EXPERIMENTAL RESEARCH ON THREE-LEVEL VIBRATING SCREENING OF BUCKWHEAT BASED ON DISCRETE ELEMENT METHOD
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基于离散元法的荞麦三级振动筛分试验研究

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ABSTRACT

To improve the operating effect of buckwheat classifying equipment and meanwhile reduce the dependence on tests in the process of operating parameter optimization of the equipment, this paper designed a three-level classifying screen for buckwheat, confirmed the structure and parameters of upper and lower sieves, established a three-level screening discrete element model for buckwheat with the EDEM software, and conducted the numerical simulation for the sieving processes at an amplitude of 24 mm, 28 mm and 32 mm, respectively. The results indicated that when the inclination angle of screen surface was 3°, the vibrational direction angle was 30º and the vibrational frequency was 4.5 HZ, as the amplitude increased, the conveying capacity of the classifying screen increased and at the same time the seed loss rate also increased, of which at 16 s, the loss rate was 0.03%, 0.37% and 1.42%, respectively; the proportion of medium particles in the collecting box of screen overflow was 2.88%, 8.65% and 17.65%, respectively; and the proportion of small particles in the collecting box of screen residue was 0.58%, 6.06% and 19.14%, respectively. Through comprehensive analysis of conveying capacity, screening loss and classifying effect, when the amplitude of the classifying screen was 28 mm, the classifying operating effect was good. This study can provide reference for the design and operating parameter optimization of buckwheat classifying equipment.

摘要

为改善荞麦分级设备作业效果、同时减少设备工作参数优化过程中对试验的依赖。设计了荞麦三级分级筛，确定了上、下筛片的结构及参数，应用 EDEM 软件建立了荞麦三级筛分离散元模型，并对振幅分别为 24 mm、28 mm、32 mm 时的筛分过程进行了数值模拟。结果表明：在筛面倾角为 3°、振动方向角为 30°、振动频率为 4.5 HZ 时，随着振幅的增大，分级筛输送能力增加，同时籽粒损失率也增大，16 s 时损失率分别为 0.03%、0.37%、1.42%，筛上物收集箱内中颗粒占比分别为 2.88%、8.65%、17.65%，筛中物收集箱内小颗粒占比分别为 0.58%、6.06%、19.14%。综合分析输送能力、筛分损失、分级效果，分级筛振幅为 28 mm 时分级作业效果较好。本研究可为荞麦分级设备的设计及工作参数优化提供参考。

INTRODUCTION

As one of pseudocereals, buckwheat has abundant nutritional value and powerful medicinal value, and it is an ideal raw material of functional food *(Mazahir et al., 2022; Ahmed et al., 2022; Cao et al., 2022)*. In recent years, rational diet and balanced nutrition have received more and more attention, and buckwheat food has appeared in people's lives in the forms of staple food, convenience food, leisure food, etc., a demand that is gradually increasing *(Ren et al., 2018; Ren et al., 2022)*. With the increase of the market demand for buckwheat food, the better operating effect and efficiency of relevant food processing and raw material handling equipment are requested. The rough grain harvested mechanically usually undergoes preliminary cleaning and de-stone processing to obtain buckwheat seeds, and then buckwheat rice is obtained after the hulling treatment of buckwheat seeds *(Liu, 2014)*. Since buckwheat seeds have various sizes, crisp and fragile kernels and a smaller space between hulls and kernels, screening classification must be performed for

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buckwheat seeds before the hulling treatment in batches to reduce the broken rate of buckwheat rice in the hulling treatment, and the more the classification, the lower the broken rate of buckwheat rice will be *(Li et al., 2016; Quan et al., 2014)*. The working performance of classifying procedure relates to the quality of buckwheat food, so research and development of efficient multi-level buckwheat screening equipment has great significance to promote the development of buckwheat deep-processing industry.

In recent years, many scholars have researched the cleaning and classification of buckwheat from the aspects of the design and operating parameter optimization of cleaning device, screen surface, etc. Zhang Longxiang et al. designed an air-and-screen cleaning device with pre-cleaning structure, performed numerical simulation tests for buckwheat cleaning processes on the basis of gas-solid coupling technology, and determined the optimum working parameter combination of air blower and vibrating screen, thus providing evidence for the operating parameter optimization of cleaning device *(Zhang, 2020)*. Lu et al. designed an air-and-screen cleaning device used for Buckwheat threshers, and conducted prototype experiments, which showed that when the wind speed of blower was 8 m/s and the vibration frequency of vibrating screen was 25.12 rad·s^{-1}, the cleaning loss rate was 1.96% *(Lu et al., 2022)*. In order to solve the problems of high loss rate and impurity rate in the screening of buckwheat extractions, Fan et al. performed simulated screening tests for 5 different screen surfaces with the EDEM software, and the results revealed that non-planar convex-column screen surface had the best screening effect *(Fan et al., 2022)*. Moreover, taking the threshing material of buckwheat at the harvest time as research object, recently they carried out single factor experiments on cleaning testing platforms for 7 factors that may affect cleaning quality, and screened out the factors that can influence loss rate and impurity rate significantly, thus laying a good foundation for the operating parameter optimization of cleaning device *(Fan et al., 2023)*. To improve the separating effect between buckwheat rice and unhulled buckwheat, Liu Chuang et al. designed a new type of circular sieve plate, and conducted sieve tests, which showed that the screening effect of the new type of circular sieve plate proposed was better than that of traditional circular and triangular sieve plates *(Liu, 2014)*. Quan Yajing et al. conducted an experimental study on buckwheat classification and its influence on the hulling effect, and designed an elongated round hole sieve used in the buckwheat classification from the two aspects of reducing the differential in the classification and changing the hole pattern, in order to perfect the situation of buckwheat classification *(Quan, 2014)*. Aiming at the problems of severe screen hole blocking and low classification efficiency in the process of buckwheat classification, Chang Rong et al. explored the effect of bouncing ball screen cleaning, and investigated the influencing rule of bouncing ball quantity on classification efficiency via tests, which showed that the effect of bouncing ball screen cleaning was remarkable and an appropriate number of bouncing balls could enhance classification efficiency *(Chang et al., 2016)*.

