MEASUREMENT OF PHYSICAL PROPERTY PARAMETERS AND SIMULATIVE CALIBRATION OF DEM PARAMETERS FOR GREEN ONION SEEDS
/
大葱种子物性参数测量及 DEM 参数仿真标定

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***Keywords:** calibration, contact parameters, green onion seed, discrete elements method, small irregular*

ABSTRACT

The contact parameters setting determines the accuracy of discrete element method (DEM) simulation analysis, while there is a lack of research on contact parameters of green onion seed. In this paper, the physical parameters of green onion seeds were measured by experiment, and the DEM parameters were calibrated by simulation. Based on EDEM software, the Hertz-Mindlin no-slip model was used to create the particle model of green onion seeds that takes on the shape of peltate with the irregular surface, and the repose angle was measured by the measurement method of lifted cylinder. Plackett-Burman test was designed to screen the significance of parameters, and the optimal range of significance parameters was further determined through the steepest climbing test. Then the regression model of seeds repose angle was obtained by Box-Behnken test and the optimal parameter combination was calculated: the static friction factor between seeds was 0.424, the rolling friction factor was 0.085, the static friction factor between seeds and steel was 0.310. The optimized repose angle in the simulation had an overall relative error of 0.54%, indicating that the contact parameters of the calibrated green onion seed had high accuracy.

摘要

离散元法（DEM）仿真分析的精度取决于接触参数的设置，而目前缺乏对大葱种子接触参数的相关研究。因此，本文通过实验测量了大葱种子的物理参数，并通过仿真对其离散元参数进行了标定。基于EDEM软件，采用Hertz-Mindlin无滑动接触模型，建立了大葱种子呈盾形且表面不规则的颗粒模型，并采用圆筒提升法测量堆积角。通过 Plackett-Burman 试验筛选参数的显著性，并使用最陡爬坡试验进一步确定显著性参数的最佳范围。然后通过 Box-Behnken 试验得到大葱种子堆积角的回归模型，并计算出最优参数组合:大葱种子间静摩擦系数为0.424，大葱种子间滚动摩擦系数为0.085，大葱种子与钢板静摩擦系数为0.310。经过优化后的仿真堆积角与实际数值的相对误差为0.54%，说明标定出的大葱种子接触参数具有较高的精度。

INTRODUCTION

As a seasoning vegetable and cash crop widely cultivated in China, green onion plays an extremely important role in vegetable production in China *(Liu D. et al., 2017).* The average annual planting area green onion reaches half a million hectares and its annual export share reaches 70% of the world one *(Wang H.X. et al., 2019).* The mechanization level of green onion planting in China is currently low, so the method of green onion planting mainly relies on artificial sowing, which seriously restricts the development of mechanization in the whole process of green onion production. In order to deeply study the movement mechanism between green onion seeds and the seeding mechanism during the sowing process, it is necessary to study the physical parameters and contact parameters of green onion seeds. Due to the small volume, irregular shape and poor fluidity of green onion seeds, it is effective to use physical test to measure the physical parameters and to calibrate the DEM parameters combined with simulation experiment *(Wang W.W. et al., 2021),* that can accurately obtain the parameters of green onion seeds. The research results are of great significance for the theoretical analysis of the precise seeding process and the performance optimization of the sowing device *(Lu F.Y. et al., 2018).*

