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Research article

Comparative evaluation of the structural and tenderness properties of minced beef from angus and akbas cattle using a penetration-based approach

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Abstract

Background and Aim. Meat tenderness is a key determinant of consumer acceptance and product quality; however, its evaluation in minced meat systems remains challenging due to the disruption of muscle fiber structure. The present study aimed to assess the structural and tenderness properties of minced beef derived from Angus and Akbas cattle using a penetration-based approach combined with the Rebinder equation.

Materials and Methods. A comparative analysis was performed on minced beef samples obtained from Angus and Akbas cattle (12 samples per breed). The structural and mechanical properties were determined using a Structurometer ST-2 (Radius, Russia) fitted with a 60° cone indenter at 4–6 °C. Structural resistance values were calculated using the Rebinder equation using penetration force and depth parameters.

Results. Angus samples exhibited significantly lower force values (282.19 ± 42.24 N) compared to Akbas (308.68 ± 56.82 N), indicating reduced structural resistance and improved tenderness ($p = 0.028$). Distribution analysis revealed greater variability in Akbas samples, suggesting more heterogeneous structural properties. The application of the Rebinder model enabled normalization of mechanical resistance and facilitated interpretation of structural behavior. These findings demonstrate that penetration-based methods are suitable for minced meat systems and reveal significant breed- related differences relevant for meat quality optimization.

Conclusion. Penetration-based analysis using the Structurometer ST-2 was effective for evaluating the structural and mechanical properties of minced beef. Angus beef demonstrated lower structural resistance and greater tenderness compared to Akbas beef. The results confirm the usefulness of the Rebinder equation for interpreting mechanical properties and support the application of this approach in meat quality assessment and industrial quality control. The study also highlights the potential to improve beef processing efficiency and promoting high-quality domestic meat products in Kazakhstan.

Keywords: Akbas cattle; Angus cattle; meat quality; minced beef; penetration test; tenderness.

Introduction

Beef quality is a critical determinant of consumer acceptance, market competitiveness, and export potential, particularly in countries seeking to expand their presence in the global meat industry. As international trade becomes increasingly competitive, the demand for consistently high-quality meat products continues to grow, making the evaluation of quality attributes an essential component of modern meat science. Among these attributes, tenderness and structural integrity are widely recognized as key sensory and technological parameters that directly influence both consumer satisfaction and processing efficiency. Tenderness is closely associated with the overall eating experience, while structural integrity determines the behavior of meat during handling, processing, and storage. These properties are interrelated; rather, they are governed by complex interactions involving muscle fiber composition, the amount and organization of connective tissue, and a series of postmortem biochemical processes, including proteolysis, water redistribution, and changes in muscle ultrastructure [1–4].

In recent years, increasing attention has been directed toward the evaluation of meat texture using objective instrumental methods. This shift is largely driven by the limitations of traditional sensory assessments, which, although valuable, are inherently subjective and influenced by panelist variability, training, and environmental conditions. In contrast, instrumental techniques provide reproducible, quantifiable, and standardized data, allowing for more accurate comparisons across studies, production systems, and processing conditions. These methods are particularly important in research and industrial settings, where measurement consistency and reliability are critical [5, 6].

Among the available instrumental approaches, penetration-based analysis has become a practical and informative technique for assessing the structural resistance and mechanical strength of meat systems. Unlike conventional shear force methods, such as Warner-Bratzler shear force, which are primarily designed for intact muscle cuts, penetration methods offer distinct advantages when applied to minced or ground meat products. In such systems, the disruption of muscle fiber orientation limits the applicability of shear-based measurements, making penetration analysis a more suitable alternative. By measuring the force required for a probe to penetrate a sample, this technique provides insight into the resistance of the meat matrix to deformation and fracture [7, 8].

Parameters derived from penetration testing, including penetration resistance and structural strength (e.g., PNS), serve as valuable indicators of the internal organization and stability of meat matrices. These parameters reflect the combined effects of protein network formation, fat distribution, moisture retention, and interactions between structural components within the product. As a result, penetration-based measurements can be used not only to assess texture but also to monitor changes in product quality during processing, storage, and formulation adjustments. Overall, the application of such objective methods enhances the ability to characterize meat quality in a precise and scientifically robust manner, supporting both research advancements and practical improvements in the meat industry.

