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RESULTS OF EXPERIMENTAL STUDIES ON THE CLEANER-SEPARATOR FOR FODDER PUMPKIN SEEDS

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Modern agriculture pays significant attention to the efficient use of plant raw materials for obtaining high-quality seed material and feed products. One of the promising crops in this regard is fodder pumpkin, whose seeds are used for oil production, while the pulp and other residues serve as valuable animal feed. However, the effective extraction of seeds and separation of waste require specialized technical solutions. Therefore, the development and improvement of equipment for the mechanized cleaning and sorting of fodder pumpkin seeds is a relevant area of scientific research. The extraction of pumpkin seeds consists of three main operations: fruit destruction, separation of seeds from the placenta and pulp, and removal of seeds from the crushed pulp mass. The primary energy expenditures in the seed extraction process are associated with the separation stage. It is known that pumpkin fruits contain only 2.5–4.0% seeds by total mass, necessitating the processing of a significant amount of raw material. A new design of a cleaner-separator for fodder pumpkin fruits has been proposed, incorporating a system of rollers with rubber edges, which effectively capture, transport, and clean the seeds. The use of pentagonal rollers with varying elasticity ensures optimal cleaning parameters, reduces seed losses, and improves seed quality. Research on the impact of roller rotation frequency has shown that the optimal range is 200–300 rpm. At this speed, the best balance is achieved between seed cleaning efficiency, minimal seed damage, and contamination levels. The results of experimental studies confirmed the effectiveness of the proposed design. It was found that for optimal cleaning performance, the roller elasticity should be within the range of 1.2–2.2 MPa. Additionally, it was established that the overlap between the rollers is not a decisive factor in cleaning quality, but a 1–3 mm overlap is recommended to increase the durability of the mechanism. The obtained results can be applied in the development of new technological solutions for pumpkin seed cleaning and separation, contributing to improved efficiency in its cultivation and processing in the agricultural sector.

Key words: *pumpkin, pulp, cleaning, separation, seeds, waste, feed, research, parameters, equipment, efficiency.*
Eq. 11. Fig. 9. Ref. 17.

1. Problem formulation

Modern agriculture places significant emphasis on the efficient use of plant raw materials to obtain both high-quality seed material [1, 2] and feed products [3, 4]. One of the promising crops in this regard is fodder pumpkin [5, 6], whose seeds are used for oil production [7], while the pulp and other residues serve as valuable animal feed [8]. However, the efficient extraction of seeds and separation of waste require specialized technical solutions. Therefore, the development and improvement of equipment for the mechanized cleaning and sorting of fodder pumpkin seeds is a relevant area of scientific research.

The production of high-quality fodder pumpkin seeds and the efficient use of its residues in animal husbandry are important tasks for the agricultural sector [9]. The use of modern cleaner-separators improves the quality of seed material, reduces losses during seed extraction, and ensures the rational use of pumpkin biomass as livestock feed. The implementation of innovative technologies in the separation process enhances equipment productivity and reduces energy consumption [10, 11].

2. Analysis of recent research and publications

During the extraction of pumpkin seeds, the most complex operation is their separation from the fruit. This process determines the technological workflow and influences the subsequent seed cleaning method. Low seed separation purity necessitates additional cleaning, followed by drying and sorting. It is also known that pumpkin fruits contain only 2.5–4.0% seeds by total mass, requiring the processing of large volumes of fruit, which are generally characterized by high mechanical strength (e.g., pumpkins, squash, cucumbers, etc.). As a result, the majority of energy consumption in seed production is spent on the separation process.

Long-term experience in pumpkin seed extraction has shown that this process consists of three main operations [12, 13]:

– destruction of the fruit;
– separation of seeds from the placenta and pulp;
– removal of seeds from the crushed pulp mass.

Seed separators have been classified according to three main characteristics [14]:

– the type of fruit crushing;
– the principle of seed extraction;
– the design of the working unit for separating seeds from the pulp.

The classification is based on fruit crushing methods, including cutting, impact, and compression. Each method requires corresponding working units (knives, knife or pin drums) [15].

