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IMPROVING EFFICIENCY OF CORN SEED SEPARATION AND CALIBRATION PROCESS

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ABSTRACT

The paper analyzes the existing theoretical research of corn seed separation and calibration processes. The machines, tools and equipment that implement the process were studied. An innovative sieve with

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sieve,
separator performance,
open area

openings in the Cassini oval shape was proposed for the economical separation and calibration of corn seeds. The results of operation of the proposed sieve in the operating conditions of Kharkiv Feed Mill on BSH-100 serial separators were considered. The study of the effectiveness of sifting corn seeds through the holes of the sieves was carried out in partnership with the State University "Ukrainian Research Institute of Forecasting and Testing of Agricultural Production Techniques and Technologies named after Leonid Pohorily" (Kharkiv Branch). The use of sieves with openings in the Cassini oval shape, instead of classic circular base openings, was found to result in an increase in throughput capacity of the sieve and open area of up to 20%.

Introduction

In the context of military aggression in 2022, a significant part of the land for grain crops is temporarily unsuitable for use. The proportion of degraded agricultural land has increased by 13%. According to the researchers, even 90 years after the end of the Second World War, excessive concentrations of heavy metals were recorded on former battlefields. To restore sustainable food security in Ukraine, it is necessary to increase the performance and quality of the process of separation of grain materials at all production process stages. The technological line for production of high-quality seeds includes a complex of machines, equipment, and devices for harvesting in the field, lifting, and transporting machines, drying, separating, and packing machines. In order to obtain the maximum productivity of the process while maintaining the quality indicators of the process, all machines of the line must work in harmony and be configured to process a specific crop while observing the optimal kinematic parameters of the machines.

The need to improve the qualitative and quantitative characteristics of the process is motivated by the stringent requirements that foreign buyers of agricultural products from Ukraine impose on grain and, especially, seed materials (Szwedziak et al., 2023). From January to August 2022, Ukraine exported over 20 million tons of grain crops, 25 per cent less than during the same period in 2021. In the first eight months of 2022, 4.1 million tons of wheat (1.2 billion US dollars), 15.1 million tons of corn (3.8 billion US dollars) and 0.8 million tons of barley (0.2 billion US dollars) were sold abroad. The biggest buyers of Ukrainian grain in January-August 2022 were still Asian, EU and African countries. Analysis of the grain market indicates that the production of corn in 2022 was 16,718 thousand tons, in 2021 – 17,373 thousand tons. Accordingly, corn in Ukraine is the leader among the grain crops (Seed Crops, 2023).

Thus, the research will focus on the separation and cleaning of corn.

Financial indicators can be significantly increased by improving the qualitative characteristics of the final product. To increase the performance and quality of the process of receipt of high-quality grain material, it is necessary to modernize the existing and develop new high-efficiency and resource-saving machines, technologies, and equipment.

There is a number of scientific and technical developments that serve to improve the quality indicators of the corn seed calibration process. However, such developments do not fully satisfy modern requirements. Thus, in the work (Giyevskiy et al., 2018; Dziki, 2023), the authors proposed a generalized technology for the process of separating grain seeds without taking into account the physical and mechanical properties of specific raw materials. In

the work (Priporov et al., 2021), the process of seed separation by semi-permeable surfaces without taking into account intralayer processes was considered. The research presented in (Bredykhin et al., 2012) presents a mathematical apparatus for determining the trajectories of the movement of material particles of different densities and allows to effectively predict the purity of the main fraction. However, these studies can be used in the study of the separation process with flat working surfaces. In works (Yanovych et al., 2018; Kaletnik et al., 2020; Mykhaiov et al., 2021), the kinematics of the seed separation process by vibro-pneumatic grain separators were investigated without providing specific recommendations. In the work (Vasylkovska et al., 2019), the parameters of inertial release of surplus seeds of grain crops were studied. Oscillatory processes of separating machines were studied in (Olshanskiy et al., 2017). The author of the study (Piven, 2017) considered the process of separating the seed material into the vibrating tray without researching the previous components of the separation process. The results of studies of the operation of the pneumatic gravity separator are given in (Lezhenkin et al., 2021), but the author did not take into account the geometric features of the grain particles. The use of continuum mechanics model or material two-phase flow dynamics was divided into two parts: dynamics of carrier phase and dynamics of disperse particles.

