PARAMETRIC CALIBRATION OF COTTON STRAW PARAMETERS IN XINJIANG BASED ON DISCRETE ELEMENTS
/
基于 EDEM 对新疆棉花秸秆接触参数仿真标定

Peng ZHANG [1), Hu ZHANG [2), Jinming LI [1), Chunlin TAN [3), Jiaxi ZHANG *[1)
[1) Xinjiang Agricultural University, School of Mechanical and Electrical Engineering, Urumqi / China;
[2)Autonomous Region Agricultural Machinery Product Quality Supervision and Management Station, Urumqi / China
[3)School of Mechanical and Electrical Engineering, Xinjiang Changji vocational and Technical College, Changji / China
Tel: 8613899961137; E-mail: 563810112@qq.com
Corresponding author: Zhang Jiaxi
DOI: https://doi.org/10.35633/inmateh-67-32

Keywords: *Cotton straw, Harvest, EDEM, Bending test, Parameter calibration*

ABSTRACT
The lack of accurate simulation model parameters of cotton straw in the conveying process causes large differences between simulation effects and actual operation, which to a certain extent limits the development of conveying devices. In this paper, Xinjiang cotton straw was used as the test material. The angle of repose of cotton straw was measured by the cylinder lifting method. The Hertz-Mindlin no-slip model was applied to simulate the angle of repose of cotton straw. Using Box-Behnken optimization research and development of key components such as the cotton straw preparation test, the regression equation of cotton straw was obtained, and the variance and interaction effect of the regression model analysis. The regression model was used to find the optimal solution in Design-Expert software with the angle of repose of 28.62º, the collision recovery coefficient between cotton straws was 0.5, the static friction factor was 0.41, and the rolling friction factor was 0.06, and the collision recovery coefficient between cotton straw and steel was 0.5, the static friction factor was 0.37, and the rolling friction factor was 0.08, with an angle of repose error of 1.04%. It shows that the contact parameters are highly reliable and can be used to propose a theoretical reference for the development of cotton straw conveying device in Xinjiang region.

摘要
由于棉花秸秆在输送过程中缺乏准确的模拟模型参数，从而造成模拟效果与实际运行存在较大差异，这在一定程度上限制了输送装置的发展。本文以新疆棉花秸秆为试验材料，采用圆筒提升法测量棉花秸秆的堆积角。应用 Hertz-Mindlin 无滑动模型模拟棉秆的堆积角。利用 Box-Behnken 优化研究和开发棉秆制备试验等关键部件，得到了棉秆堆积角的回归方程，并分析了回归模型的方差和交互效应。利用回归模型在 Design-Expert 软件中找到最优方案，堆积角为 28.62°，棉秆之间的碰撞恢复系数为 0.5，静摩擦系数为 0.41，滚动摩擦系数为 0.06，棉秆与钢材之间的碰撞恢复系数为 0. 5，静摩擦因数为 0.37，滚动摩擦因数为 0.08，静止角误差为 1.04%,说明接触参数的可靠性很高， 可以为新疆地区棉花秸秆输送装置的发展提出理论参考。

INTRODUCTION
Cotton is one of the world's major cash crops, and its production and processing have formed a more complete system, but cotton straw as by-product of the cotton harvest has not been well developed and utilized. As the world's largest producer and consumer of cotton, China planted an area of 3,028 thousand hectares in 2021. As the main planting base of cotton in China, Xinjiang's cotton planting area was 2,506 hectares in 2021, and the output of each hectare was 2,046.4 kilograms, accounting for 67.6% of the country's cotton planting area (*Announcement of the National Bureau of Statistics on cotton production in 2021, 2021*).

The annual yield of cotton straw is large and the mechanized harvesting rate is low, and for the key steps of cotton straw harvesting, conveying process, etc., continuous improvement of various parameters of cotton straw is needed. However, for some parameters that are difficult to measure and obtain accurately, the use of simulation software is often a key method to overcome such problems.