At present, many studies on buckwheat screening mainly focus on two aspects: (1) the cleaning and separation of buckwheat extractions in the harvesting link; and (2) the separation between buckwheat rice and buckwheat hulls as well as unhulled buckwheat in the hulling link. However, there is little research on classification, which is an intermediate link between the above two links. To improve the operating effect of buckwheat classification, this study intended to design the overall structure of buckwheat three-level classifying screen, and confirm the structure and parameters of sieves. It built a three-level vibrating screening model with the discrete element method, and performed the numerical simulation for vibrating screening processes under different amplitudes to determine suitable working parameters.

MATERIALS AND METHODS

The structure and parameters of buckwheat three-level classifying screen

The buckwheat three-level classifying screen consists of rack, electromotor, drive system, crank, connecting rod, feed hopper, suspender, sieve etc., and its overall structure is shown in Figure 1.

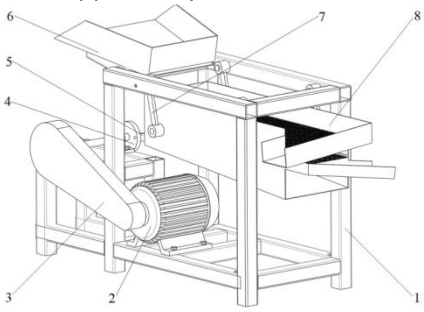


Fig. 1 - The overall structure of buckwheat three-level classifying screen

1- rack; 2- electromotor; 3- drive system; 4- crank; 5- connecting rod; 6- Feed hopper; 7- suspender; 8- sieve

The sieve is comprised of upper sieve, side board, front board, lower sieve, bottom board, discharge chute of screen overflow and discharge chute of screen residue, as shown in Figure 2.

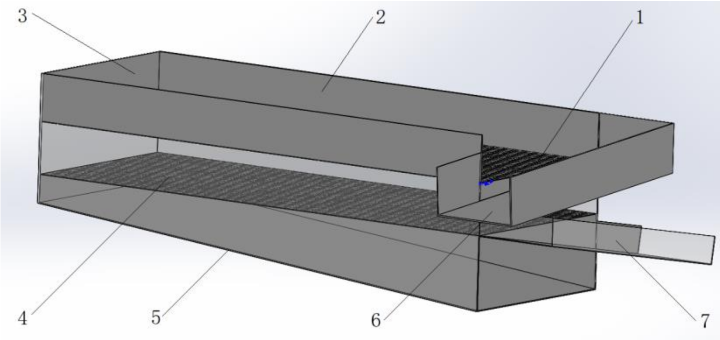


Fig. 2 - Schematic diagram of screen body structure
1- upper sieve; 2- side board; 3- front board; 4- lower sieve; 5- bottom board; 6- discharge chute of screen overflow; 7- discharge chute of screen residue

The upper and lower sieves are both made of stainless steel with the thickness of 0.8 mm, and have the shape of 720 mm×270 mm rectangle. Since the shape and size of sieve aperture as well as its distribution rule on the sieve all have impacts on screening quality, the design of sieve aperture needs to take into account factors such as seed shape, size distribution and classification requirement. The pertinent literature shows that over 90% of buckwheat seeds have a particle size of 3.8 mm~5.0 mm *(Li et al., 2016)*. Thus, this study planned to divide buckwheat seeds into: particle size<4.2 mm, particle size>4.8 mm and 4.2 mm~4.8 mm.

Round stamped sieve was adopted in both upper and lower sieves, the size and distribution of sieve aperture were designed according to GB 3943-83 Type Ⅰ Sieve *(China Academy of Agricultural Mechanization Sciences, 2007)*.

The center of sieve aperture is located at the vertex of equilateral triangle, and the direction of material motion is perpendicular to a side of the equilateral triangle, as shown in Figure 3.

The relevant parameters of the sieve are shown in Table 1.