We established the main equations for dynamics of each phase:

$$\rho_i \vec{a}_a^{(i)} = div\hat{T}^{(i)} + \vec{f}_{ji} + \rho_i \vec{g} (i = 1,2) \tag{1}$$

where:

ρ_i – density of medium in *i* phase;

$\vec{a}_a^{(i)}$ – absolute acceleration of particles in continuum of *i* phase;

$\hat{T}^{(i)}$ – stress tensor of medium in *i* phase;

$\vec{f}_{ji}$ – bulk density of force, with which *j* medium acts upon *i* phase in such a way, that the third Newton law is implemented: $\vec{f}_{21} = -\vec{f}_{12} = -\vec{f}$.

In (Kroulík et al., 2016), the process of pneumatic separation of seeds in an air stream is considered. However, rational air flow speed parameters are not given, if they are exceeded, the process of seed injury is possible.

Previous researchers paid a lot of attention to the research on the interaction of grain material with the working tools of separating machines (Badretdinov et al., 2019).

Researchers proposed a criterion of guaranteed passage of seeds through the opening (Nesterenko et al., 2017):

$$0{,}5mV_ц^2 < Gy \tag{2}$$

where:

m and *G* – the mass and weight of the conglobation that falls into the opening;

$V_ц$ – the velocity of the center of mass of the conglobation at the moment it makes contact with the opening edge;

y – the value of falling of the conglobation into the opening at the moment it makes contact with the edge.

The sifting of corn seed into the opening of the sieve is guaranteed by falling of the ball into the opening by the value $z_{cm.}^*$ determined by the expression:

$$z^*_{cm.} = \begin{cases} m\vartheta^{/2}(2F_{con})^{-1}, & \text{если} \quad m\vartheta^{/2}(2F_{con})^{-1} \le 0{,}5d \\ 0{,}5d, & \text{если} \quad m\vartheta^{/2}(2F_{con})^{-1} > 0{,}5d \end{cases}, \tag{3}$$

where:

m, d – the mass and weight of the ball, respectively;

$\vartheta^{/}$ – is the reflection velocity component of the ball after it has come into contact with the opening edge perpendicular to the opening plane;

F_{con} – the resistance force against the ball moving in the direction of $\vartheta^{/}$.

The above studies do not fully allow to mathematically model the process of seed calibration and do not allow to achieve high efficiency of the process.

Thus, the development of new work surfaces for efficient calibration of maize seeds with higher throughput and process productivity are urgent. The goal of the work is to develop and produce new separation machines, and therefore, to replace the existing machines that are already in use at enterprises, which is an economically burdensome process. Thus, the actual direction of research is modernization of the existing machines without significant changes in kinematic parameters.

However, theoretical research, examined samples and developments, implemented into production, do not fully satisfy current requirements as to performance, resource economy and necessity to decrease grain damage.

For primary corn cleaning there are used separators of BSH type with different performance. A sieve with openings of different diameter and oblong openings is a working tool of the separator.

Piven et al., (2021) proposed innovation sieves with guide intensifiers and openings in pent apetalous activators shape.

The analysis of the existent working surfaces (Havrylenko et al., 2021; Cieśla and Skowron, 2020; Demir et al., 2017; Karaiev et al., 2021), and separation technologies shows that the existent sieves have a small open area, which essentially lowers the sieve separation level (Liang et al., 2019; Chebrolu et al., 2016; Du J. et al., 2017).

The research is conducted within the framework of the National Development Program No. 3-22-23 Budget topic “Increasing food security through the development of competitive technologies for obtaining high-quality seeds with increased biopotential”.

The purpose of the study is: development of a new work surface; experimental studies of the efficiency of the working surface with holes in the shape of the Cassini oval; determination of optimal operating parameters of the separating machine using a new working surface.

Materials and Methods

When processing the results of experimental studies with the help of probability theory and mathematical statistics, generally accepted Fisher-Student criteria were used. Verification of the adequacy of the theoretical provisions and the results of experimental studies is based on the following methods: “Separators and grain cleaning machines. “Testing program and procedure” and “Testing of agricultural machinery. Grain cleaning machines and aggregates, grain cleaning and drying complexes. Program and procedure of testing”. The research objects were grain-cleaning separators of BSH-100 type and developed innovative sieves

with openings in the Cassini oval shape. Examined samples of the sieve (perforation with Ø12 round openings and with openings in the Cassini oval shape with diameter of each focus Ø12) were made. The aim of testing was the comparative determination of the binding level of openings of sieves of two samples.