In single-drum crushers, a pin drum was used to crush the fruit by impact to maximize seed release from the placenta. In modern separators, the pin drum is used for preliminary fruit crushing, during which seeds are only partially separated from the fruit. Additionally, it facilitates the further transfer of the mass to the beater drum, which completes the process of breaking the connections between the seeds and the pulp [16].

Practical experience with existing seed separators indicates that seed separation from the pulp occurs not only due to the direct action of dedicated mechanisms but also through operations such as separation and rubbing [17]. This provides a basis for further improvement of both the technology and design of fodder pumpkin seed separators.

3. The purpose of the article

Therefore, experimental studies of the effectiveness of a cleaner-separator for fodder pumpkin fruits are of great importance for increasing the economic feasibility of its cultivation and processing.

4. Results and discussion

The developed cleaner-separator for fodder pumpkin fruits includes a channel formed by two counter-rotating rollers (Fig. 1). Each roller is designed as a polygonal structure, consisting of a shaft with coaxially inserted supports. The body of the rollers (3) is made using a rubber casting method. The number of edges on the rollers is the same. The edges are positioned on the rollers with a surface offset relative to each other by an angle of π/n, where n is the number of edges on the roller.

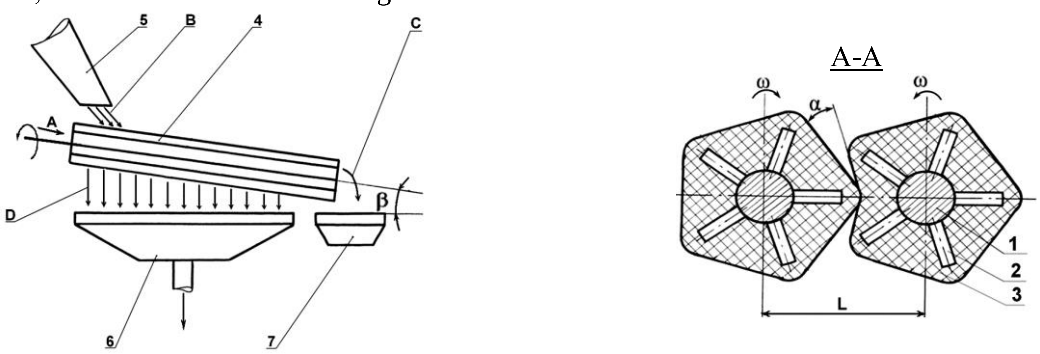


Fig. 1. Structural and Technological Diagram of the Cleaner-Separator for Fodder Pumpkin Fruits: 1 – shaft; 2 – support; 3 – roller body; 4 – rollers (beater block); 5 – loading device; 6 – pulp tray; 7 – hopper for cleaned seeds

The casting of rollers from rubber allows them to be installed with overlapping trajectories of circumferential points. As a result, an interlocking angle **α** appears in the channel formed by the rollers, periodically varying from its maximum value to zero. Initially, the interlocking angle significantly exceeds twice the friction angle of the mass on rubber, causing the mixture to settle at the bottom of the channel. This mechanism ensures that plant residues are drawn into the channel and trapped between the rollers. As the interlocking angle decreases, the seeds are expelled from the channel, while the plant residues pass under the working surfaces.

The roller edge does not compress due to the presence of a support. Each face has elasticity, determined by the mechanical properties of rubber. As a result, when entering contact, the edge compresses the body of the face, and upon exiting contact, the face returns to its original shape. This abrupt curvature change leads to intense shaking and self-cleaning of the surface from adhered dirt.

Since the design allows for adjusting the center-to-center distance L, and consequently the overlap magnitude, the initial capture angle and belt tension—and thus its elasticity—can be varied. This elasticity affects the gripping force on plant residues and the intensity of shaking when the face disengages from the edge of the adjacent roller.

A significant advantage of the new design is that, unlike traditional round rollers used in cleaners, the proposed design increases the contact area due to the straight sections of the faces entering contact. Combined with the elastic surface, this reduces the likelihood of seed damage during cleaning.

The cleaner-separator for fodder pumpkin fruits operates as follows (Fig. 1). The loading device delivers a mixture of pulp and seeds into the channel formed by the rollers (flow B). At the moment when the interlocking angle significantly exceeds the friction angle of the pulp-seed mixture on rubber, the mixture moves to the bottom of the channel. The fruit rind has a much smaller thickness and is flatter, which allows it to be gripped by the rollers, clamped, and transported toward the tray (flow D). As the interlocking angle decreases, the seeds are expelled from the channel and remain on the roller surface until the next opening of the interlocking angle. This cycle repeats. Due to the inclination angle of the beater block, the seeds gradually move toward the hopper (flow C).

