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The impact of grain combine harvester working parts on damage and quality of winter wheat seeds

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Abstract. The aim of the study was to improve the quality of winter wheat seeds of the Fortuna and Yuvileina varieties by reducing damage during harvesting with a combine harvester at various stages of the technological process. Based on a comprehensive approach and the interrelation of climatic and soil characteristics, theoretical calculations, mathematical models, experimental, production and laboratory studies, the influence of the working parts of drum and rotary grain harvesting threshing units on microtrauma to seeds and its impact on the development of microorganisms and, in turn, on seed quality indicators, which significantly affect crop yield. The mathematical model of a damaged spring-viscous ellipsoidal grain provided by the authors shows

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that during the impulse force of relative and absolute trajectories of motion and acceleration, Coriolis forces, inertia, friction, and friction, when the rotation speed of the drum or rotor increases, the deformation of grains weighing 0.03-0.06 g with a transverse diameter of 3-5 mm within the range of 600-700 rpm is 0.015-0.035 mm, and damage increases significantly due to a decrease in seed strength, stress and force. Microtrauma at drum speeds of 700 to 1,000 rpm increases almost 9 times, and at rotor speeds 3 times. Microtrauma of Fortuna seeds before harvesting was 4.5%, and after unloading 56.2%, and for Yuvileina seeds 5.1% and 59.3%, respectively. There was no macro-damage to the seeds of either variety before threshing, but after unloading the grain from the combine harvester's hopper, it amounted to 7.3% and 6.2%. Damage by microorganisms, in particular Fusarium in the Fortuna variety after threshing, increased to 40.1%, Helminthosporium to 24.3%, Septoria to 13.6%, Alternaria to 4.6%, and in the Yuvileina variety to 18.2; 13.0%, 11.8% and 3.9%, respectively. During the threshing process, damage, injury and microorganisms affected the quality of the seeds, in particular in the Fortuna variety, the purity at unloading was 96.2%, the number of weed seeds per 1 kg was 281, and the germination rate was 92.1%. The weight in grams was 44.0, the specific weight was 741 g/litre, the raw gluten content was 24.6, and the protein content was 14.7. Accordingly, for the Yuvileina variety, these indicators were 95.0; 170; 94.8; 44.4; 740; 23.1; 13.7. The moisture content of the grain mass after harvesting both varieties was within the range of 14.6 and 14.3%

Keywords: force; impact impulse; speed; grain; microtraumas; microorganisms; yield

INTRODUCTION

Achieving high yields of winter wheat and ensuring gross grain production in Ukraine of over 100 million tonnes will significantly improve the economic and financial capacity of the state and at the same time contribute to meeting the comprehensive food needs of the population, in particular with high-quality products of various types of bread, various baked goods, pasta, confectionery, etc. Over the past few years, gross harvests have reached more than 60 and even 70 million tonnes, with an average yield of more than 50 centners per hectare, However, in order to increase these indicators, it is necessary to improve the quality of seed material by reducing damage and microtrauma to seeds at the technological stages of harvesting, processing, transportation, storage and processing, i.e. by improving and modernising technical means.

It should be noted that some modern technological lines and agricultural machinery are metal-intensive, bulky and expensive, and the level of injury and damage to grain is high, Therefore, both in theory and in practice, it is important to scientifically substantiate the results of theoretical, experimental and production research on the impact of working parts of machines and equipment on the injury and quality of grain seeds throughout the entire technological process of their cultivation. The results of experimental and production research by D. Derevjanko *et al.* (2020) show that damage and injury during the technological process by various working parts during threshing, i.e. reapers, conveyors, threshing units, and sieves, reach 20%, and sometimes more than 40% due to the biological condition of the plant, humidity of 20-25%, weed infestation, the preparedness of units and aggregates, and the professionalism of operators. and when a grain weighing 0.005 g falls onto the surface of a working body rotating at a speed (ω) of 6 rad s^{-1}, it causes tangential deformation of the seed in the plane O, ξ η, which is 0.021 and 0.025 mm. An increase in the linear U and angular parameters Θ with a decrease in angular velocity over a certain period of time indicates damage to the seed parameters. Therefore, when the seeds pass over the surface of the combine's threshing apparatus, which rotates at a speed of 700-800 rpm and above, there is an increase in deformation and injury, which contributes to a decrease in grain quality.

External factors, including climatic and soil conditions, are important components of plant growth and development throughout the growing season and significantly affect the size and quality of the crop (Talwar *et al.*, 2023). The impact of the working parts of various technical means during the technological process of plant development reduces the germination and other quality indicators of seeds, while limited soil moisture, light, and temperatures below 15°C have a negative effect on seed germination efficiency, resulting in low crop quality and quantity. Production, experimental and laboratory studies show that the impact of working parts on seed damage during sowing sometimes reaches 20% or more, depending on the interaction of different working parts (Yu *et al.,* 2020). Studies of the impact of working body surfaces when seeds weighing 0.04-0.006 g hit the working surfaces while rotating at a speed (ω) of 6 rad s^{-1} contribute to the occurrence of deformation and the formation of cracks to a depth of 0.25-0.75 mm, and the influence of microorganisms, which reduces the quality of the grain material, and the working parts are located at an angle of 10-15°, which move the seeds and, during drying, increase seed damage. According to J. Mellmann *et al.* (2018), temperature, temperature fluctuations, light and mechanical stress, if they exceed the optimal values, for example, temperatures above 25°C or below -20°C for a long time, also have a negative impact on damage, quality and yield of grain crops.

