SIMULATION RESEARCH ON THE INFLUENCE OF INCLINATION ANGLE OF LINEAR VIBRATING SCREEN ON BUCKWHEAT SIZING EFFECT

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直线振动筛筛面倾角对荞麦分级效果影响的模拟研究

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ABSTRACT

In the buckwheat industry, buckwheat sizing effect has played a significant role in the subsequent hulling effect and food quality in its deep processing. In order to study the influence of inclination angle of linear vibrating screen on buckwheat sizing effect, EDEM was used for numerical simulation of sizing process with the inclination angle of the screen separately at 2º, 3º, 4º, and 5º. By observing particle distribution on the screen deck and calculating the different types of particles in various statistical areas, qualitative comparison and quantitative analysis on the conveying capability of the screen and the penetrating capability of particles at different inclination angles were made, and the results revealed that with the increase in the inclination angle of the screen, the conveying capability of the screen was enhanced, while particles became less capable of penetrating through the sieve. When the inclination angle was increased from 2º to 3º, the conveying capability of the screen was significantly improved, while the penetrating capability of particles on both screen decks was slightly reduced. By taking the penetrating capability of particles and the conveying capability of the screen into comprehensive consideration, it turned out that better sizing effect would be achieved at the inclination angle of 3º. Our research will provide a reference for optimizing the processing parameters during the vibrating separation of buckwheat.

摘要

荞麦产业精深加工过程中，荞麦分级效果对后续脱壳效果乃至食品品质都有重要的影响，为探究直线振动筛筛面倾角对荞麦分级效果的影响，利用 EDEM 软件对筛面倾角为 2°、3°、4°、5°时的分级过程进行了数值模拟，通过观察筛面颗粒分布及对各统计区不同类型颗粒的统计，对不同筛面倾角下筛面输送能力、颗粒透筛能力进行定性比较和定量分析，结果表明：随着筛面倾角增大筛面输送能力增强，而颗粒透筛能力降低，当筛面倾角由 2°增加到 3°时，两层筛面颗粒透筛能力略有降低的情况下，筛面输送能力显著提高，综合颗粒透筛能力及筛面输送能力两项指标，筛面倾角为 3°时分级效果较好。本研究可为荞麦振动分级过程中工艺参数的优化提供参考。

INTRODUCTION

Rich in multiple functional factors, such as bioflavonoid and dietary fibre, buckwheat has become an ideal raw material in health care and nutrition products *(Cheng et al., 2021; Nešović et al., 2021; Sinkovič et al., 2021)*. Also as coarse food grain, buckwheat is highly complementary to wheat and rice in terms of nutritional ingredient. In recent years, buckwheat has been a basic ingredient in more and more products, such as buckwheat noodle, buckwheat biscuit, and buckwheat tea, all of which have attracted wide attention from the healthy consumption market, leading to the increasing yield of buckwheat in the world *(Cheng et al., 2021; Hou et al., 2022)*.

Due to the small gap between buckwheat hull and kernel, shell breakage rate is very high although buckwheat hull is rich in lignin and cellulose, and it has become one of the main factors restricting the scale production of buckwheat and the development of its processing industry *(Ma et al., 2022)*. Research has proved that improved sizing effect will increase the whole rice yield in the shelling process *(Quan et al., 2014)*.

In recent years, numerous studies on vibratory screening of agricultural materials have been made by many scholars at home and abroad.

