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## PHYSICAL AND MECHANICAL PROPERTIES OF CORN COBS AND KERNELS PROCESSED IN AN UPGRADED THRESHING MACHINE

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### SUMMARY

The study comprised investigations based on the physical and mechanical properties of maize cobs and kernels using the ameliorated or upgraded threshing machine. The study considers the maize seeds classification into two shape categories of round and flat, based on their positional characteristics and dimensions. The measurement criteria included the average seed thickness (hor), width (bor), and length (lor). Additionally, the seed dimensions and mass determination primarily depended on the 1000-kernel weight and the scrutiny of variations in the biometric traits, moisture content, and other internal properties of various cultivars. The size and mass traits of the cob and its core, the frictional and aerodynamic properties, the natural inclination angle of the kernel, and the static forces affecting its dispersion also entailed analysis. The promising results can serve as a baseline for optimizing the threshing machine and minimizing kernel losses during postharvest processing.

**Keywords:** Maize (*Z. mays* L.), cob size, maize kernels, kernel mass and size, moisture, correlation, frictional properties, postharvest processing

**Key findings:** Physical and mechanical properties of maize (*Z. mays* L.) cobs with different maturity stages helped in selecting proper parameters and operating modes in the threshing machine used in postharvest processing to minimize yield losses.

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## INTRODUCTION

The timely study provides detailed information on the applied research methods based on the analysis of meteorological influences observed in different growing seasons and the comparative traits of various maize (*Zea mays* L.) cultivars. Moreover, the provision of recommendations helps optimize the threshing machine parameters for increased productivity and reduced postharvest losses. These aspects underline the practical significance of the research and its pivotal role in the development of sustainable agricultural technologies (Erenstein *et al.*, 2022).

By studying the bibliometric trends and insights on the potential of maize (*Z. mays* L.) genotypes over different growing seasons revealed there exists a certain linear relationship between kernel weight and linear dimensions. Particularly, the correlation coefficient between grain weight and the transverse section varies from 0.693 to 0.738 (Kotu *et al.*, 2022; Padhan *et al.*, 2024).

For categorization purposes, maize seeds succeeded in dividing conditionally into two groups based on shapes, as round and flat. The rounder and larger seeds typically appear on the lower part of the cobs, while the smaller seeds are evident on the upper part. The main mass, comprising flat seeds, emerges in the middle of the cobs. Regarding their dimensions, these seeds were more uniform than those found in the lower and upper regions of the cob and, therefore, grouped separately. For the characterization of maize seeds, criteria such as hor (the average thickness of the seed in mm), bor (the average width of the seed in mm), and lor (the average length of the kernel in mm) have been operational (Bi *et al.*, 2024).

As a result of the sorting process, selecting first the maize kernels was according to size and the 1000-kernel weight, as determined (Table 1) (Omar *et al.*, 2023; Shi *et al.*, 2025; Xue *et al.*, 2025). The presented study also aimed to carry out the investigations based on the physical and mechanical properties of maize cobs and kernels used under the ameliorated machine (Salimov and Huseynov, 2025).

## MATERIALS AND METHODS

The study selected the three most widely cultivated maize cultivars in Azerbaijan, comprised of Zaqatala, Zaqatala-68, and Zaqatala-514. Within the batch of maize harvested from the field, they underwent direct threshing, with the cobs classified for research purposes based on kernel moisture content, as follows: dry (up to 16%), moderately dry (16%–18%), moderately moist (18%–20%), and fresh (above 20% moisture) (Mamedov, 2015).

The kernel dimensions' recording had their ranges, as follows: length (6 to 14 mm), width (5.5 to 12 mm), and thickness (3 to 8 mm). The differences in measurements ranged from 2 to 6 mm, and most maize kernels exhibited dimensional differences between 0.8 and 2.5 mm. The correlation also involved detection of the kernel mass and its linear dimension. The considerable correlation was notable between mass and width, and the correlation coefficient ( $r$ ) ranged from 0.693 to 0.738. However, these values exceeded the threshold value of  $r = 0.127$ , and it was reasonable to assert a linear dependency between the kernel mass and width (Mamedov *et al.*, 2015; Huseynov *et al.*, 2025).