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At present, DEM simulation is an effective method to solve the problem of modern agricultural technology, many studies have been carried out on the calibration of discrete element simulation parameters of agricultural materials at home and abroad in order to ensure the accuracy of simulation. *Peng Z. et al., (2022),* calibrated the parametric calibration of cotton straw parameters in Xinjiang through the simulation and actual measurement tests of the repose angle. *Lu F.Y. et al., (2018),* constructed a regression equation for the friction angle of rice bud seeds based on the DEM, and calibrated the main contact parameters with different moisture contents. *Xuejie M. et al., (2022),* calibrated the contact parameters of seed and powder by the repose angle trial and error method. *Ma W.P. et al., (2020),* calibrated the optimal combination of discrete element contact parameters of alfalfa seeds by using a device that can simultaneously measure the repose angle and the repose angle of materials. *Li Y.X et al., (2019),* simplified the irregular wheat flour into soft spherical particles, and adopted the Hertz-Mindlin with JKR model to obtain the accurate contact parameters of wheat flour discrete element simulation. *Zhou H. et al., (2022),* determined the DEM parameters of paddy soil with high moisture content (>40%) by using the Hertz–Mindlin with JKR model. *Yan D. et al., (2022),* measured and calibrated the RFCP-P and RFCP-B of soybean seed particles of three varieties with different sphericity. The above studies have calibrated the key DEM parameters of the particles, which improved the accuracy of related simulation studies, but there is no related study reported on green onion seeds and similar seeds.

In this paper, the intrinsic parameters of green onion seeds were measured, and the physical stacking test and simulation test were conducted on green onion seeds. With the repose angle as the index, Plackett-Burman test was used to screen out the factors that had significant influence on the index, and the steepest climbing test was used to quickly find the interval of the optimal value of each factor. The second-order regression models of the repose angle and the static friction factor between green onion seeds, the rolling friction factor between seeds and the static friction factor between seeds and steel was established by the design-expert optimization module, then, the key contact parameters that had significant influence on the discrete element simulation study of green onion seeds were obtained. Finally, the reliability of the model and simulation parameters was verified by the repose angle test, in order to provide reliable discrete element model parameters for the simulation analysis of the precision sowing of green onion and other mechanized devices. The result provides essential theoretical parameters for the study of the performance of the seeding machinery for green onion.

MATERIALS AND METHODS

Test material and physical parameter determination

For the DEM simulation, physical properties and contact parameters of seeds are required to be set. The physical parameters of green onion seeds include shape, size, density, moisture content, Poisson's ratio, shear modulus and Young's modulus, which could be obtained directly through test measurement. While the recovery coefficient, static friction coefficient and rolling friction coefficient between seed particles or between seed particles and boundary are difficult to measure inaccurately and therefore need to be calibrated.

Determination of triaxial size, 1000-grain weight, density and moisture content

This paper takes the green onion seeds of Zhangyou 006 variety in Shandong Province as the research object, which has the advantages of strong disease resistance, frost resistance and fast growth rate. Green onion seeds belong to bulk materials, and the basic physical property parameters need to be measured include triaxial size, 1000-grain weight, density, moisture content, Poisson's ratio, Young's modulus and shear modulus.

In order to accurately establish the three-dimensional model of green onion seed, 500 seeds of Zhangyou 006 variety were randomly selected. In this paper, it was used to measure the maximum triaxial size of green onion seeds by SZX16 advanced research stereological microscope of OLYMPUS (accuracy is 0.01 mm) (Fig.1). Image View software was used to calibrate the range, added a ruler, and measured the data, which made the data more accurate. The measured results showed that green onion seeds took on the shape of black peltate with the irregular and angular surface (Fig.2), and the average values of the maximum length, width and thickness of the seeds were 3.08, 2.02 and 1.23 mm.

One thousand seeds were randomly selected and weighed with a high-precision electronic analytical balance. The average value was obtained by measuring five times. The thousand seeds of green onion is 2.49 g. Then the density of 100 green onion seeds was measured by the pycnometer method, and the average value was taken ten times, and the density of green onion seeds was obtained as 1085 kg/m³.