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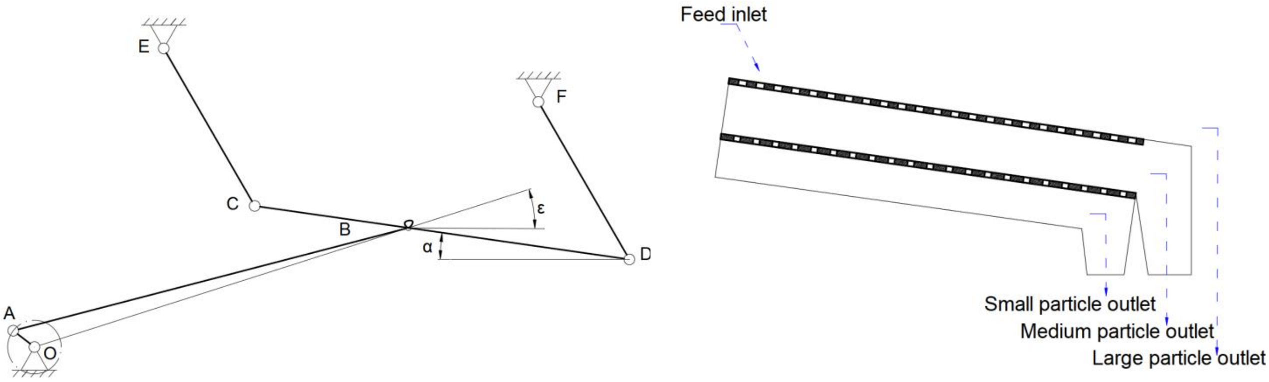
Fan et al. used QXS-3.0 air-and-screen cleaning testing platform for buckwheat cleaning test to analyse the distribution rule of screen underflow at different fan speeds, wind directions, rotation speeds of crank, and diameters of crank *(Fan et al., 2023)*. Jia et al. proposed a double-layer screening method to establish the relationship between the screening efficiency of a double-layer vibrating screen and the elements in screening process with screening parameters according to the discrete element method *(Jia et al., 2022)*. Hu et al. performed simulation analysis on the vibrating separation effect based on the discrete element method under different processing parameters by taking the mixed materials of buckwheat hull and kernel as research objects *(Hu et al., 2023)*. In 2019, A. Davoodi et al. discovered the better screening performance by determining the optimal shape of mesh after contrastive analysis was made on the screening performance of screens in different shapes and different mesh sizes based on DEM *(Davoodi et al., 2019)*. Xu et al. used automatic filling method to establish a DEM for buckwheat grains, where all of the contact parameters were calibrated. It laid a foundation for the application of DEM to the production of buckwheat and the development of processing equipment *(Xu et al., 2021)*. Also, they made simulation analysis on the sizing process under different amplitudes by designing a three-stage sizing device for the separation of buckwheat *(Xu et al., 2022)*.

Buckwheat is a kind of minor coarse cereal, and generally there are few studies on its sizing devices and processes. Based on the previously designed three-stage sizing device, this study explores the influence of inclination angle of the screen on the separation effect of buckwheat. The simulation on various sizing processes at different inclination angles based on DEM will provide a reference for optimizing the vibrating separation process of buckwheat.

MATERIALS AND METHODS

Principle of buckwheat vibration sizing screen

When linear vibrating screen was adopted to separate buckwheat grains, the vibration of screen box would be made by vibrating screen via the crank-link mechanism to loosen, stratify, or sift out buckwheat materials, which will then be conveyed for screening. The connection between crank centre and the hinged joint of connecting rod on the screen box is also the vibrating direction of the screen. The angle ε between this direction and the horizon is the vibrating direction angle, and the angle α between screen box and the horizon is the inclination angle of the screen *(Geng et al., 2011; China Academy of Agricultural Mechanization Sciences, 2007)*. The schematic diagram for the mechanism of vibrating screen is indicated in Figure 1 (a), where the screen box consists of two parallel screen decks, which have meshes in different sizes to separate buckwheat grains into three sizes as shown in Figure 1(b).



