



INVESTIGATIONS BASED ON HUSK REMOVAL FROM MAIZE (*ZEa MAYS* L.) EARS

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SUMMARY

The maize (*Zea mays* L.) crop holds strategic importance for food and feed industries in Azerbaijan and worldwide. During production processing, the kernels' damage directly affects grain storage durability and quality. When feeding husked ears into stationary threshers, kernel damage considerably increases, causing serious losses in the food industry and seed production. However, to minimize these threshing problems, the preliminary use of rubber-surfaced roller husk removers is of foremost importance. These husk removers separate the husks more smoothly from the cobs, considerably reducing mechanical damage to the kernels, and consequently, the product quality improves and decreases processing losses. In the presented study, the best possible ear deformation angle (ψ_a) that ensures prompt and delay-free husk removal reached successful determination experimentally for three Zaqatala maize cultivars. This parameter plays an important role in minimizing kernel damage during mechanical processing. Experiments conducted had maize ear moisture contents of 28.8%–32.4%, which also seemed the optimal technological condition for maize processing. The results revealed that correct selection of the ear deformation angle preserves kernels' integrity while concurrently increasing productivity of the processing equipment. These parameters will enable the development of more efficient technologies in the future.

Keywords: Maize (*Z. mays* L.), husk removal, ear deformation angle, rubber roller husker, postharvest technology, Zaqatala maize cultivars, kernel damage reduction

Key findings: The maize (*Z. mays* L.) ear deformation angle (ψ_a) considerably enhanced with rising husk pulling speed. Within the compressive force range of 85–457 N, the effect on the optimal angle was minimal. A 90° pressure direction combined with a roller surface that follows the ear curve considerably reduced the risk of kernel damage in maize.

Communicating Editor: Dr. Sajjad Hussain Qureshi

Manuscript received: April 17, 2026; Accepted: June 28, 2026

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Citation: Mammadov AI, Mammadova NO, Mammadova GA, Huseynov MA, Mammadov NA (2026). Investigations based on husk removal from maize (*Zea mays* L.) ears. *SABRAO J. Breed. Genet.* 58 (5) 2502-2511. <http://doi.org/10.54910/sabrao2026.58.5.49>.

INTRODUCTION

Postharvest processing is one of the most decisive stages in maize (*Zea mays* L.) production. Obtaining high-quality maize kernels, the crop products' storage and further processing depend on proper agronomic practices and the efficient organization of postharvest operations. In maize production, the primary objectives should be preserving the kernels' integrity, minimizing damage, and ensuring that the product is suitable for long-term storage (Darfour and Rosentrater, 2022; Asadullayev *et al.*, 2024; Huseynov *et al.*, 2026a). In conventional stationary threshers, feeding ears with intact husks results in high levels of kernel damage, which leads to both quantitative losses and a decline in kernel quality. Maize-damaged kernels spoil rapidly during storage and considerably become more vulnerable to fungal and bacterial decay, often becoming unsuitable for seed purposes. Therefore, the application of new technological solutions to minimize kernel damage in maize production is essential (Yewle *et al.*, 2024; Demir and Çolak, 2023; Mammadov and Mammadova, 2025b).

Recent past research enunciated the preliminary use of rubber-surfaced roller husk removers considerably reduced the kernel damage in maize (Zhang *et al.*, 2024; Chen *et al.*, 2025). Chen *et al.* (2025) investigated the design and operating principles of a mobile seed maize husking machine. The authors demonstrated the rubber-coated working elements provide a gentler interaction with the ear, ensure gradual husk removal, and significantly reduce mechanical damage to kernels. This is particularly important for seed maize, where maintaining germination capacity is a critical requirement. Zhang *et al.* (2024) studied the husk removal and kernel damage process in roller-type husking systems using high-speed video analysis. Their findings showed the rubber-surfaced roller mechanisms reduce impact and friction forces acting on the kernels compared with conventional metallic components. As a result, kernel integrity gains better preservation, with processing losses considerably reduced (Mammadov and

Mammadova 2025a; Huseynov *et al.*, 2026b, Huseynov *et al.*, 2026c).