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[1]*Peng Zhang, M.S.Stud.Eng.;* [2]*Hu Zhang, M.S.Stud.Eng.;* [1]*Jinming Li, M.S.Stud.Eng.;* [3]*Chunlin Tan, M.S.Stud.Eng.;* **[1]*Jiaxi Zhang, Prof.Ph.D.Eng.*

Many scholars have used physical tests such as the cylinder lifting method (*Liao Y.T et al., 2020*), iron plate tilting method *(Du X et al., 2012*), and funnel dropping method (*Wang W.W et al., 2021*) as experimental ways to calibrate contact parameters for maize seeds (*Wang Y.X et al., 2016*), potatoes (*Liu W.Z et al., 2018*), Pseudo ginseng seeds (*Yu Q.X et al., 2018*), mung bean seeds (*Zhang S.W et al., 2022*), peanut seeds (*Wu M.C et al., 2020*), and rape stalks (*Liao Y.T et al., 2020*) to obtain relevant contact parameters by EDEM software. The above experiments show that there is great variability between contact parameters for different plants. Up to now, no simulation study has been conducted on the calibration of cotton straw parameters. The straw was used as the test object and the cotton straw contact parameters were simulated by mock tests. The simulation tests are measured several times, the response surface is used for optimization, and the angle of repose are targeted to find out the best stimulation parameters, which make further theoretical reference for cotton straw harvesting and conveying.

MATERIALS AND METHODS

Test material

In this paper, Xinjiang cotton straw was used as the test material. The sampling site is the Anning Township in Urumqi City. (43°58′ N, 87°30′ E). As the most dominant cotton variety in the region, Xinluzao 66 has the advantages of high yield, good product and few diseases.

Test method

Plackett-Burman test design: Plackett-Burman test was conducted using Design-Expert software to screen the parameters, and the resulting parameters were ranked for significance to screen out the parameters affecting the angle of repose test.

Steepest climbing test design: the screened parameters are subjected to the climbing test, and the best value of the selected five groups of combinations are sorted and simulated, and the test results of each group are recorded to find out the best combination according to the error variation.

Box-Behnken test design: Through the above test analysis, the obtained parameters are subjected to BBD response surface analysis, and the binary regression equation is derived, with the physical test angle of repose as the target, the best value parameters are derived.

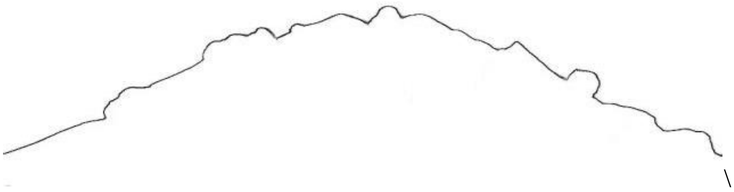
Physical experiment on the angle of repose of cotton straw

Collision recovery coefficient, static friction factor, and rolling friction factor between cotton straws, and collision recovery coefficient, static friction factor, and rolling friction factor between cotton straw and steel affect the angle of repose, and the method used for measuring the angle of repose of cotton straw is the cylinder lifting method. The cylinder was made of Q235 steel with a height of 240 mm and an inner diameter of 120 mm. Before the test, the harvested cotton straw was cut, each section being cut to a length of about 26,30,36,40 mm to be measured, and the amount of straw filled was half the volume of the cylinder, with each of the different lengths of cotton straw accounting for about 25% of the total volume. During the test, the cylinder will rise at a uniform speed of 0.05 m/s (*Liu F.Y et al., 2016*), wait until the cotton straw pile up completely, after standing for a minute, measure the bottom plate and the angle between the slope left and right, take the average value. The test was repeated five times for data integration. The angle of repose image was binarized by MATLAB software, and the Photoshop software was used to extract the edge lines from the image. Finally, the least squares method was used to fit the boundary curve as shown in Figure 1, where the horizontal and vertical coordinates are the horizontal pixel points and vertical pixel points of the image, respectively. The slope of the fitted line is the angle of repose. The slope of the fitted line is the tangent value of the angle of repose (*Hao J.J et al., 2021*), and the tangent value is converted into the angle of repose, and the average value of the angle of repose is 28.62°.