(a) Schematic diagram of vibrating screen mechanism (b) Schematic diagram of classification process

Fig. 1 - Schematic diagram of vibrating sizing screen

DEM for three-stage buckwheat vibrating screen

Buckwheat grains vary very much in size during the harvesting time with the real picture shown in Figure 2. According to the different sizes of buckwheat grains, discrete element models for buckwheat grains in large, medium, and small size were separately built in EDEM. In the vibration screening process, the motion of particles must take the process of mutual contact between different particles or between particles and the surface of sizing screen into account *(Hu et al., 2023)*. In this paper, Hertz-Mindlin no-slip contact model was adopted *(Wang et al., 2010)*, where the intrinsic and contact parameters of the materials required in buckwheat vibration screening process and determined according to the relevant references (*Zhang et al., 2020; Hou et al., 2019; Xu et al., 2021; Fan et al., 2022; Xu et al., 2022*) were provided in Table 1 and Table 2, respectively.

Fig. 2 - Buckwheat grains in different sizes

Table 1

Material intrinsic parameters

Material	Poisson's ratio	Shear modulus / Pa	Density / (kg·m^{-3})
Buckwheat	0.30	3.43×10^{7}	2.54×10^{3}
Vibrating screen	0.29	7.00×10^{10}	8.00×10^{3}

Table 2

Material contact parameters

Material	Restore collision coefficient	Static friction coefficient	Rolling friction coefficient
Buckwheat-buckwheat	0.200	0.532	0.010
Buckwheat-Vibrating screen	0.508	0.700	0.043

The common feeding methods include continuous feeding and fixed time feeding *(Jia et al., 2022)*. In order to be closer to the real situation during the simulation, continuous feeding method was used for simulation in our research. It means that particles in three different sizes have been uniformly produced by the particle factory at the front end of screen box from the beginning to the end of simulation at a speed of 1,200 pcs/s with the simulation time set as 16 s.

Design of experiments

In order to explore the influence of inclination angle of the screen on the buckwheat vibration screening effect, single factor experiments were designed based on the previous research after vibration frequency, vibrating direction angle, and amplitude were determined, as indicated in Table 3.

Table 3

Design of experiments

Number	Inclination angle of screen surface / (°)	Vibrational frequency / (HZ)	Vibrational direction angle / (°)	Amplitude / (mm)
1	2	4.5	30	28
2	3	4.5	30	28
3	4	4.5	30	28
4	5	4.5	30	28

In order to facilitate the processing and analysis of simulation results, statistical areas were built on the constructed buckwheat vibration screening model.

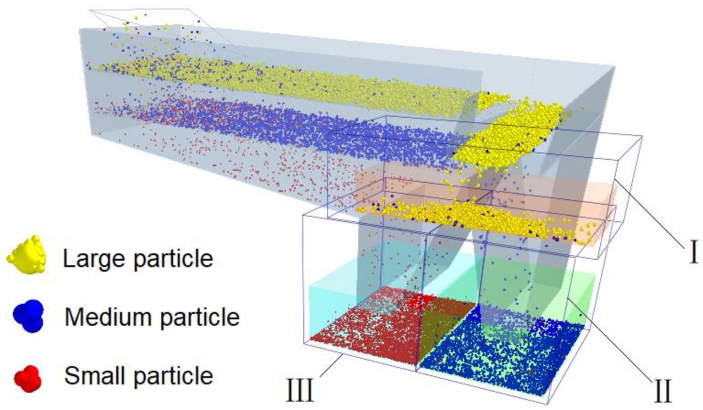


Fig. 3 - Division of statistical domains

As indicated in Figure 3, Area **I**, **II**, and **III** were the statistical areas for screen overflow, screen residue, and screen underflow, respectively. In each area, the number of large, medium and small-size particles simulated at any time could be separately calculated. Moreover, with the adoption of observation method in our research, particle distribution on two screen decks at different inclination angles was simultaneously observed to compare the particle penetration.

RESULTS

Figure 4 shows the particle distribution on the first screen deck at different inclination angles of the screen at 16 s after the simulation.