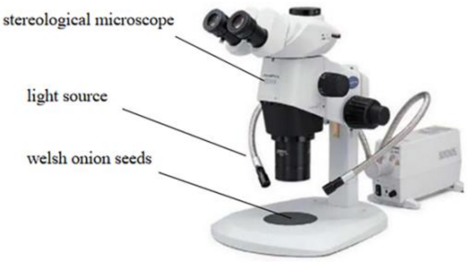


Fig. 1 - Stereological microscope

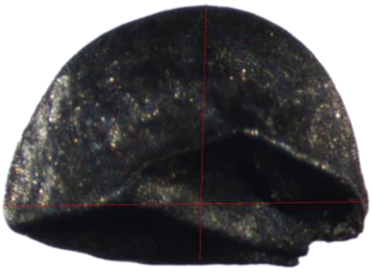


Fig. 2 - Welsh onion seed

The green onion seeds are oil crops, so the electric heating constant temperature drying oven is used to dry the green onion seeds at a low temperature for 8 hours. 500 seeds were selected randomly to measure their weight at room temperature, and then dried continuously for eight hours at a temperature of 103°C ± 2°C. The temperature in the oven was lowered to room temperature before the green onion seeds were taken out and weighed. The moisture content on a dry basis is obtained from Eq.1.

The average moisture content of the dry base of green onion seeds is 6.8% through measurement test and calculation with 5 repetitions.

$$M_a = \frac{m_b}{m_c} \times 100\% \tag{1}$$

where:

m_b is the mass of water contained in the material, g;

m_c is the mass of dry matter contained in the material;

M_a is the dry basis moisture content.

Poisson's ratio determination

As the shape of green onion seeds is small and irregular, professional physical property tester (TA.XT Plus C) from Stable Micro Systems UK was adopted to measure the Poisson's ratio of seeds accurately. First of all, 20 seeds were randomly selected and labeled to measure thickness (axial) and width (transverse), and a cylindrical probe with a diameter of 8 mm that loaded at 0.1 mm/s along the direction of the green onion seed thickness (axial) was used to apply pressure until the seed was cracked to stop it *(Xiangqian D. et al., 2022)*. At the moment the deformation of the positive strain in the direction of seed thickness was measured by the mass spectrometer, and the deformation of the positive strain in the direction of width was measured by the digital vernier caliper. At last, the Poisson's ratio of green onion seeds was calculated from Eq.2. Through measurement test and calculation with 20 repetitions, the average value of Poisson's ratio of green onion seeds was 0.481.

$$t = \frac{|c'|}{c} = \frac{Q_1 - Q_2}{S_1 - S_2} \tag{2}$$

where:

t is Poisson's ratio;

c' - the deformation amount of green onion seed in the width direction, mm;

c - the amount of deformation in the direction of seed thickness, mm;

Q_1 - the seed width of scallion before loading, mm;

Q_2 - the seed width of green onion after loading, mm;

S_1 - the seed thickness of scallion before loading, mm;

S_2 - the thickness of onion seed after loading, mm.

Determination of elastic modulus and shear modulus

20 seeds selected randomly were labeled from 1 to 20 in order. The cylindrical probe with a diameter of 8 mm that loaded at 10 mm/min along the direction of the seeds thickness was used to apply pressure *(Fei L. et al., 2020).* 20 labeled seeds were tested separately, and the average value of the 20 sets of test data was taken. According to the following Eq.3 and Eq.4, the average elastic modulus of the green onion seeds is 29.8 MPa and shear modulus is 10.06 MPa.

$$E = \frac{\alpha}{\varepsilon} \tag{3}$$

$$G = \frac{E}{2(1+t)} \tag{4}$$

where:

E is the elastic modulus of green onion seeds, MPa;

α - the maximum compressive stress;

ε - the line strain;

G - shear modulus, MPa;

t - Poisson's ratio of green onion seeds.

Contact parameter determination

The inclined plane method was used to measure the static friction coefficient between green onion seeds and boundary (the main material of the precision sowing device is steel), and the interspecific static friction coefficient of seeds. The seeds were arranged closely and glued on the cardboard with double-sided adhesive to form a board composed of seeds to eliminate rolling friction caused by seeds on the steel plate *(Zhang W., 2022),* as shown in the Fig.3. The seeds board was placed on the steel plate with the side of the seed in contact with the steel plate. When the test was started, right end of the steel plate was placed on the small experimental lifting platform that was slowly lifted, and the high-speed camera was used to record the operation. When the seed board began to slide, the experimental lifting platform stopped, meanwhile, the tilt angle of the steel plate was recorded with the digital display inclinometer. The above operation was repeated 10 times and the average datum was calculated. According to Eq.5, the static friction coefficient between green onion seeds and steel is 0.326.