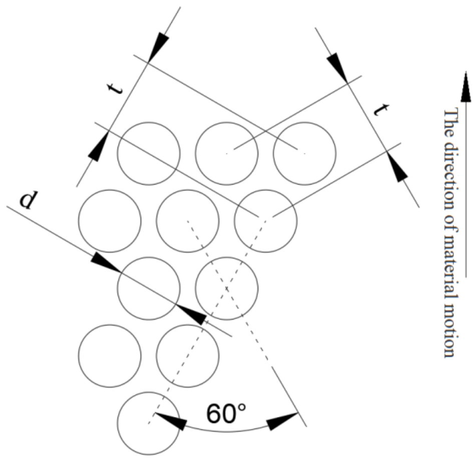


Fig. 3 - The schematic diagram of screen size and distribution

Table 1

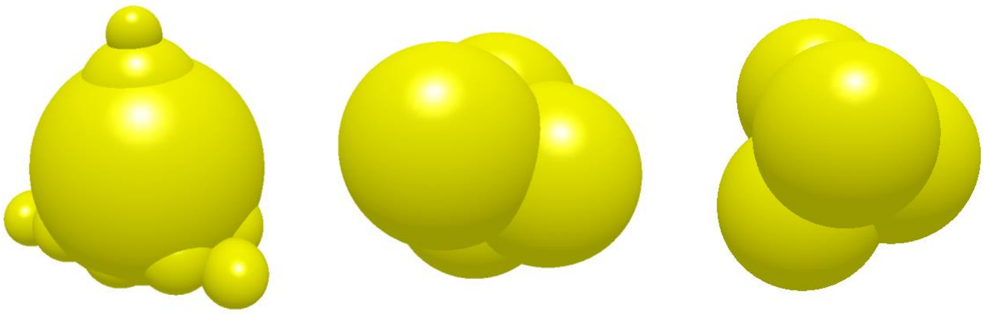
Sieve parameters

Sieve	Diameter of sieve pore / d (mm)	Hole spacing / t (mm)	Percentage of screening area / (%)
upper sieve	4.8	6	58
lower sieve	4.2	6	44

The establishment of a discrete element model for the buckwheat three-level vibrating screen

Modeling of screening materials

Buckwheat seeds present a triangular pyramid. As different seeds have different sizes, it is impossible to build a seed group model exactly according to the actual size of all seeds. In order to simplify the modeling process, manual filling was only used to establish models for seeds in three sizes - small, medium and large, and these models were saved as particle template, as shown in Figure 4. The diameter of the three dimensions of all large particles is greater than 4.8 mm, the diameter of the three dimensions of all medium particles is between 4.2 mm and 4.8 mm, and the diameter of the three dimensions of all small particles is less than 4.2 mm.



（a） large particle （b） medium particle （c） small particle

Fig. 4 - Particle Models

Establishment of three-level vibrating screening model

The three-dimensional model of sieve was established in accordance with the structure and parameters of the sieve, and it was transformed into STEP format to induct to EDEM. Then, the templates of small, medium and large particles were inducted to EDEM. By referring to relevant literature and our preliminary research, the parameters required in the screening simulation tests were determined and set, as shown in Table 2 *(Zhang et al., 2020; Hou et al., 2019; Xu et al., 2021; Fan et al., 2022; Fan et al., 2021)*.

Table 2

The list of parameters in the screening simulation tests

Parameters	Values
Poisson's ratio of stainless steel	0.29
Shear modulus of stainless steel （MPa）	70000
Density of stainless steel （kg/m^3）	8000
Poisson's ratio of buckwheat	0.3
Shear modulus of buckwheat （MPa）	34.3
Density of buckwheat （kg/m^3）	2540
Buckwheat-buckwheat restitution coefficient	0.2
Buckwheat-buckwheat static friction coefficient	0.532
Buckwheat-buckwheat rolling friction coefficient	0.01
Buckwheat-stainless steel restitution coefficient	0.508
Buckwheat-stainless steel static friction coefficient	0.7
Buckwheat-stainless steel rolling friction coefficient	0.043

The factory of particles in the size of 260 mm×160 mm was established above the upper sieve and near the feeding inlet of the sieve, and it was used to produce the mixed material containing small, medium and large particles in the initial phase of simulation tests. The factory of particles in all simulation tests in this study was set as follows: the type was “dynamic”; the total number of particles in the mixed material was 6,000; the mixed material was produced evenly within 2 s before simulation tests; and the initial velocity of particles at the Z-axis direction was -0.5 m/s. The collecting boxes of screen overflow, screen residue and screen underflow were respectively established in the model. The discrete element model for buckwheat three-level screening is shown in Figure 5.