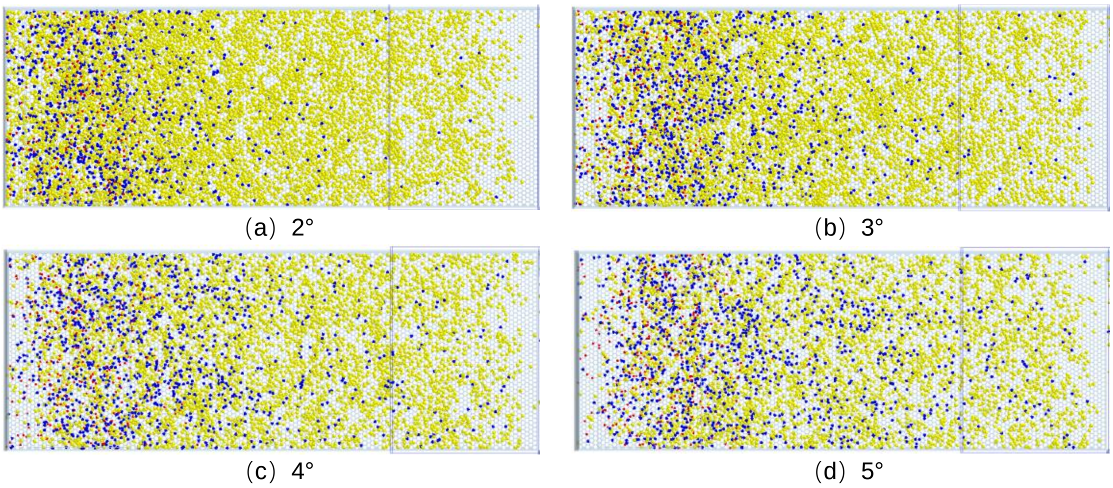


Fig. 4 - Particle distribution on the first screen deck at 16 s

It can be seen from Figure 4 that in the process of conveying materials from the front end of the screen to the tail on the first screen deck, most of the small particles penetrated through the sieve within the length that was 2/3 of the total in the front of sieve plate at the four inclination angles, suggesting strong penetrating capability. However, it varied very much regarding the penetrating capability of medium-size particles. With the increase in the inclination angle of the screen, more medium-size particles were conveyed to the tail area, indicating that medium-size particles are less capable of penetrating through the sieve with the increase in the inclination angle of the screen. To facilitate the quantitative analysis of the conveying and penetrating capabilities on the first screen deck, the number of different types of particles in the statistical area for screen overflow at 16 s was calculated, as indicated in Table 4.

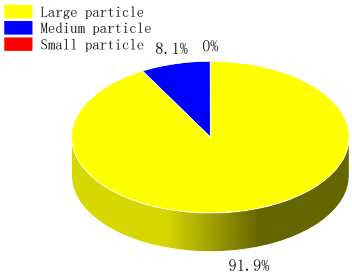
Table 4

Number of particles in the statistical area for screen overflow at 16 s

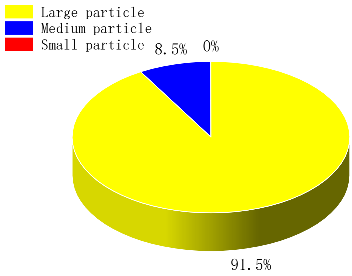
Inclination angle of screen surface/ (°)	Number of large particles/pcs	Number of medium particles/pcs	Number of small particles/pcs	Total number of particles/pcs
2	677	60	0	737
3	1278	118	0	1396
4	1893	213	0	2103
5	2403	383	7	2793

It can be known from Table 4 that the number of large-size particles in the statistical area for screen overflow at the four inclination angles was separately 677, 1,278, 1,893, and 2,403 at the end of simulation, proving that with the increase in the inclination angle of the screen, the conveying capability of the first screen deck was enhanced.

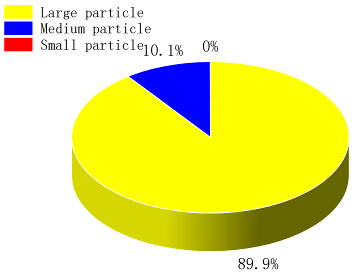
According to Table 4, the distribution of different types of particles in the statistical area for screen overflow at different inclination angles was shown with a pie chart, as indicated in Figure 5.