The use of reliable, timely, accurate, cost-effective and environmentally safe methods for assessing seed quality is indicated by S. Stepanenko *et al.* (2024) point to the use of reliable, timely, accurate, cost-effective, and environmentally safe methods for assessing seed quality, as well as the creation of a structural model of the separation process and the development of a criterion equation that includes quality indicators, allowing for the assessment of grain damage under the influence of key factors such as impact force, force momentum, elasticity modulus, density, etc. The influence on the efficiency of separation and, accordingly, on the quality of the seeds obtained is highlighted in the study by V. Bredykhin *et al.* (2021) on the parameters of the pneumatic vibration and centrifugal separation process, which is critically influenced by the circular rotation frequency of the cylindrical working surface, the frequency and amplitude of its oscillation, which are within the range of $\omega = 24\text{-}25$ rad/s and $\omega = 15.0\text{-}15.6$ rad/s, and the air velocity is $V = 2$ m/s.

Scientific evidence of the impact of technical means on the quality of seeds with the lowest biological potential is provided in the studies by V. Bredykhin *et al.* (2023), which propose mathematical models of the technological processes of loading grain elevator buckets, the nonlinear dynamics of a multiphase medium on the disc spreader of a vibrating separator, and the separation of seeds by density in a pneumatic fluidised bed. Technical features of seed calibration on screens with Cassini oval-shaped holes, etc. are provided. Researchers O. Pivovarov *et al.* (2023) propose innovative methods for assessing the quality of grains of various crops and provide a description of modern laboratory equipment that allows determining the nature, moisture content, purity, vitreousness, and mass of grains and legumes from the perspective of innovative methods. The authors K. Szwedziak *et al.* (2023) indicated in their research that harvesting, transportation, and storage technologies affect seed quality, and the use of electrical engineering support allows for the detection and selection of image elements. The study describes the development of a technology for evaluating grain in storage using electrical engineering and computer technology.

In connection with the research results considered, on the basis of which it is possible to study the physical, mechanical, technological and biological characteristics of seeds and the operation of machines and technologies, it is possible to improve the operation of working parts in interaction with grain material, reduce damage and injury, and significantly improve seed quality. The aim of the study was to justify the improvement of the quality of seeds of new modern high-yielding varieties of winter wheat of Ukrainian selection by reducing its macro- and micro-injuries and damage at various stages of the harvesting process, i.e. before threshing, in the reaper, in the threshing machine, on the sieve, during the operation of the transport working parts of the LEXION 770 combine harvester.

MATERIALS AND METHODS

A LEXION 770 combine harvester (Germany) was used to harvest winter wheat (Fig. 1).

Figure 1. *General view of the LEXION 770 combine harvester during the harvesting process of Yuvileina winter wheat*

Source: *CLAAS (n.d.)*

This combine harvester is equipped with a high-performance, powerful and fuel-efficient engine from Mercedes-Benz, which uses an individual cylinder feed system with solenoid valves in combination with an electronic control system (Fig. 2).

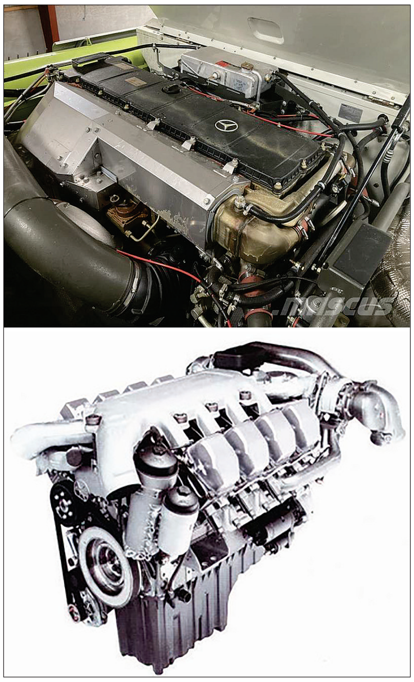

Figure 2. *General view of the engine*

Source: *CLAAS (n.d.)*

Features of the threshing system of this combine harvester model with a pre-accelerator, significant acceleration of grain mass movement up to 20 m/sec, and an effective separation device equipped with a multi-finger system ensure high productivity and efficiency of the machine (Fig. 3).