During the research, a full-scale model of the cleaner-separator was used. The working material was a natural mixture of seeds and pulp.

The experimental setup (Fig. 2) consists of a frame, on which the rollers are mounted in bearing supports.

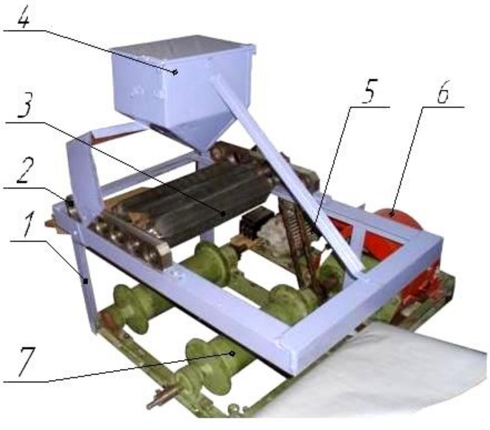


Fig. 2. General View of the Experimental Sample of the Working Elements of the Cleaner-Separator for Fodder Pumpkin Fruits: 1 – frame; 2 – bearing supports; 3 – rollers; 4 – loading hopper; 5 – electric motor; 6 – gearbox; 7 – conveyor drive

The rollers are positioned in such a way that the working field of the cleaner-separator has a tilt of 15–20º to ensure material discharge from the surface.

The central roller receives rotational torque from the electric motor through the gearbox, while the other rollers are driven by friction forces. A conveyor is installed for waste separation.

The work was carried out in the following sequence. The fodder pumpkin was cut open, its internal contents were removed, weighed, and its mechanical and technological properties were determined. The required rotational speed was set using the gearbox, and the drive mechanism was activated. The seed box of the cleaner-separator was manually filled with the seed mixture, the system was turned on, and the time required for complete cleaning was measured. The drive mechanism was activated, the cleaned seeds were collected, and their weight was measured. The ratio of the cleaned seed mass to the total mass of the internal contents provided the percentage of seeds in the mixture.

Subsequently, the waste was weighed. The ratio of waste mass to the mass of cleaned seeds determined the contamination percentage.

Damaged seeds were separated from the cleaned ones based on visual inspection, the total number of seeds was counted, and the percentage of damaged seeds was calculated.

For the research, three groups of five-sided rollers with different elasticity levels were manufactured. The elasticity was adjusted by creating cavities of various diameters inside the roller body (Figure 3).

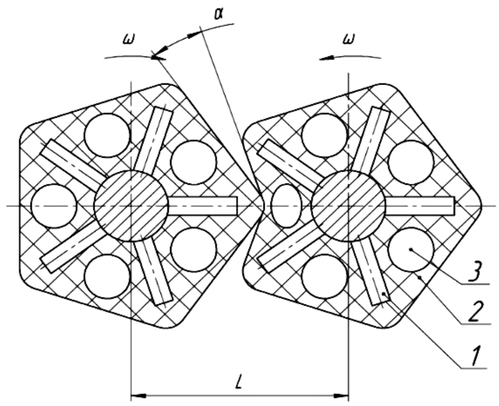


Fig. 3. Diagram of Cavity Formation in the Roller Body

This solution is acceptable as it allows for maintaining the composition of the rubber in the roller. Therefore, the experiments were conducted under identical conditions with regard to the quality of the working surfaces.

The developed cleaner is intended for final (finish) cleaning of the mixture, so the mixture fed to the rollers had undergone preliminary cleaning. As shown by the analysis of factory test protocols for serial machines, the degree of final contamination is 25–35% by weight. Therefore, this level of contamination was used in the experiment.

The moisture content of the mixture was not considered, as observations showed that the process occurs almost in a water environment.

Experimental data show that when the elasticity of the rollers exceeds 2.1 MPa, the performance quality indicators remain virtually unchanged.