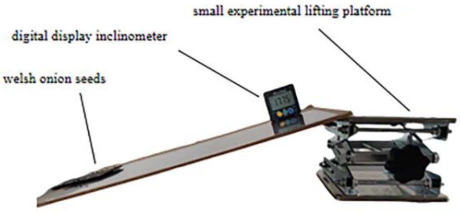


Fig. 3 - Small experimental lifting platform

$$\theta = \tan\beta \tag{5}$$

where:

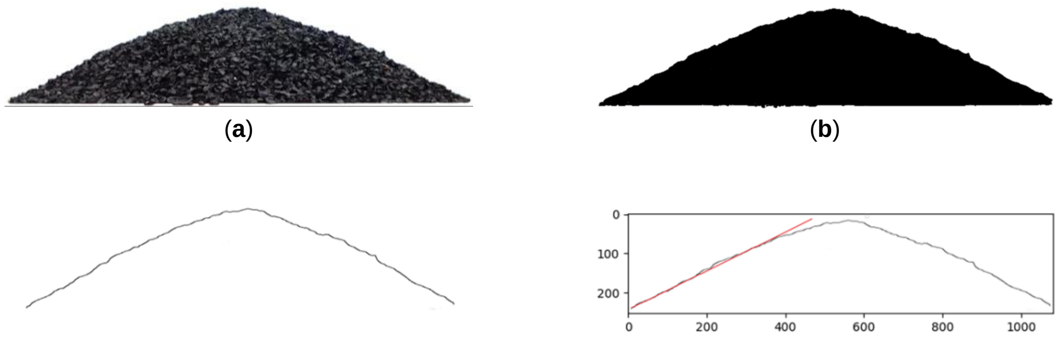
θ is the static friction coefficient;

β is the angle indicated by the digital display Inclinometer, °.

The friction coefficient between green onion seeds was measured using the above method, and seeds were closely arranged and bonded on the plate to make up a seeds surface. At the beginning, green onion seeds were placed on the seeds surface, and the height of the acrylic plate was slowly raised with the experiment platform until the seeds slipping, then the tilt angle of the seeds surface was recorded by a digital angle gauge. The average interspecific static friction coefficient was 0.493 after 10 repetitions.

Physical experiment on the repose angle

The repose angle of green onion seeds was measured by the measurement method of lifted cylinder device consisting of a cylinder with diameter of 100 mm and length of 200 mm and a plate of 2 mm thickness. The steel cylinder filled with a certain amount of seeds was lifted slowly and uniformly. After all the seeds were completely stationary on the steel plate, the high-definition camera was used to take vertical pictures of the positive side of the stacked seeds. The repose angle image obtained by the test was processed by Python to make the result more accurate. Firstly, the image of seeds repose angle was processed by grayscale, then the binarization was processed by threshold method, and the image contour was extracted by the findContours () function in Open CV. After the edge contour was obtained, Python was used to process the image, extract the straight line, and calculate the angle of the straight line *(Zenghui G. et al., 2022).* The average repose angle of green onion seeds was 25.34° after ten repetitions. The original image and edge contour curve image are shown in Fig.4.



(**a**) (**b**)

(**c**) (**d**)

Fig. 4 - Physical stacking test of green onion seeds
(a) Original image; (b) Binarized image contour extraction; (c) Edge contour; (d) Fitting the straight lines.

Simulation experiment on repose angle

Simulation model

EDEM software was used to build the simulation particle model based on the basic physical property parameters of green onion seeds determined by the previous physical test and pre-test. The nine-ball model was used to establish the particle model of green onion seeds in order to establish the shape of peltate with the irregular surface *(Min F. et al., 2023).* The triaxial dimensions of the particle model were consistent with the determined size (Fig.5).