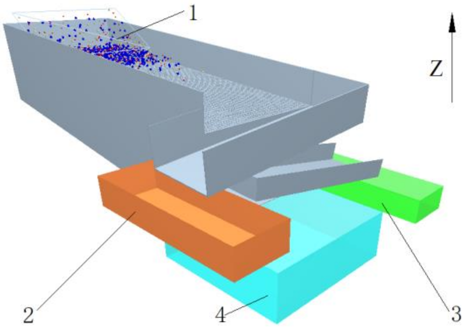


Fig. 5 - Discrete element model for the buckwheat three-level vibrating screen

1- factory of particles; 2- the collecting boxes of screen overflow; 3- the collecting boxes of screen residue; 4- the collecting boxes of screen underflow;

Simulation tests for buckwheat three-level vibrating screening

On the basis of our previous research, the three amplitudes of 24 mm, 28 mm and 32 mm for the classifying screen were determined, and vibrating screening tests were separately performed with the EDEM software. The corresponding installation and vibration parameters of the classifying screen in simulation tests are shown in Table 3.

Table 3

Installation of the classifying screen and vibration parameters

Number	Amplitude / (mm)	Vibrational frequency / (HZ)	Inclination angle of screen surface / (°)	Vibrational direction angle / (°)
1	24	4.5	3	30
2	28	4.5	3	30
3	32	4.5	3	30

The simulated time was set as 16 s in each test, and the interval of data storage was set as 0.25 s in the simulation process. In order to compare and analyze the screening performance of classifying screen under different amplitudes, the EDEM post-processing module was used to establish analog computational domain and statistical domain of the collecting boxes of screen overflow, screen residue and screen underflow in the screening model after screening tests, as shown in Figure 6.

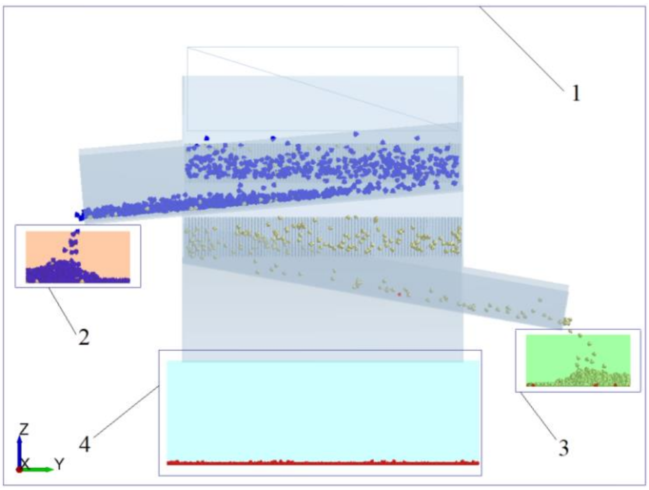


Fig. 6 - Division of statistical domains

1- analog computational domain; 2- statistical domain of the collecting boxes of screen overflow; 3- statistical domain of the collecting boxes of screen residue; 4- statistical domain of the collecting boxes of screen underflow

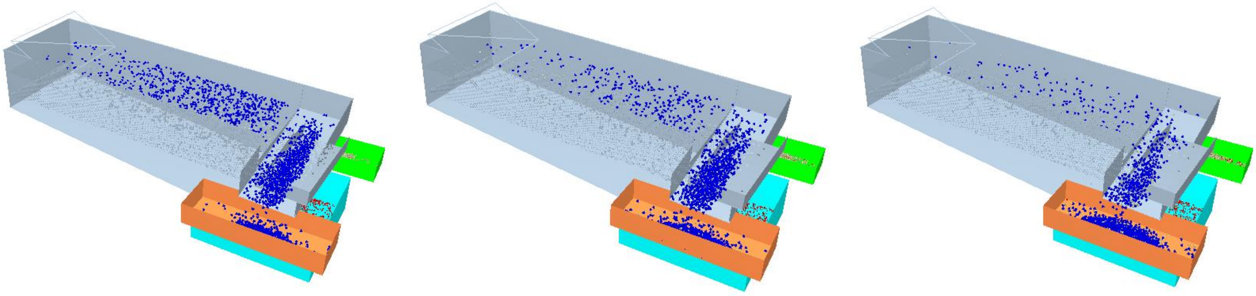
Evaluation indexes

This study evaluated the screening performance of vibrating screen under three amplitudes from the three aspects of conveying capacity, screening loss and classification effect.

The conveying capacity is related to many factors such as the inclination angle of screen surface, vibrational frequency and amplitude *(Li et al., 2011)*. This study performed qualitative analysis of the conveying capacity only through comparing the total number of particles in the three collecting boxes under different amplitudes in the same time. In the process of vibration classification, due to the interaction among particles as well as between particles and the sieve, some particles fly off the computational domain, leading to the screening loss, and the loss rate is defined as the ratio of lost particles to the total particles produced by the particle factory. The most desirable outcome of classification is that small, medium and large particles fall into the collecting boxes of screen underflow, screen residue and screen overflow, respectively. But some small and medium particles may not complete the screening process because of their insufficient contact with the screen surface in the process of classification, causing that the collecting box of screen overflow contains a certain amount of small and medium particles, and the collecting box of screen residue contains a part of small particles. This study took the ratio of small and medium particles to the total particles in the collecting box of screen overflow and the ratio of small particles to the total particles in the collecting box of screen residue at 16 s as indexes to evaluate the classification effect.