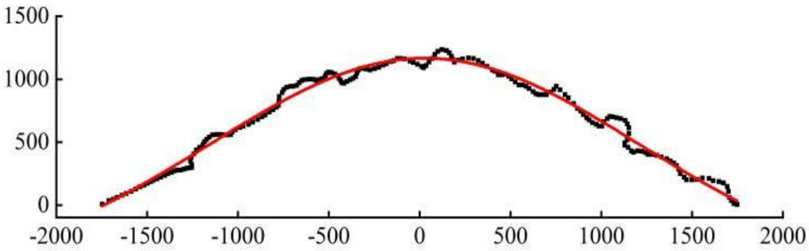
(a) Original image

Fig. 1a - Image processing

(b) Binarization process



(c) Extraction edge



(d) Fitting the curve

Fig. 1 (b-d) - Image processing

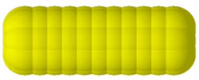
SIMULATION EXPERIMENT ON ANGLE OF REPOSE OF COTTON STRAW

Contact model selection

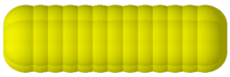
EDEM has three main contact modes: Hertz-Mindlin no-slip contact model, Hertz-Mindlin with bonding, and Hertz-Mindlin with JKR Cohesion. In this paper, the Hertz-Mindlin no-slip contact model is selected to simulate the angle of repose test on cotton straw. Mainly for the small bonding between particles (*Du X et al, 2012*), according to the physical property of surface adsorption between the cotton straw epidermis and small bonding force, this model was selected to effectively measure the contact parameters between cotton straws and between cotton straw and steel.

Simulation model building

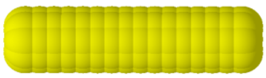
The Hertz-Mindlin no-slip contact model of cotton straw was established in EDEM, and since the shape of the cut cotton straw is approximately cylindrical, the simulation of cotton straw was combined with multiple particles (*Li P.P et al., 2016*) to establish four models of cylindrical simulated straw with a diameter of 10 mm and lengths of 26, 30, 36, and 40 mm, respectively, as shown in Figure 2.



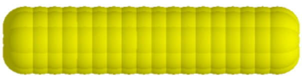
(a) 26mm



(b) 30mm



(c) 36mm



(d) 40mm

Fig. 2 - Cotton straw repose of cotton model

The cylinder was created in SOLIDWORKS with the same size as the physical test, and the dynamic production method was used to create a virtual plane above the cylinder as a particle factory, and the cotton straw model was dropped inside the cylinder to stop particle generation after generating about half of the volume of cotton straw in the cylinder, and after the cotton straw model was completely stationary, the cylinder was raised at a uniform speed of 0.05 m/s. After the straw model is slid down and a hill is formed, the angle between the slope of the hill and the bottom plate is measured, as shown in Figure 3.

Fig. 3 -Experiment on simulated angle of repose of cotton straw

Characteristic parameters

Forty randomly selected cotton stalks without disease and damage were selected as the test material, and the average diameter of cotton straw was measured to be 9.98 mm at the middle part of the straw about 400 mm from the roots. The uniaxial compression test was carried out on cotton straw, and the modulus of elasticity obtained from the before and after variation of cotton straw height and diameter was 1.86 GPa, Poisson's ratio was 0.35, and the relationship between shear modulus G, elastic modulus E, and Poisson's ratio μ was as follows:

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

Where:

μ - Poisson's ratio;

G - Shear modulus, MPa;

E - Elastic modulus, GPa.

The above physical tests and a review of relevant literature show the characteristic parameters of cotton straw and steel in Table 1. A review of the relevant literature (*Zhang T et al., 2018; Jia H.L et al., 2022*) yielded a range of values for the angle of repose of cotton straw contact parameters as shown in Table 2.