The analysis of the obtained data indicates that, regardless of the rubber's elasticity, to ensure the least contamination of the seeds, the optimal rotation frequency of the cleaner-separator for pumpkin fruit should be 200–300 rpm (Fig. 4).

At rotation frequencies lower than 200 rpm, the contamination of pumpkin seeds worsens. This trend persists regardless of the elasticity of the roller material.

When the rotation frequency exceeds 300 rpm, the seed cleaning quality deteriorates only when using rollers with lower elasticity (Fig. 4). For rollers with higher elasticity, this indicator (as well as the seed quality) remains almost stable (Fig. 4). Furthermore, when $n > 300$ rpm, the seed loss with the waste and its slight damage (small cracks) during cleaning with rollers of higher elasticity tends to decrease. However, the amount of completely damaged seeds sharply increases (Fig. 5). Based on this, the rotation frequency of the cleaner-separator rollers should be kept in the range of 200–300 rpm.

It should be noted that in terms of the absolute contamination level, the best performance is achieved with rollers of lower elasticity. For example, at a value of 1.2 MPa, the lowest contamination is approximately 3% (Fig. 4), while at 2.1 MPa, it is almost 7 times higher (Fig. 5).

At rotation frequencies of 200–300 rpm, rollers with lower elasticity show better performance: higher seed quality, fewer losses, and less damage. The best performance is achieved with rollers having elasticity in the range of 1.2–2.2 MPa (Fig. 6).

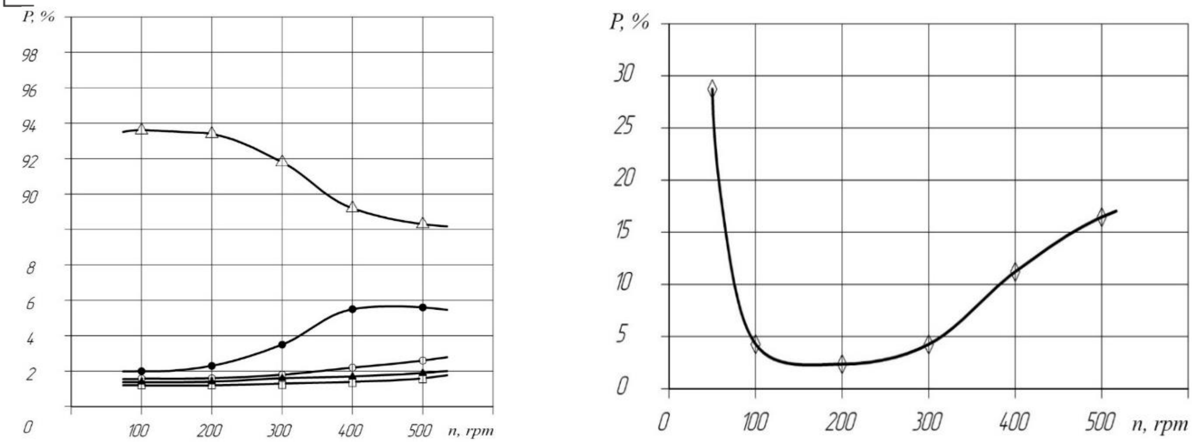


Fig.4. Quality performance indicators of the cleaner-separator for pumpkin fruits (roller elasticity – 1.2 MPa): Δ – conditionable seeds; ○ – small cracks; □ – damaged without embryo injury; ▲ – fully damaged; ● – lost with waste; ◊ – contamination