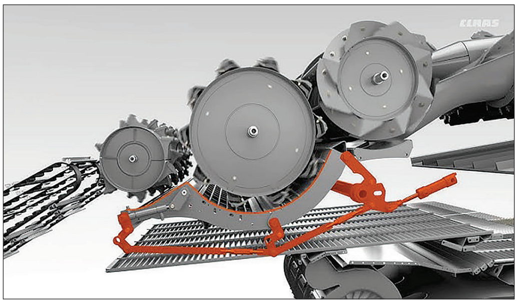

***Figure 3**. Special threshing unit on MSS*
***Source:** CLAAS (n.d.)*

The LEXION 770 combine harvester features the innovative MULTI CONTOUR system for efficient control of the swivel frame and adjustment of the cutting angle depending on the position of the bridge, ensuring that all process control functions are performed (Fig. 4).

***Figure 4**. Innovative MULTI CONTOUR system*
***Source:** CLAAS (n.d.)*

Figure 5 shows the latest equipment for more even distribution of cut mass in the combination of stalks and grain for better feeding and threshing.

***Figure 5**. Equipment for uniform mass distribution*
***Source:** CLAAS (n.d.)*

Theoretical research and calculations were performed by mathematical modelling of the working parts of the technical device and technological processes using the basic laws of mechanics, modern methods of computer calculations for constructing a system of differential equations, graphical definitions, integrations, transformations, etc. When compiling differential equations of relative motion of seeds on the working surface, its motion in the absolute coordinate system was considered, for which the methodology of Academician P.M. Vasylenko (1960) (1) was used. In this regard, a polar coordinate system (R, ϴ) was chosen, in which the absolute velocity is calculated from the expression:

$$V_a = \sqrt{\dot{R}^2 + R^2\theta^2}, \tag{1}$$

where $\acute{R}$ – the radial component of vector $\overline{V}_\alpha$; $R\dot{\theta}$ – the tangential component of vector $\overline{V}_\alpha$.

To differentiate the equations of seed movement, Lagrange equations of the second kind were used in accordance with the research objective of reducing seed damage and injury, to improve its quality at various stages of the threshing process on this combine harvester of modern, high-yielding varieties of winter wheat of domestic selection, for which it is necessary to substantiate and perform theoretical calculations of the influence of the working parts of the combine harvester on the deformation and injury of seeds, the impact of various types of injuries on the breaking force and maximum stress, the impact of the rotation speed of the working parts of threshing machines on the injury and quality of seeds of new, modern high-yielding varieties of winter wheat in the soil and climatic conditions of the central part of the Right-Bank Forest-Steppe of Ukraine. To this end, new designs with rubber-coated threshing apparatus beaters were improved and proposed, and laboratory equipment was manufactured to study the effect of mechanical factors on the strength, damage and microtrauma of cereal crops, in particular winter wheat. The motion of the applied mechanical system, which at the initial moment of time ($t = 0$) was oriented along the Ox axis and begins to move from a state of rest, is described by Lagrange equations of the 2nd kind:

$$\frac{d}{dt}\left(\frac{\partial T}{\partial \dot{q}_s}\right) - \frac{\partial T}{\partial q_s} = Q_s\left(s = \overline{1,6}\right), \tag{2}$$

where T – the kinetic energy of the mechanical system; q_s – the generalised coordinate; s – the coordinate number; Q_s – the generalised force corresponding to the generalised coordinate q_s.

The kinetic energy of a mechanical system is calculated as the sum of the kinetic energies of each link in the system:

$$T = \sum_{i=1}^{4} T_i = \frac{1}{2}\sum_{i=1}^{4}\left[m_i\left(\dot{x}_i^2 + \dot{y}_i^2\right) + I_i\omega_i^2\right], \tag{3}$$

where I_i – the moment of inertia of the i-th link relative to the vertical axis passing through its centre of mass; $\omega_i = \dot{\beta}_i$ – the angular velocity of rotation of the i -th link; $\dot{x}_i, \dot{y}_i$ – the projection of the velocity vector of the centre of mass of the i -th link of the system.

The coordinates of the centre of mass of the i-th ($i=\overline{2,4}$) link can be expressed in terms of x_1, y_1, the coordinates of the centre of mass and the angles of rotation of the previous links and the given parameters:

$$\left.\begin{aligned} x_2 &= x_1 - (l_1 - a_1)\cos\beta_1 - a_2\cos\beta_2, \\ y_2 &= y_1 - (l_1 - a_1)\sin\beta_1 - a_2\sin\beta_2, \end{aligned}\right\} \tag{4}$$

$$\left.\begin{aligned} x_3 &= x_1 - (l_1 - a_1)\cos\beta_1 - l_2\cos\beta_2 - a_3\cos\beta_3, \\ y_3 &= y_1 - (l_1 - a_1)\sin\beta_1 - l_2\sin\beta_2 - a_3\sin\beta_3, \end{aligned}\right\} \tag{5}$$

$$\left.\begin{aligned} x_4 &= x_1 - (l_1 - a_1)\cos\beta_1 - l_2\cos\beta_2 - l_3\cos\beta_3 - a_4\cos\beta_4, \\ y_4 &= y_1 - (l_1 - a_1)\sin\beta_1 - l_2\sin\beta_2 - l_3\sin\beta_3 - a_4\sin\beta_4. \end{aligned}\right\} \tag{6}$$