RESULTS

After numerical simulation tests, by entering into the EDEM post-processing module, the dynamic process of simulation tests under the three amplitudes was observed and compared. The distribution of particles in the sieve under the three amplitudes at 16 s is shown in Figure 7.



(a) 24 mm (b) 28 mm (c) 32 mm

Fig. 7 - The distribution of particles in the sieve under different amplitudes at 16 s

It can be known from Figure 7 that there were obvious differences in the distribution of particles in the sieve under different amplitudes. The total number of particles outputted in the three collecting boxes under each amplitude at different times was counted, and its changing curve with time was drawn, as shown in Figure 8. The number of particles flown out the analog computational domain in the process of screening was counted, and its changing curve with time was drawn, as shown in Figure 9.

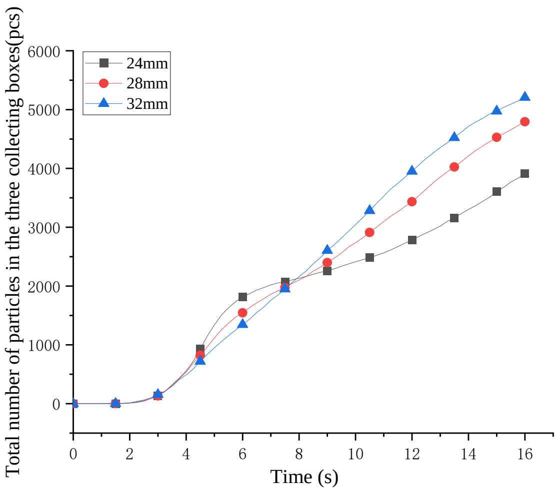


Fig. 8 - The change of the total number of particles in the three collecting boxes under different amplitudes

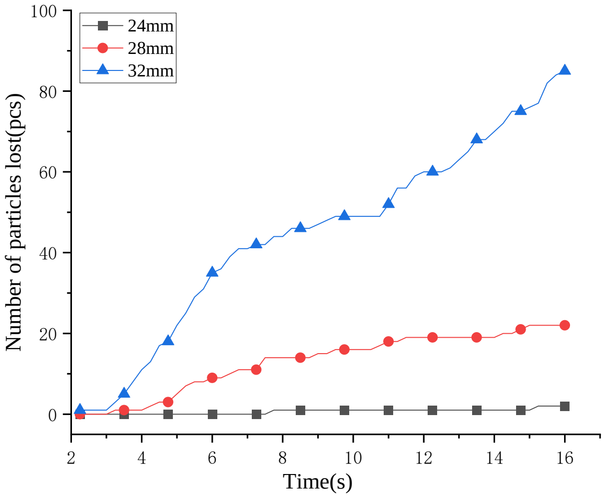


Fig. 9 - The changing curve of particle loss under different amplitudes

It can be seen from Figure 8 that there were no significant differences in the number of particles in the collecting boxes under the three amplitudes before 7.5 s, during which the particle material was moving from the front sieve to the back sieve, while the number of particles in the collecting boxes increased with the increase of amplitude after 7.5, suggesting the increase of conveying capacity. It can be seen from Figure 9 that when the amplitude was 24 mm, particle loss was the least, but when the amplitude was 32 mm, particle loss was the most, and the number of lost particles under the three amplitudes of 24 mm, 28 mm and 32 mm at 16 s was 2, 22 and 85, respectively, with the loss rate of 0.03%, 0.37% and 1.42%, respectively.

The total number of particles in the collecting box of screen overflow and the number of small and large particles contained were counted at different times in the three tests, and their changing curve with time was drawn, as shown in Figure 10. The data of particles outputted in the collecting box of screen overflow at 16 s are shown in Table 4.