This type of equipment separates the husks more gently from cobs, minimizes mechanical impact, and protects kernel integrity. As a result, the product quality enhances, processing losses decrease, and economic efficiency for producers improves. The ear deformation angle is a key parameter that directly manipulates the level of kernel damage during mechanical processing. However, if the angle is too small, the removal of husks is incomplete, compressing the kernels and damaging the maize. Conversely, if the angle is too large, the husks' removal is too rapid; consequently, the increased mechanical stress can again damage the kernels. Hence, identification of the optimal angle is more crucial from both technological and economic perspectives (Demir and Çolak, 2023; Chen *et al.*, 2025).

Experiments performed on maize ears had moisture contents in the range of 28.8%–32.4% (Li *et al.*, 2021; Huseynov *et al.*, 2025; Huseynov and Aghayev, 2024). This moisture level was the considered optimal for maize processing, as excessively dry ears proved sensitive to mechanical impact, while overly, the moist ears create stickiness during husking. Therefore, past findings detailed that the determined optimal deformation angle reduced the kernel damage by a factor of 2–3 and also improved the storability of the final product (Chen *et al.*, 2025; Musayeva *et al.*, 2026; Salimov and Huseynov, 2025).

The practical significance of the following research lies in the fact that the obtained results will provide essential parameters for the designing of the industrial husk removers. Maize processing enterprises can also optimize their equipment by accounting for these indicators, thereby improving both productivity and quality. Furthermore, these parameters emerged as important in seed production, as the less damaged kernels retain higher germination capacity (Chen *et al.*, 2025; Salimov *et al.*, 2025; Najafov *et al.*, 2026). Overall, the efficient organization of postharvest processing has a direct impact on product quality, economic efficiency, and producers'

profitability in maize production. In this context, the determination of the optimal ear deformation angle is of greater importance from a scientific research standpoint and also in meeting the practical needs of the industry (Yewle *et al.*, 2024; Darfour and Rosentrater, 2022; Demir and Çolak, 2023). Therefore, the presented study aimed to experimentally determine the optimal ear deformation angle (ψ_a) in Zaqatala maize cultivars.

MATERIALS AND METHODS

The experiments on husks' removal from maize (*Z. mays* L.) ears using a specially designed rubber-surfaced roller husk remover took place in the laboratory at the Institute of Agricultural Engineering, Baku, Azerbaijan. The unit comprised two counter-rotating rollers. The roller diameter was 150 mm, while the rubber hardness selected was at 60 Shore A. This rubber hardness level was the considered optimal for minimizing kernels' damage while ensuring effective husks removal. The rotational speed of the unit had the control of a frequency converter, controlling the precise adjustment of different speed regimes (Demir and Çolak, 2023; Chen *et al.*, 2025).

The required compressive force proceeded application via a pneumatic cylinder, with the force measurement performed with a calibrated load cell. The well-managed approach considerably enhanced the experimental accuracy and enabled comparison of various loading regimes. Freshly harvested ears of the maize cultivars Zaqatala, Zaqatala-68, and Zaqatala-514 were samples used in the trials. The selection of maize cultivars was not at random, as these cultivars were the most widely cultivated and industrially important in the region (Shukurova *et al.*, 2026).

The ear moisture content ranged from 28.8% to 32.4%. Moisture determination precisely used the oven-drying method, which is one of the most reliable laboratory techniques and ensured the accuracy of results. Maintaining moisture within this interval seemed optimal for maize processing, as very dry ears occurred sensitive to mechanical stress and very moist ears cause stickiness during husking (Yewle *et*

al., 2024; Li *et al.*, 2021; Darfour and Rosentrater, 2022).