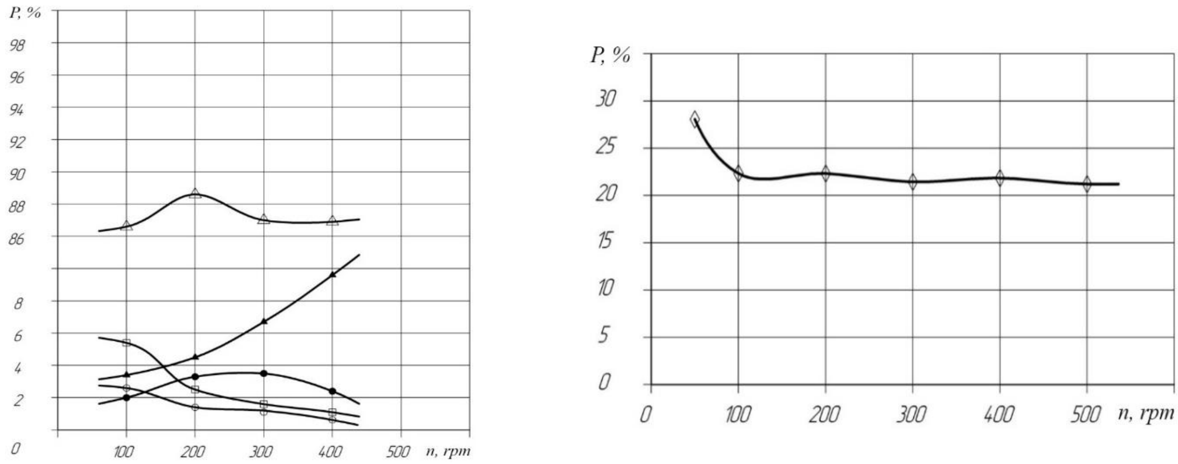


Fig.5. Quality performance indicators of the cleaner-separator for pumpkin fruits (roller elasticity – 2.1 MPa): Δ – conditionable seeds; ○ – small cracks; □ – damaged without embryo injury; ▲ – fully damaged; ● – lost with waste; ◊ – contamination

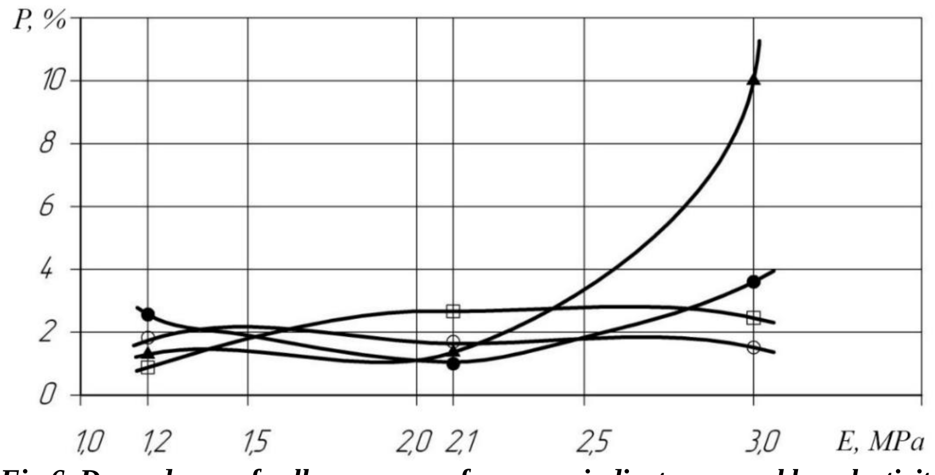


Fig.6. Dependence of roller group performance indicators on rubber elasticity: Δ – conditionable seeds; ○ – small cracks; □ – damaged without embryo injury; ▲ – fully damaged; ● – lost with waste; ◊ – contamination

The dependencies mentioned above were obtained with the minimum overlap of the described and inscribed circle of the rollers Δ = 0–0.5 mm (Figure 7)

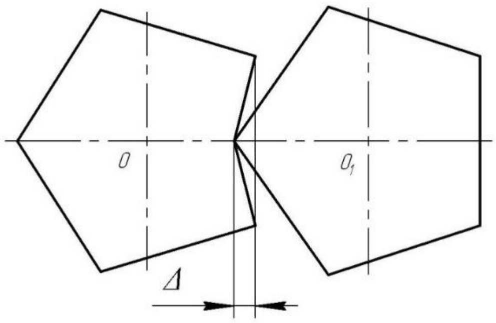


Fig.7. Diagram for determining the overlap magnitude Δ

Figure 8 shows the results of the study on the impact of the overlap magnitude on the main performance indicators under optimal values of elasticity and rotation frequency. As the analysis of the presented dependencies shows, the effect of the overlap magnitude is not decisive. Therefore, to increase the service life of the unit and reduce energy consumption, it is recommended to set Δ = 1–3 mm.

