ANALYSIS OF GRAIN DAMAGE BY THE BUCKET ELEVATOR DURING LOADING/UNLOADING

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Resume

The purpose of the study was to identify problematic issues in the operation of bucket elevators during the loading and unloading of grain, which can lead to damage to seeds. To achieve this goal, methods of analysis and evaluation of factors that affect the damage rate of grain were used. The main results were an increase in the safety of the grain loading and unloading process using bucket elevators and a reduction in the risks of crop losses. The analysis of grain damage by a bucket elevator is of practical importance for the agricultural sector and can bring the following practical benefits: reducing the risk of product losses, as it helps to identify problem areas in the operation of the elevator and develop measures to eliminate them, improving the efficiency of work and the quality of seed grain.

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1 Introduction

With the favourable development of the seed grain industry, problems have recently arisen related to their damage. Damage to the grain leads to serious consequences, as they not only damage the seed germs, but also lead to a decrease in nutrient reserves in the main part of the grain, the endosperm. The study of the grain damage is an important aspect of ensuring efficiency and safety in the agricultural sector, since damaged grains are not only losses for producers, but lead to a decrease in the yield and product quality, as well. Destruction of valuable seed grains and thinning out of crops prevent the maximum possible yield from healthy grains. Technological processes of seed treatment should be organized in such a way as to minimize the impact of ups and downs on them, including the number of bends and turns. Sheet rubber should be used to cover the places of bends and turns. Excessive movements and sharp protrusions on the route of the movement of seeds should be eliminated. The equipment must be loaded at least half of the rated capacity. To avoid damage to seeds in bucket elevators, it is necessary to limit the number of lifts to five or six throughout the seed treatment process, and the speed of movement of the burrowing belts should be reduced. It is important to detect and eliminate areas where the seed damage is possible in time. The purpose of the study was to identify damage to grain seeds caused by the use of bucket elevators and substantiate the best design for the elevator, which will avoid damage to seeds.

To bridge the gap between the grain production and availability, it is crucial to adopt sustainable grain storage practices. The study conducted by Tushar et al. [1] explores the key factors affecting grain stability in emerging economies. Using a combination of analytical methods, it identifies "Proper training on advanced storage operations" as the most important factor in ensuring the sustainable grain storage. These findings can guide practitioners and policymakers in enhancing agricultural sustainability and food security.

2 Literature review and research gap

In their research, Kumar and Kalita [2] provide a comprehensive literature review of the grain postharvest losses in developing countries, the status and causes of storage losses, and discuss the technological interventions to reduce these losses.

Reducing postharvest losses, especially in developing countries, could be a sustainable solution to increase food availability, reduce pressure on natural resources, eliminate hunger, and improve farmers' livelihoods. Cereal grains are the basis of staple food, and account for the maximum postharvest losses on a calorific basis among all agricultural commodities. As much as 50% to 60% of cereal grains can be lost during the storage stage due only to the lack of technical efficiency. Use of scientific storage methods can reduce these losses to as low as 1% to 2%. The authors discussed in detail the basics of hermetic storage, various technology options, and their effectiveness on several crops in different localities.

According to Syzdykova et al. [3], grain damage is influential because damaged grain can cause significant crop losses and reduce the quality and value of the product. Damaged grain can lead to the loss of valuable nutrients and vegetable oils, which can reduce its total weight and reduce its price. Moreover, damaged grain can cause increased oxidation and rotting processes, which leads to loss of quality and unsuitability of the product for consumption. It may be less attractive to consumers. Damaged grain may have a degraded taste or a damaged shell, which may reduce its aesthetic appeal. In addition, damaged grain may contain various impurities, such as dust, dirt, and other pollutants, which may increase the risk of diseases associated with the use of products.

Following Irmulatov et al. [4], analysis of grain damage reduction is extremely important to guarantee high product quality. It is important to take measures to prevent plant diseases and pests, as this can affect the quality and value of the crop. It is necessary to carry out mechanical processing of grain, such as cleaning and separation from impurities using specialized equipment. This helps in avoiding the damage to the grain and improves its quality.

Mesterhazy et al. [5] outlined in their research that the main task is to reduce grain losses during production and storage and consumption. Better harvest and storage conditions could prevent losses of 420 mt. The education of farmers by adopting the vocational school system is a key issue in the prevention of grain loss. In addition, extension services should be created to demonstrate farmers' crop management in practice.