Dependencies (4)–(6) can be written in general form:

$$\left.\begin{aligned} x_i &= x_1 - (l_1 - a_1)\cos\beta_1 - a_i\cos\beta_i - \textstyle\sum_{j=2}^{i-1} l_j\cos\beta_j, \\ y_i &= y_1 - (l_1 - a_1)\sin\beta_1 - a_i\sin\beta_i - \textstyle\sum_{j=2}^{i-1} l_j\sin\beta_j, \left(i = \overline{2,4}\right). \end{aligned}\right\} \tag{7}$$

Taking derivatives with respect to time from expressions (7), determine the velocities of the centres of mass of the system links:

$$\left.\begin{aligned} \dot{x}_i &= \dot{x}_1 + (l_1 - a_1)\beta_1\sin\beta_1 + a_i\beta_i\sin\beta_i + \textstyle\sum_{j=2}^{i-1} l_j\beta_j\sin\beta_j, \\ \dot{y}_i &= \dot{y}_1 - (l_1 - a_1)\beta_1\cos\beta_1 - a_i\beta_i\cos\beta_i - \textstyle\sum_{j=2}^{i-1} l_j\beta_j\cos\beta_j, \left(i = \overline{2,4}\right). \end{aligned}\right\} \tag{8}$$

Substituting (8) into (3), an expression for the kinetic energy of the system is obtained:

$$T = \frac{1}{2}\left[m_1(\dot{x}_1^2 + \dot{y}_1^2) + I_1\dot{\beta}_1^2 + \right.$$
$$\left. + \textstyle\sum_{i=2}^{4}\left(m_i(\dot{x}_i^2 + \dot{y}_i^2) + I_i\dot{\beta}_i^2\right)\right]. \tag{9}$$

The basis of elastic strength theory is the strength criterion, whereby the onset of a dangerous condition in a specific location under the action of stress and load causes damage to increase, i.e. the intensity coefficient reaches a critical value. Over time, the growth and accumulation of forces in the plastic deformation zone causes numerous microdamages, which is the beginning of crack formation and then destruction. The stress intensity factor k_{im} egulates the intensity and zone of plastic deformation, since strength depends on crack formation and the safety factor, i.e:

$$k_{im} = \sigma\sqrt{l\pi}, \tag{10}$$

where l – deformation distance, and σ – permissible stress.

Experimental and production studies of the impact of combine harvester working parts on macro- and micro-damage to grains of modern winter wheat varieties Fortuna and Yuvileina were conducted at the "Dnipro" agricultural enterprise in the Cherkasy region by selecting wheat samples in 2023 at various stages of the technological process during threshing. The authors determined the damage and its impact on the main quality indicators, namely purity, germination, moisture content, seed weight, nature, etc., as well as damage by microorganisms, at the regional agricultural seed laboratory. Experimental studies of plants (both cultivated and wild), including the collection of plant material, complied with institutional, national and international guidelines. The authors adhered to the standards of the Convention on Biological Diversity (1992).

RESULTS AND DISCUSSION

The emergence of resistance to injury and damage to seeds during threshing is associated with the action of external and internal factors that cause the displacement of organic matter from stresses and an increase in the distances between individual particles, which weakens strength and is the beginning of the formation of a rupture. This process consists of the onset of destruction, i.e. the physical characteristics of destruction and the mechanics of destruction, which have different patterns that are not yet sufficiently studied, and the correlation between microtrauma and macrodestruction is very important from the point of view of grain destruction theory and strength theory. Thus, the strength of the seed depends on the force, stress and occurrence of a crack, and its growth leads to damage and macrotrauma. Experimental studies show that force and stress affect cracks and damage and increase the stress intensity factor (Fig. 6).

Damage and injury to the embryo, seed coat, and endosperm affect seed strength, while stress, deformation, and applied force lead to micro-damage and rupture (Table 1).

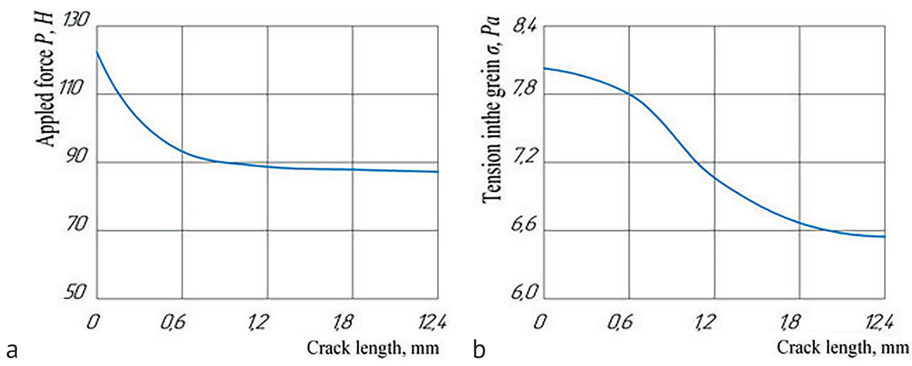

***Figure 6**. Dependence of seed destruction force (a) and stress value (b) on the degree of destruction*
***Source:** developed by the authors based on own research*

***Table 1**. Dependence of seed strength on damage*

Type of damage	Damage due to force P, N	Damage due to deformation Δl, mm	Stress value, Y, V
Cracked embryo	47.4	0.17	5.55
Damaged endosperm	79.1	0.27	7.15
Injured embryo	85.2	0.25	7.0
Damaged seed coat	96.1	0.24	7.45
Injured seed coat and embryo	105.4	0.23	7.90
Damaged seed coat of endosperm	105.2	0.25	7.95
No damage	105.5	0.29	8.55

***Source:** developed by the authors*

The results obtained, presented in Table 2 in percentage values of seed microtrauma (y_1)and damage (y_2),which depend on the increase in the rotation speed of the combine harvester's working parts (x, rpm), indicate a proportional dependence on the increase in the number of damages.

