balls, [mm]; D is the diameter of the ball, [mm].

In the following, a soybean seed with 85% sphericity will be used as an example to illustrate the process of constructing a soybean seed particle model. First, to simplify the calculation process, the thickness and width of the soybean seeds were supposed to be equivalent. According to Formula 3, the distance S between the outermost two balls is 1.52 mm and the diameter D of ball is 5.49mm. In the EDEM particle system, to begin with, three balls are generated. The three balls are on the same layer and have the same diameter, as well as the spherical centers of the three balls are (-0.76,0,0), (0,0,0) and (0.76,0,0) respectively. The three balls were used to simulate soybean seeds, and the final combination resulted in a soybean seed model with 85% sphericity. In this way, the spherical polymerization model of soybean seeds with the same diameter and other different sphericity was established. Soybean seed model is shown in Figure 2.

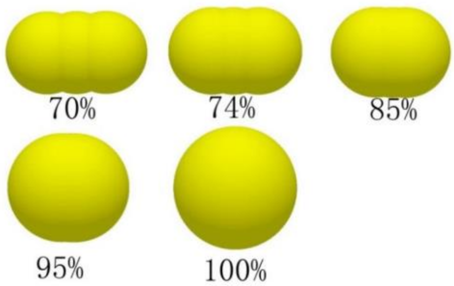

Fig. 2 - Soybean seed model

Quadratic orthogonal simulation experiment

Test parameters

The contact model (particle to particle and particle to geometry) was set as Hertz-Mindlin (no slip) build-in with discrete element simulation software EDEM 2.6. A 3D model removed the complex structure was built in the Solid works which could be imported into EDEM2.6, based on the Shuang Fu brush cell wheel feed (Figure. 3).

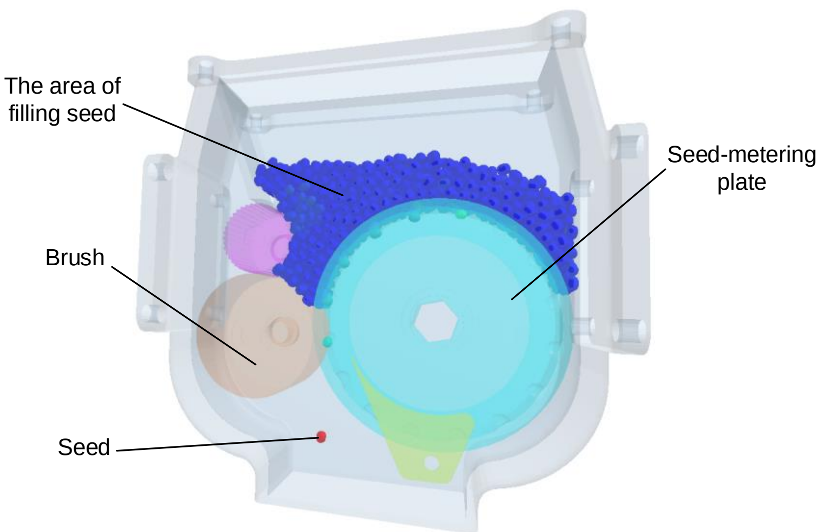

Fig. 3 - The EDEM model of seed metering device

Related previous studies (*Dun et al., 2016*) have shown that, there was the best effect on the cell wheel feed when the diameter of the holes on the cell wheel feed disk was 1.5 to 1.7 times as long as the seeds' mean diameter. Therefore, the diameter of holes was set to 9.6 mm, which was 1.6 times as long as the seeds' mean diameter, (*the mean diameter of seeds was 6 mm*). The diameter of the seeding disk was 130 mm, and 25 holes were arranged around it. The theoretical plant spacing was 5 cm, and the maximum working speed was 0.5 m/s. By calculation, the rotational speed of the seeding disk was 0.4 r/s, and the rotation speed of the brush was set to be 0.5 r/s.

The virtual particle factory was created at the upper seed box of the model. The central coordinate of the virtual plane was set as (0, 0, 110), the size of the long side was 80 mm, and the size of the short side was 30 mm. Particles were set in dynamic generation mode, and the number of particles was set as 300, and the generation speed was 5000 seeds per second. The particle diameter was subject to the normal distribution mode (*Ma et al., 2015; Wang et al., 2018; Wang et al., 2018*), and the soybean seeds' variation coefficient of mean diameter was matched with data presented in Table 2. The simulation started from 0 seconds and the particle's downward velocity was set to 2.5 m/s. The duration was 15 seconds, and the fixed time step was set to 5×10-6 s.

