DISCRETE ELEMENT SIMULATION CALIBRATION OF CONTACT PARAMETERS FOR MILLET SEEDS

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谷子种子离散元仿真接触参数标定

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ABSTRACT

In order to obtain accurate contact parameters for foxtail millet seeds in discrete element method (DEM) simulations, this study selected the Jinmiao K10 variety as the research object. Physical experiments and DEM simulations were integrated to calibrate the contact parameters. First, the restitution coefficient, static friction coefficient, and rolling friction coefficient between foxtail millet seeds and polylactic acid (PLA) material were measured using methods such as free-fall and inclined plane tests. Subsequently, based on the experimentally measured repose angle of 21.93°, a Plackett–Burman design was employed to screen the key parameters significantly influencing the repose angle. These included the inter-seed static friction coefficient, rolling friction coefficient, and restitution coefficient. The steepest ascent test was then conducted to determine the direction of parameter optimisation. A quadratic regression model was established using the Box–Behnken response surface methodology to determine the optimal combination of contact parameters: restitution coefficient of 0.512, static friction coefficient of 0.22, and rolling friction coefficient of 0.041. These parameters were imported into EDEM software for simulation validation. The simulated repose angle is 22.2°, with a relative error of 1.23%, demonstrating high accuracy and practical applicability of the calibrated parameters. This study provides reliable simulation parameter support for the design and optimization of critical components in foxtail millet seeding machinery.

摘要

为获取谷子种子在离散元仿真种精确的接触参数，本文以金苗K10谷子品种为研究对象，结合物理实验与离散元仿真方法开展接触参数标定研究。首先通过自由落体法、斜面法等方法测得谷子种子与PLA材料间的碰撞恢复系数、静摩擦系数及滚动摩擦系数范围；随后基于实际休止角角测量结果（21.93°），采用 Plackett-Burman 试验筛选出对休止角影响显著的关键参数，包括种间静摩擦系数、滚动摩擦系数和碰撞恢复系数；进一步通过最陡爬坡试验确定参数优化方向，并利用 Box-Behnken 响应面法建立二次回归模型，求解最优接触参数组合：种子间碰撞恢复系数为0.512，静摩擦系数为0.22，滚动摩擦系数为0.041。将该组合导入 EDEM 软件进行仿真验证，所得休止角为 22.2°，相对误差为 1.23%，表明标定参数具有较高精度和实用性。研究成果可为谷子播种机械关键部件的设计与优化提供可靠的仿真参数支持。

INTRODUCTION

As a country with a large population, China feeds nearly 18% of the world's population with only about 9% of the world's arable land (*Liu et al., 2021*). Food is a strategic resource for China and is central to national security and the cornerstone of social stability. Millet is an important grain crop originating in China and is one of the earliest cereal crops to be domesticated and cultivated by humans (*Zhao and Diao, 2022*). Millet not only requires little water, but also has the advantages of being resistant to poor soil and rich in nutrients *(Xiao et al., 2022*). After being hulled, millet is known as Xiaomi, which has unique nutritional components and is easily digestible, making it particularly suitable for pregnant women, new mothers, and infants. According to data from the National Bureau of Statistics of China, the annual sowing area of millet in China is approximately 900,000 hectares, accounting for about 9% of China's total grain sowing area.

The advent of millet sowing machinery has promoted the transformation of China's millet industry from traditional small-scale farming methods relying on human and animal labour to modern industrial production methods (*Li et al., 2021*). In sowing machinery, the seed dispenser is a core component, and its performance directly affects sowing quality and efficiency (*Lai et al., 2020*). Traditional testing methods typically require the actual device to be manufactured for testing. This method is not only time-consuming and labour-intensive, but also difficult to observe the detailed interactions between millet seeds and seeders, as well as between millet seeds themselves, due to the complex contact relationships and mechanical interactions involved. With the widespread adoption and advancement of computer technology, the DEM has become an effective method for analysing and solving complex discrete system dynamics problems. Discrete element simulation can be used to obtain detailed parameters such as force, displacement, and velocity of seeds in mechanical devices, visualise the movement process of seeds, and provide intuitive references and theoretical basis for the structural design and optimisation of mechanical devices.