**Table 1.** Corn kernels with different botanical traits and 1000-kernel weight.

No.	Botanical characteristics	1000-grain weight (g)	
		Minimal	Maximal
1	Flint-like	200	450
2	Tooth-shaped	200	520
3	Semi-tooth-shaped	200	400
4	Starchy	170	300
5	Popping	105	140

**Table 2.** Variations in biometric indicators of corn cobs over the years.

No.	Indicators	Measurement unit	Cultivation year		
			2022	2023	2024
1	Cob diameter	mm	41.0±1.3	39.4±1.7	42.3±0.5
2	Cob length	mm	117.0±4.9	117.1±5.1	200.8±3.9
3	Number of kernels on the cob	Unit (s)	395±17	350±29	482±22
4	Mass of kernels on the cob at 14% moisture	g	117±7.1	97±10.2	132±6.0
5	Mass of 1000 kernels at 14% moisture	g	301±6.0	277.0±16.0	273±11.0
6	Cob core diameter	mm	21.9±0.4	22.6±0.9	24.1±0.4
7	Mass of the cob core at 14% moisture	g	16.8±1.8	14.2±0.8	27.2±0.9

**Table 3.** Size-mass characteristics of corn cobs.

No.	Length (mm)	Total mass (%)	Diameter (mm)	Total mass (%)	Mass (kg)	Total mass (%)
1	Up to 100	9	Up to 35	10	0.05–0.15	28
2	150–200	51	35–40	52	0.15–0.2	50
3	200–250	40	40–45	38	0.2–0.3	22

## RESULTS AND DISCUSSION

The mass and dimensions of the maize cobs may vary within different limits based on the type and cultivar. However, since maize cobs and kernels are biological masses, even kernels from the same type and cultivar could exhibit varying masses, dimensions, and biometric characteristics across different growing seasons (Table 2) (Liu *et al.*, 2017).

Variations in the biometric characteristics of maize cobs in terms of different seasons seemed primarily related to changes in the meteorological conditions during the kernel formation and development period. In October 2024, the total rainfall was only 10.4 mm. Correspondingly, the maize cobs harvested during that crop period showed the lowest value of the 1000-kernel weight (Quliyev and Huseynov, 2019).

Among the biometric parameters, the most influential during the postharvest processing of maize cobs were the average diameter of cobs and their cores, as well as their overall shape. Observations revealed the gap between the husks during dehulling precisely based on the variation between the cob diameter and its core. However, this phenomenon can refer solely to the cylindrical cobs. In contrast, conical cobs entailed division into two unequal parts during processing.

Therefore, the cob shape requires consideration when aligning the husk removal apparatus to prevent kernel losses (Aliyev *et al.*, 2017; Salimov *et al.*, 2025).

The overall mass, size, and mass characteristics of the maize cobs utilized in the concerned study are available in Table 3. The percent ratio of the kernel mass to cob core mass was as follows: the kernels accounted for 74.1%–80.5%, while the cob core represented 25.9%–19.5%. The hygroscopic properties of the kernels and the cobs core were also significantly different. In cobs with a moisture content of up to 16.7%, the maize kernel exhibited a higher moisture content than the cob core; in cobs with a moisture content exceeding 16.7%, the moisture content in the maize kernels was lower than that of the cob core (Quliyev and Huseynov, 2019).

The bulk densities of the maize cobs, cob cores, and kernels varied within the following ranges: for cobs (350 to 450 kg/m<sup>3</sup>,  $\sigma = 35.1$  kg/m<sup>3</sup>,  $v = 5.3\%$ ); for cob cores (200 to 250 kg/m<sup>3</sup>,  $\sigma = 7.3$  kg/m<sup>3</sup>,  $v = 2.7\%$ ); and for kernels (600 to 800 kg/m<sup>3</sup>,  $\sigma = 9.4$  kg/m<sup>3</sup>,  $v = 1.3\%$ ) (Rahimov, 2017). In a bulk sample of loosely collected kernels, the air void between the kernels sustained characterization by the percentage ratio of the void volume to the total volume of the sample. The said parameter was 54.5% for large maize kernels,