Table 1

Characteristic parameters

Parameter	Value	Units
Cotton straw density	1080	kg/m^3
Poisson's ratio of cotton straw	0.35	-
Shear modulus of cotton straw	0.69	GPa
Steel density	7850	kg/m^3
Poisson's ratio of cotton steel	0.30	-
Shear modulus of cotton steel	79.4	GPa

Table 2

Range of contact parameter values

Parameter	Value
Straw-straw collision recovery coefficient	0.3~0.7
Straw-straw static friction factor	0.3~0.6
Straw-straw rolling friction factor	0.05~0.1
Steel-straw collision recovery coefficient	0.3~0.7
Steel-straw static friction factor	0.3~0.6
Steel-straw rolling friction factor	0.05~0.1

Significance screening test of contact model parameters

The basic contact parameters affecting the angle of repose of cotton straw were screened (collision recovery coefficient (A), static friction factor (B), rolling friction factor (C) between cotton straws and cotton straw-steel collision recovery coefficient (D), static friction factor (E), rolling friction factor (F)) for significance analysis, and two levels of high and low were set for each parameter, and the level and factor designs are shown in Table 3.

Table 3

Experimental factors and levels

Level	A	B	C	D	E	F
-1	0.3	0.3	0.05	0.3	0.3	0.05
0	0.5	0.45	0.075	0.5	0.45	0.075
1	0.7	0.6	0.1	0.7	0.6	0.1

RESULTS AND ANALYSIS

Plackett-Burman screening test and significance analysis

The basic contact parameters affecting repose of cotton straw were screened, and the basic contact parameters were analysed for significance by the Plackett-Burman test, and the parameters in Table 3 were brought into the test with a total of 12 groups in the experimental design. The Plackett-Burman test design is shown in Table 4, and the parameters were analysed for significance as shown in Table 5.

Table 4

Experimental design of contact parameters

Serial number	A	B	C	D	E	F	Angle of repose / （°）
1	-1	1	-1	1	1	-1	32.85
2	1	1	-1	-1	-1	1	29.09
3	1	-1	1	1	1	-1	34.49
4	1	1	-1	1	1	1	32.76
5	-1	1	1	1	-1	-1	32.69
6	-1	1	1	-1	1	1	37.47
7	1	-1	1	1	-1	1	28.81
8	1	1	1	-1	-1	-1	32.64
9	-1	-1	-1	1	-1	1	25.55
10	-1	-1	-1	-1	-1	-1	25.78
11	1	-1	-1	-1	1	-1	29.13
12	-1	-1	1	-1	1	1	33.69

Table 5

Parameter significance analysis

Parameter	Effect	Mean square	Influence rate	F Value	P- Value	Significance ranking
A	-0.92	2.53	2.51	2.43	0.179	4
B	2.61	20.41	20.28	19.63	0.006	3
C	3.37	34.10	33.89	32.80	0.002	2
D	-0.17	0.092	0.091	0.088	0.778	5
E	3.57	38.27	38.03	36.80	0.001	1
F	-0.10	0.031	0.031	0.030	0.869	6

Significance analysis of the above parameters, as shown in Table 5, according to the significance screening, the static friction factor (B) between cotton straws, rolling friction factor (C), and static friction factor (E) between cotton straw and steel have significant effects on the angle of repose test, and the static friction factor (E) between cotton straw-steel has the highest significance on the angle of repose. The restoration coefficient of collision between cotton straws (A), the restoration coefficient of collision between cotton straw and steel (D), and the static friction factor between cotton straw and steel (F) had lower effects on the angle of repose test. For the three parameters with greater influence on the subsequent climbing test, the remaining parameters were selected as intermediate level values, (A) as 0.5, (D) as 0.5, (F) as 0.08.

Analysis of the steepest climbing test

With the increase of static friction factor (B), rolling friction factor (C) between cotton straw, and rolling friction factor (E) between cotton straw and steel, the simulation test of the angle of repose shows a gradual increase trend, and the relative error with the physical test shows a trend of first decreasing and then increasing, because the relative error of test 3 is the smallest and closest to the physical value. Therefore, test 3 is chosen as the central level value, and test 2 and test 4 are chosen as the low level and high level; the steepest climbing test was carried out as shown in Table 6.