Three-dimensional materialized model of the lifted cylinder device established according to the cylinder size and thickness used in physical test was imported into EDEM software. A particle factory for generating green onion seeds was established above the cylinder, and the generation mode of the particles was set as dynamic generation with a generation rate of 1000 units/s *(Gong X. et al., 2022).* The total number of green onion seeds was set to 2000, and the generation time was set to 2.5 s. Significantly, the sizes of all seeds were generated according to the normal distribution law of determined size. Then motion of the cylinder was the set to move along the vertical upward direction with the uniform speed of 0.1 m/s.

The seeds in the cylinder (Fig.6) are slowly scattered into piles, the repose angle cannot be measured until all seeds are completely stationary. The total simulation time is set to 5 s.

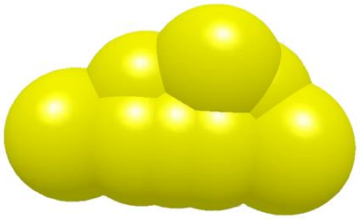


Fig. 5 - Discrete element model of green onion seeds

Fig. 6 - Simulation test of green onion seeds

DEM parameters calibration

Green onion seeds density, Poisson's ratio and Young's modulus were determined according to previous studies. The ranges of density, Poisson's ratio, Young's modulus as well as the recovery coefficient, static friction coefficient and rolling friction coefficient of seed-seed and seed-steel, were selected from pre-experiment and literature (Table 1) *(Xiaolong H. et al., 2022).*

The Plackett-Burman test was used to screen out the parameters that had significant influence on the repose angle by taking the repose angle of the particle model of green onion seeds as the response value.

Table 1

Parameters and corresponding value ranges in the Plackett–Burman test

Symbol	Parameter	Unit	Value	
			Low level (-1)	High level (+1)
S_1	Poisson's ratio of green onion seeds	-	0.28	0.48
S_2	Green onion seeds density	Kg/m³	885	1285
S_3	Young's modulus of green onion seeds	MPa	9.88	49.80
S_4	Collision recovery coefficient of seed-seed	-	0.10	0.20
S_5	Static friction factor of seed-steel	-	0.28	0.38
S_6	Static friction factor of seed-seed	-	0.30	0.60
S_7	Rolling friction factor of seed-seed	-	0.05	0.17
S_8	Collision recovery coefficient of seed-steel	-	0.29	0.49
S_9	Rolling friction factor of seed-steel	-	0.05	0.17
S_{10}, S_{11}	The virtual parameters	-	-1	+1

RESULTS

Plackett-Burman test

The Plackett-Burman test was designed on 15 groups, and the parameters of each group were set according to S_1 to S_{11}, then the repose angle of seed particles was simulated by EDEM software. Each group repeated 5 times. The post-processing clip function was adopted to slice the simulation results with a thickness of 3 mm after each group of simulation tests, and the simulation repose angle of green onion seeds was measured with the angle measuring function (Fig.7). The result of the Plackett-Burman's was shown in Table 2. Design-Expert10.0 software was used to conduct ANOVA on the test results, and the significant results of each simulation parameter were obtained as shown in Table 3. According to the significance screening, the static friction factor of seed-seed (S_6), rolling friction factor of seed-seed (S_7) have the highest significance, and the static friction factor of seeds-steel (S_5) has significant effects. Other factors S_1, S_2, S_3, S_4, S_8 and S_9 have little influence on the angle of repose.