In discrete element simulation, the accuracy of contact parameters directly affects the reliability of the simulation (*Awuah et al., 2023; Aikins et al., 2021*). The shape of millet seeds is irregular, indicating low flatness, and the interaction between millet seeds is complex. This may lead to significant errors when directly measuring their contact parameters. Furthermore, some parameters are difficult to measure directly through testing. Many scholars have calibrated contact parameters by conducting simulated pile angle tests to measure and calibrate the contact parameters of materials (*Cui et al., 2025; Sun et al., 2022; Wang et al., 2023; Zheng et al., 2024*). *Ma et al. (2025)* calibrated the main contact parameters between Gansu winter wheat seeds and various materials. *Liang et al. (2025)* conducted experiments on the angle of repose of corn and PLA using the uplift and lateral collapse methods, and a mathematical regression model was established to optimise the combination of contact parameters for the corn-PLA pile angle. The relevant experiments showed that the discrete element method model has high accuracy. *Zhang et al. (2020)* performed parameter calibration of rice grains in the EDEM software, with the grains magnified to the same scale. The test structure showed that CPU time was reduced by 60% compared to the unmagnified model, and the test error was within 1%. The method of using the angle of repose to calibrate contact parameters is widely used in the study of large seeds such as beans, wheat, and corn, but there is a lack of relevant research on small seeds such as millet.

Therefore, this paper takes the Jinmiao K10 millet variety as the research object and combines physical experiments with EDEM discrete element simulation to conduct contact parameter calibration research. The range of contact parameters between seeds and PLA materials was determined through free-fall collision tests, inclined plane sliding and rolling friction tests. Based on this, key parameters were selected using Plackett-Burman test based on actual measured angle of repose, and parameter combinations were optimised using steepest climb test and Box-Behnken test. The accuracy of the parameters was verified through simulation, and the optimal contact parameters suitable for simulating the millet sowing process were ultimately obtained, providing a fundamental basis for the digital design and performance optimisation of millet sowing machinery in the future.

MATERIALS AND METHODS

Test materials and measurement of their physical parameters

Jinmiao K10 was selected as the millet variety for the experiment and was provided by the Inner Mongolia Chifeng Academy of Agriculture and Animal Husbandry Sciences. Considering that the moisture content of millet at the time of sowing is approximately 12% to 20%, and that moisture content has a significant impact on the physical parameters of millet (*Qiu et al., 2021*). In view of this, millet with a moisture content of 15% was selected as the measurement object in this study. The density of millet was measured using the drainage method, using anhydrous ethanol as the medium. The measurement was repeated five times, yielding a density of 1054 kg/m3. One hundred seeds were randomly selected and weighed using an electronic balance with an accuracy of 0.001 g. The measurement was repeated five times, resulting in a hundred-seed weight of 0.305 g.

To establish a simulation model of this variety of millet, the three mutually perpendicular dimensions of the millet were defined as characteristic dimensions based on its shape, namely the length (L), width (W), and thickness (T) of the millet, as shown in Figure 1. A random sample of 100 grains with a moisture content of 15% was selected from this variety. The L and W of the grains were measured using a digital vernier calliper (accuracy 0.01 mm), and the T was measured using a digital thickness gauge (accuracy 0.001 mm).

The K-S test was used to analyse the measurement results, which showed that the three-axis dimensions of this variety of millet seeds were normally distributed, as shown in Figure 2.

The average length of 100 millet seeds was 2.061 mm, the average width was 1.753 mm, and the average thickness was 1.342 mm.