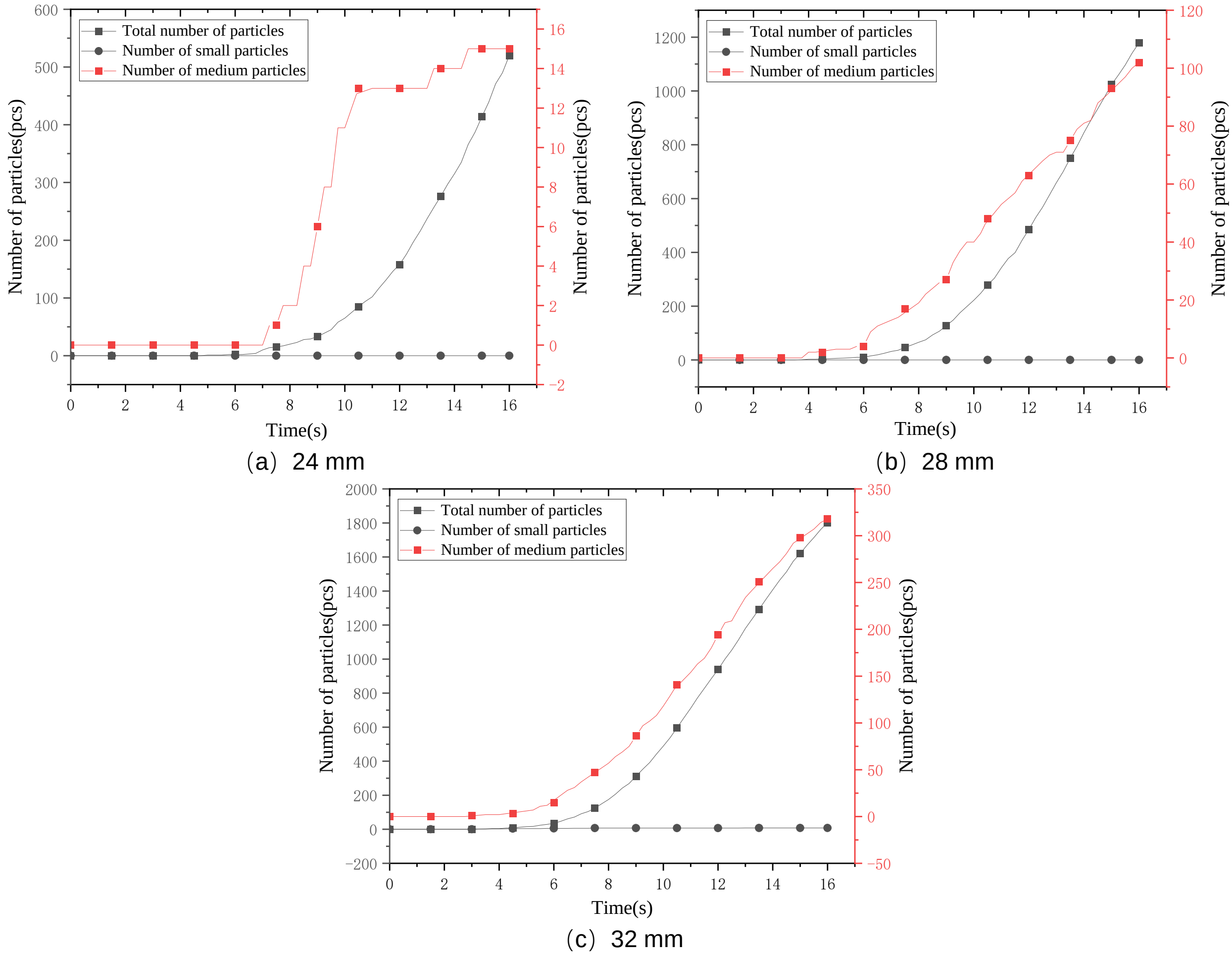


Fig. 10 - The change of particles in the collecting box of screen overflow

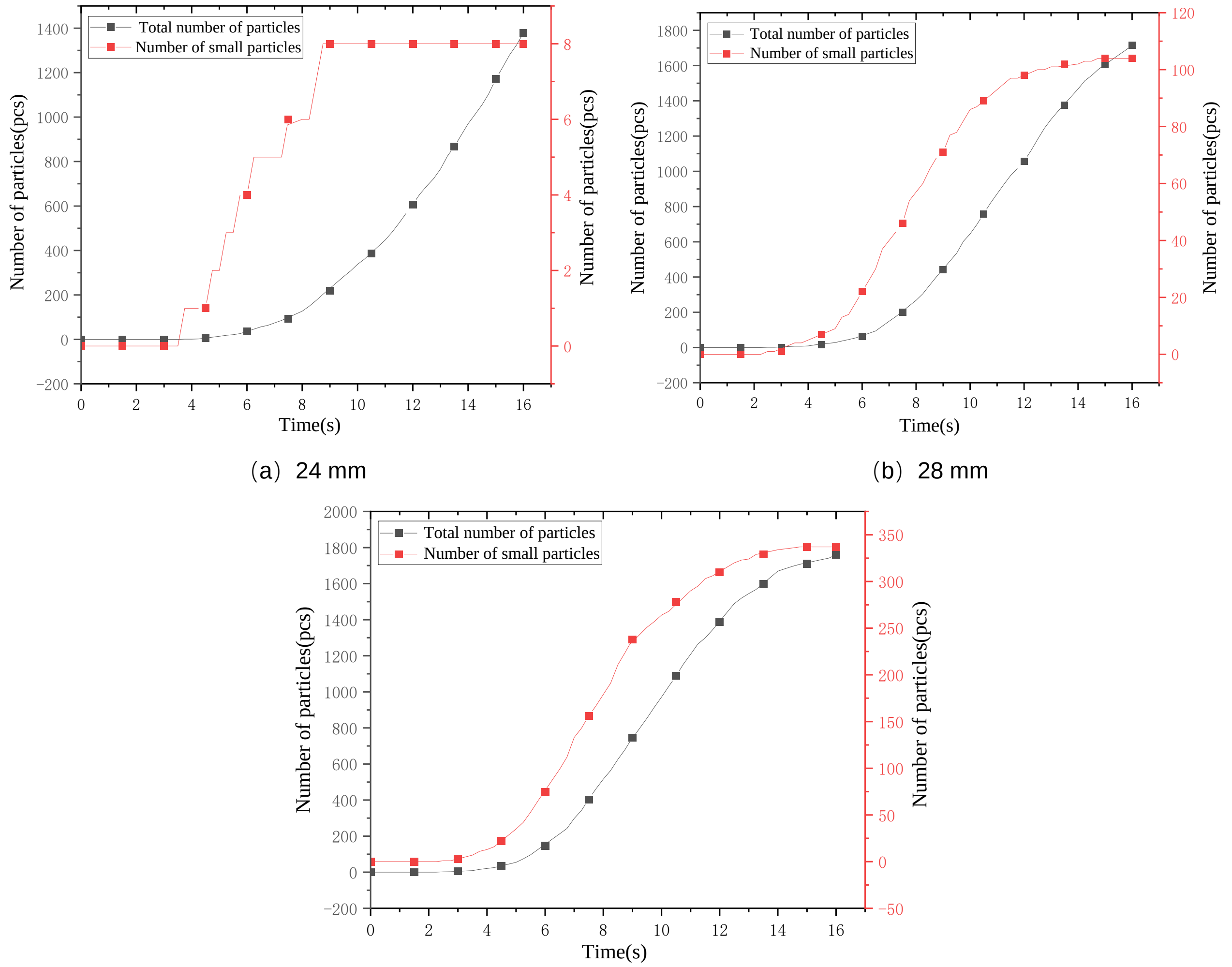
Table 4

The number of particles in the collecting box of screen overflow at 16 s

Amplitude mm	Total number of particles pcs	Medium particle		Small particle	
		Number pcs	Proportion %	Number pcs	Proportion %
24	520	15	2.88	0	0
28	1179	102	8.65	0	0
32	1802	318	17.65	8	0.04

It can be known from Figure 10 and Table 4 that there were few small particles in the collecting box of screen overflow under the three amplitudes, but with the increase of amplitude and conveying capacity, the total number of particles in the collecting box of screen overflow increased and meanwhile the number of medium particles that didn't complete the screening process also increased, and the proportion of medium particles in the collecting box of screen overflow at 16 s was 2.88%, 8.65% and 17.65%, respectively.

The total number of particles in the collecting box of screen residue and the number of small particles contained were counted at different times in the three tests, and their changing curve with time was drawn, as shown in Figure 11. The data of particles outputted in the collecting box of screen residue at 16 s are shown in Table 5.



(a) 24 mm (b) 28 mm

(c) 32 mm

Fig. 11 - The change of particles in the collecting box of screen residue

Table 5

The number of particles in the collecting box of screen residue at 16 s

Amplitude mm	Total number of particles pcs	Small particle	
		Number / pcs	Proportion / %
24	1379	8	0.58
28	1715	104	6.06
32	1760	337	19.14