The aim of this study was to compare the structural and mechanical properties of minced beef obtained from Angus and Akbas cattle using a penetration-based method combined with the Rebinder equation in order to objectively evaluate meat tenderness and structural resistance.

The novelty of the study lies in the application of penetration analysis combined with the Rebinder equation for the evaluation of minced beef systems, where traditional shear force methods are less informative due to the disruption of muscle fiber orientation. In addition, this is one of the first comparative studies conducted in Kazakhstan using the Structurometer ST-2 to assess breed-related differences between Angus and Akbas beef. The findings demonstrate the potential of this approach for objective meat quality evaluation, industrial quality control, and optimization of beef processing.

Materials and Methods

A controlled comparative study was conducted using meat samples from Angus and Akbas cattle. A total of twelve independent samples per breed were analyzed. The *Longissimus dorsi* muscle was excised 24 hours post-mortem, vacuum-packaged, and stored at −20 °C. Prior to analysis, samples were thawed at 4 °C for 24 hours to minimize structural alterations.

The samples were minced using a standardized meat grinder to obtain a homogeneous minced structure. The minced meat was then placed into cylindrical containers of uniform dimensions to ensure consistent geometry and boundary conditions during testing (Figure 1).

Figure 1. Minced meat samples used in the study

Structural analysis was performed using a Structurometer ST-2 texture analyzer (Radius, Russia) equipped with a 60° conical indenter. The penetration test was conducted at a controlled temperature of approximately 4–6 °C. During the test, the indenter penetrated vertically into the sample while force and penetration depth were continuously recorded. The cone constant was set to K = 0.334.

Structural resistance was calculated using the Rebinder equation:

$$\theta = K \times \frac{F}{h^2} \tag{1}$$

where:

F-load value, H;

h is the penetration depth of the cone, m;

K is the cone constant, which depends on the cone apex angle (α).

The stability applied to the cone of the device with an angle of height α was calculated using the following equation:

$$K = \frac{cos^2(a/2)}{\pi * tg(a/2)} \tag{2}$$

where:

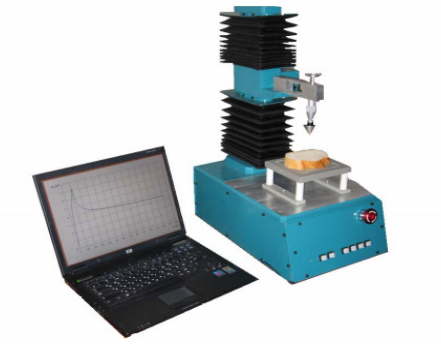
α is the cone apex angle.

For a 45° cone: K ≈ 0.612

For a 60° cone: K ≈ 0.334

This equation enables normalization of force relative to deformation and provides a more accurate representation of the internal structural strength of the minced meat system.

Statistical analysis was performed using R software. Data were tested for normality using the Shapiro–Wilk test, and differences between groups were assessed using an independent t-test. Statistical significance was defined as $p < 0.05$. Descriptive statistics were calculated, and data distribution was visualized using boxplots and mean comparison charts.



a) b)

Figure 2. Experimental setup for the Structurometer ST-2:
a) laptop used for data acquisition; b) Structrometer ST-2

Results

The penetration test revealed clear differences in the structural properties between the two cattle breeds. The mean penetration force for Akbas samples was 308.68 ± 56.82 N, whereas Angus samples exhibited a lower mean value of 282.19 ± 42.24 N. This corresponds to an approximately 8.6% reduction in structural resistance in Angus samples. The range of values was wider in Akbas samples (197.1–411.1 N) compared to Angus (220.0–380.0 N), indicating greater variability.

The difference between the groups was statistically significant ($p = 0.028$), confirming that breed has a measurable effect on the structural properties of minced beef. Structural resistance values calculated using the Rebinder equation followed the same pattern, with Akbas exhibiting higher values (2.58) compared to Angus (2.36), indicating a denser and more cohesive internal structure.

The distribution of penetration force values is illustrated in Figure 3. The boxplot shows that Akbas samples had a higher median and a wider interquartile range, reflecting greater variability. In contrast, Angus samples were more tightly clustered, indicating more uniform structural behavior.