The sphericity and variation coefficient of mean diameter were selected as experimental factors, and the two-factor and five-level quadratic regression orthogonal test was designed to analyze the effect on filling performance. The experimental factors and horizontal code were shown in Table 3.

Table 3

Experimental factors and horizontal code

Levels	Factors	
	Sphericity X1/%	**Variation coefficient of mean diameter X2**
+1.267	100	0.068
+1	96.8	0.065
0	85	0.055
-1	73.2	0.045
-1.267	70	0.041

Simulation data and analysis

Variance analysis

According to the two-factor five-level quadratic regression orthogonal experiment (*Li et al., 2023*) as designed above, the single-seed rate, empty-seed rate, and multi-seed rate were obtained by the simulation, as shown in Table 4. The data were analyzed by design-expert 8.0.6 software, as shown in Table 5.

Table 4

The result of simulation

Test serial number	Sphericity X_1	Variation coefficient of mean diameter X_2	The single seed rate Y_1	The multi-seed rate Y_2	The empty hole rates Y_3
1	-1	-1	77.6	10.8	11.6
2	1	-1	87.9	8.4	5.3
3	-1	1	71.4	13.8	14.8
4	1	1	85.5	14.2	0.3
5	-1.267	0	62.9	11.6	20.5
6	1.267	0	89.1	10.6	0.2
7	0	-1.267	85.3	4.7	10
8	0	1.267	81.8	12.8	6.4
9	0	0	84.6	7.7	7.7
10	0	0	80.7	9.5	9.8
11	0	0	82.4	9.3	8.3
12	0	0	84.9	8.9	6.2
13	0	0	81.1	9.2	9.7

Table 5

Analysis of variance

Evaluation Index	Variation source	Sum of squares	Freedom	Mean square	F value	*P* value	Significance
The single seed rate	Model	561.93	5	112.39	15.17	0.0012	**
	X_1	460.06	1	460.06	62.10	0.0001	**
	X_2	23.56	1	23.56	3.18	0.1177	-

Evaluation Index	Variation source	Sum of squares	Freedom	Mean square	F value	*P* value	Significance
	X_1X_2	3.61	1	3.61	0.49	0.5077	-
	X_1^2	69.11	1	69.11	9.33	0.0185	*
	X_2^2	5.59	1	5.59	0.75	0.4139	-
	Residual	51.86	7	7.41	-	-	-
	Lack of fit	36.77	3	12.26	3.25	0.1424	-
	Pure error	15.09	4	3.77	-	-	-
	Cor total	613.79	12	-	-	-	-
The multi-seed rate	Model	73.92	5	14.78	13.08	0.0019	**
	X_1	1.48	1	1.48	1.31	0.2901	-
	X_2	50.40	1	50.40	44.58	0.0003	**
	X_1X_2	1.96	1	1.96	1.73	0.2294	-
	X_1^2	19.01	1	19.01	16.82	0.0046	**
	X_2^2	1.07	1	1.07	0.95	0.3620	-
	Residual	7.91	7	1.13	-	-	-
	Lack of fit	5.87	3	1.96	3.82	0.1142	-
	Pure error	2.05	4	0.51	-	-	-
	Cor total	81.84	12	-	-	-	-
The empty hole rate	Model	327.22	5	65.44	16.24	0.0010	**
	X_1	300.14	1	300.14	74.50	< 0.0001	**
	X_2	5.61	1	5.61	1.39	0.2764	-
	X_1X_2	16.81	1	16.81	4.17	0.0804	-
	X_1^2	2.76	1	2.76	0.69	0.4349	-
	X_2^2	1.90	1	1.90	0.47	0.5144	-
	Residual	28.20	7	4.03	-	-	-
	Lack of fit	19.23	3	6.41	2.86	0.1683	-
	Pure error	8.97	4	2.24	-	-	-
	Cor total	355.42	12	-	-	-	-

Note: P<0.01 (Highly significant, **), 0.01<P<0.05 (Very Significant, *), P>0.05 (not significant)

The single-seed rate model indicated that the model has reached the highly significant level and the misfit was not significant to account for. By analyzing the reliability of the test model, the determination coefficient (R^2=0.8621) was obtained, which indicated that the 86.21% of the response values came from the selected factors, so the test fits well. The significance test of the model showed that the P of X_1 was less than 0.01, and the P of X_1^2 was less than 0.05. indicating that the sphericity and sphericity square had a significant impact on the single-seed rate, while other interactions were less significant. The regression equation of the variation coefficient of mean diameter and sphericity was:

$$Y_1 = -92.10 + 4.71X_1 - 1809.70X_2 + 7.53X_1X_2 - 0.03X_1^2 + 9172.52X_2^2 \tag{4}$$

According to the P value, the less significant terms were removed one by one. The regression equation after removing was shown.