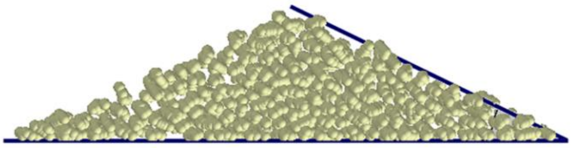


Fig. 7 - Measure the simulation repose angle

Table 2

Plackett-Burman test parameters

No.	Green onion seeds Plackett-Burman test parameter											
	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8	S_9	S_{10}	S_{11}	Repose angle (°)
1	0.48	1285	9.88	0.05	0.38	0.30	0.17	0.29	0.20	-1	1	27.41
2	0.38	1085	29.80	0.125	0.33	0.45	0.11	0.39	0.125	0	0	26.15
3	0.48	885	49.80	0.20	0.38	0.30	0.17	0.49	0.05	-1	-1	30.05
4	0.28	1285	49.80	0.05	0.28	0.60	0.17	0.49	0.05	-1	1	33.23
5	0.48	885	49.80	0.20	0.28	0.60	0.05	0.29	0.20	-1	1	28.40
6	0.28	1285	49.80	0.20	0.38	0.30	0.05	0.29	0.05	1	1	23.43
7	0.48	885	9.88	0.05	0.38	0.60	0.05	0.49	0.05	1	1	27.35
8	0.38	1085	29.80	0.125	0.33	0.45	0.11	0.39	0.125	0	0	29.22
9	0.28	885	49.80	0.05	0.38	0.60	0.17	0.29	0.20	1	-1	35.70
10	0.48	1285	9.88	0.20	0.28	0.60	0.17	0.29	0.05	1	-1	30.65
11	0.28	885	9.88	0.05	0.28	0.30	0.05	0.29	0.05	-1	-1	19.80
12	0.48	1285	49.80	0.05	0.28	0.30	0.05	0.49	0.20	1	-1	21.80
13	0.28	1285	9.88	0.20	0.38	0.60	0.05	0.49	0.20	-1	-1	32.30
14	0.38	1085	29.80	0.125	0.33	0.45	0.11	0.39	0.125	0	0	28.12
15	0.28	885	9.88	0.20	0.28	0.30	0.17	0.49	0.20	1	1	24.96

Table 3

Significance analysis of Plackett-Burman test results

Parameters	Sum of squares	Degree of freedom	F values	P values
S_1	1.18	1	0.73	0.4564
S_2	0.55	1	0.34	0.6022
S_3	8.57	1	5.29	0.105
S_4	1.69	1	1.04	0.3825
S_5	25.23	1	15.58	0.029*
S_6	134.54	1	83.06	0.0028**
S_7	69.70	1	43.03	0.0072**
S_8	1.54	1	0.95	0.4013
S_9	3.06	1	1.89	0.263
S_{10}	4.44	1	2.74	0.1963
S_{11}	2.54	1	1.57	0.2993

*Note: ** indicates an extremely significant effect ($p<0.01$), * indicates a significant effect ($p<0.05$).*

Analysis of the steepest climbing test

In order to further determine the relationship between S_1, S_2, S_3 and the repose angle of green onion seeds, the steepest climbing test was designed to screen out the optimal value range of three simulation parameters of green onion seeds. The relative error between the measurement and simulation of repose angle was taken as the evaluation index, and the steepest climbing test design scheme was shown in Table 4. The test results show that the 3rd group of data has the smallest relative error.

Table 4

Steepest ascent experiment design scheme and results

No.	Green onion seeds steepest ascent experiment design and results				
	S_5	S_6	S_7	Repose angle	Relative Error (%)
1	0.28	0.3	0.05	21.80°	13.97
2	0.30	0.36	0.074	24.15°	4.70
3	0.32	0.42	0.098	25.02°	1.30
4	0.34	0.48	0.122	26.13°	3.10
5	0.36	0.54	0.146	31.58°	24.60
6	0.38	0.60	0.170	34.70°	36.90

Box-Behnken test

Based on the steepest ascent experiment results, the Box-Behnken test with the test parameter levels shown in Table 5 was conducted. The 3rd group of data from the steepest climb test was set as the central point, the second group of data as the low level, and the fourth of data as the high level to find the optimal results. The design scheme and results of the Box-Behnken test were shown in Table 5. The values of other non-significant factors in the Box-Behnken test were the same as those in the steepest climbing test to ensure the accuracy of the results.