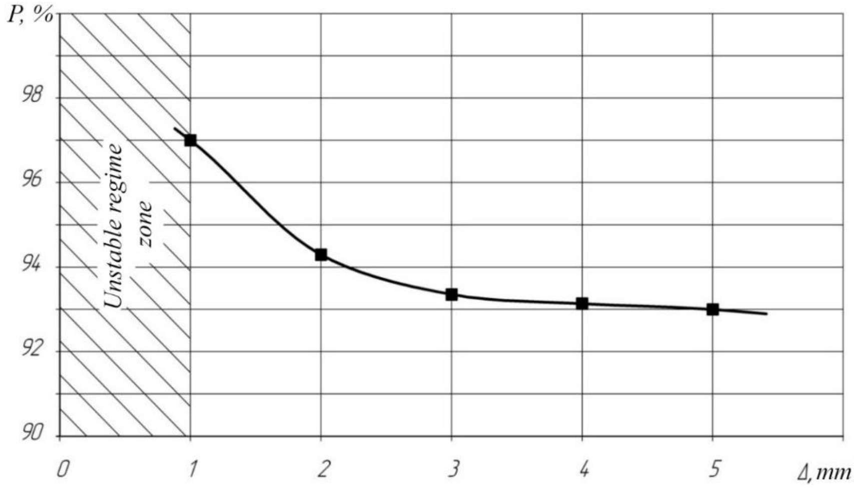
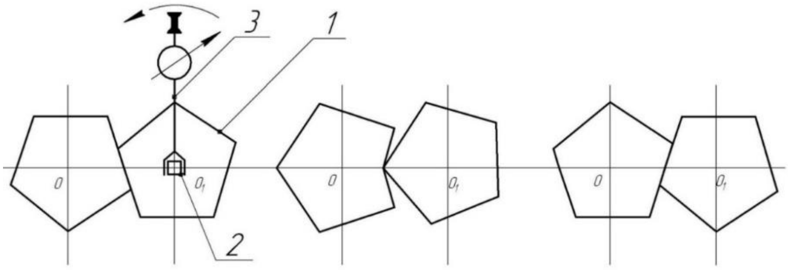


Fig.8. Influence of the overlap magnitude Δ on the content of fully conditioned seed at the output of the cleaner: rotation frequency n = 200 min^{-1}; elasticity 2.1 MPa

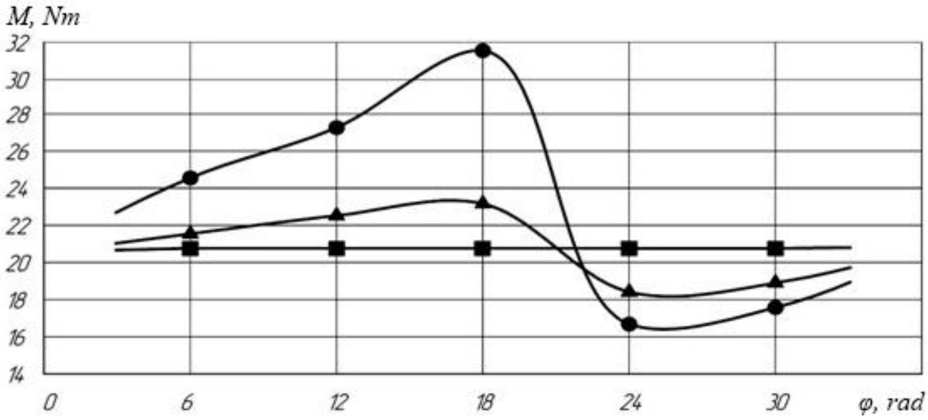
However, the analysis of the conditions for the production of rollers shows that such overlap requires increased precision in formation, which significantly increases the manufacturing cost. Therefore, during the development of the unit for field trials, we focused on an overlap magnitude of 3 mm.

The rotational moment of the roller group is cyclical, and a significant portion of it is spent on the deformation of the rubber. Returning to the calculation diagram, the transition from position I to position II is accompanied by energy consumption for deformation, while the transition from position II to position III, conversely, releases the energy accumulated by the rubber and returns it to the transmission, where it is spent on rotating the rollers. Part of the energy dissipates in the process. As a result, energy consumption measurements using traditional methods will not provide a fully objective picture. Therefore, we determined the energy consumption through the rotational moment using the following scheme – Figure 9.