Table 6

Steepest climbing test

Serial number	B	C	E	Angle of repose / （°）	Error / %
1	0.30	0.05	0.30	25.26	11.740
2	0.35	0.06	0.35	26.58	7.128
3	0.40	0.07	0.40	29.37	2.621
4	0.45	0.08	0.45	31.06	8.526
5	0.50	0.09	0.50	33.27	16.247

BBD response surface test results and analysis

The BBD response surface test was conducted for the three parameters of rolling friction factor between cotton straws (B), static friction factor between cotton straws (C), and rolling friction factor between cotton straw-steel (E). A three-factor, three-level combination design test was established with 17 test simulations and five sets of tests at the central level. The BBD response surface test design is shown in Table 7, and the BBD response surface test analysis of variance is shown in Table 8.

Table 7

BBD Response surface design

Serial number	B	C	E	Angle of repose / （°）
1	0	0	0	29.12
2	0	-1	1	29.70
3	1	0	1	31.96
4	0	1	-1	29.86
5	0	-1	-1	27.96
6	0	1	1	31.03
7	0	0	0	29.18
8	1	0	-1	29.81
9	-1	1	0	29.57
10	0	0	0	29.05
11	-1	0	1	30.01
12	-1	0	-1	28.04
13	1	-1	0	29.57
14	1	1	0	31.72
15	-1	-1	0	28.23
16	0	0	0	29.18
17	0	0	0	29.16

Table 8

BBD Response surface analysis of variance

Source	Freedom Degrees	Mean Square	F Value	P-Value Prob
Model	9	1.71	105.96	0.0001
A	1	4.06	251.04	0.0001
B	1	5.23	323.44	0.0001
C	1	4.95	305.70	0.0001
AB	1	0.024	1.49	0.2625
AC	1	0.17	10.65	0.0138

Table 8
(continuation)

Source	Freedom Degrees	Mean Square	F Value	P-Value Prob
BC	1	0.026	1.58	0.2482
A^2	1	0.25	15.69	0.0055
B^2	1	0.24	14.74	0.0064
C^2	1	0.37	23.11	0.0019
Residual	7	0.016	-	-
Lack of Fit	3	0.013	0.73	0.5874
Pure Error	4	0.018	-	-
Cor Total	16		-	-

Analysis of the above response surface test variance data, (AB) and (BC) have no significant impact on the angle of repose. Yielded a coefficient of determination R^2 of 0.9927 and a variance model close to 1, indicating that the regression model was highly significant and the misfit term P was greater than 0.05.

The coefficient of variation (CV) was 0.43%, indicating good reliability of the test, and the binary regression equation is shown in equation (2):

$$\begin{aligned}\theta = 29.16 + 0.71F + 0.81J + 0.79I + 0.078FJ \\ -0.21FI - 0.08JI + 0.25F^2 + 0.24J^2 + 0.30I^2\end{aligned} \tag{2}$$

By using the Design-Expert software constraint solving tool to find the minimum extreme value of the error point for equation (3), the physical test stacking angle is used as the target to find the best value of parameters, and the static friction factor (B) between cotton straws, rolling friction factor (C), and static friction factor (E) between cotton straw and steel are 0.41, 0.06, and 0.37.

Cotton straw simulation test validation

In order to verify the reliability of the above contact parameters (collision recovery coefficient, static friction factor, rolling friction factor between cotton straws, and collision recovery coefficient, static friction factor, rolling friction factor between cotton straw and steel), they were verified by the angle of repose tests. The required parameters for the simulation model are shown in Table 9.

Table 9

Cotton straw simulation parameters

Parameter	Value	Units
Cotton straw density	1080	kg/m^3
Poisson's ratio of cotton straw	0.35	
Shear modulus of cotton straw	0.69	GPa
Steel density	7850	kg/m^3
Poisson's ratio of cotton steel	0.30	
Shear modulus of cotton steel	79.4	GPa
Straw-straw collision recovery coefficient	0.5	
Straw-straw static friction factor	0.41	
Straw-straw rolling friction factor	0.06	
Steel-straw collision recovery coefficient	0.5	
Steel-straw static friction factor	0.37	
Steel-straw rolling friction factor	0.08	

Through five simulation tests, the average angle of repose is 28.32°. The test results show that the difference between the physical test angle of repose and the simulation test angle of repose after calibration of simulation parameters is small, and the relative error is 1.04%, which further verifies the reliability and authenticity of the simulation test. The simulation test is shown in Figure 4.