(a) Characteristic dimensions of millet (b) Measurement of millet thickness (T) (c) Measurement of grain length (L) and width (W)

Fig. 1 - Characteristic dimensions of millet and measurement of characteristic dimensions

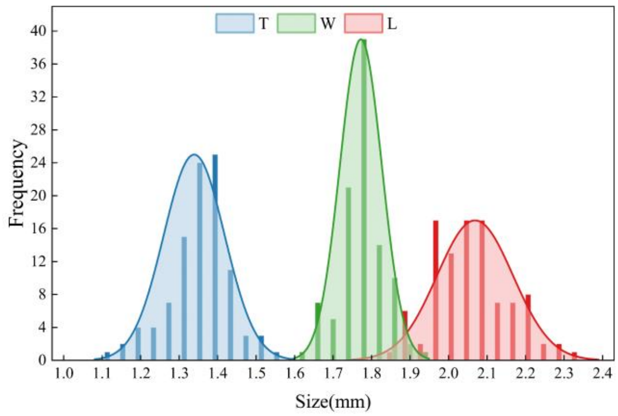


Fig. 2 - Normal distribution of the three-axis dimensions of millet: length, width, and thickness

Determination of seed-PLA contact parameters

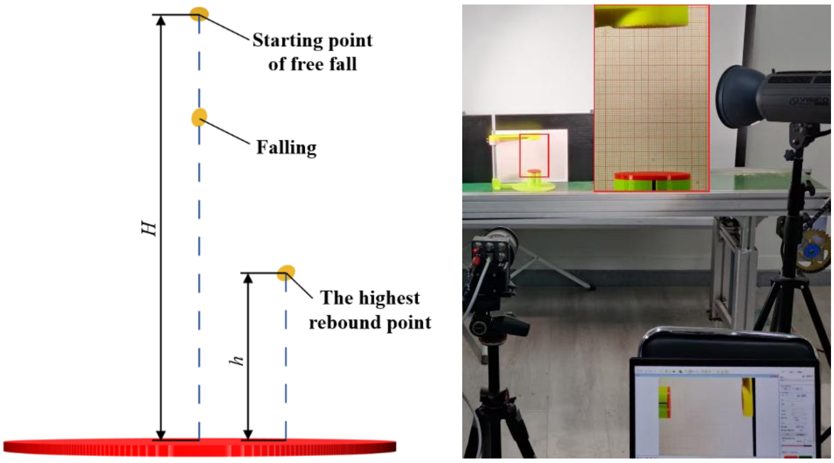
Determination of seed-PLA collision recovery coefficient

The collision recovery coefficient e_x is a parameter that measures the degree of rebound of two objects after a collision. It can be expressed as the ratio of the instantaneous separation velocities v_1 and v_2. That is, it is the ratio of the maximum rebound height h of the tested seed after colliding with the tested material to the initial falling height H.

The calculation formula is as follows:

$$e_x = \frac{v_1}{v_2} = \frac{\sqrt{2gh}}{\sqrt{2gH}} = \sqrt{\frac{h}{H}} \tag{1}$$

This experiment employed the free-fall collision method to determine the collision recovery coefficient between millet seeds and PLA plates (*Ding et al., 2023*). The measurement principle and experimental setup are shown in Figure 3. A seed was randomly selected using tweezers and released from a height of H = 100 mm directly above the PLA plate, allowing it to fall freely without initial velocity. The process, from the moment the tweezers were released until the seed collided with the PLA plate and rebounded to its highest point (h), was recorded using a high-speed camera with a resolution of 1280×720 and a frame rate of 1200 fps. After five repeated trials, the recorded data were substituted into Equation (1) to calculate the collision recovery coefficient, which ranged from 0.361 to 0.640, with an average value of 0.475.



