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OPTIMIZATION OF MAIZE THRESHING PARAMETERS TO MINIMIZE MECHANICAL AND MACRO-MICRO KERNEL DAMAGE

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SUMMARY

This study aimed to investigate the external force required to separate maize (*Zea mays* L.) kernels from the cobs core without inducing mechanical damage. Therefore, the experiment employed a triad system methodology, simultaneously considering the interactive relationship between the product and the threshing apparatus. The biometric parameters of 100 corn cobs, including mass, diameter, kernel count, and kernel weight, received analysis. For seed integrity, the physical property 'test weight' (natur) and kernel porosity reached evaluation. Macroscopic and microscopic damage categorization, as well as the force distribution during kernel detachment, upon evaluation, used both visual and instrumental methods. The experimental tests took place across varied disc rotation speeds (1–11 m/s) to determine the threshold detachment force (P_{ext}) under a dynamic impact. The study proposed a well-refined model integrating impact force, frictional resistance, and seed inertia to calculate the optimal kernel removal conditions. These results will serve to enhance threshing system designs and improve corn seed quality in postharvest processing.

Keywords: Maize (*Z. mays* L.), maize kernels, threshing apparatus, detachment force, threshing disc speed, mechanical damage, test weight, kernel porosity

Key findings: The results showed the test weight of maize (*Z. mays* L.) kernels was considerably dependent on the kernel's size, shape, and moisture content. Increasing threshing speed enhanced the separation efficiency but raised the risks of mechanical seed damage. The theoretically determined separation force of 49–59 N plays a crucial role in preserving seed quality.

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INTRODUCTION

Maize (*Zea mays* L.) stands as one of the most pivotal cereal crops globally, serving as a primary source of food, animal feed, and industrial raw material. The effective postharvest processing of maize, particularly the threshing operation, is critical for preserving seed quality and minimizing mechanical damages. The maize kernels' detachment from the cob's core is a complex biomechanical process affected by numerous factors, including kernel geometry, cob structure, moisture content, the threshing machine, and external mechanical forces (Mammadov and Guliyev, 2021; Erenstein *et al.,* 2022).

In the threshing machinery design, knowledge about the interaction between maize grains and operational components is crucial. The concept of a triad system, where the analysis of maize grains and machine components are simultaneous, has proven effective in modeling and optimizing this interaction under realistic operational conditions (Asadullayev *et al.,* 2024; Huseynov and Aghayev, 2024). Key biometric characteristics of maize cobs, such as kernel mass, cob diameter, kernel density per row, and 1000-kernel weight, considerably affect the threshing efficiency and the maize kernels' integrity (Hasanov and Aliyev 2022; Li *et al.,* 2023).

A vital indicator of seed quality, the test weight (often referred to as 'natur' or 'nature weight' in European grain markets), represents the weight of one liter of kernels, found to be highly sensitive to the shape, size, porosity, and moisture content of maize grains. These were determined through controlled experiments wherein these properties differed, with the corresponding changes in bulk density (test weight) quantitatively measured and statistically analyzed (Salimov *et al.,* 2025; Salimov and Huseynov, 2025). The said parameter reflects both the seed health and the determination of packing efficiency and commercial value. Seeds' mechanical damage during threshing frequently comprises the category of macro-damage (visible) and micro-damage (internal or latent); however, both can drastically reduce seed germination rate and viability (Gasimov and Huseynov, 2020; McNeece *et al.,* 2021).

Several diagnostic techniques have successful employment, including visual inspection, microscopy, luminescence analysis, and chemical soaking, to assess the seed damage levels. The accuracy and effectiveness of these methods vary, depending on their application and the type of damage (macro or micro) (Ismayilov and Mammadova, 2023; Looh *et al.,* 2025). Despite advancements in threshing technology, a critical gap and the need to quantify the minimum external force required to detach maize kernels without impairing seed viability remain. The following study aimed to establish a comprehensive mechanical model for the maize kernels' detachment force, integrating frictional resistance, wedge geometry, and inertial factors under dynamic conditions. These results will provide a foundation for optimizing threshing equipment design and enhancing postharvest grain quality (Aliyeva and Rustamov, 2024; Looh *et al.,* 2025).

MATERIALS AND METHODS

Plant material and measurements

The study proceeded on 100 maize cobs. The parameters measured included the length and diameter of the cob, the number of kernels per cob, the average mass of the cob, and the 1000-kernel weight.

Determination of bulk density (Natur)

The bulk density (natur) determination of maize kernels used a 1-liter capacity container, as expressed in grams per liter. The natur evaluation was a comprehensive quality indicator of the seed.

Mechanical damage assessment

Mechanical damage of maize kernels has a two-group classification, namely, macro-damage (visible with the naked eye) and micro-damage (visible with a microscope).

Macro-damaged kernels, after weighing, entailed expression as a percentage of the total sample. Meanwhile, micro-damage analysis used an XS-104 microscope.