$$Y_1 = -162.91 + 5.12X_1 - 0.03X_1^2 \tag{5}$$

The multi-seed rate model P = 0.0019 shown that the model has reached the highly significant level and the misfit was not significant. By analyzing the reliability of the test model, the determination coefficient R^2=0.9033 was obtained, which indicated the 90.33% of the response values came from the selected factors, so the test fits well. The significance test of the model showed that the P value of X_2, and X_1^2 was less than 0.01. It showed that the variation coefficient of mean diameter and sphericity square had significant effects, while other interactions were less significant. The regression equation of the variation coefficient of mean diameter and sphericity was:

$$Y_2 = +135.19 - 2.67X_1 - 662.08X_2 + 5.55X_1X_2 + 0.01X_1^2 + 4022.52X_2^2 \tag{6}$$

According to the P value, the less significant terms were removed one by one. The regression equation after removing was shown.

$$Y_2 = -2.12 + 248.13X_2 - 1.77E - 004X_1^2 \tag{7}$$

The empty-seed rate model P=0.0010 suggested that the model has reached the highly significant level and the misfit was not significant. By analyzing the reliability of the test model, the determination coefficient R^2=0.9207 was obtained, which indicated that 92.07% of the response values came from the selected factors, so the test fitted well.

The significance test of the model showed that the P value of X_1 was less than 0.01. It showed that sphericity had significant effects, while other interactions were less significant. The regression equation of the variation coefficient of mean diameter and sphericity was:

$$Y_3 = +5.85 - 0.55X_1 + 1881.69X_2 - 16.25X_1X_2 + 5.22X_1^{\ 2} - 5347.94X_2^{\ 2} \tag{8}$$

According to the P value, the less significant terms were removed one by one. The regression equation after removing was shown.

$$Y_3 = +54.85 - 0.54X_1 \tag{9}$$

Response surface analysis

The response surface method was applied to analyze the effect and interaction of two factors on the test indicators (Figure 4).

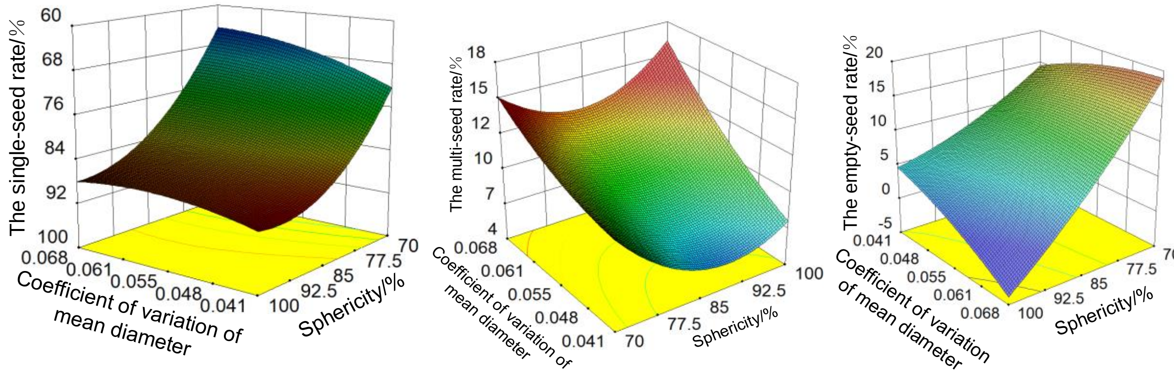

Fig. 4 - Response surface diagram of (a) single- seed, (b) multi-seed and (c) empty-seed rate

Fig. 4a was the response surface diagram of single-seed rate with the change of the experimental factors. When the sphericity was at a low level (S_P=70%), the variation coefficient of mean diameter had little effect on the single-seed rate. However, when the sphericity had other levels, the single-seed rate decreased with the increase of variation coefficient of mean diameter. When the variation coefficient was at a high level (C=0.068), the sphericity had little effect on single-seed rate. However, in other levels, the single-seed rate increased with the increase of sphericity. In Fig. 4b is shown the response surface diagram of multi-seed rate with the change of the experimental factors. When the variation coefficient of mean diameter at a high level of (C=0.068), the multi-seed rate decreased and then increased with the increase of sphericity. However, in other levels, the sphericity had little effect on multi-seed rate and increased with the increase of the variation coefficient of mean diameter. The effect of the variation coefficient of mean diameter on multi-seed rate was more significant than the sphericity. In Fig. 4c is shown the response surface diagram of empty-seed rate with the change of experimental factors. With the increase of sphericity, the empty-seed rate decreased. When the sphericity was at a low level (S_P=70%), the empty-seed rate increased with the increased of variation coefficient of mean diameter; however, when the sphericity had other levels, the empty-seed rate decreased with the increased of variation coefficient of mean diameter.