For each speed-force combination, 50 ears per maize cultivar entailed testing. The experiments had replications three times to enhance statistical reliability. Thus, a total of 150 ears reached evaluation for each parameter combination. The said methodology ensured the stability and repeatability of the results. The ear deformation angle (ψ_a) recording was successful using a digital angle meter. In addition, high-speed video recordings continued to observe the dynamics of the husking process and to perform a visual analysis of mechanical effects. Through video analysis, the variation rate in the deformation angle, the completeness of husk removal, and the level of maize kernel damage gained assessment with greater precision (Tang *et al.*, 2024; Zhang *et al.*, 2024). All parameters, including roller speed, compressive force, ear moisture content, and varietal characteristics, underwent systematic variations and recording during the experiments. This systematic approach enabled a comparative analysis of the results and provided a reliable basis for determining the optimal deformation angle (Tang *et al.*, 2024; Jukić, 2024).

The experimental data obtained from the three replications incurred processing using descriptive statistical methods. Mean values, standard deviations (SD), and coefficients of variation (CV) reached calculations where appropriate. The average values reported in the tables and figures represent the mean of three independent experimental replications.

The obtained results analysis revealed the deformation angle (ψ_a) plays a crucial role in the efficiency of husk removal and the preservation of maize kernels' integrity. An increase in roller speed led to a corresponding rise in the deformation angle, which enhanced the husk's detachment; however, it also enhanced the risk of kernel damage beyond a certain threshold. Similarly, the compression force significantly influenced the said process. At lower force levels, husk removal was incomplete due to insufficient contact pressure between the rollers and the ear surface. However, excessive force resulted in structural damage to maize kernels. Therefore, an optimal

range of compression force attained detection, within which husk removal efficiency was at maximum, minimizing kernel damage (Li *et al.*, 2021; Kuliyeu *et al.*, 2026; Mammadov *et al.*, 2026).

The ear moisture content was another key factor affecting the process performance. Ears with moisture levels within the range of 28.8%–32.4% exhibited the balanced mechanical behavior, allowing effective husk separation without excessive deformation. Outside this range, either brittleness or excessive adhesion negatively influenced the process (Zhang *et al.*, 2024; Teymurov *et al.*, 2026; Sadigov *et al.*, 2026b). Comparative analysis among the tested maize cultivars revealed slight differences in deformation behavior due to structural and morphological characteristics. However, the general trend remained consistent across all maize cultivars, confirming the robustness of the identified optimal parameters (Mammadov, 2025; Chen *et al.*, 2025; Zafar *et al.*, 2026).

Overall, the results revealed the achievement of the optimal deformation angle was successful through a balanced combination of roller speed, compression force, and moisture content. These results provide a scientific basis for improving the design and operational parameters of next-generation maize husk removal machines, aiming to enhance the efficiency while minimizing grain mechanical losses (Li *et al.*, 2021; Gumbatov *et al.*, 2024).

RESULTS AND DISCUSSION

Postharvest operations, principally the processing of maize (*Z. mays* L.) ears in stationary threshers, represent one of the most critical stages in maize production. The experimental results revealed feeding maize ears with intact husks into the thresher considerably enhanced the probability of kernel damage. This leads to both quantitative losses in grain yield and a decline in seed quality. Damaged kernels spoil rapidly during storage, become more vulnerable to fungal and bacterial decay, and often emerge unsuitable for seed production. In this context, pretreatment of maize ears using rubber-surfaced roller husk

removers is essential (Kassa *et al.*, 2025; Mammadov *et al.*, 2025).

Previous studies emphasized that pre-removal of husk layers significantly reduced the mechanical stress on maize kernels during threshing, thereby lowering the probability of kernel breakage and quality deterioration (Tang *et al.*, 2024). Kassa *et al.* (2025) also reported the use of rubber-coated roller husk removers improved the postharvest processing efficiency and enhanced the storage stability by minimizing the grains' microbial susceptibility and structural damage.