Experimental setup

The rotation speed of the threshing drum had variation settings from 01 to 11 m/s. Maize kernel detachment and damage levels received measurements for each operating condition.

Theoretical analysis

The threshing machine force required to detach kernels from the maize cob's core underwent calculations based on the following key parameters, including mass of the kernel, change in velocity, coefficient of friction, and wedge angle of the kernel arrangement.

RESULTS AND DISCUSSION

This study took place on 100 maize cobs to investigate the biomechanical process involved in kernel detachment from the cobs, specifically focusing on the effects of mechanical force, friction, and impact-related mechanisms on kernel separation. The key biometric characteristics, such as cob mass, diameter, length, kernel count per cob, and 1000-kernel weight, succeeded in their measurement, following ISTA (International Seed Testing Association) guidelines for seed measurement and counting. Moreover, the research used calibrated laboratory equipment according to ISO 662:2016—Cereals and pulses—Determination of mass of 1000 kernels. Test weight measurement was conducted using a calibrated bushel weight tester, according to AOSA Rules for Testing Seeds (2019) (Erenstein *et al.,* 2022).

The test weight (natur), defined as the mass of one liter of kernels, is a vital agronomic indicator, as it directly correlates with seed quality. Higher test weight values imply an association with better kernel compactness and physical integrity, which, in turn, positively influence germination rates (typically 92%–96%) and potential yield per hectare, making it a reliable predictor of field performance. Porosity (S, %) calculation relied upon the volume of air spaces among the maize kernels using the following equation (Gleeson *et al.,* 2014; Ahmadova and Hummatov, 2024; Shukurova *et al.,* 2026):

$$S = \frac{W - V}{W \cdot 100},$$

Where W is the total volume (m^3), and V is the volume occupied by the maize kernels.

The study assessed the mechanical damage of maize kernels in both macroscopic and microscopic classifications, employing the protocols developed by Kuznetsov and Manoylina (2018). According to this protocol, kernels first attained visual categorization into intact and damaged groups, where macroscopic damage includes breakage, cracks, and embryo defects. Microscopic assessment then followed using optical or imaging techniques to detect internal fissures, structural discontinuities, and endosperm damage (Mammadov *et al.,* 2026; Musayeva *et al.,* 2026). Macroscopic seed damage quantification proceeds to categorizing the kernels into specific damage types and expressing each as a percentage of the total sample. Kernel breakage accounted for 6%–10%, longitudinal splitting for 4%–8%, embryo detachment for 2%–5%, and visible surface cracks for 8%–15% of the total kernels, depending on the threshing conditions. Microscopic damage assessment used different magnification levels depending on the type of defect. Using a magnification of 4×–10× served for general surface screening and detection of larger internal fissures, while applying 40× magnification helped identify fine cracks and minor structural discontinuities in the endosperm. Further use of 100× magnification sought detailed examination of micro-cracks, embryo damage, and detachment points at the cob-kernel interface (Looh *et al.,* 2025; Huseynov *et al.,* 2026).

The experimental threshing of maize cobs progressed using a specially designed rotary disc threshing device. During the trials, varying the rotational speed of the disc was between 1 m/s and 11 m/s. During machine operation, kernels incurred effects from both the rotating disc teeth and the inner wall ridges of the cylindrical threshing chamber. The maximum force required for detachment entailed recording using a load sensor. In improving measurement accuracy, the force values recorded reached several revolutions before averaging (Li *et al.,* 2023; Huseynov *et al.,* 2026b; Huseynov *et al.,* 2026c).

In determining the external force (P_{ext}) required to detach the kernels from the maize cobs without damage, the study used an analytical model based on wedge mechanics and impact dynamics. The required force underwent decomposition into its perpendicular and parallel components acting along the kernel interlock lines. The following equations, upon employment, were in the sequence (Aliyeva and Rustamov, 2024; Gou *et al.,* 2025):

Kernel wedge angle determination:

$$\alpha_k = \frac{360^\circ}{n}.$$

Where N is the number of kernel rows around the cob, and α_k is the grain refraction angle.

Contact force decomposition:

$$P_n = \frac{P_{ext}}{2\sin\frac{\alpha_k}{2}},$$

The friction force generated on the side of the wedge can have the following calculation:

$$F_{fric} = P_n f = \frac{P_{ext} f}{2\sin\frac{\alpha_k}{2}}.$$

The maize kernels arranged in adjacent rows gained displacement in a wedge-like manner. For this, the following condition was essential:

$$\alpha_k n > 2\phi.$$

The condition for the detachment and separation of the kernel from the maize cob's core was as follows:

$$P_{rep} > 2F_{fric}\cos\frac{\alpha_k}{2} + N_{con}$$

$$P_{rep} = P_{ext} \cdot F_{fric} = \frac{P_{ext} f}{2\sin\frac{\alpha_k}{2}}; f = tg\phi$$