It can be known from Figure 11 and Table 5 that when the amplitude increased from 24 mm to 28 mm, the total number of particles in the collecting box of screen residue increased significantly, while when the amplitude increased from 28 mm to 32 mm, there was no significant increase in the total number of particles in the collecting box of screen residue, but the number of small particles that didn't complete the screening process increased remarkably from 104 to 377, and the proportion of small particles in the collecting box of screen residue at 16 s was 0.58%, 6.06% and 19.14%, respectively.

CONCLUSIONS

(1) According to the requirement of buckwheat classification, this study designed a three-level classifying screen for buckwheat and determined the structure and parameters of upper and lower sieves.

(2) This study established a discrete element model for the buckwheat three-level vibrating screen, and conducted numerical simulation for the classification process under the three amplitudes of 24 mm, 28 mm and 32 mm. The results indicated that when the inclination angle of screen surface was 3°, the vibrational direction angle was 30° and the vibrational frequency was 4.5 HZ, as the amplitude increased, the conveying capacity of the classifying screen increased and at the same time the seed loss rate also increased, of which at 16 s, the loss rate was 0.03%, 0.37% and 1.42%, respectively; the proportion of medium particles in the collecting box of screen overflow was 2.88%, 8.65% and 17.65%, respectively; and the proportion of small particles in the collecting box of screen residue was 0.58%, 6.06% and 19.14%, respectively. Through comprehensive analysis of conveying capacity, screening loss and classifying effect, when the amplitude of the classifying screen was 28 mm, the classifying operating effect was good.

(3) This study is a single factor experiment on amplitude, but the operating effect of classifying screen is related to many factors such as the inclination angle of screen surface, vibrational direction angle and vibrational frequency. This study can lay a foundation for multi-parameter combination optimization in the future.