***Table 2**. Microtrauma and damage to seeds depending on the rotation speed of the working part*

Drum-type threshing machine							
x	700	800	900	920	950	970	1,000
y_2	0.8	0.84	1.45	1.51	3.35	5.40	7.05
y_1	27.0	28.15	29.50	33.15	40.40	50.15	54.25
Rotary type threshing machine							
x	700	800	900	920	950	970	1,000
y_2	0.12	0.25	0.34	0.45	0.35	1.15	3.05
y_1	29.15	34.40	36.10	39.20	42.10	46.65	47.15

***Source:** developed by the authors*

The investigation regarding the influence of force on injury and damage to the seeds according to the theorem of change in momentum during impact interactions between working parts and grains in projections on the axes of the Cartesian coordinate system, the expression will be as follows:

$$\begin{aligned} mV_{2x} - mV_{1x} &= S_x(t) \\ mV_{2y} - mV_{1y} &= S_y(t)\cdot \end{aligned} \quad (11)$$

During the passage of the grain heap between the blades of the drum apparatus, the trajectory of the grain can be presented according to the diagram (Fig. 7).

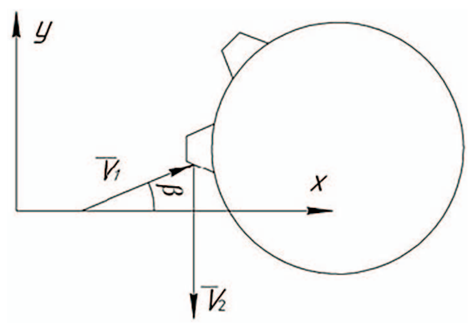

***Figure 7**. Scheme of speed dynamics*
***Source:** developed by the authors*

After performing calculations according to the dynamics diagram (Fig. 2), expression (11) took the following form:

$$\begin{aligned} O - V_1 \cos\beta &= S_x/m \\ -V_2 - V_1 \sin\beta &= S_y/m, \end{aligned} \qquad (12)$$

where β – the angle of grain mass entry into the drum.

Continuing the calculation yielded:

$$\frac{S}{m} = \sqrt{V_1^2 \cos^2\beta + V_2^2 + V_1^2 \sin^2\beta + 2V_1 V_2 \sin\beta}\,. \qquad (13)$$

During the threshing process using a rotary combine harvester, the path of the seeds is as follows (Fig. 8).

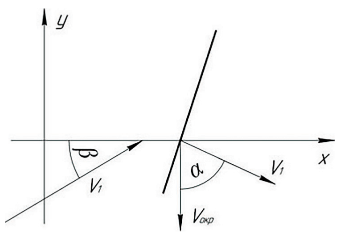

***Figure 8**. Diagram of the dynamics of movement speed*
***Source:** developed by the authors*

In this regard, the expression will be as follows:

$$\begin{aligned} V_2 \sin\alpha - V_2 \cos\beta &= S_x/m \\ -2V_2 \cos\alpha - V_1 \sin\beta &= S_y/m. \end{aligned} \qquad (14)$$

Continuing the calculation yielded:

$$\frac{S}{m} = \sqrt{V_2^2 \sin^2\alpha + V_1^2 \cos^2\beta - 2V_1 V_2 \sin\alpha \cdot \cos\beta +} \sqrt{+V_2^2 \cos\alpha + V_1^2 \sin^2\beta + 2V_1 V_2 \sin\beta \cdot \cos\alpha}\,. \qquad (15)$$

Analysis of the calculations showed that the impact forces in the drum apparatus have advantages over the rotary one, therefore damage and injury will be more severe. Experimental studies of various threshing devices of a grain combine harvester are presented in Table 2 in the form of percentage values of microtrauma to seeds (function y_1) and damage (function y_2) depending on the rotation of the drum and rotor (rpm). An analysis of these data indicated that increasing the revolutions of both apparatuses promotes a rise in injury and damage to the grain, but the grains are more heavily injured and damaged in the drum apparatus. The data in Table 3 showed that embryo injury for the Fortuna seed variety increases from 3.7 to 6.0%, and that of the Yuvileina variety from 3.3 to 6.2%.