Shaimerdenova [6] states that in the conditions of growing demand for agricultural products, reducing crop losses and improving product quality are becoming especially urgent tasks for the agricultural sector. Therefore, it is necessary to pay attention to the problem of grain damage and take measures to reduce it, such as the use of modern equipment, prevention of plant diseases, and proper storage and transportation of grain. Such measures can help increase the efficiency of agricultural production and ensure the stable development of agriculture. In addition, reducing the damage rate of grain can reduce the cost of its processing and transportation, since damaged grain is often not suitable for the production of high-quality products and requires additional processing. It is also worth noting that reducing the damage contributes to decreasing the environmental impact, since damaged grain can become a source of soil and water pollution.

According to Koyshybaev et al. [7], bucket elevators have several disadvantages that can lead to grain damage and a decrease in its quality. Firstly, when the lifting grain, buckets can create strong friction, which leads to mechanical damage to the grain. Secondly, bucket elevators do not always provide uniform lifting and movement of grain, which can lead to its damage and mixing with other grains. In addition, elevators can have a negative impact on grain due to dust and pollution that can come from the environment or from the elevator itself.

Kaharmanova [8] notes that in order to reduce the negative consequences of using bucket elevators, it is necessary to take measures such as proper maintenance and lubrication of equipment, the use of special materials in buckets that reduce friction, and the installation of a grain quality control system at all the stages of its movement and storage. It is also worth considering that bucket elevators are not the only way to move grain, and there are more modern and efficient technologies that can be used in the agricultural sector.

Rsaliev [9] reports that there are a number of more modern methods of seed transportation that can reduce grain damage and increase processing efficiency, such as pneumatic transportation, which is based on the use of air to move grain, or gravity transportation. In this method, the seeds are moved along special inclined trays, which avoids sudden height changes and reduces the likelihood of damage. In some cases, special conveyors are used, which are equipped with soft belts or rubber coatings, which reduce impacts and decrease the amount of damage to grain during transportation.

In this comprehensive study, examining the impact of bucket elevators on grain damage, a significant research gap was identified. While existing literature thoroughly investigates general postharvest grain losses and various storage and transportation techniques, there is a notable lack of in-depth analysis specifically focused on the operational drawbacks of bucket elevators in agricultural processes. This gap is critical as it overlooks the detailed mechanisms through which the bucket elevators contribute to grain damage during the loading and unloading, a factor that can significantly influence overall grain quality and yield. Addressing this gap is essential for developing more efficient and less damaging grain handling methods, thereby enhancing agricultural productivity and reducing postharvest losses in the sector. The study is aimed at identifying the negative aspects of the operation of bucket elevators, which can damage seeds during their loading and unloading.

3 Methodology

3.1 Data

As a part of the study, the statistics of incidents at bucket elevators, associated with damage to seeds, during the loading and unloading of grain, were analysed. The work of elevators was monitored and problematic points were identified that could lead to seed damage. In addition, an analysis of the design of elevators was carried out and technical factors that may affect safety when working with them were identified. In this regard, a direct method of staining seeds was chosen, followed by viewing through a magnifying glass. This method is the most suitable for agricultural enterprises with a small number of mechanised processes and has sufficient accuracy to determine the degree of damage to seeds. It allows visualising and studying structural changes, such as damage to the shell, the presence of cracks, destruction of the embryo and changes in the colour or texture of seed tissues, and also has a number of advantages over other methods. For example, this method does not require complex tools or special conditions. This is a relatively fast and affordable procedure that can be performed using a conventional microscope or magnifying glass. If desired, it is possible to carry out a quantitative assessment of grain damage by counting damaged and undamaged seeds, which can be useful for the comparative analysis of various seeds. This method is non-invasive, that is, it does not require the destruction or separation of seeds into parts, which preserves the integrity of the seeds for further use or additional research. Staining seeds and viewing through a magnifying glass is a relatively inexpensive method, it does not require the use of expensive equipment or chemicals, which makes it available both in the laboratory and in production.