To study the calibration process, the ternary modified corn hybrid "Donor MV" was used. The mass of 1000 grains is 300 g, the nature is 0.790 units, the particle density is 760 $kg \cdot m^{-3}$, the moisture content is 14%.

During the operation of the separator, the corn seeds were calibrated according to their geometric dimensions, by penetrating holes of the appropriate diameter.

The process of preparation of grain and seed material consists of process operations, which are carried out in a strict sequence.

Grain material is separated according to a set of physical and mechanical properties, namely dimensional characteristics, density of grains, and aerodynamic characteristics, etc.

At the stage of primary processing of the grain material, the material which consists of the grain of the basic crop and impurities, which should include the grain of another crop, stones, metal, and earth impurities, etc., enters the separating machine. The material is cleaned at the primary stage due to the dimensional characteristics of the material.

Thus, the use of high-efficient sieves for material separation and cleaning is of paramount importance.

Sieves structure was installed on BSH-100 separator. Tests were taken on an elevator by Private Joint Stock Company Kharkiv Feed Mill, Kharkiv city Bulk density of corn varied in accordance to batch from 680 to 820 unit, humidity – from 16 to 25%. Proportion of separating impurities is from 3 to 10%. Accordingly, operational performance of a machine, due to batches heterogeneity, changed from 33 to 54 unit.

The binding level of sieves openings in the Cassini oval shape was estimated after eleven hours of separator continuous operation in elevator mode at the primary cleaning stage. The machine was stopped; the upper layer of mesh frames was removed (sheet of variable geometry perforation, fixed to the frame). Structurally each frame was divided into sectors. The general number of sectors on a frame was 15 units. After finishing each turn of continuous operation, the number of clogged openings was estimated during 10 days.

The information changed regarding to the general number of openings, the number of clogged openings. The sectors, involved in the research, were chosen liberally check wise, horizontally, and vertically three sectors for each test.

To achieve the goal, it is envisaged to determine the throughput capacity of the sieve and the kinematic parameters of the separator in interaction with the corresponding physical and mechanical properties of the material.

Tasks are set:

– conduct a critical analysis of theoretical research and scientific and technical developments on the selected research topic,
– conduct experimental studies to determine the carrying capacity of the developed working surface,
– determine the kinematic and physical-mechanical parameters that have a decisive influence on the process parameters,
– to build and analyze the response surfaces of the dependences of the determining parameters of the process.

Results and Discussion

The sieve with openings in the Cassini oval shape was developed and presented (Fig. 1). The surface of the robot is made by stamping.

Unlike (Giyevskiy et al., 2018) the implementation of the proposed sieve, it does not require an increase in energy consumption, while at the same time it reduces the metal capacity of the machine that implements the process.

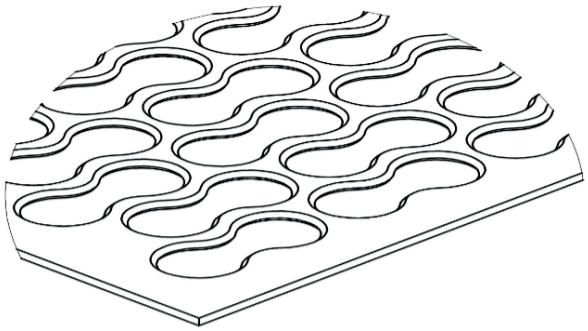

Figure 1. Sieve with openings in the Cassini oval shape

The sieves are made of cold-rolled steel sheet by pressing method and have innovative openings of the innovative geometry of the Cassini oval shape (the shape was used for the first time) (Fig. 1).

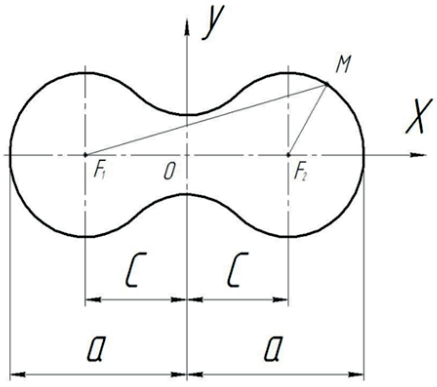

Figure 2. Cassini oval graph

where:
X and *Y* – coordinates;
M – current point of Cassini oval;

F_1, F_2 – focuses of Cassini oval with coordinates a;
C – half of distance between focuses.