(a) Test principle (b) Actual test

Fig. 3 - Seed and PLA collision recovery coefficient measurement test

Static friction coefficient between seeds and PLA

A homemade static friction angle measuring device was used to measure the static friction coefficient using the inclined plane method (*Wang et al., 2022*). The test apparatus is shown in Figure 4. The principle of the static friction test is that when the seed is at rest on the inclined plane, the force equilibrium formula is as follows:

$$\mu_s = \frac{f}{F} = \frac{mgsin\alpha}{mgcos\alpha} = tan\alpha \tag{2}$$

In the formula: μ_s is the static friction coefficient between the seed and PLA; f is the friction force between the seed and the PLA plate (N); F is the component of the seed's gravitational force perpendicular to the PLA plate (N); m is the mass of the seed (g); g is the gravitational force acting on the seed (N); α is the inclination angle of the PLA plate (°).

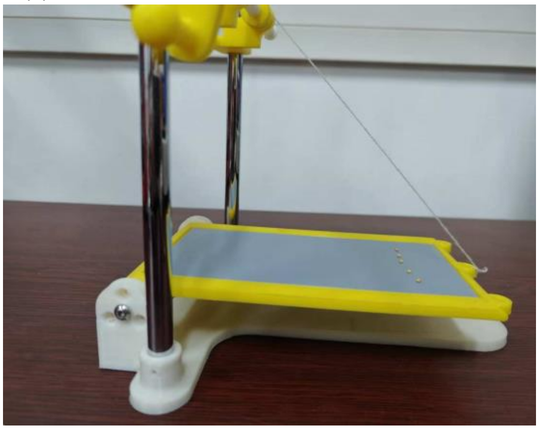


Fig. 4 - Homemade static friction angle measuring device

In each experiment, 10 seeds were randomly selected and placed on a PLA plane. The lifting device was then rotated at a constant speed to gradually tilt the plane. When more than three seeds began to slide, the rotation was immediately stopped, the plane was fixed, and the angle of the slope was measured. The experiment was repeated five times, and the static friction coefficient between the seeds and the PLA was found to be between 0.510 and 0.727, with an average value of 0.6224.

Determination of rolling friction coefficient between seeds and PLA

The rolling friction coefficient between seeds and PLA was determined using the inclined plane rolling method. The experimental diagram is shown in Figure 5. The experimental principle is to release seeds with an initial velocity of 0 from an inclined plane with an angle of inclination β. The seeds roll down the inclined plane with a length of S and roll a distance L on the horizontal plane. Assuming that the seeds roll purely during this process, they are only affected by rolling friction. According to the law of conservation of energy, it can be obtained:

$$\mu_r = \frac{mgSsin\beta}{mg(Ssin\beta + L)} = \frac{Ssin\beta}{Ssin\beta + L} \tag{3}$$

In the formula, μ_r is the rolling friction coefficient between the seed and PLA.

Fig. 5 - Schematic diagram of the inclined plane rolling test

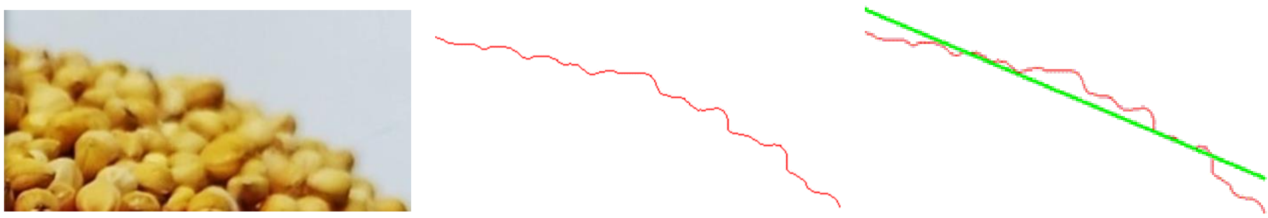
Since millet seeds are not ideal spheres in shape, they tend to bounce and slide during rolling. To improve the accuracy of the test, after extensive preliminary testing and adjustments, the slope angle was set to 30° and the rolling distance on the slope to 30 mm. The above test was repeated 10 times, yielding a rolling friction coefficient range of 0.06 to 0.15 between the seeds and PLA, with an average value of 0.1.