3.2 Research description

Before the analysis, two samples of grain weighing 1,000 g each were selected: one from the intake pit with a manual sampler before entering the bucket elevator, and the other before entering the grain cleaning machine. Two portions weighing 50 g each were taken from each sample and 200 seeds were randomly selected from each weighted portion for analysis, which eventually amounted to 400 seeds. Each of the 200 seed portions was immersed in a glass flask with an aniline dye for 2 minutes, used for dyeing cotton fabrics. Then the excess dye was removed, and the seeds were thoroughly washed with water, placed on filter paper, and dried in air. After that, the damaged seeds were randomly selected from each subsample using a manual magnifying glass and weighed on a scale. According to the literature data, the percentage of damaged seeds was determined in:

$$\Delta = \frac{W_{dam}}{W_{sub}} * 100\%, \quad (1)$$

where:
W_{dam} - weight of damaged seeds;
W_{sub} - weight of the initial subsample (200 seeds).

According to Equation (1), the number of damaged seeds in the intake pit (Δ_1) and before entering the grain cleaning machine (Δ_2) was determined. Since there were two subsamples in each sample, the average value in Equation (2), (3) was determined:

$$\Delta_1^{avg} = \frac{\Delta_1^1 + \Delta_1^2}{2}, \quad (2)$$

$$\Delta_2^{avg} = \frac{\Delta_2^3 + \Delta_2^4}{2}, \quad (3)$$

where:

$\frac{\Delta_1^1 + \Delta_1^2}{2}$ - respectively, the percentage of damaged seeds in the intake pit for the first and second subsamples;

$\frac{\Delta_2^3 + \Delta_2^4}{2}$ - respectively, the percentage of damaged seeds before entering the grain cleaning machine for the third and fourth subsamples.

The full amount of damage to seeds by the bucket elevator was determined based on:

$$\sum \Delta = \Delta_2^{avg} - \Delta_1^{avg} \quad (4)$$

Data on experimental studies and calculations of Equations (1)-(4) were entered in the Table 1.

4 Results

In this experiment, the two grain samples were selected, each weighing 1000 g. One sample was taken from the intake pit before entering the bucket elevator, and the other was collected before entering the grain cleaning machine. From these samples, we took smaller subsamples for detailed analysis. Using an aniline dye, we stained 200 seeds from each subsample for two minutes. After removing excess dye, washing, and drying the seeds, we inspected them using a magnifying glass to identify and weigh the damaged seeds. Our objective was to calculate the percentage of damaged seeds based on their weight relative to the total weight of the subsample.

In this study, the damage of grain by one burrow for a particular farm was 4.25 %. This means that for every 100 tonnes of grain loaded into the elevator, approximately 4.25 tons of grain were damaged. This level of damage can affect the quality of the product and lead to losses of harvest and income. But in general, the percentage of grain damage in the range from 3 % to 5 % is a fairly common indicator. For example, according to studies conducted in the USA in the period from 2005

Table 1 *Data on experimental studies and calculations*

Sample number	First (before the elevator)		Second (after the elevator)	
Subsample number	Subsample No. 1 (200 seeds)	Subsample No. 2 (200 seeds)	Subsample No. 3 (200 seeds)	Subsample No. 4 (200 seeds)
Weight of the subsample, g	8.66	8.53	7.95	7.86
Weight of damaged seeds, g	1.67	1.77	1.94	1.89
Δ_1 - % of damage to seeds before the bucket elevator, %	19.2	20.7	-	-
Δ_2 - % of damage to seeds before the bucket elevator, %	-	-	24.4	24
Average amount of damage to seeds	19.95		24.2	
% of damage to seeds by the bucket elevator	4.25			

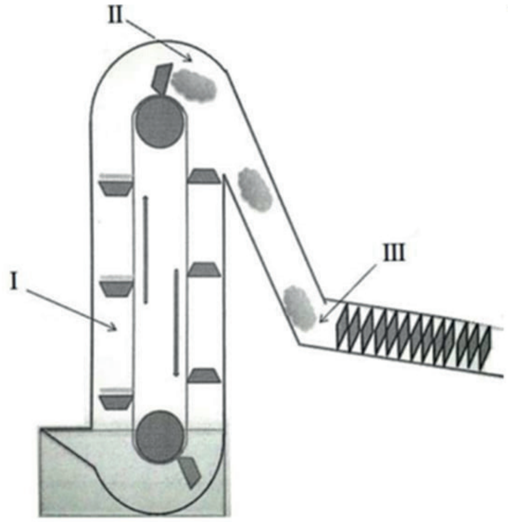

Figure 1 *Zones of the greatest damage to seeds*

to 2010, the percentage of damage to seeds ranged from 2% to 5%, depending on the type of grain and its storage method. In other studies, conducted in different regions of the world, the percentage of damage also ranged from 3% to 6%. Thus, a damage rate of 4.25% is quite typical for this situation, and to reduce it, it is necessary to apply special methods and technologies to protect the seed grain from mechanical damage (Table 1).