Explanation of mechanical principles

During the 'grasping and pulling' process of husk removal, both the compressive force applied by the rollers to the ear and the pulling speed of the husks play a decisive role in ensuring high-quality processing. However, the key issue was the correct selection of the ear's efficient deformation angle (ψ_a). Therefore, if not selecting the optimal angle, then the husks may not reach complete removal, and the maize kernels will suffer mechanical damage (Dong *et al.*, 2023; Dong *et al.*, 2024).

The efficiency of the 'grasping and pulling' husk removal process mainly depends on the proper balance between the compressive force and the pulling speed, which directly determines the optimal deformation angle of maize ears (Dong *et al.*, 2023; Amanova *et al.*, 2026; Yusifova *et al.*, 2026). Dong *et al.* (2024) further emphasized that incorrect selection of this angle leads to incomplete husk removal and also increases mechanical damage to kernels, reducing overall processing quality.

Analysis of experimental results

Based on preliminary observations, the ear deformation angle (ψ_a) entailed experimental determination as a function of the roller pulling speed and the compressive force applied to the ears. Experiments continued using the maize cultivars Zaqatala, Zaqatala-68, and Zaqatala-514. For each cultivar, the deformation angle received measurement under different combinations of roller-pulling speed and compressive force. The obtained data

subsequently served to evaluate the relationship between operating parameters and ear deformation behavior.

Mechanical modelling

Mechanical modeling of the ear deformation angle exhibited that this variable primarily depends on the modulus of elasticity, frictional force, and the morphological structure of maize ears. When elasticity is high, the husks' pulling and removing are easier, and the higher elasticity reduced the stress concentration during contact with threshing elements (Chen *et al.*, 2023). In this context, the frictional force determines the intensity of contact between the roller and the maize ears. If the friction force is too low, the husks may not gain full removal; and if the said force is excessively high, kernel damage could occur (Dong *et al.*, 2023; Tang *et al.*, 2024). The optimal deformation angle attained determination from the balance between these two forces, which has been evident to influence the kernel breakage and threshing efficiency in mechanical models of maize processing (Chen *et al.*, 2023; Tang *et al.*, 2024).

Previous studies stated the ear deformation angle received robust influences from the modulus of elasticity, as higher elasticity better facilitates husk removal and reduces the stress concentration during contact with threshing elements (Chen *et al.*, 2023). Dong *et al.* (2023) and Tang *et al.* (2024) further emphasized that frictional force is a key determining factor in roller-ear interaction, where insufficient friction leads to incomplete husk removal. Meanwhile, excessive friction causes kernel damage, proving that the balance between these forces is essential for optimal deformation and threshing efficiency.

Maize cultivars' comparison

Morphological differences were evident among the different maize cultivars, and these varietal variations influenced the processing parameters and mechanical behavior. Maize cultivars with

thicker husks generally require greater deformation before effective husk removal occurs, whereas thinner husks allow effective removal at smaller deformation angles (Dong *et al.*, 2023; Tang *et al.*, 2024).

Role of moisture content

Increased moisture content enhances the elasticity of the ear, thereby facilitating the husking process. Decreased moisture makes the ear more brittle and raises the risk of kernel damage. The experimental results revealed the 28.8%–32.4% ear moisture interval was optimal. Within this moisture range, both the speed of husk removal and kernel integrity attain preservation. However, when ear moisture content decreased below 25%, the deformation angle needs reduction by approximately twofold (Figure 1) to minimize kernel damage (Zhang *et al.*, 2024). Their findings further detailed that increasing moisture content improves ear elasticity, which facilitates husk removal and helps in preserving the kernel's integrity during processing (Zhang *et al.*, 2024). They further emphasized the optimal moisture range of 28.8%–32.4%, while moisture levels below 25% require a significant reduction in deformation angle to prevent kernel damage.