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REFERENCES

[1] Cao R.G., Guo Z.C., Wang L.J., et al., (2022), Processing and Quality Improvement of Buckwheat Noodles: A Review *(荞麦面条加工及品质提升的研究进展). Food Research and Development*. http://kns.cnki.net/kcms/detail/12.1231.TS.20221014.1907.002.html,Online,pp.1-16, Tianjin/China;

[2] Chang R., Du W.L., Chen W. et al., (2016), Experiment Study of the Influence of Bouncing Ball Screen Cleaning on Buckwheat’s Grading Efficiency (*弹球清筛对荞麦分级效率影响的试验研究). Journal of Agricultural Mechanization Research,* Vol.38,Issue 03,pp.187-190+195,Haerbin/China;

[3] Fan R., Cui Q.L., Zhang Y.Q. et al., (2021), Analysis and calibration of parameters of buckwheat grain. *INMATEH - Agricultural Engineering*, Vol. 64, No. 2, pp.467-476, Bucharest/Romania;

[4] Fan R., Cui Q.L., Lu Q. et al., (2022), Experimental study on non-planar screening device for buckwheat threshing material. *INMATEH Agricultural Engineering*, Vol.66, Issue 1, pp.73-80, Bucharest/Romania;

[5] Fan R., Cui Q.L., Lu Q. et al., (2023), Parameter Optimization and Experimental Study of Cleaning Device on Buckwheat Threshing Material（*荞麦混合脱出物清选装置参数优化及试验研究*）. *Journal of Agricultural Mechanization Research*，Vol.45, Issue 05, pp.136-142, Haerbin/China;

[6] Hou H.M., (2019), *Experimental study on cleaning dynamic characteristics of coarse cereals crops harvested by machinery（杂粮作物机械收获清选动力学特性研究）*. PhD Dissertation. Shanxi Agricultural University, Taiyuan/China;

[7] Li H.C., Li Y.M., Tang Z., (2011), Numerical simulation and analysis of vibration screening based on EDEM (*基于EDEM的振动筛分数值模拟与分析*). *Transactions of the CSAE*, Vol.27, Issue 5, pp.117-121, Beijing/China;

[8] Li J.C., Zhao X.H., Zhao J.C. et al., (2016), Study on physical characteristics of buckwheat seeds（*荞麦籽粒的物理学特性研究*）. *Food and Machinery*, Vol.32, Issue 7, pp.1-4+79, Changsha/China;

[9] Liu C., (2014), Analysis and Experimental Study of the Sieving Performance Parameters in Sieving of Shelled Buckwheat *(荞麦米分离过程中筛分性能参数的分析与试验研究).* Master thesis. Inner Mongolia Agricultural University, Huhehaote/China;

[10] Lovro S., Matjaž D., Rok K. et al., (2022), Macro/microelements, nutrients and bioactive components in common and Tartary buckwheat (Fagopyrum spp.) grain and stone-milling fractions. *LWT-Food Science and Technology*, Vol.161, 113422. Ed. Elsevier, London/England;

[11] Lu Q., Zheng D.C., Li L.H., et al., (2022), Design and experiment of 5TG-85 buckwheat thresher. *INMATEH Agricultural Engineering*, Vol.66, Issue 1, pp.289-300, Bucharest/Romania;

[12] Mazahir M., Ahmed A., Ahmad A. et al., (2022), Extraction and determination of bioactive compounds and antioxidant activity of buckwheat seed milling fractions. *Food Science and Technology*, Vol.42, pp.1-6, Rio de Janeiro/Brazil;

[13] Quan Y.J., (2014), Experiment Study on Buckwheat Grading and the Shucking Effect Caused by Buckwheat Grading（*荞麦分级及其对荞麦剥壳效果的影响研究*）. Master thesis. Inner Mongolia Agricultural University, Huhehaote/China;

[14] Quan Y.J., Du W.L., Liu C. et al., (2014), The Research on the Influence of Elongated Apertures with Round Screens Grading to Buckwheat Shelling Effect（*长圆孔筛分级对荞麦剥壳效果的影响试验*）. *The Food Industry*, Vol.35, Issue 10, pp.205-208, Shanghai/China;

[15] Ren C.Z., Cui L., He F. et al., (2018), Construction and Development of China Oat and Buckwheat Industrial Technology System（*我国燕麦荞麦产业技术体系建设与发展*）. *Journal of Jilin Agricultural University*, Vol.40, Issue 04, pp.524-532, Changchun/China;

[16] Ren C.Z., Shan F., Wang M. et al., (2022), Review on the Nutrition and Functionality and the Food Product Development of Buckwheat（*荞麦营养与功能性研究及其产品开发*）. *Journal of the Chinese Cereals and Oils Association*. Online DOI：10.20048/j.cnki.issn.1003-0174.000001, Beijing/China;

[17] Xu B., (2021). Construction of a discrete element model of buckwheat grain and calibration of parameters. *INMATEH-Agricultural Engineering*, Vol.64, Issue 2, pp.175-184, Bucharest / Romania;

[18] Zhang L.X., (2020), Research and Design of Buckwheat Harvester Cleaning Device Based on FLUENT-EDEM Coupling（*基于 FLUENT-EDEM 耦合的荞麦收获机清选装置研究设计*）. PhD Dissertation. Cheng du University, Chengdu / China;

[19] ***China Academy of Agricultural Mechanization Sciences, (2007), *Agricultural Machinery Design Manual*（*农业机械设计手册*）. ISBN 9787802333352, China Agricultural Science and Technology Press, Beijing/China.