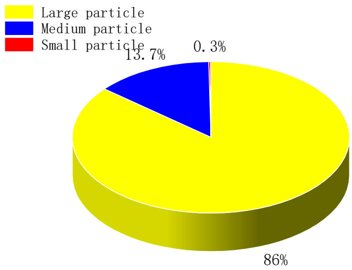
(a) 2°



(b) 3°



(c) 4°

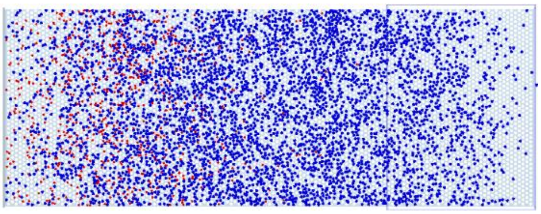


(d) 5°

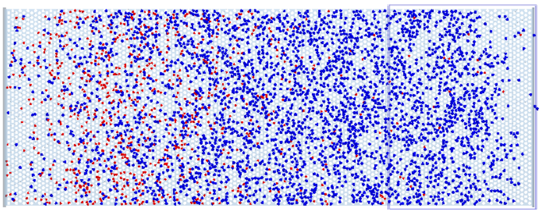
Fig. 5 - Proportion of different types of particles in the statistical area for screen overflow

The medium and small-size particles that failed to penetrate through the first screen deck were conveyed along with the large-size particles to the statistical area for screen overflow. According to Figure 5, at the four inclination angles of the screen, the percentage of medium-size particles in the statistical area for screen overflow was separately 8.1%, 8.5%, 10.1%, and 13.7%. On the first screen deck, medium-size particles were slightly less capable of penetrating through the sieve with the increase of the inclination angle from 2° to 3°. However, the penetrating capability of medium-size particles was significantly reduced when the inclination angle varied between 3°~5°.

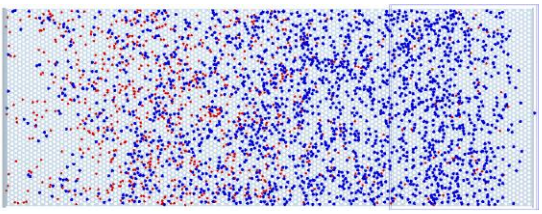
Figure 6 shows the distribution of particles on the second screen deck at 16 s.



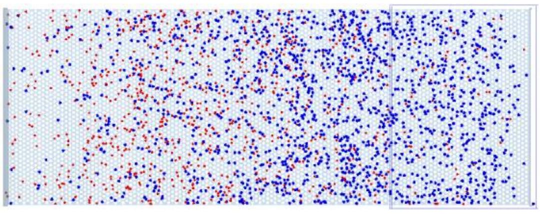
(a) 2°



(b) 3°



(c) 4°



(d) 5°

Fig. 6 - Particle distribution on the second screen deck at 16 s

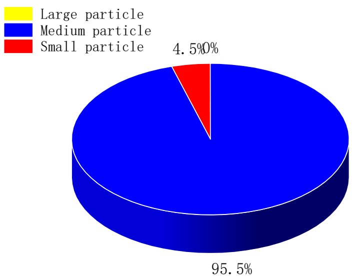
As shown in Figure 6, small particles varied in penetrating capability in the process of conveying materials from the front end of the screen to the tail on the second screen deck. More small particles were conveyed into the tail area with the increase in the inclination angle of the screen, suggesting that the penetrating capability of small particles was reduced with the increase in the inclination angle of the screen. To facilitate the quantitative analysis of the conveying and penetrating capabilities on the second screen deck, the number of different types of particles in the statistical area for screen residue at 16 s was calculated, as indicated in Table 5.