Calibration of contact parameters between seeds

When calibrating inter-species contact parameters using the aforementioned experimental methods, seeds must be adhered together to form a seed plate. However, due to the inconsistent shapes and uneven surfaces of the seeds, using seed plates in experiments results in significant deviations in experimental outcomes. Particles accumulate on a horizontal surface under the influence of gravity, and the angle formed between the accumulated surface and the horizontal plane is referred to as the angle of repose. This angle reflects the friction characteristics and flowability of the particulate material. Therefore, this study is based on actual pile tests of millet seeds, using the measured pile angle as the response value, and the contact parameters between seeds and PLA material and inter-seed contact parameters as factors, to conduct Plackett-Burman tests, steepest ascent tests, and Box-Behnken tests. Through the tests, the optimal combination of contact parameters is obtained, and the combination parameters are verified through simulation.

Actual angle of repose test

The actual angle of repose test refers to GB/T 16913-2008, using the injection method to measure the angle of repose of millet seeds. The funnel's outlet has a cone angle of 70°, an inner diameter of 10 mm, and the distance between the outlet edge and the material tray surface is 50 mm. The diameter of the material tray is 50 mm. During the test, a shield is first used to cover the bottom of the outlet. 7.5g of seeds are then poured into the funnel. The shield is removed, allowing the seeds to flow out of the outlet. Once all the seeds have flowed out and the pile remains stable, a camera captures a frontal view image of the seed pile. This process is repeated five times. The captured images are processed using Python to generate a binary image, yielding the coordinate data of the boundary pixels of the seed pile. The pixel coordinate data is linearly fitted using the least squares method, and the tangent value of the slope of the fitted line represents the angle of repose. The angle of repose θ of the tested seeds is 21.93°, with the image processing process illustrated in Figure 6.

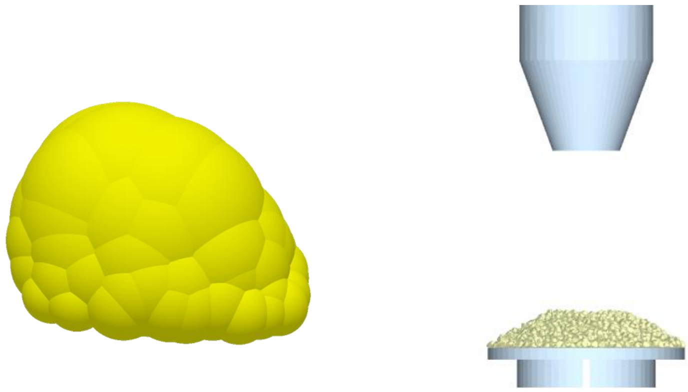


(a) Original image (b) Boundary Contour (c) Straight line fitting

Fig. 6 - Image processing of seed accumulation angle test

Discrete element simulation model and parameters

Based on the three-axis dimensions of the eight seed types and the morphological characteristics of millet measured in this study, a three-dimensional solid model of millet was created using SolidWorks software. The three-dimensional model was saved in STL format and imported into EDEM software. Using the software's built-in non-spherical particle automatic filling tool, the smoothness value was set to 4, the number of triaxial grids was set to 45, and the minimum spherical filling radius was set to 0.2 mm to complete the seed filling. Based on actual pile tests, models of the funnel, baffle, and material tray were created using SolidWorks software and imported into EDEM software in STEP format. The Seed Discrete Element Model and Angle of Repose Angle Test Simulation Model are shown in Figure 7.



(a)Seed Discrete Element Model (b)Angle of Repose Test Simulation Model

Fig. 7 - Seed Discrete Element Model and Angle of Repose Angle Test Simulation Model

In EDEM software, simulations of the angle of repose test for millet seeds were conducted. Based on relevant literature and previous experiments (*Dun et al., 2025; Ma et al., 2025; Zhang, 2023*), the simulation parameters for the angle of repose test were determined, as shown in Table 1.