Unlike (Yanovych et al., 2018), the proposed sieve improves the process of passive orientation of corn seeds to the sieve openings, thanks to a much larger cross-section of the sieve opening.

Sieves with holes in the shape of an oval Cassini have a much higher throughput than the working bodies, which is justified in the work (Vasylkovska et al., 2019).

The authors (Piven et al., 2018) studied a sieve with volumetric activators, which serve to improve the orientation of corn seeds, before they are immersed in the holes of the sieve. Such sieves improve the intensification of the process but have a smaller live cross-section than the sieve with holes in the Cassini oval shape proposed in the article.

In the work (Cieśla and Skowron, 2020), the process of material separation by a magnetic separator, which is much more expensive than a BSH separator, is considered.

The use of the sieves with openings in the Cassini oval shape, instead of classical round basic openings, leads to the increase of sieve throughput capacity. The task is solved by the fact that openings of the proposed shape have variable crosscut. This provides particles of material with space to maneuver, taking into account mutual intersection between particles, which decreases jamming in openings to minimum. Moreover, variable cross-section of the crossout in the proposed opening provides an opportunity to neutralize variety of material particles forms. At the expense of tapered wave transition of oval one half into the other, particles damage represented by mechanical peeling is minimized (Fig. 1).

Cassini's engineered sloped oval hole surface has a higher degree of grain-to-passage orientation than research designs (Demir et al. 2017; Liang et al, 2019).

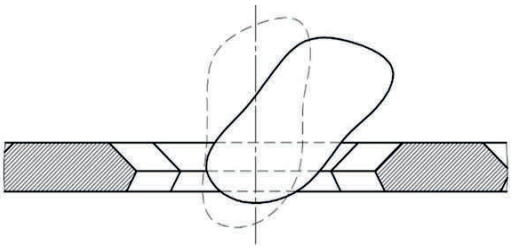

Figure 3. Orientation of bruchid in the Cassini oval shape opening

For the research conduction we made sieves (Fig. 3) with corresponding openings (sieve width – 770 mm, length – 990 mm); openings location is according to rows displacement in relation one to each other (Fig. 4).

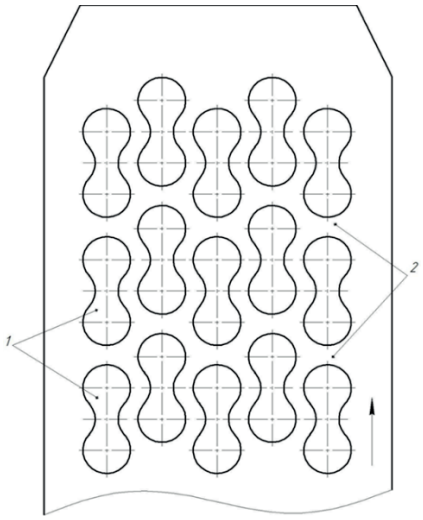

Figure 4. Location of openings in the Cassini oval shape: 1) – openings; 2) – seals

Openings sizes: b24 mm (12 x 8 x 24, 12 mm – diameter of one focus in opening; 8 mm – size of opening "waist"; 24 mm – opening length; the variable t was chosen as a minimum allowable – (the size is smaller, essentially decreases the sieve reliability characteristics) and m was performed 10 mm.

The received data were put in Table 1, where the date of testing was registered also.

Table 1.
Comparative value of clogging bridges of developed and standard grates

Date	Selected sector number		Number of clogged sector openings (units)		General number of sector openings (units)	
	Cassini	Round	Cassini	Round	Cassini	Round
19.10.22	10	1	2	15	110	186
	11	5	1	12	110	186
	12	9	2	19	110	186

During research we took into account the coefficient, which depends on grain culture, humidity, and proportion of separating impurity (Table 2).

Table 2.
The value of the coefficient, which depends on the grain culture, humidity, and the fraction of the separate admixture.

At humidity, (%)															
To 16			16-18			18-20			20-22			22-25			
Impurity proportion, (%)															
3	5	10	3	5	10	3	5	10	3	5	10	3	5	10	
1	1	1	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.55	0.55	0.55	

Performance of BSH-100 separator was calculated according following formula:

$$Q = q \cdot K\ 0.6;\ (t \cdot h^{-1}) \quad (4)$$

where:

q – rated performance of a machine during cleaning (operation manual for BSH.RE., Khorol city);

K – coefficient, which depends on grain culture, humidity, proportion of separating impurity (Table 2);

0.6 – correlation of actual performance to rated during grain cleaning.