Table 5

Box-Behnken experimental design and results

No.	Green onion seeds test design and results			
	S_5	S_6	S_7	Repose angle (°)
1	0.30	0.42	0.122	26.57
2	0.32	0.42	0.098	25.66
3	0.32	0.42	0.098	25.78
4	0.34	0.48	0.098	27.70
5	0.32	0.42	0.098	25.93
6	0.32	0.42	0.098	25.60
7	0.32	0.48	0.122	28.89
8	0.34	0.42	0.122	30.40
9	0.30	0.36	0.098	24.58
10	0.32	0.36	0.122	26.20
11	0.34	0.42	0.074	27.40

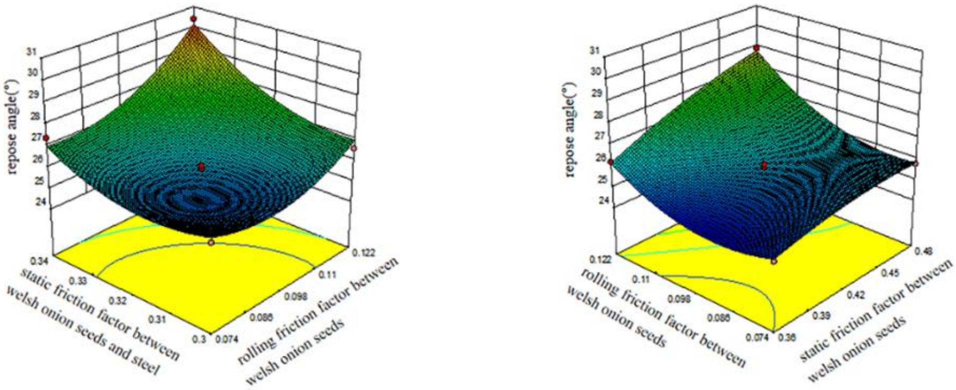
No.	Green onion seeds test design and results			
	S_5	**S_6**	**S_7**	**Repose angle (°)**
12	0.34	0.36	0.098	26.43
13	0.32	0.42	0.098	25.72
14	0.32	0.36	0.074	24.90
15	0.32	0.48	0.074	25.77
16	0.30	0.48	0.098	26.63
17	0.30	0.42	0.074	25.80

The variance analysis of Box-Behnken test is shown in Table 6. The analysis results show that S_5, S_6, S_7, S_5^2 and S_7^2 have highly crucial effects on the repose angle. S_5S_7 and S_6S_7 have significant influence on the repose angle; S_5S_6 and S_6^2 have no marked effect on the repose angle. The response surface of repose angle is shown in Fig.8. The results of Box-Behnken ANOVA shows that S_5S_7 and S_6S_7 had significant effects on the repose angle. It can be seen from the figure that with the increase of static friction coefficient and rolling friction coefficient, the repose angle also increases gradually, and the relative error between simulated repose angle and physical repose angle decreases first and then increases.

Table 6

Analysis of variance for Box-Behnken test results

Analysis of variance for green onion seeds test result					
Source of variance	**Sum of Squares**	**Degree of freedom**	**Mean Square**	**F Value**	**p-value Prob > F**
Model	32.6	9	3.62	27.81	0.0001
S_5	8.72	1	8.72	66.92	< 0.0001**
S_6	5.92	1	5.92	45.43	0.0003**
S_7	8.38	1	8.38	64.38	< 0.0001**
S_6S_7	0.83	1	0.83	6.36	0.0397*
S_5S_6	0.15	1	0.15	1.17	0.3156
$S_5 S_7$	1.24	1	1.24	9.55	0.0176*
S_5^2	3.04	1	3.04	23.35	0.0019**
S_6^2	0.27	1	0.27	2.07	0.1938
S_7^2	3.84	1	3.84	29.47	0.0010**
Residual	0.91	7	0.13		
Lack of Fit	0.85	3	0.28	17.63	0.009
Pure Error	0.064	4	0.016		
Cor Total	33.51	16			



(S_5×S_7) **(S_6×S_7)**

Fig. 8 - Response surface of green onion seeds repose angle. (S_5×S_7) Effect of interaction between S_5 and S_7 on repose angle error. (S_6×S_7) Effect of interaction between S6 and S7 on repose angle error.