**Table 4.** Natural angle of repose of corn cobs.

No.	Tray surface material	The initial rolling angle of the upper cobs relative to the lower cobs (degrees)		Tray inclination angle at the moment the lower cobs start moving (degrees)	
		*Kernel moisture content: 14.1%	* Kernel moisture content: 33.7%	* Kernel moisture content: 14.1%	* Kernel moisture content: 33.7%
		*Cob core moisture content: 12.3%	* Cob core moisture content: 41.8%	* Cob core moisture content: 12.3%	* Cob core moisture content: 41.8%
1	Wood	16–20	21–24	26–29	32–36
2	Steel sheet	16–20	21–24	26–28	31–34
3	Rubber belt	16–20	21–24	29–33	34–44

**Table 5.** Friction coefficient of corn cobs and kernels.

No.	Objects	Studied Surface		
		Rubber	Plywood	Steel
1	Cob	0.53	0.25	0.20
2	Kernel	0.81	0.26	0.24

52.3%–53.1% for medium-sized kernels, and 50.8%–51.2% for small kernels (Petrov and Pavlov, 2019; Ibrahimov, 2021).

The flight speed of the maize kernels was 12.5%–14 m/s, while the flight speed of cob cores with 11% moisture content ranged from 10 to 17 m/s. This range can be an acceptable reference speed for the transportation of the cob cores (Kim *et al.*, 2022; Zhang *et al.*, 2023).

The natural slope angle of the kernel depends on its moisture content, bulk density, temperature, inclination, and other factors. When the kernel moisture content varied from 11.5% to 19% (a variation of up to 7.5%), the natural slope angle increased by only 2.5°. However, when the kernel moisture increased from 19% to 26.5%, the natural slope angle rose to 19.5°–20.2° (an increase of more than eight times than the first case). Therefore, the moisture content of the maize kernels must be essential when determining their natural slope angle. The experimental results for determining the slope angle were vital to initiate the movement of maize cobs (Table 4) (Garcia and Miller, 2021).

The determined specific density of maize kernels emerged as 1.16 g/cm<sup>3</sup> (with a moisture content of 18.3%–23.9%) and 1.21 g/cm<sup>3</sup> (with a moisture content of 20%–32%), depending on the cultivar. In bulk, the density of maize was 700 kg/m<sup>3</sup>. In the postharvest

processing of maize cobs, the friction properties of the kernels and the cob coverings play a vital role. This property reached characterization by the coefficient of friction under both static and dynamic conditions. Past studies enunciated obtaining the highest coefficient occurred on a rubber surface, while recording the lowest value was on a steel sheet surface (Table 5) (Patel *et al.*, 2021; Sonawane *et al.*, 2022; Ji *et al.*, 2024).

The static friction coefficient of corn kernels was 1.5 to 2 times higher than the sliding friction coefficient across all surfaces (Table 6) (Zheng *et al.*, 2023; Chen *et al.*, 2024). During mutual friction, the static coefficient of friction for specific parts of the product was as follows: between kernels (0.36), between cob coverings (0.35), and between the kernel and cob covering (0.29). Past research revealed a reduction in moisture also decreases the coefficient of friction between kernels (Muxtarov, 2015). For a bulk of maize kernels with a bulk density of 0.7–0.75 ton/m<sup>3</sup>, the static coefficient of friction on a wooden surface was 0.7, whereas after falling from the conveyor, during movement, the coefficient of friction was 0.53. Under the same conditions, the coefficients of friction on a steel sheet were 0.58 and 0.36, respectively (Qasimov, 2020; Asadullayev *et al.*, 2024).

**Table 6.** Sliding friction coefficient of corn kernels.

No.	Moisture (%)	Friction Surface			
		Plywood	Sink	Steel	Rubber
1	13.2	0.21	0.25	0.25	0.53
2	36.5	0.34	0.39	0.57	0.62

**Table 7.** Rolling angles of corn cobs and kernels.

No.	Product Name	Rolling angle (degrees)			
		Painted tray		Unpainted tray	
		$\varphi_1$	$\varphi_2$	$\varphi_1$	$\varphi_2$
1	Husked corn	21.0	24.0	19.0	24
2	Husked corn	16.5	23.5	15.0	21