It can be concluded with great certainty that in the process of operation of the bucket elevator under study, three factors have the greatest influence on the damage of seed grain [10] (Figure 1):

1. The presence of a "backlagging" when lifting seeds up. "Backlagging" when lifting seeds can have a negative impact on the quality and quantity of the crop, as well as on the safety of working with bucket elevators. The problem of the presence of "backlagging" in the elevator arises from the fact that some seeds may remain on the walls of the elevator and begin to fall down in the opposite direction due to gravity during the next ascent, thereby reducing the efficiency of pumping seeds. The problem may arise when using bucket elevators, especially in the case of an incorrect choice of operating mode. All this can lead to product losses, reduced productivity and increased costs for maintenance and repair of equipment.
2. The problem of the method of unloading buckets in the elevator and the impact on the damage of grain. There are several factors that can affect the damage of grain when using the bucket elevators. One of the main factors is the speed of unloading. If the unloading speed is too high, the grain may be damaged when falling into the elevator. Another factor that can affect the damage of grain when unloading buckets is the air pressure in the burrow. If the air pressure in the burrow is too high, it can also lead to damage to the grain when falling. Moreover, the design of the bucket elevator can also affect the damage to grain. For example, if the buckets are too narrow or too deep, this can damage the grain when filling them. The design of the buckets can also affect how the grain will be unloaded from the buckets, which can affect the damage of the grain.
3. The problem of collision of the discharged material with the working body of the subsequent machine. This factor is also a serious problem that can lead

to significant losses in grain quality. This problem arises due to the fact that the buckets when unloading the burrows can strongly toss grain, which can lead to collision with other surfaces inside the elevator. At this level, the speed of unloading the grain is the highest, and the buckets are at the maximum height. The grain must move quickly from the elevator to the next machine so as not to slow down the production process. But at such a high unloading speed, the buckets are at the maximum height, which leads to additional loads on the grain and, as a result, damage to its structure. For example, grain can be crushed or deformed, which can lead to loss of product quality.

There are several suggested ways to reduce the grain damage. The first one, is the installation of rubberised plates at the bottom of the bucket elevator, is one of the ways to eliminate the problem of "backlagging" when lifting seeds up. The process of installing the plates does not require special skills and can be performed by operators on the spot. Such plates are usually produced from high-quality rubber, which provides good adhesion to the grain and does not cause damage upon contact with it. They can be installed on the bottom of each bucket or only on those that work with the most difficult materials to pump. The use of rubberised plates in the lower part of the buckets allows reducing or completely eliminating the "backlagging" and preventing the grain loss. In addition, it can reduce the load on the elevator and extend its service life. However, the use of rubberised plates can affect the performance of the elevator and lead to an increase in energy consumption. In addition, such plates must be replaced periodically to maintain the efficiency of the installation. Thus, the use of rubberised plates at the bottom of the bucket elevator can be an effective way to eliminate the problem of "backlagging" when lifting seeds up, which can lead to a reduction in grain losses and improve product quality. However, before installing them, a thorough analysis and assessment of possible negative consequences should be carried out. In addition, the use of rubberised plates in the lower part of the bucket elevator may be ineffective when pumping bulk materials with a high moisture content since the rubber may not adhere well to wet grain and does not provide the necessary adhesion. In such cases, alternative methods of eliminating the problem can be considered, such as installing special foamed materials at the bottom of the bucket or using additional means to increase friction between the grain and the bucket. It is also necessary to remember that rubberised plates can be subject to wear and damage, especially when working with heavy materials, which may lead to the need for frequent replacement. In addition, the installation of rubberised plates may require additional maintenance and replacement costs, which should also be considered when choosing this method [11].