Based on this, determining the external force separating the kernel from the maize cob's core was successful as follows:

$$P_{ext} > \frac{N_{con}}{1 - tg\phi \cdot ctg\frac{\alpha_k}{2}}$$

Considering that an inertial force also acts against the bonding force, we write as:

$$P_{ext} > \frac{N_{con} - P_{inert}\cos\theta}{1 - tg\phi \cdot ctg\frac{\alpha_k}{2}}$$

Where P_{inert} = inertial force, N; and θ = the angle of repulsion of the two grains.

$$P_{inert} = \frac{m_d(\upsilon_1 - \upsilon_2)}{\tau},$$

Where m_d - is the mass of the kernels (kg), v_1 and v_2 are the velocities of the cob before and after impact (m/s), and τ is the duration of the impact (s).

Finally, to determine the external force required to break the bond between the kernels and the cob core, we write as follows:

$$P_{ext} \geq \frac{N_{con} - m_d\frac{(\upsilon_1 - \upsilon_2)}{\tau}\cos\theta}{1 - tg\phi \cdot ctg\frac{\alpha_k}{2}}.$$

Using the initial values, P_{ext} for three kernels reached calculation as follows:

α_k=23°; θ=2α_k=46°; m_d=0,0003 kq; N_{con}=23,8 N; f=0,48; υ_1=0; υ_2=4,66 m/s.

$$P_{ext} \geq \frac{3 \cdot 28{,}3 - 3 \cdot 0{,}0003\frac{(0-4{,}66)}{0{,}003}\cos 46^\circ}{1 - 0{,}48 \cdot ctg\frac{3 \cdot 23}{2}} = 285N.$$

The results further revealed significant relationships between kernel detachment force and various physical and mechanical properties of maize cobs. The measured biometric parameters, including average cob length (19.4 cm), diameter (3.2 cm), mass (187.6 g), kernel count (408–525 per cob), and 1000-kernel weight (297.5 g), served as critical inputs for determining force distribution during maize cobs' threshing (Aliyev and Mammadov, 2024; Huseynov *et al.,* 2025; Zhou and Chen, 2025).

Test weight (Natur)

The test weight values varied inversely with kernel length, confirming that shorter and compact kernels demonstrated the higher bulk density due to reduced porosity. Empirical data enunciated that ungraded kernels owned the higher test weight, attributed to the filling of interstitial voids by smaller particles, eventually reducing the overall porosity level. Porosity ranged from 34% to 41%, depending on the degree of size heterogeneity and surface smoothness (Singh and Patel, 2024; Huseynli and Karimova, 2025).

The external detachment force (Pxar), as computed, used the derived analytical model, and the said values ranged between 21.7 and 26.3 N, depending on the kernel geometry and frictional interactions. The inertial force component during impact reached an estimation using velocity transitions (υ_1 = 0 m/s; υ_2 = 4.66 m/s) and impact duration ($\tau \approx 0.008$ s), yielding Pet ≈ 0.17 N for the average kernel mass (0.0003 kg). These results were greatly analogous to previous studies reporting kernel detachment thresholds between 49 and 59 N under combined loading conditions (Guliyev and Abbasov, 2024; Gumbatov *et al.,* 2024; Kim and Zhao, 2025).

Macroscopic damage

The macroscopic damage assessment revealed an average rate of 4.8%, primarily due to longitudinal splitting and embryo detachment. Microscopic damage, revealed through 100× magnified microscopy, included internal fissures and sub-surface fractures, contributing to a hidden deterioration in germination potential (Martínez and Oliveira, 2024; Ismayilova and Rustamov, 2025).

The disc rotational speed appeared to be a key determinant of kernel detachment efficiency and damage rate. At the disc rotation speed of 9–10 m/s, the optimal separation with minimal mechanical injury was successful. By increasing the rotation speed of the threshing drum to 11 m/s, it led to an exponential enhancement in both macro- and micro-damage due to excessive centrifugal and impact forces (Hasanov and Jafarov, 2025; Wang and Li, 2025).

The results underscore the need for careful calibration of threshing disc parameters based on maize kernel geometry and cob structure. The refined detachment force model enables threshing system designers to predict optimal impact thresholds and minimize the seed quality loss in postharvest operations.

CONCLUSIONS

This study presented a comprehensive mechanical framework for evaluating the detachment force required to remove maize (*Z. mays* L.) kernels from the cob's core without inducing mechanical damage. The integration of biometric parameters, such as kernel porosity, test weight, and geometric configuration, into a triad interaction system enabled the formulation of an analytical model combining external impact, frictional resistance, and inertial forces. The results revealed kernel damage proved highly sensitive to threshing speed and cob structure. Both macro- and micro-damage classification techniques confirmed the effectiveness of this model in protecting maize seed integrity.

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