The results are represented on Fig. 5.

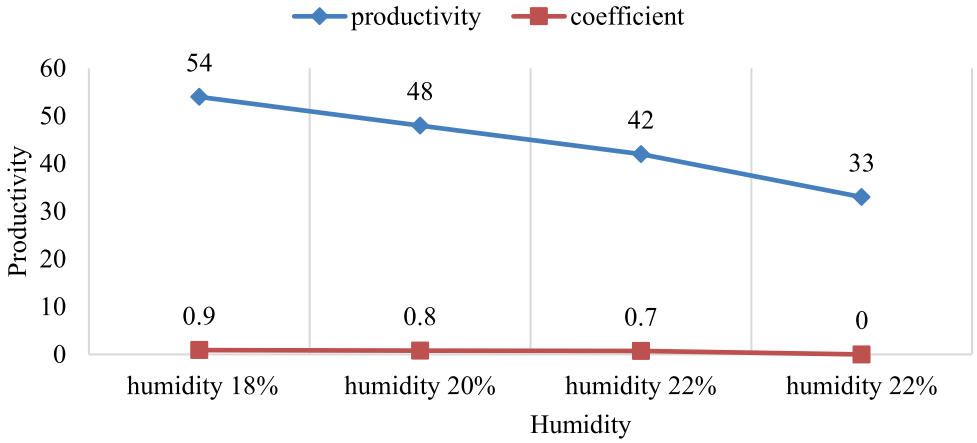

Figure 5. Graph of separator performance changing ($t \cdot h^{-1}$) due to humidity of grain and correspondence coefficient

One of the important quality indicators - the purity of its main fraction - is adopted as the criterion for the efficiency of the separation process using. Purity of the main fraction means the content of the main culture in it, expressed as a percentage of the weight taken for analysis:

$$\text{Purity} = (\text{mb.c.} + \text{mad.}) \cdot 100\%, \quad (5)$$

where:

mb.c. – the mass of the main crop;

mad. – mass of impurities.

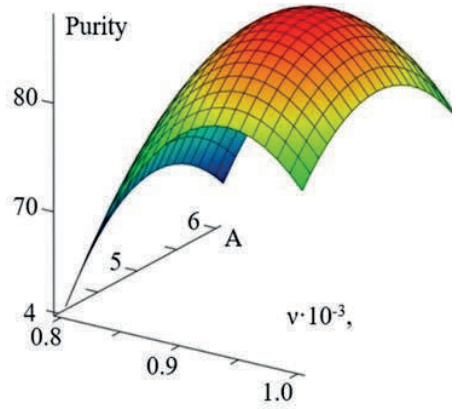

Figure 6. Dependence of the purity of the main fraction on the amplitude (A, mm) and frequency of oscillations (v, os·min^{-1}) of the working surface

During separation in production conditions, the weight of the final product (seeds at the output) was manually sorted, separating two groups: seeds of the main crop and waste consisting of various impurities. Next, the content of the main fraction of corn seeds was calculated as a percentage.

Three main factors were identified that changed during the research: sieve rotation frequency, material feed and sieve angle.

Shown in Figure 6 surfaces have an extreme character. On them there are maxima of the purity of the main fraction, which correspond to the rational values of the amplitude and frequency of vibrations of the working surface of the separator. Since these surfaces provide only a general view of the dependencies, the intersecting surfaces should be provided for a more detailed analysis (Fig. 7).

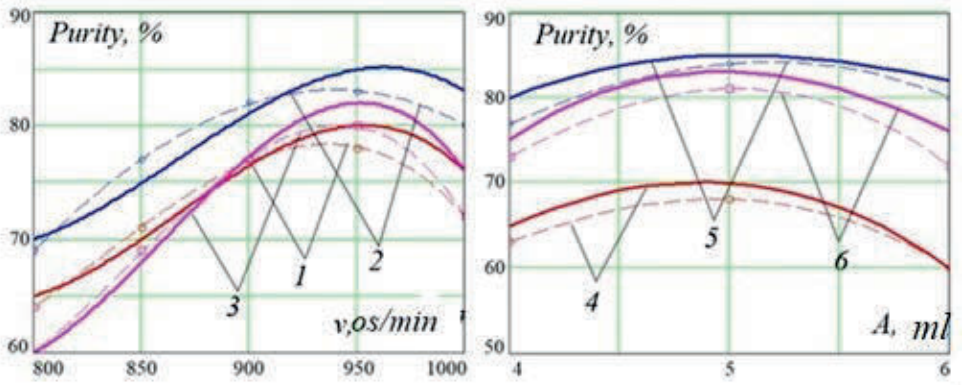

Figure 7. Sections of dependences of the purity of the main fraction on the frequency (a) and amplitude of oscillations (b) of the working surface