The second one, to ensure the optimal way of unloading buckets, is an important aspect of ensuring high-quality grain and efficient operation of bucket elevators. When choosing the optimal method of unloading buckets, it is important to consider the following parameters: the size and shape of the buckets, the speed of the conveyor, the type of material that is pumped, and the characteristics of the elevator, such as the angle of inclination and dimensions. One of the ways to achieve the optimal method of unloading buckets is to build the outline of the bucket head only for a specific brand with knowledge of its parameters and the drive mechanism. The use of an irregular shape of the bucket head can lead to problems with unloading grain. For example, if the head of the bucket elevator has a too sharp shape, that can lead to an uneven load on the buckets, which can lead to damage to the grain and reduce its quality. If the head of the elevator is too flat, then this can lead to congestion and reduce the capacity of the elevator. The optimal way of unloading buckets can be achieved only by constructing a bucket head, which considers all the parameters of the bucket elevator, including the size, shape of the buckets, the speed of the conveyor, and the type of material. This will help to reduce the grain damage, improve the quality of the product, and ensure the efficient operation of the bucket elevator [12].

The third way is to install a dispenser in the upper part of the elevator in the unloading area, which can help reduce damage to seeds when they collide with the working body of the subsequent machine. The dispenser is a device that controls the speed of unloading grain from the elevator, and also allows grain to be distributed over the unloading surface, which can reduce the likelihood of its collision with the working body. When installing the dispenser in the unloading area of the elevator, it can be configured to a certain speed of unloading grain, which allows controlling the process and preventing possible overloads that can lead to grain damage. In addition, the dispenser can be configured to evenly distribute the grain over the unloading surface, which can prevent its accumulation and reduce the likelihood of collision with the working body [13].

Dispensers can be of various types, including mechanical, electronic, and hydraulic. Mechanical dispensers are used for unloading grain with low productivity, while electronic and hydraulic dispensers are used for high-performance unloading systems. Electronic and hydraulic dispensers can be equipped with sensors to control the unloading speed and grain level, which allows automatically adjusting the unloading speed and preventing possible overloads [14]. Dispensers can also have different shapes and designs, depending on the operating conditions and user requirements. They can be installed both inside and outside the elevator, depending on the specific needs. In addition, dispensers can be made of various materials, such as steel, aluminium, plastic. When installing the dispenser, it is necessary to consider various parameters, such as the type and design of the elevator, the type of grain, the required volume of unloading. It is also important to properly configure the dispenser for specific operating conditions. An additional advantage of installing a dispenser is the ability to control the process of unloading grain, which allows increasing the efficiency of the elevator and reduces the likelihood of emergencies [15-17]. Thus, the installation of a dispenser in the upper part of the elevator in the unloading zone is an effective way to reduce the damage of grain in collision with the working body of the subsequent machine. This allows improving the quality of unloaded seeds and reduces losses of crop and income.

5 Discussion

This study, aligning with the conclusions on the effectiveness of direct staining methods and magnifying glass inspection for assessing seed damage during transportation in bucket elevators, underscores the significance of these approaches. As indicated by Shahbazi [18], the staining technique, which uses brightly colored solutions, enhances the visibility of surface damage, providing crucial immediate feedback on transportation quality. This method is essential for pinpointing the causes of seed quality deterioration and taking corrective measures, although it falls short in revealing internal seed damage.

The observed 4.25% seed damage rate within the bucket elevator, as noted in our findings, aligns with the insights from Fraczek and Slipek [19] regarding elevator efficiency and its impact on crop yield and quality. Regular measurements, as suggested by Warechowska et al. [20], are vital for maintaining and enhancing elevator performance. Innovative designs and modernizations, such as those explored by Gieroba and Dreszer [21] and Grundas and Mis [22], including diverse bucket shapes and sizes, improved drive mechanisms, and optimized unloading processes, have shown efficacy in minimizing seed damage.

Particular attention to modifications like rubberized plates in the elevator's lower section, customizing the bucket head outlines as per brand specifics as discussed by Wozniak [23], and installing dispensers in the upper unloading area has been emphasized. Those modifications, echoing the suggestions of Kaharmanova [8] and Rsaliev [9], have not only enhanced productivity but significantly reduced the rate of grain damage, as well. Those changes also facilitated continuous and slower grain movement, positively impacting transportation, as highlighted by Mesterhazy et al. [5] and Shaimerdenova [6]. Optimising the size and shape of buckets in bucket elevators, as discussed by Grundas and Mis [22], and controlling conveyor speed [24] are crucial for improving the efficiency of separators and avoiding grain damage. The integration of modern automation and quality control technologies, using sensors and control algorithms, can further enhance separator efficiency [25-28]. However, considerations such as the need for proper grain storage and processing before pumping [29], the potential for reduced capacity and increased equipment wear in new designs [30-33], and the importance of testing new designs [33], are essential for effective elevator operation.