Effect of pulling speed

Based on the experimental results, the favorable deformation angle of the ear in different maize cultivars, as determined, had husk pulling speeds ranging from 0.08 to 6.54 m s⁻¹, as presented in Table 1. The ear's moisture content ranged from 28.8% to 32.4% (Figure 2). The results also revealed that an increase in husk pulling speed requires a larger ear deformation angle. This phenomenon had the explanation of the reduction in contact time at higher speeds. In other words, when the rollers rotate faster, the ear must undergo greater deformation to ensure the complete husk removal (Dong *et al.*, 2023; Tang *et al.*, 2024).

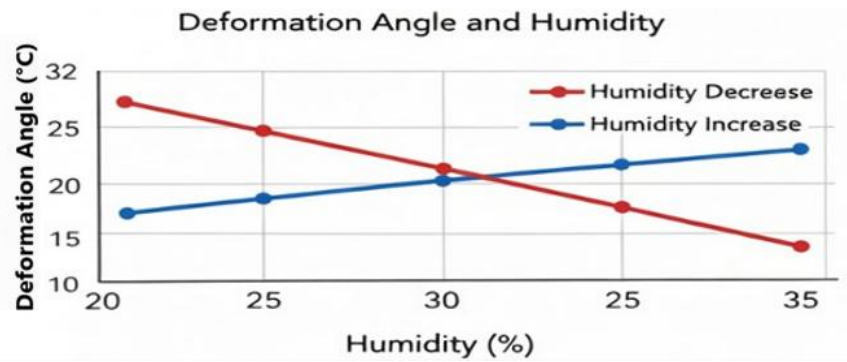


Figure 1. Effect of humidity on ear husk removal and kernels' quality in maize.

Table 1. The limiting ear deformation angle depending on husk-pulling speed (degrees).

Maize cultivars	Coat tensile rate / ear deformation angle (degrees)				
	0.08	2.40	3.30	4.70	6.54
Zagatala	21.8	26.4	28.2	29.0	30.9
Zagatala-68	21.5	21.7	23.2	25.2	28.9
Zagatala-514	25.4	25.4	27.0	29.7	33.2

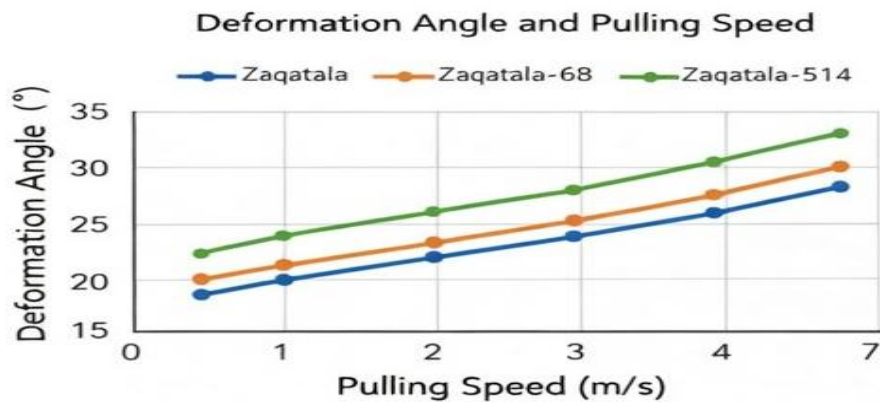


Figure 2. Effect of pulling speed on ear husk removal and kernels' quality in maize.

Dong *et al.*'s (2023) findings disclosed that the favorable ear deformation angle increased with the husk pulling speed due to the reduction in contact time between the rollers and the ear, which necessitates greater deformation for complete husk removal. Tang *et al.* (2024) also confirmed this relationship has a considerable influence from process dynamics, where the higher rotational speed requires enhanced deformation to maintain husking efficiency across the different maize cultivars.

These experimental values received valid recognition for freshly harvested ears with relatively high moisture content. For ears with reduced moisture and partially degraded husks, the ear deformation angle must be reduced by a factor of two. The results exhibited that a decrease in moisture content also reduces the mechanical elasticity of the ear, and the husk removal may occur at smaller angles (Zhang *et al.*, 2024).