As the sphericity increased, the seed particle was closer to a positive sphere, and it was easier to enter the mold hole during seed filling, so single-seed rate increased, and empty-seed rate decreased. When the variation coefficient of mean diameter increased, the dispersion degree of seed particles became larger, and seeds became flatter and longer. As a result, the probability of filling more than two seeds in the mold hole would become bigger, and the multi-grain rate would increase accordingly.

Verification of bench test

Considering the feasibility of the test, the Shuang Fu brush cell wheel feed was used in bench test to verify the veracity of the simulation experience (Figure 5).

Fig. 5 - Verification of bench test

The working speed of the feeder was set as 0.5 m/s, the rotational speed of the seeding disk was 0.4 r/s, and the rotational speed of the brush was 0.5 m/s. In addition, Ken Feng 17 (sphericity 96.4%, variation coefficient of mean diameter 0.041), Ken Dou 40 (sphericity 96%, variation coefficient of mean diameter 0.046), Black soybean (sphericity 89.9%, variation coefficient of mean diameter 0.057) and Qing Ren black soybean (sphericity 87.1%, variation coefficient of mean diameter 0.068) were selected for testing on the performance test bench of JPS-12 seed feeder. The sphericity and variances coefficient of mean diameter were substituted into above regression equations (5), (7) and (9) to obtain the theoretical values of single, multiple and empty seed rates of the above seeds, as shown in Table 6.

Table 6

Data comparison

Variety		Sphericity/%	Variation coefficient of mean diameter	Single-seed rate/%	Multi-seed rate/%	Empty-seed rate/%
Ken Feng17	Experimental value	96.4	0.041	85.5	9.2	5.3
	Theoretical value			87.49	6.41	2.79
	Relative error			2.27	43.53	89.96
Ken Dou40	Experimental value	96	0.046	83.5	10.7	5.8
	Theoretical value			87.46	7.66	3.01
	Relative error			4.53	39.69	92.69
Black soybean	Experimental value	89.9	0.057	79.3	12.8	7.9
	Theoretical value			85.88	10.59	6.30
	Relative error			7.66	20.87	25.40
Qing Ren Black Soybean	Experimental value	87.1	0.068	77.6	14.2	8.2
	Theoretical value			84.50	13.41	7.82
	Relative error			8.17	5.89	4.86

The experimental values of single-seed rate were little smaller than that of the theoretical values, in contrast, the experimental values of multi-seed rate and empty-seed rate were little larger than the theoretical values.

While the sphericity of Ken Feng 17, Ken Dou 40, Black soybean and Qing Ren Black Soybean decreased, the variation coefficient of mean diameter increased. It could be seen from Table 6 that the single-seed rate of Ken Feng 17, Ken Dou 40, Black Soybean and Qing Ren Black Soybean decreased, multi-seed rate and empty-seed rate increased. The relative error between the verified values and the theoretical values of the equation was small and had the same response trend to factor index. Therefore, it was feasible to study the effect of sphericity and variation coefficient of mean diameter on seeding performance by using simulation test.

CONCLUSIONS

(1) The physical parameters of Ken Dou 40, Ken Feng 17, Qing Ren Black Soybean, Black Soybean, Hei He 44, Bei Jiang 91 and Dong Nong 52 were measured. The sphericity range of seeds was 75.5 to 99.8% and the variation coefficient of mean diameter was 0.041 to 0.068.

(2) Based on the measured seed parameters, the simulation was carried out by using EDEM, and the simulation results were carried out by quadratic regression orthogonal experiment, and the mathematical models of single-, multi-, empty-seed rates, sphericity and variation coefficient of mean diameter were established, respectively.

(3) According to the analysis of response surface, with the increase of sphericity, the single-seed rate increased, and the empty-seed rate decreased, and with the increase of variation coefficient, the multi-seed rate increased.

(4) Ken Feng 17, Ken Dou 40, Black Soybean and Qing Ren Black Soybean were used in the bench test. While the sphericity of Ken Feng 17, Ken Dou 40, Black soybean and Qing Ren Black Soybean decreased, the variation coefficient of mean diameter increased, so the single-seed rate of Ken Feng 17, Ken Dou 40, Black Soybean and Qing Ren Black Soybean decreased in turn, but multi-seed rate and empty-seed rate increased. The relative error between the verified values and the theoretical values of the equation was small and had the same response trend to factor index. Therefore, it was feasible to study the effect of sphericity and variation coefficient of mean diameter on seeding performance by using simulation test.

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