The experiment was conducted with respect to one pair of rollers (others were removed) and proceeded as follows: a square tip was installed on one of the rollers, and a dynamometric wrench was attached to it. The rollers were rotated with the dynamometric wrench, and the readings of the dynamometer were recorded depending on the angle of rotation φ. The results of the measurements are presented in Figure 9, b.



a



b

Fig.9. Diagram for determining the rotational moment (a) and research results (b):
1 – roller; 2 – square tip; 3 – dynamometric wrench;
■ – overlap δ = 0; ▲ – overlap δ = 1 mm; ● – overlap δ = 3 mm

From Figure 9 (a), we can see that the maximum torque is 31.5 N·m, the minimum is 16.2 N·m, and the average is 23.8 N·m.

At an angular speed of rotation of the rollers ω = 200·3.14/30 = 21 s^{-1}, we have the following required power values:

- maximum – 31.5·21 = 660 W = 0.66 kW;
- minimum – 16.2·21 = 0.34 kW;
- average – 23.8·21 = 0.50 kW.

5. Conclusion

It was established that to ensure the lowest seed contamination of pumpkin, the optimal rotational speed of the separator-cleaner rollers should be in the range of 200–300 rpm. Outside this range, the seed contamination rate worsens, and this trend remains unchanged regardless of the elasticity of the roller material.

At rotation speeds of 200–300 rpm, rollers with lower elasticity ensure higher seed quality, fewer losses, and less damage. To maintain the required quality of operation, the optimal value of this parameter should be in the range of 1.2–2.2 MPa, and the absolute deformation of the roller should not exceed 3 mm.

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РЕЗУЛЬТАТИ ЕКСПЕРИМЕНТАЛЬНИХ ДОСЛІДЖЕНЬ ОЧИСНИКА-СЕПАРАТОРА ПЛОДІВ КОРМОВОГО ГАРБУЗА

Сучасне сільське господарство приділяє значну увагу ефективному використанню рослинної сировини для отримання якісного насіннєвого матеріалу та кормових продуктів. Однією з перспективних культур у цьому напрямку є кормовий гарбуз, насіння якого використовується для виробництва олії, а м'якоть та інші відходи – як цінний корм для тварин. Однак ефективне виділення насіння та сепарація відходів потребують спеціальних технічних рішень. Саме тому розробка та вдосконалення обладнання для механізованого очищення та сортування насіння кормового гарбуза є актуальним напрямом наукових досліджень. Виділення насіння гарбуза складається з трьох основних операцій: руйнування плода, відокремлення насіння від плаценти й м'якоті, а також виділення насіння від подрібненої мезги. Основна частина енергетичних витрат у процесі отримання насіння припадає саме на його відокремлення. Відомо, що у плодах гарбуза міститься лише 2,5–4,0 % насіння від *загальної маси, що зумовлює необхідність переробки значного обсягу сировини. Запропоновано нову конструкцію очисника-сепаратора плодів кормового гарбуза, яка включає систему вальців із гумовими гранями, що дозволяє ефективно захоплювати, транспортувати та очищати насіння. Використання п'ятигранних вальців із різною пружністю забезпечує оптимальні параметри очищення, зменшує втрати насіння та покращує його кондиційність. Дослідження впливу частоти обертання вальців показали, що оптимальними є значення у діапазоні 200–300 хв⁻¹. При такій швидкості забезпечується найкраще співвідношення між ступенем очищення насіння, мінімізацією його травмування та рівнем засміченості. Результати експериментальних досліджень підтвердили ефективність використання запропонованої конструкції. Виявлено, що для найкращих показників очищення оптимальною є пружність вальців у межах 1,2–2,2 МПа. Крім того, встановлено, що величина перекриття між вальцями не є визначальним фактором якості очищення, однак для підвищення строку служби механізму рекомендовано значення 1–3 мм. Отримані результати можуть бути використані при розробці нових технологічних рішень для очищення та сепарації насіння гарбуза, що сприятиме підвищенню ефективності його вирощування та переробки в аграрному секторі.*

Ключові слова: *гарбуз, мезга, очищення, сепарація, насіння, відходи, корма, дослідження, параметри, обладнання, ефективність*

Рис. 9. Літ. 17.

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