The repose angle regression fitting model P=0.0001. The regression model coefficient of determination R^2=0.9728 and Adjusted R^2=0.9378, which is very close to 1, and the coefficient of variation CV=1.36%.

The second-order regression equation of the repose angle of green onion seeds (Eq.6) was obtained by fitting the Box-Behnken test results. In conclusion, the regression model is extremely significant, which is of great significance for analysing and predicting the repose angle of green onion seeds.

$$\theta=+25.74+0.86S_6+1.02S_7+1.04S_5+0.45S_6S_7-0.20S_5S_6+0.56S_5S_7-0.25S_6^2+0.95S_7^2+0.85S_5^2 \tag{6}$$

Simulation parameter calibration and test verification

The data was further optimized with the objective of the physical repose angle (25.34°) of green onion seeds by the optimization module of Design-Expert10.0 software, and the second-order regression equation was solved. The group of optimal parameters closest to the actual value was calibrated: the static friction factor of seed-seed (S_6) was 0.424, the rolling friction factor of seed-seed (S_7) was 0.085, the static friction factor of seeds-steel (S_5) was 0.310, and other non-significant parameters value were determined by measured value. The average value of repose angle with the optimal parameter combination is 25.48° after 5 repetitions of simulation tests, and the error between the value and the physical real repose angle is 0.54%, which further verifies the reliability and authenticity of the simulation experiment. The comparison of simulation test and physical test is shown in Fig.9 and Fig.10. The results showed that the physical repose angle of green onion seeds was similar to the repose angle in the simulation results in morphology and angle, indicating that there was no significant difference between the simulation results and the physical test values.

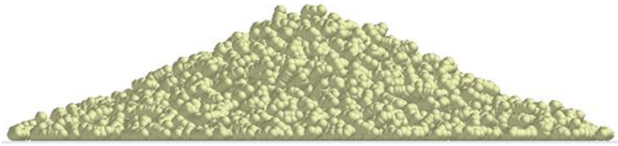


Fig. 9 - Green onion seeds simulation test

Fig. 10 - Green onion seeds physical test

CONCLUSIONS

In this paper, the physical parameters of Zhangyou 006 green onion seeds were determined by physical experiments, and Placket-Burman test, steepest climbing test, Box-Behnken test and the design-expert optimization module were used to calibrate the contact parameters that had a significant impact on the repose angle. The accuracy of the simulation parameters is verified by repose angle test. The conclusions are as follows:

(1) The static friction coefficient of seed-seeds (S_6), the rolling friction coefficient of seed-seeds (S_7), and the static friction coefficient of seed-steel (S_5) had significant effects on the repose angle of green onion seeds and therefore need to be calibrated.

(2) The optimal parameter combination was S_6 of 0.424, S_7 of 0.085, and S_5 of 0.310 and the average value of the simulated repose angle was 25.48° with the optimal parameter combinations.

(3) The verification test shows that the simulated repose angle is similar to the physical repose angle, and the overall relative error of 0.54% is low. The results show that physical parameters measured, the contact parameter calibrated and the seed particle model created by DEM are accurate and reliable.

In conclusion, parameter calibration can help researchers accurately obtain contact parameters that are difficult to measure. The research method in this paper can provide reference for the parameter calibration of other small and irregular seeds. The model of green onion seeds in this study only shows the characteristics of the specific variety Zhangyou 006. In future studies, it should be considered to analyse the commonness and differences of the seed particle models and parameters of different varieties of green onion, and establish a model database of green onion seeds.

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