***Table 3**. Winter wheat seed injury during harvesting in percentages*

Farm	Variety	Research stage	Macrotrauma				
			Embryo		Total injury	No damage	Macrotrauma
			Crushed	Damaged			
PFH "Dnipro," Cherkasy Region, 2023	Fortuna	At the root	0	0	4.5	95.5	0
		During harvesting	2.1	3.7	21.5	78.5	3.1
		After threshing	3.8	4.2	41.6	58.4	4.5
		After screening	4.2	4.9	44.4	55.6	5.2
		In the bunker	4.9	5.5	53.4	46.6	6.1
		After the bunker	5.8	6.0	56.2	43.8	7.3
	Yuvileina	At the root	0	0	5.1	95.9	0
		During harvesting	2.7	3.3	21.2	78.8	2.7
		After threshing	3.8	4.4	50.3	49.7	3.8
		After screening	4.9	5.1	52.2	47.8	4.9
		In the bunker	5.6	5.9	57.6	42.4	5.6
		After the bunker	6.2	6.2	59.3	40.7	6.2

***Source:** developed by the authors*

The total number of microtraumas in Fortuna seeds increased by 51.7%, i.e. 43.8% were undamaged, while for Yuvileina seeds these figures were 54.2% and 40.7%. Macrotrauma increased to 7.3% and 6.2%, and embryo damage to 6.0% and 6.2% for both varieties, respectively. Thus, injury and damage to grains is observed in both varieties, but with a slight difference, i.e. the resistance to damage and destruction of these varieties is almost at the same level. The research data (Table 4) showed that during the harvesting of winter wheat, the purity of seeds and the amount of weeds before the cleaning system was more than 3-4 times higher, and after the combine harvester's cleaning screens, the purity remained at 96.5-95.0% and 281-270 weed seeds per 1 kg of grain mass until the end of harvesting. Germination during the technological process decreased from 95.1-97.7% to 92.1-94.8% due to the influence of contamination, injuries and damage, especially to the embryo, on which it primarily depends. Moisture content during harvesting decreased from 15.8-15.4% to 14.6-14.3% due to the separation of impurities, especially raw weed seeds, chopped straw, chaff, weed stems, and drying due to air movement, blowing, and mixing. The weight, naturalness and vitreousness of the seeds decreased at all stages of harvesting, while the amount of protein and gluten increased from 13.1% and 21.4% before harvesting to 14.7% and 24.6% after threshing, i.e. after unloading from the bunker.

***Table 4**. Influence of injury on winter wheat seed quality during harvesting*

Farm	Variety	Research stage	Purity, %	Weed seeds, pcs/kg	Germination, %	Moisture content,	Thousand grain weight, g	Test weight, g/litre	Vitreousness, %	Protein, %	Raw gluten %
PFH "Dnipro," Cherkasy Region, 2023	Fortuna	At the root	98.6	101	95.1	15.8	46.5	769	83.1	13.9	22.8
		During harvesting	97.4	188	94.5	15.1	46.4	761	81.2	14.2	23.3
		After threshing	96.8	415	93.3	15.0	45.5	757	78.1	14.4	24.1
		After screening	96.5	291	92.0	14.9	44.4	44.9	76.7	14.4	
		In the bunker	96.7	286	92.5	14.8	44.4	750	75.2	14.5	24.3
		After the bunker	96.2	281	92.1	14.6	44.0	741	74.7	14.7	24.6
	Yuvileina	At the root	98.9	103	97.7	15.4	46.1	770	66.7	13.1	21.4
		During harvesting	98.1	190	96.2	15.0	45.6	761	66.0	13.2	21.6
		After threshing	96.2	320	96.0	14.6	45.1	755	65.1	13.3	21.9
		After screening	95.8	255	95.8	14.5	44.0	753	64.2	13.4	22.0
		In the bunker	95.7	250	95.0	14.4	44.8	750	59.1	13.6	22.5
		After the bunker	95.0	170	94.8	14.3	44.4	740	58.4	13.7	23.1

***Source:** developed by the authors*

Damage by microorganisms (Table 5) during the harvesting process occurred in both varieties, but higher values were observed in the Yuvileina variety, because the damage here is also greater. The prevalence of Fusarium before harvesting was 2.8%, Helminthosporium 0.3%, Septoria 0.1%, Alternaria 0.2%, and after harvesting these figures were 42.2%, 23.4%, 14.9 and 7.7, respectively, indicating a significant increase. Thus, damage and microorganisms have a negative impact on the quality of seed material.

***Table 5**. Winter wheat seed damage by microorganisms during harvesting in percentages*

Farm	Variety	Research stage	Fusarium	Helminthosporiosis	Septoria	Alternaria	Mould fungi
1	2	3	4	5	6	7	8
PFH "Dnipro," Cherkasy Region,2023	Fortuna	At the root	2.9	0.3	0.2	0.1	-
		During harvesting	19.0	15.4	7.1	2.7	-
		After threshing	14.3	19.3	8.8	3.8	-
		After screening	28.1	18.5	10.6	4.1	-
		In the bunker	40.3	20.4	14.0	5.1	-
		After the bunker	40.1	24.3	13.6	5.6	-
1	2	3	4	5	6	7	8
PFH "Dnipro," Cherkasy Region, 2023	Yuvileina	At the root	2.9	0.3	0.1	0.2	-
		During harvesting	21.3	17.2	7.2	3.3	-
		After threshing	17.2	20.6	9.7	5.1	-
		After screening	30.5	21.1	12.4	6.0	-
		In the bunker	41.4	21.5	14.5	7.5	-
		After the bunker	42.2	23.4	14.9	7.7	-