**Table 8.** Firmness of kernels from different corn cultivars at various moisture levels.

No.	Cultivars	Static force to separate the grain from the kernel (N)			
		Moisture content: 12%	Moisture content: 20%	Moisture content: 23%	Moisture content: 27%
1	Zaqatala	250	258	287	196
2	Zaqatala - 68	260	269	300	213
3	Zaqatala - 514	277	288	330	230

Experimentally, the angle of repose entailed determining it for dehusked maize and kernels on both painted and unpainted metal chutes. In this process, the angle of repose recording used two indicators: the initial angle at which the product begins to move freely along the chute ( $\varphi_1$ ) and the final angle corresponding to the complete repose of the product on the chute ( $\varphi_2$ ) (Table 7) (Rahimov, 2017; Quliyev and Huseynov, 2019).

Maize cobs characterization relied on their large dimensions, the ability to assume various positions during movement, their capacity to be tightly packed, as well as their temperature and surface condition. Maize cobs on a moving surface respond differently as compared with the cobs on a stationary surface. Additionally, loosely arranged cobs—those not held in place by adjacent cobs—begin to settle on a moving surface (conveyor) as and when the inclination is between 4 and 7 degrees (Rahimov, 2017; Quliyev and Huseynov, 2019).

Unlike kernels of other cereal crops, maize kernels are compact on the cob and do not scatter. Their separation from the cob core

requires the application of force. In maize cultivars with stone-like kernel shapes, the kernel's resistance to breakage is higher than in cultivars with half-tooth and tooth-shaped kernels. The force needed to disintegrate the kernels depends upon their mass and moisture content; the more moisture and the heavier the kernel, the greater the force required. Moreover, maize cultivars with toothed kernels exhibited higher impact resistance than those with half-tooth and stone-like kernels. The kernels' strength for some maize cultivars at different moisture levels reached detection and appears in Table 8 (Rahimov, 2017; Quliyev and Huseynov, 2019).

As seen from the table, depending on the cultivar, as the kernel moisture content increases up to a certain threshold, the force required for its disintegration also increases; however, with further increase in moisture, the force decreases sharply. The maize kernel strength rises with moisture and depends on the cultivar. Yet, by determining the kernel strength for fracture resistance along its width, it was evident that as moisture increases, its strength decreases. Kernels with a moisture

**Table 9.** Firmness of corn kernel attachment to the cob core.

No.	Indicators	Measurement unit	Maturation phase		
			Phase 3 21/VIII	Phase 4 5 - 25/IX	Phase 5 1/IX
1	Kernel tensile force	N	14.5	15.7–20.3	23.6
2	Kernel extraction force from the base	N	10.01	6.86–7.85	5.9
3	Kernel moisture content	%	40–42	18– 35	15

content of up to 20% sustained a static load of 206 N. At 29.3% moisture, the endurance limit dropped to 89 N. Under impact load, the maize kernels disintegrated under a force ranging from 31.4 to 36.3 N, which was approximately three times lower than in the static load (Quliyev and Huseynov, 2019).

The conditions for the kernels' separation from the cob core also underwent studies. It was evident that for kernels with a moisture content of 22%–23%, the force required to separate them from the cob core was 21 N when applied radially. When applied tangentially to the cob circumference, it was 6 N, and it was 13 N when applied along the cob length (Karimova and Aliyev, 2018). Furthermore, the maturity stage also affects the kernels' separation from the core and the kernel damage ratio. The assessment of the adhesion strength between the kernels and the cob core at different maturity stages also ensued, with reports presented in Table 9 (Rahimov, 2017).

## CONCLUSIONS

Based on the analysis, maize kernels exhibited variability in their size-weight traits, strength properties, friction coefficients, and aerodynamic properties, both across different cultivars and even within the same cultivar through various growing seasons. Under static loading, the strength of the kernels varies dramatically when the direction of the applied force shifts along their length, width, and thickness. Under static compression, the disintegrating force was significantly lower than the impact force. The friction coefficient of the kernels depends on the type of material and the specific friction conditions. Moreover, when the moisture content of the maize kernels increases up to a certain limit (22%–28%), the force

required to disintegrate the kernels also increases; however, if the moisture level rises beyond that threshold, the required disintegrating force decreases.

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