Table 1

Discrete Element Method Angle of Repose Test Simulation Parameter Table

Simulation parameters	Value
Poisson's ratio of seeds	0.39
seed density (kg/m^3)	1054
Seed shear modulus (Pa)	5.252e+05
Poisson's ratio of PLA	0.3
PLA density (kg/m^3)	1290
PLA shear modulus (Pa)	1.04e+07
Seed-seed collision recovery coefficient	0.1~0.8
Seed - seed static friction coefficient	0.1~0.6
Seed - seed rolling friction coefficient	0~0.1
Seed-PLA collision recovery coefficient	0.361~0.64
Seed - PLA static friction coefficient	0.51~0.727
Seed-PLA rolling friction coefficient	0.06~0.29

Plackett—Burman Experiment

Since there are many parameters that affect the angle of repose, a Plackett-Burman test was used to screen out the parameters that have a greater impact on the angle of repose (*Kong et al., 2024*). The experiment used the measured angle of repose from actual experiments as the response value (*Yang et al., 2024*). Design-Expert software was used to design two-level factorial designs for different factors, as shown in Table 2. The experimental designs were randomly generated by the software, and simulations were conducted on each group according to the design sequence, with the angle of repose recorded. The experimental designs and results are shown in Table 3.

Table 2

Plackett-Burman Experiment parameter list

Simulation parameters	Low level (-1)	High level (+1)
Seed-seed collision recovery coefficient (A)	0.100	0.800
Seed - seed static friction coefficient （B）	0.100	0.600
Seed - seed rolling friction coefficient (C)	0.000	0.100
Seed-PLA collision recovery coefficient (D)	0.361	0.610
Seed - PLA static friction coefficient (E)	0.510	0.727
Seed-PLA rolling friction coefficient (F)	0.060	0.150

Table 3

Plackett-Burman Experiment design and results

Number	Simulation parameters						Simulation test angle of repose θ'/ (°)
	A	B	C	D	E	F	
1	+1	+1	-1	+1	+1	+1	24.710
2	-1	+1	+1	-1	+1	+1	35.770
3	+1	-1	+1	+1	-1	+1	15.995

Number	Simulation parameters						Simulation test angle of repose θ'/ (°)
	A	B	C	D	E	F	
4	-1	+1	-1	+1	+1	-1	26.865
5	-1	-1	+1	-1	+1	+1	16.340
6	-1	-1	-1	+1	-1	+1	13.410
7	+1	-1	-1	-1	+1	-1	11.700
8	+1	+1	-1	-1	-1	+1	24.225
9	+1	+1	+1	-1	-1	-1	31.350
10	-1	+1	+1	+1	-1	-1	34.820
11	+1	-1	+1	+1	+1	-1	7.650
12	-1	-1	-1	-1	-1	-1	11.9550
13	0	0	0	0	0	0	26.410

The results of the analysis of variance are shown in Table 4. As can be seen from the table, the three factors that have the greatest influence on the angle of repose are, in order of importance, the Seed - seed static friction coefficient B, the Seed - Seed rolling friction coefficient C, and the Seed-seed collision recovery coefficient A. Therefore, these three simulation parameters were selected for subsequent experiments. The remaining factors have a relatively minor influence on the angle of repose. Therefore, the average values from the previous experiments are used as the simulation values for the remaining factors (Seed-PLA collision recovery coefficient is 0.475, Seed - PLA static friction coefficient is 0.6224, and Seed-PLA rolling friction coefficient is 0.1).