***Source:** developed by the authors*

Thus, the results of the studies show that the working parts of drum and rotary threshing machines affect the injury and development of microorganisms, and in combination and interrelation affect such quality indicators as purity, germination, weight, naturalness, vitreousness, protein and gluten, etc. These indicators are decisive for the characterisation of seed material in terms of yield potential, as well as for the taste and nutritional properties of food, which are the basis of human energy and health. A significant contribution to the theoretical scientific research on the interaction and influence of the working parts of various machines and mechanisms was made by Ukrainian scientists P. Vasylenko (1960), P. Zaika (2006), L. Tischenko *et al.* (2011), who developed the theoretical foundations of the interaction of working bodies and materials, in particular grain, optimal operating modes of machine working bodies during harvesting and post-harvest processing, and vibrating screen separation of bulk materials.

Research by V.M. Arendarenko *et al.* (2020) on the movement of grain material on inclined surfaces of working bodies and experimental studies by T. Samoylenko *et al.* (2021) on the movement of grain material on inclined surfaces of working parts and the experimental studies of T. Samoylenko *et al.* (2021) show that the speed of material movement, the rotation of working surfaces, the angle of inclination of working bodies, and the movement and placement of grain mixtures and seeds on them, in particular taking into account their biological characteristics, moisture content, purity, and other factors, affect productivity and efficiency. Similar theoretical and experimental studies by V. Bulgakov *et al.* (2023) on the impact interaction of grains with working surfaces and their effect on seed damage and quality during technological processes of grain pile processing, transportation and other operations confirm other experimental, laboratory and production results. The results of studies by I. Strona (1974), T. Samoylenko *et al.* (2020) confirm that during the processing of grain piles after threshing, the inclination of working surfaces at an angle of 10° or more, the speed of working parts exceeding 5-7 m/s, and the rotation of working parts exceeding 600 rpm increase the damage to grain seeds. Damage to cereal seeds increases depending on their biological and physical properties.

Research data from D. Derevyanko *et al.* (2023) substantiate a series of experimental influences of working parts on damage and microtrauma to winter wheat and rye seeds during harvesting, with these indicators reaching 20% or more, and during post-harvest processing, sometimes more than 40%, and during sowing, 12-16%, which significantly affects the quality of the grains. Researchers V. Zabrodin and M. Sukhanova (2019) confirm the impact of working parts of technical equipment during seed movement on its damage, which reaches 20-22%, as well as a decrease in the germination of cereal crops, on which the quality of the future harvest fully depends. Authors J. Mellmann *et al.* (2018) investigated the impact of technological processes during the processing and drying of grain crops under different conditions with different mechanical loads, energy costs, the influence of special conditions, temperature fluctuations, light, moisture and oxidation in combination with the interaction with the working surfaces of machines and equipment, seeds are damaged, microtraumatised and their quality, especially germination, is reduced. Analytical studies on germination, growth energy, and the effect of temperature on fodder crop seeds were conducted and confirmed such an effect on these indicators by W. Chaleb *et al.* (2021) and V. Oleksiak *et al.* (2023). In addition, the authors S. Bayram *et al.* (2024) showed the negative impact of salinisation on plant growth and development, and I. Buranji *et al.* (2019) confirm a decrease in germination with an increase in soil acidity. The justification of the impact of the parameters of individual working elements of technical means during the transportation of grain materials, conducted by A. Rucins *et al.* (2024) and the assessment of the level of damage and injury to grain in the studies by O.M. Ivanov and K.V. Simonov (2021) indicate their impact on seed injury, which in turn will affect its quality.

In general, studies by various researchers indicate the relevance of studying the impact of various factors of external and internal characteristics of grain varieties, in particular different varieties of winter wheat, soil and climatic factors, especially soil fertility, moisture, acidity, soil and air temperature regimes, light and, of course, the impact of working parts of machines and equipment in interaction and interconnection on microtrauma, damage by microorganisms and seed quality, which significantly affects the yield and gross grain production in Ukraine.

CONCLUSIONS

Theoretical studies of injury and damage to seeds of modern, new, high-yielding varieties of winter wheat of domestic selection by the working parts of the foreign grain combine LEXION 770 occur due to additional forces, stress and deformation, which is a condition for the accumulation of microtraumas and the creation of mandatory causes of microtrauma and destruction. The process of the onset of injury and destruction depends on soil and climatic factors, external and internal forces, deformation, biological condition, quality, especially moisture content, mass, the presence of protein and gluten, etc. Increasing the speed of the combine's working parts from 700 to 1,000 rpm led to an increase in the number of microtraumatised seeds from 27.1% to 54.3% in the drum threshing machine, and in the rotary threshing machine, this increase was 18%. Thus, the working surfaces of the rotor have a mitigating effect on the operating mode by 9.1% compared to the drum thresher.