The simulation test is shown in Figure 4.

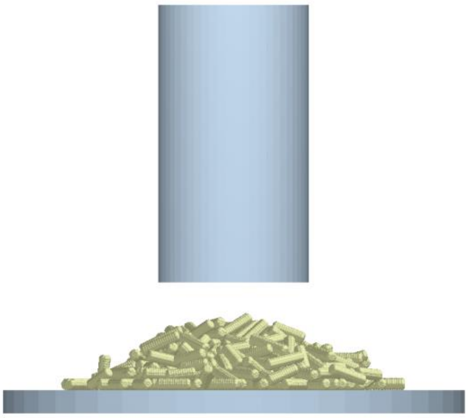


Fig.4 - Experiment on simulated angle of repose of cotton straw

CONCLUSIONS

(1) The interaction between cotton straw and steel and between cotton straws was studied using the discrete element method. By using EDEM software, the Hertz-Mindlin no-slip contact model was selected for parameter calibration to lay the foundation for the study of cotton straw equipment in Xinjiang.

(2) Using the Plackett-Burman principle, the contact parameters were screened, and it was found that the static friction factor between cotton straws, rolling friction factor, and static friction factor between cotton straw and steel had a greater influence on the angle of repose, and the collision recovery factor between cotton straws, collision recovery factor between cotton straw and steel, and rolling friction factor between cotton straw and steel had a smaller influence on the angle of repose. The steepest climbing test was used to select the best value range of contact parameters, and after that, the significant parameters were analysed by the BBD principle. The binary regression equation was obtained.

(3) Through the binary regression equation, the angle of repose was used as the target, and the optimized solution yielded the collision recovery coefficient, static friction factor, rolling friction factor between cotton straws and the collision recovery coefficient, static friction factor and rolling friction factor between cotton straw-steel as 0.5, 0.41, 0.06, 0.5, 0.37 and 0.08, respectively. The simulation angle of repose test was carried out using the above parameters brought in, and the simulation. The relative error between the simulation test and the physical test is 1.04%.

ACKNOWLEDGEMENTS

This study was funded by the Autonomous Region Innovation Team Project (2020D14037), Natural Science Foundation of the Autonomous Region (2019D01A45), National Natural Fund Projects (51865058).

REFERENCES

[1] Du X., Liu C.L., Jiang M., Yuan H., Dai L., Li F.L., (2021), Parameter Calibration of Bonding Model of Coated Fertilizer Based on Discrete Element Method (基于离散元的包膜肥料 Bonding 模型参数标定), *Transactions of the Chinese Society for Agricultural Machinery*, pp.1-10;

[2] Du X., Zeng Y.W., Gao R., Yan J., Zao Y., (2012), Study on the influence of particle shape on friction mechanism by discrete element method (用离散元方法研究颗粒外形对摩擦机理的影响), *Journal of Southwest Jiaotong University*, vol. 47, issue.02, pp. 252-257;

[3] He J.J., Wei W.B., Huang P.C., Qin J.H., Zhao J.G., (2021), Calibration and experimental verification of discrete element parameters of oil sunflower seeds (油葵籽粒离散元参数标定与试验验证), *Transactions of the Chinese Society for Agricultural Machinery*, vol. 37, issue.12, pp. 36-44

[4] Jia H.L., Deng J.Y., Deng Y.L., Chen T.Y., Wang G., Sun Z.J., Guo H., (2022), Discrete element simulation contact parameter analysis and calibration of rice straw, *Agricultural engineering technology* (水稻秸秆的离散元仿真接触参数分析与标定), vol. 42, issue.03, pp. 96;