Incorporating these references, the study underscores the practical importance of grain damage analysis in bucket elevators for the agricultural sector. It aids in identifying operational issues and developing solutions to reduce product losses and improve seed quality, as also supported by the findings of Kumar and Kalita [2] and Koyshybaev et al. [7]. This analysis is vital for comparing the grain handling methods, informing equipment manufacturing and maintenance, supporting operator training programs, and providing a standardized testing approach, as suggested by Syzdykova et al. [3] and Irmulatov et al. [4]. The economic, productivity, and quality benefits of reducing the grain damage through analysis and improved handling techniques are significant, contributing to the broader goal of food security.

For a more accurate and comprehensive assessment of the seed damage caused by bucket elevators, various research methods, including visualization techniques, should be employed, as discussed in the wider literature. Implementing these advanced technologies and developments can significantly reduce the seed damage rates, thereby enhancing product quality and elevator efficiency. Moreover, these advancements can lead to reduced wear and tear on equipment, decreasing maintenance and repair costs, as outlined by the broader research community. Future research could focus on analyzing and improving various factors that influence the grain damage during the loading and unloading processes in bucket elevators.

6 Conclusion

The use of the method of direct staining of seeds and their subsequent inspection through a magnifying glass is an effective way to assess the degree of damage to seeds during transportation using bucket elevators. This method quickly determines the presence of damage on the surface of the seeds and its degree. Staining of seeds is carried out with special solutions that allow identifying the damage, and also differ in bright colour, which facilitates their detection during examination. This method enables quick feedback on the quality of transportation, which can be useful in determining the reasons for the decline in seed quality and taking measures to eliminate problems. However, this method does not provide information about the internal state of the seeds and does not determine the presence of hidden damage. Therefore, to fully assess the quality of seeds, it is necessary to use additional methods and tools, such as strength tests and other methods of analysis.

According to the measurement results, the percentage of seeds damaged as a result of the bucket elevator operation is 4.25%. This indicator is important for assessing the quality of the elevator, as damaged seeds can lead to a decrease in the yield and quality of the final product. The measurement results can be used to optimise the operation of the elevator and reduce the percentage of seed damage. Such measurements should also be carried out regularly to monitor and improve the quality of the bucket elevator. The reduction of seed damage caused by the bucket elevator can be achieved through the application of patent inventions and modernisation of the elevator design. These developments may include new bucket shapes and sizes, improved drive mechanisms, and methods to optimise the unloading process.

Special attention was paid to the installation of rubberised plates in the lower part of the bucket elevator, the construction of the outline of the bucket head only for a specific brand with knowledge of its parameters and drive mechanism, and the installation of a dispenser in the upper part of the elevator in the unloading area, which eliminated the presence of "backlagging", to ensure the optimal way of unloading buckets and to reduce the probability of collision of grain with the working body of the subsequent machine, resulting in a significant increase in productivity and a decrease in the percentage of damage to grain. This design also ensured the continuous supply of grain from the bucket elevator to the subsequent machine and reduced the speed of grain movement, which also had a positive impact on the transportation process.

The analysis of grain damage by a bucket elevator is of a great practical importance for the agricultural sector, as it helps to identify the problems in elevator operation and develop solutions to reduce product losses, improve work efficiency and seed quality, optimize equipment and processes to minimize mechanical damage, allow comparison of grain handling methods, inform equipment manufacturing and maintenance procedures, support operator training programs, and provide a standardized testing approach. Reducing the grain damage through analysis and improved handling provides economic, productivity, and quality benefits across the sector while supporting the food security.

For a more accurate assessment of the seed damage caused by a bucket elevator, various research methods can be used, for example, visualisation methods. The use of such patent developments can help significantly reduce the percentage of damage to seeds, which will positively affect the quality of products and increase the efficiency of the bucket elevator. In addition, the use of new technologies can reduce the wear and tear of equipment and decrease the cost of its maintenance and repair. Further study of grain damage by the bucket elevator during loading/unloading can be aimed at analysing and improving various parameters that affect the damage of grain.

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Conflicts of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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