Table 4

Significance analysis of Plackett-Burman Experiment parameters

Source	Standardized Effects	Sum of Squares	F-value	P-value
A	-3.92	46.12	4.70	0.0823
B	16.78	844.96	86.14	0.0002
C	4.84	70.35	7.17	0.0439
D	-1.31	5.18	0.53	0.5000
E	-1.45	6.34	0.65	0.4578
F	1.02	3.12	0.32	0.5974

Steepest Climb Experiment

The three simulation parameters identified in the previous experiment as having the greatest influence on the angle of repose were subjected to a Steepest Climb Experiment to further narrow the range of values for the experimental measurement parameters. This experiment began at the centre point of the Plackett-Burman Experiment and proceeded in the direction of decreasing angles, using the parameter with the most significant influence as the baseline, with a step size ratio of 0.2. The experiment was conducted using the relative error σ between the measured angle of repose θ and the simulated angle of repose θ' as the evaluation criterion. The experimental design and results are shown in Table 5. As can be seen from the table, the relative error caused by the angle of repose is the smallest at the 4th level. In the range from the 1st to the 6th level, the trend of the relative error caused by the angle of repose is from large to small and then back to large. Therefore, the 4th level is taken as the central point, with the 3rd and 5th levels as the low and high levels, respectively, for the subsequent Box-Behnken Experiment.

Table 5

Steepest Climb Experiment Plan and Results

Number	Seed-seed collision recovery coefficient (A)	Seed - Seed Static Friction Coefficient (B)	Seed - Seed rolling friction coefficient (C)	Simulation test angle of repose θ'/(°)	Relative error σ （%）
1	0.450	0.35	0.050	29.800	35.890
2	0.467	0.30	0.047	27.025	23.233
3	0.483	0.25	0.044	24.980	13.910
4	0.500	0.20	0.041	21.395	2.440
5	0.516	0.15	0.038	18.445	15.890
6	0.533	0.10	0.036	17.000	22.480

Box-Behnken Experiment

Using Design-Expert software, the three factors and three levels determined from the Steepest Climb Experiment were entered, and the software generated 17 randomized test plans. The test plans and corresponding results are presented in Table 6. Variance analysis was then performed on the experimental data to derive the quadratic regression equation for the angle of repose simulation test:

$$\theta' = 21.4039 + 2.108325A + 2.4703B + 0.775625C - 0.378AB - 1.17025AC + 0.1955BC + 1.030575A^2 + 0.825325B^2 + 0.600775C^2 \quad (1)$$

Table 6

Box-Behnken experiment design and results

Number	Seed-seed collision recovery coefficient (A)	Seed - seed static friction coefficient (B)	Seed - seed rolling friction coefficient (C)	Simulation test angle of repose θ'/(°)
1	0.516	0.15	0.041	18.4563
2	0.483	0.15	0.041	23.5629
3	0.516	0.25	0.041	23.7127
4	0.483	0.25	0.041	27.3073
5	0.516	0.20	0.038	19.0754
6	0.483	0.20	0.038	25.4986
7	0.516	0.20	0.044	22.9124
8	0.483	0.20	0.044	24.6546
9	0.500	0.15	0.038	19.5321
10	0.500	0.25	0.038	24.5219
11	0.500	0.15	0.044	20.7471
12	0.500	0.25	0.044	26.5189
13	0.500	0.20	0.041	21.5145
14	0.500	0.20	0.041	21.4555
15	0.500	0.20	0.041	21.3091
16	0.500	0.20	0.041	21.1330
17	0.500	0.20	0.041	21.6074

RESULTS

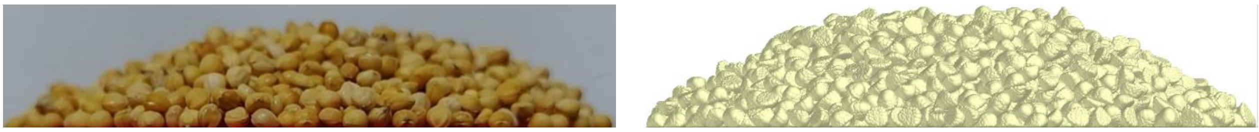
The analysis of variance for the quadratic regression model of the simulated angle of repose of millet seeds is shown in Table 7. As can be seen from the table, the model as a whole is highly significant ($p<0.0001$), and the main effects of factors A, B, and C, as well as the quadratic terms A2, B2, and C2, are all significant. The interaction effects of AB ($P=0.0329$) and AC ($P<0.0001$) are significant, The BC interaction effect is not significant ($P = 0.2123$), and the model shows no significant misfit ($P = 0.1022$), indicating that it can adequately explain the changes in the angle of repose. The determination coefficient $R^2 = 0.9946$, adjusted $R^2 = 0.9877$, and predictive $R^2 = 0.9330$ are all close to 1, indicating high model fit quality. The coefficient of variation CV = 1.26% indicates low data dispersion, and the signal-to-noise ratio is 41.9, indicating that the model has good reliability and accuracy.