Table 5

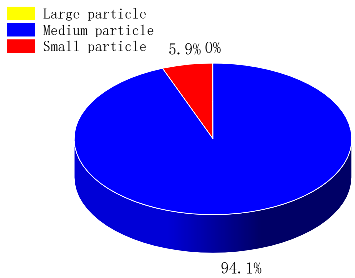
Number of particles in the statistical area for screen residue at 16 s

Inclination angle of screen surface / (°)	Number of large particles/pcs	Number of medium particles/pcs	Number of small particles/pcs	Total number of particles/pcs
2	0	1189	56	1245
3	0	2240	141	2381
4	0	2886	289	3175
5	0	3260	529	3789

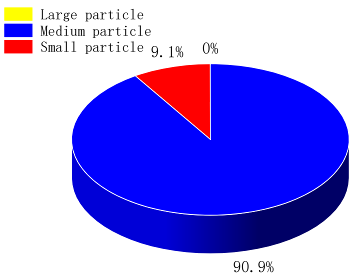
It can be seen from Table 5 that the number of medium-size particles in the statistical area for screen residue at the four inclination angles was separately 1,189, 2,240, 2,886, and 3,260 at the end of simulation, indicating that with the increase in the inclination angle of the screen, the conveying capability of the second screen deck was enhanced. According to Table 5, the distribution of different types of particles in the statistical area for screen residue at different inclination angles was shown with a pie chart, as indicated in Figure 7.



(a) 2°



(b) 3°



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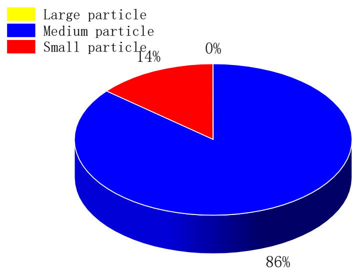

(d) 5°

Fig. 7 - Proportion of different types of particles in the statistical area for screen residue

Small particles that failed to penetrate through the second screen deck were conveyed along with the medium-size particles to the statistical area for screen residue. Figure 7 shows that at the four inclination angles of the screen, the percentage of small particles in the statistical area for screen residue was separately 4.5%, 5.9%, 9.1%, and 14%. On the second screen deck, small particles were slightly less capable of penetrating through the sieve with the increase in the inclination angle of the screen from 2° to 3°. However, the penetrating capability of small particles was significantly reduced when the inclination angle varied between 3°~5°.

Comprehensive analysis on the conveying and penetrating capabilities on both screen decks revealed that when the inclination angle of the screen was increased from 2° to 3°, the conveying capability could be enhanced significantly, while the penetrating capability of particles on both screen decks was slightly reduced.

CONCLUSIONS

(1) Based on the previously designed three-stage vibration screening device, a three-stage vibration screening model at different inclination angle was constructed in this paper.

(2) Numerical simulation on buckwheat sizing processes was performed separately at the inclination angles of 2°, 3°, 4°, and 5°. Through visual observation, the distribution of particles simulated at the same time on both screen decks at different inclination angles revealed that small particles had strong penetrating capability on the first screen deck when the inclination angle varied between 2°~5°. However, medium-size particles on the first screen deck and small particles on the second screen deck were less capable of penetrating through the sieve with the increase in the inclination angle of the screen.

(3) At the end of the simulation, quantitative analysis on the proportion of different types of particles in various statistical areas at different inclination angles revealed that with the increase in the inclination angle from 2° to 3°, the conveying capability could be significantly improved, while particles on both screen decks became slightly less capable of penetrating through the sieve. By taking the penetrating capability of particles and the conveying capability of the screen into comprehensive consideration, it turned out that better sizing effect would be achieved at the inclination angle of 3°.