[5] Liao Y.T., Liao Q.X., Zhou Y., Wang Z.T., Jiang Y.J., Liang F., (2020), Calibration of discrete element simulation parameters of stalk breakage in harvest stage of rape stalks (饲料油菜薹期收获茎秆破碎离散元仿真参数标定), *Transactions of the Chinese Society for Agricultural Machinery*, vol. 51, issue.06, pp. 73-82;

[6] Liao Y.T., Wang Z.T., Liao Q.X., Wang X.Y., Zhou Y., Liang F., (2020), Parameter calibration of discrete element contact model of feed rape stalks at early pod stage（果荚初期饲料油菜茎秆离散元接触模型参数标定）, *Transactions of the Chinese Society for Agricultural Machinery*, vol. 51, issue S1, pp. 236-243;

[7] Li P.P., Wu S., Zhang X.L., Wang J.Z., Xu Y.F., (2016), Parameter optimization of vertical spiral mixing equipment for tomato straw and fermentation strains (番茄秸秆与发酵菌种立式螺旋混合设备参数优化), *Transactions of the Chinese Society for Agricultural Machinery*, vol. 47, issue 11, pp. 114-120;

[8] Liu F.Y., Zhang J., Li B., Chen J., (2016), Parameter analysis and calibration of wheat discrete element based on stacking test (基于堆积试验的小麦离散元参数分析及标定), *Transactions of the Chinese Society for Agricultural Machinery*, vol. 32, issue 12, pp. 247-253;

[9] Liu W.Z., He J., Li H.W., Li X.Q., Zhang K., Wei Z.C., (2018), Micro-potato simulation parameter calibration based on discrete element (基于离散元的微型马铃薯仿真参数标定), *Transactions of the Chinese Society for Agricultural Machinery*, vol. 49, issue 05, pp. 125-135+142;

[10] Wang W.W., Can D.Y., Xie J.J., Zhang C.L., Liu L.C., Chen L.Q., (2021), Parameter calibration of discrete element model for dense moulding of corn stalk powder (玉米秸秆粉料致密成型离散元模型参数标定), *Transactions of the Chinese Society for Agricultural Machinery*, vol. 52, issue 03, pp. 127-134;

[11] Wang Y.X., Liang Z.J., Zhang D.X., Cui T., Shi S., Li K.H., Yang L., (2016), Calibration of interspecific contact parameters of corn seed particle model based on discrete element method (基于离散元的玉米种子颗粒模型种间接触参数标定), *Transactions of the Chinese Society of Agricultural Engineering*, vol. 32, issue 22, pp. 36-42;

[12] Wu M.C., Cong J.L., Yan Q., Zhu T., Peng X.Y., Wang Y.S., (2021), Calibration and experiment of peanut seed particle discrete element simulation parameters (花生种子颗粒离散元仿真参数标定与试验), *Transactions of the Chinese Society of Agricultural Engineering*, vol. 36, issue 23, pp. 30-38;

[13] Yu Q.X., Liu Y.,X., Chen X.B., Sun K., Lai Q.H., (2020), Calibration and experiment of pseudo-ginseng seed simulation parameters based on discrete element (基于离散元的三七种子仿真参数标定与试验), *Transactions of the Chinese Society for Agricultural Machinery*, vol. 51, issue 02, pp. 123-132;

[14] Zhang S.Y., Zhang R.Y., Chen T.Y., Fu J., Yuan H.F., (2022), Parameter calibration and seed metering experiment of mung bean seed discrete element simulation (绿豆种子离散元仿真参数标定与排种试验), *Transactions of the Chinese Society for Agricultural Machinery*, vol. 53, issue 03, pp. 71-79;

[15] Zhang T., Liu F., Zhao Q.M., Ma Q., Wang W., Fan Q., Yan P., (2018), Determination of physical parameters of corn stalk contact and calibration of discrete element simulation (玉米秸秆接触物理参数测定与离散元仿真标定), *Journal of China Agricultural University*, vol. 23, issue 04, pp. 120-127;

[16] ***Announcement of the National Bureau of Statistics on cotton production in 2021 (国家统计局关于2021 年棉花产量的公告), (2021), *China Information Daily.*