Table 7

Variance analysis of the seed simulation angle of repose quadratic regression model

Source	Sum of Square	df	Mean Square	F-value	P-value
Model	105.23	9	11.69	144.07	<0.0001
A	35.56	1	35.56	438.16	<0.0001
B	48.82	1	48.82	601.52	<0.0001
C	4.81	1	4.81	59.3	0.0001
AB	0.5715	1	0.5715	7.04	0.0329
AC	5.48	1	5.48	67.5	<0.0001
BC	0.1529	1	0.1529	1.88	0.2123
A2	4.47	1	4.47	55.1	0.0001
B2	2.87	1	2.87	35.34	0.0006
C2	1.52	1	1.52	18.73	0.0034
Residual	0.5681	7	0.0812		
Lack of Fit	0.4294	3	0.1431	4.13	0.1022
Pure Error	0.1387	4	0.0347		
Cor Total	105.8	16			

Using the data analysis optimisation module of Design-Expert software, parameter optimisation was performed on the quadratic regression model, resulting in the optimal contact parameter combination: a Seed-seed collision recovery coefficient of 0.512, a Seed - seed static friction coefficient of 0.22, and a Seed - seed rolling friction coefficient of 0.041. These parameters were then input into EDEM software for simulation verification. The simulation results are compared with the actual test results as shown in Figure 8. The actual angle of repose was 21.93°, while the angle of repose in the simulation test was 22.2°, with an error of only 1.23% compared to the actual measured value, indicating that the parameters have high precision and reliability.



(a) Actual Test (b) Simulation Test

Fig. 8 - Comparison chart of millet seed accumulation angle tests

CONCLUSIONS

This study used the Jinmiao K10 variety as the reference sample, with a density of 1051 kg/m³ and a hundred-grain weight of 0.305 g when the moisture content was 15%. The three-axis dimensions of 100 seeds of this millet variety were also measured, with an average length of 2.061 mm, width of 1.753 mm, and thickness of 1.342 mm. All dimensions followed a normal distribution, providing a data basis for constructing a generalised millet grain model.

Physical tests were conducted to measure the Seed-PLA collision recovery coefficient, Seed - PLA static friction coefficient and Seed-PLA rolling friction coefficient range and average value between millet seeds and PLA. Based on the Plackett-Burman Experiment, three factors with a significant impact on the angle of repose were identified, in descending order of impact: Seed - seed static friction coefficient, the Seed - seed rolling friction coefficient, and the Seed-seed collision recovery coefficient. The average values of other factors were taken, namely, Seed-PLA collision recovery coefficient of 0.475, Seed - PLA static friction coefficient of 0.6224, and Seed-PLA rolling friction coefficient of 0.1.

Based on the results of the Steepest Climb Experiment and the Box-Behnken Experiment, a quadratic regression equation for the simulation test of the angle of repose was established. Optimisation was performed with the angle of repose measured in the actual test (21.93°) as the target, and the optimal contact parameters between millet seeds were determined to be a collision recovery coefficient is 0.512, static friction coefficient is 0.22, and rolling friction coefficient is 0.041. The parameters were entered into the EDEM software for simulation verification, and the angle of repose was obtained to be 22.2°, with an error of 1.23% from the actual measured value, further verifying the accuracy and practicality of the calibrated parameters, and also providing a certain reference and basis for the simulation optimisation of millet sowing machinery.

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