Effect of compressive force

The variations in the favorable ear deformation angle as a function of the compressive force applied by the pressing mechanism to the rollers appear in Table 2. The results indicated that the compressive force had no statistically significant effect on the limiting ear deformation angle ($P > 0.05$) (Figure 3). Experiments have shown that the highest effect emerged when the direction of pressure on the ear was 90°. However, this situation was possible only when intensive sliding contact between the ear and the working element is precise. Such contact requires the surface of the working element to be designed in the form of a contour-copying surface that follows the maize ears' shape (Dong *et al.*, 2023; Tang *et al.*, 2024).

The study findings signified that as husk-pulling speed increases, the ear deformation angle must also increase, as explained by the reduction in contact time between the rollers and the ear at higher

speeds. The compressive force has proven to have a negligible effect on the limiting deformation angle. Experimental results further showed the highest efficiency achieved was when the pressure direction was at 90° and when the roller surface had the design closely following the contour of the maize ears. These recommendations can be applicable in industrial husk removal systems, which could reduce the kernel damage by 15%–25% (Figure 1), thereby considerably improving overall productivity (Dong *et al.*, 2023; Tang *et al.*, 2024).

These parameters obtained valid recognition for freshly harvested ears with a moisture content of 28.8%–32.4%. For ears with lower moisture content and degraded husks, the deformation angle needs reduction by approximately a factor of two. The application of the recommended parameters in industrial-type husk removers will substantially reduce the kernel damage and increase the productivity of postharvest processing.

Table 2. The limiting ear deformation angle depending on the compressive force applied to the ear by the rollers (degrees).

Maize cultivars	Compressive force applied to the ear by the rollers / ear deformation angle (degrees)				
	85	178	271	364	457
Zagatala	30.0	30.4	30.4	31.1	31.1
Zagatala-68	25.0	25.5	26.1	29.0	29.0
Zagatala-514	32.0	32.3	32.3	33.0	33.1

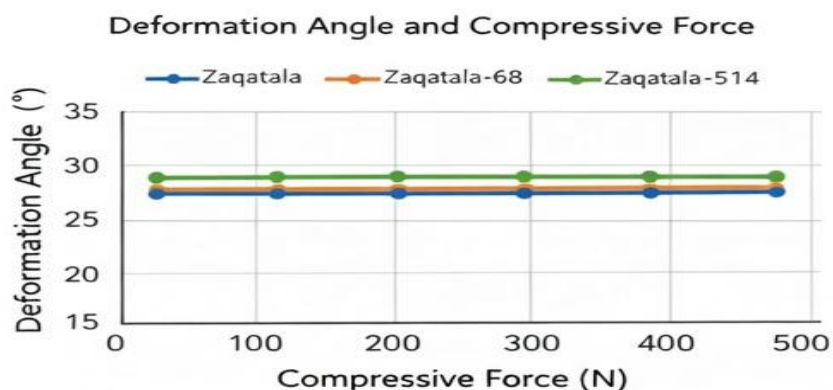


Figure 3. Effect of compressive force on ear husk removal and kernels' quality in maize.

CONCLUSIONS

The study determined the optimal ear deformation angle (ψ_a) for effective husk removal using a rubber-surfaced roller for the three Zaqatala maize (*Z. mays* L.) cultivars. The deformation angle significantly enhanced with rising husk-pulling speed and ranges from 21.5° to 33.2° within the speed interval of 0.08–6.54 m/s. Within the compressive force range of 85–457 N, the effect on the optimal angle was minimal. The highest efficiency occurred when the applied pressure was at the 90° angle to the ear axis and the roller surface copied the contour of the ear.

ACKNOWLEDGMENTS

The author expresses gratitude to the technical staff of the Azerbaijan State University of Economics (UNEC), Baku, Azerbaijan, for their assistance in conducting the experiments.

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