It was determined that the highest quality indicators of the process can be obtained by observing the optimal parameters of the process. The correlations of binding level of open area size were conducted in correspondence to standard sieve with size 770 per 990 mm with round openings, 12 mm in diameter. The open area of the sieve with round openings is 41%, and the open area of the sieve with openings in the Cassini oval shape is 63%. Accordingly, represented sieves have a bigger open area, which increases throughput capacity of sieves to 20%.

The given data are limited to corn research. The shortcoming of the given data is the regression equation, on the basis of which the response surface was built, is not given; the limitations of research on the process of separating and calibrating corn.

The further development of the research consists in the research of the process of separation of seed materials of the most common grain crops with the construction of response surfaces and the development of recommendations for the optimization of structural and kinematic parameters for separating machines.

Notes as to the test results.

The separator sieve with openings in the Cassini oval shape can be used in grain-cleaning machines in grain-cleaning enterprises instead of basic wire screens with round openings, providing increase of throughput capacity.

Performance of BCH-100 separator depending on humidity and impurity proportion:

– humidity 16-18% and impurity proportion (cleanings and grain) 3-10% (100·0.9·0.6=54 $t \cdot h^{-1}$);
– humidity 18-20% and impurity proportion (cleanings and grain) 3-10% (100·0.8·0.6=48 $t \cdot h^{-1}$);
– humidity 20-22% and impurity proportion (cleanings and grain) 3-10% (100·0.7·0.6=42 $t \cdot h^{-1}$);
– humidity 22-25% and impurity proportion (cleanings and grain) 3-10%(100·0.55·0.6=33 $t \cdot h^{-1}$).

Conclusions

The analysis of the existing scientific and technical solutions for the calibration of corn seeds does not meet modern requirements. It was determined that the developed sieves for cleaning and calibration of corn seeds increase the efficiency of operation of grain-cleaning separators. It was determined that the developed sieve has a higher throughput than common analogues.

Kinematic and physico-mechanical parameters that have a decisive influence on the process parameters are defined. The response surfaces describing the relationship between the kinematic parameters of the separator and the physical and mechanical parameters of the raw materials were constructed and analyzed.

Separator sieve with round perforation holes in the Ø12 form at the stage of pre-cleaning corn batches with different humidity and impurity content worked with 87.62% of 100% possible. Firstly, the implemented separator sieves with openings from new geometry (diameter of each focus Ø12) in the Cassini oval shape worked with 100% possible to 98.48%.

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POPRAWA WYDAJNOŚCI PROCESU SEPARACJI I KALIBRACJI NASION KUKURYDZY

Streszczenie. Niniejsza praca przedstawia analizę istniejącego badania teoretycznego nad separacją nasion kukurydzy i procesu kalibracji. Maszyny, narzędzia oraz wyposażenie, które są wykorzystywane w tym procesie zostały przestudiowane. Zaproponowano innowacyjne sito z otworami o kształcie owalu Cassiniego do ekonomicznej separacji i kalibracji nasion kukurydzy. Przeanalizowano wyniki działania zaproponowanego sita w warunkach pracy młyna paszowego w Charkowie na seryjnych separatorach BSH -100. Badanie efektywności przesiewania ziaren kukurydzy przez otwory w sicie przeprowadzono we współpracy z Państwowym Uniwersytetem "Ukraińskim Instytutem Badawczym ds. przewidywania i badania technik i technologii produkcji rolniczej im. Leonida Pohorily" (Odział w Charkowie). Zastosowanie sit z otworami o kształcie owalu Cassiniego w miejsce tradycyjnych otworów o okrągłej podstawie wpłynęło na zwiększenie wydajności sita i otwartej powierzchni aż do 20%.

Słowa kluczowe: proces kalibracji, materiał nasienny, maszyna separująca, sito, wydajność separatora, otwarta powierzchnia