Experimental, production and laboratory studies show that during the technological process of harvesting, microtrauma to Fortuna seeds increased from 7.5% to 56.2%, i.e. 43.8% were undamaged, while for the Yuvileina variety, it increased from 5.1% to 59.3%, meaning that 40.7% of the seeds remained undamaged, i.e. 3.1% more seeds of this variety were damaged than the previous one, but in general, these varieties are more resistant to damage than other varieties. Damage to grains has a significant impact on seed quality indicators during the threshing process. In the Fortuna variety, purity decreased by 2.4%, moisture by 1.2%, weight by 2.5%, and specific weight by 28 g/litre, while for the Yuvileina variety, they decreased by 3.9%, 1.2%, 2.7%, and 30%, respectively. The data obtained show a slight advantage of the impact of damage on the quality of the Yuvileina variety seeds, and in general, these indicators are more positive compared to others that were previously conducted in studies.

The results of laboratory studies show that the technological process and injury significantly affect the growth of damage by microorganisms (Table 5), when before the start of harvesting the amount of Fusarium was 1.9%, Helminthosporium – 0.3%, Septoria – 0.2%, alternaria – 0.1% in the Fortuna variety, while in the Yuvileina variety these values were 2.8%, 0.3%, 0.1% and 0.2%, respectively. After unloading the seeds from the bunker, the presence of grains damaged by microorganisms in the Fortuna variety was 40.1%, 24.3%, 13.6%, and 5.6%, respectively, and in the Yuvileina variety, it was 42.2%, 23.4%, 14.9%, and 7.7%. The complex interrelationship between damage and the presence of microorganisms contributed to a significant deterioration in seed quality. Theoretical calculations, graphical dependencies, experimental and production and laboratory studies of the effect of the working parts of a grain combine harvester on modern varieties of domestic selection have a negative impact on microtrauma, damage and seed quality of both varieties of winter wheat. The drum-type working parts of grain combines have a greater negative impact than rotary ones, but all working parts have a certain negative effect on the deterioration of quality indicators. Further research should be aimed at substantiating the impact of working parts of technical equipment on seed quality, improving machine designs using modern materials, and expanding experimental and laboratory tests in various agricultural zones of Ukraine.

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Вплив робочих органів зернового комбайна на пошкодження і якість насіння озимої пшениці

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Анотація. Мета дослідження полягала в покращенні якості насіння озимої пшениці сортів Фортуна і Ювілейна шляхом зниження його пошкодження під час збирання комбайном на різних стадіях технологічного процесу. На основі комплексного підходу і взаємозв'язку кліматичних та ґрунтових особливостей, теоретичних розрахунків, математичних моделей, експериментальних, виробничих та лабораторних досліджень, показано вплив робочих органів зернозбиральних молотильних агрегатів барабанних і роторних типів на мікро травмування насіння, та його вплив на розвиток мікроорганізмів і у взаємозв'язку на якісні показники насіння, від чого суттєво залежить урожайність культури. Надана авторами математична модель пошкодженої пружино-в'язкої еліпсоїдної зернівки свідчить, що під час сили імпульсу ударів відносної і абсолютної траєкторії руху та дії прискорення, сил Коріоліса, інерції, тертя при збільшенні частоти обертання барабана або ротора при зіткненні зернівок масою 0,03-0,06 г з поперечним діаметром 3-5 мм в межах 600-700 об/хв деформація становить 0,015-0,035 мм, а пошкодження значно зростають від зниження міцності насіння, напруження та зусилля. Мікротравмування при обертах барабана від 700 до 1000 збільшується майже у 9 разів, а ротора відповідно у 3 рази. Мікротравмування насіння сорту Фортуна перед збиранням становило 4,5 %, а після вивантаження 56,2 %, а сорту Ювілейна відповідно 5,1 та 59,3 %. Макротравмування насіння перед обмолочуванням обох сортів були зовсім відсутні то після вивантаження зерна із бункера комбайна вони становили 7,3 та 6,2 %. Пошкодження мікроорганізмами, зокрема Фузаріозом у сорту Фортуна після обмолочування зросло до 40,1 %, Гельмінтоспоріозом до 24,3 %, Септоріозом до 13,6 %, Альтернаріозом до 4,6 %, а у сорту Ювілейна відповідно до 18,2; 13,0; 11,8 та 3,9 %. Під час проходження технологічного процесу обмолочування, пошкодження, травмування і мікроорганізми впливали на якість насіння, зокрема у сорту Фортуна чистота при вивантаженні становила 96,2 %, кількість насіння бур'янів у штуках на 1 кг-281, схожість 92,1 %. Маса в грамах 44,0, натура 741 г/літр, сира клейковина 24,6, а білок 14,7. Відповідно у сорту Ювілейна ці показники становили 95,0; 170; 94,8; 44,4; 740; 23,1; 13,7. Вологість зернової маси після збирання обох сортів знаходилась у межах 14,6 та 14,3 %

Ключові слова: сила; імпульс ударів; швидкість; зернівка; мікротравми; мікроорганізми; урожайність