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REFERENCES

[1] Cheng J.L., Liu J., Mao J.Q., et al., (2021). Effects of Different Illumination Treatments on Flavonoids and Gene Expression of Related Metabolic Enzymes in Buckwheat Sprouts *(不同光照对荞麦芽黄酮类化合物及相关代谢酶基因表达的影响)*. *Food Science,* Vol.42, Issue 23, pp.72-79, Beijing/China;

[2] Davoodi A., Bengtsson M., Hulthén E., et al., (2019), Effects of screen decks' aperture shapes and materials on screening efficiency. Minerals Engineering, Vol.139,105699. Ed. Elsevier, London/England;

[3] Fan R., Cui Q.L., Lu Q., et al., (2022), Experimental study on non-planar screening device for buckwheat threshing material[J]. *INMATEH Agricultural Engineering*, Vol.66, Issue 1, pp.73-80. Bucharest/Romania. DOI: https://doi.org/10.35633/inmateh-66-07

[4] Fan R., Cui Q.L., Lu Q., et al. (2023), Study on the distribution law of materials under sieve in air-and-screen cleaning device *(风筛式清选装置筛下物料分布规律研究)*. Journal of Chinese Agricultural Mechanization, Vol.44, Issue 01, pp.142-151, Nanjing/China;

[5] Geng D.Y., Zhang D.L., Wang X.Y., et al., (2011), *Agricultural Mechanics (新编农业机械学),* ISBN 9787118075281, National Defence Industry Press, Beijing/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] Hou H.H., Liu R., Sun Y.L. et al. (2022), Optimization of the Preparation Process of Buckwheat Noodles Based on Response Surface Analysis *(基于响应面分析优化荞麦面条制备工艺)*. Food Research and Development, Vol.43, Issue 2, pp.63-70, Tianjin / China;

[8] Hu G.Y., Chen X.D., Zhao T.F., et al., (2023), Study on grading technology of walnut shell and kernel mixture vibrating screen based on EDEM *(基于 EDEM 的核桃壳仁混合物振动筛分级工艺研究)*. *China Oils and Fats*, [J/OL].1-8. DOI: 10.19902/j.cnki.zgyz.1003-7969.220419, Xi'an / China;

[9] Jia P.Y., (2022), *Parameter Optimization and Mechanism Research of Double-Layer Variable Screen Surface Vibrating Screen (双层变筛面振动筛参数优化及筛分机理研究)*. Master thesis. Fujian University of Technology, Fuzhou/China;

[10] Ma G.F., Xin H.B., Xiu L. et al., (2022), Buckwheat Seed Shelling Characters: A Review *(荞麦脱壳性状的研究进展)*. *Chinese Agricultural Science Bulletin*, Vol.38, Issue 24, pp.19-27, Beijing / China;

[11] Nešović M., Gašić U., Tosti T. et al., (2021), Distribution of polyphenolic and sugar compounds in different buckwheat plant parts. RSC Advances, Vol.11, Issue 42, pp.25816-25829. London/England;
[12] 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.
[13] Sinkovič, L., Kokalj S.D., Meglič V., Milling Fractions Composition of Common (Fagopyrum esculentum Moench) and Tartary (Fagopyrum tataricum (L.) Gaertn.) Buckwheat, Food Chemistry (2021), DOI: https://doi.org/10.1016/j.foodchem.2021.130459.Ed. Elsevier, London/England;
[14] Wang G.Q., (2010), *Discrete element method and its application in EDEM (离散单元法及其在 EDEM 上的实践)*, ISBN 9787561227978, Northwestern Polytechnic University Press, Xi'an/China.
[15] 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;
[16] Xu B., (2022). Experimental Research on Three-Level Vibrating Screening of Buckwheat Based on Discrete Element Method. *INMATEH-Agricultural Engineering*, Vol.68, Issue 3, pp.191-200, Bucharest / Romania; DOI: https://doi.org/10.35633/inmateh-68-19
[17] 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.
[18] Zhou Y., Qin D.L., Li Q.Q., et al., (2022), *Optimization design of coix vibrating screen cleaning device based on EDEM (基于 EDEM 薏苡振动筛清选装置优化设计与试验)*. Journal of Northeast Agricultural University, Vol.53, Issue 11, pp.68-76, Harbin / 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.