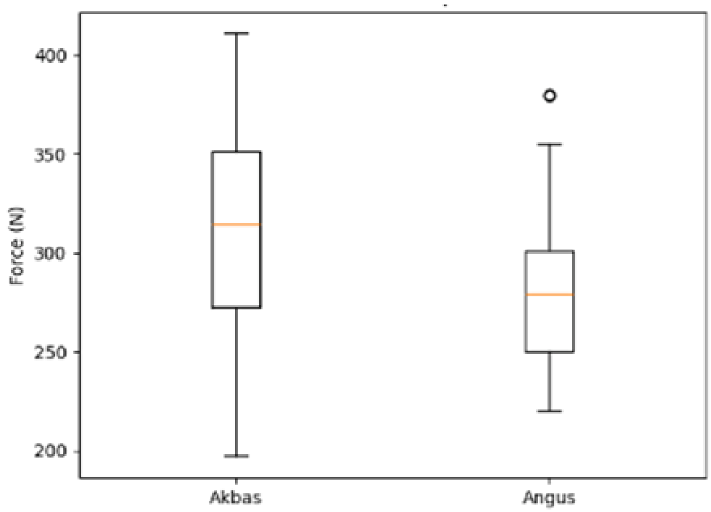


Figure 3. Distribution of penetration force values

The comparison of mean values is presented in Figure 4, which clearly demonstrates higher average force values in Akbas samples compared to Angus.

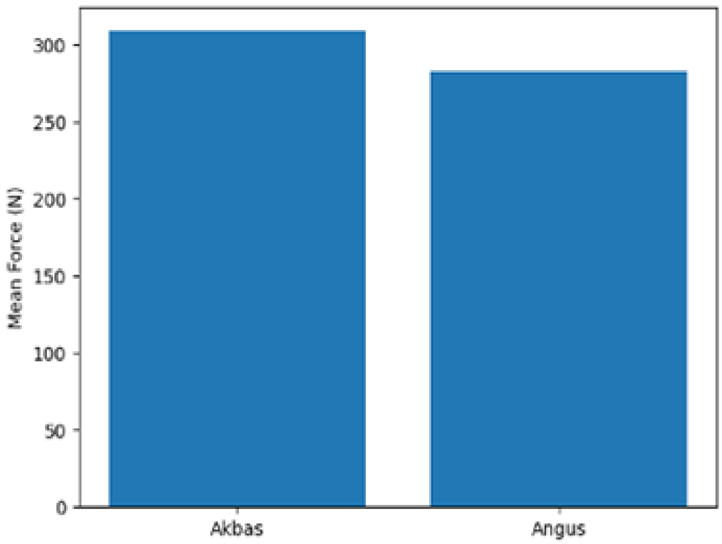


Figure 4. Mean values of penetration force

The lower penetration force values observed in Angus indicate reduced resistance to deformation and improved tenderness, whereas higher values in Akbas reflect stronger structural integrity and lower tenderness.

Table 1.The results of measuring the force during deformation of minced meat without adding fat

Sample	Akbas Hardness, g	Angus Hardness, g	Akbas (PNS, gPa)	Angus (PNS, gPa)
1	357.1	289.3	3.06	2.74
2	331.5	363.6	2.98	3.21
3	348.2	262.1	3.12	2.65
4	365.4	347.1	3.20	3.05
5	342.7	288.9	3.05	2.80
6	338.9	289.8	3.01	2.77
7	329.6	266.5	2.97	2.69
8	310.2	243.2	2.88	2.60
9	322.5	260.9	2.94	2.66
10	335.8	262.2	3.00	2.70
11	305.4	233.3	2.85	2.55
12	340.1	279.4	3.03	2.73

As shown in Table 1, significant differences were observed in the structural and mechanical properties of the Akbas and Angus minced meat samples.

In the Akbas samples, the force values ranged from 305.4 to 365.4 g, showing generally higher values than in the Angus samples. This suggests that Akbas minced meat has a denser texture and greater hardness.

In the Angus samples, the force values ranged from 233.3 to 363.6 g. Although higher values were observed in some samples (for example, 2 and 4), they tended to be lower than in Akbas.

The PNS indicators also showed a similar trend: the Akbas samples had 2.85–3.20 gPa, and the Angus samples had 2.55–3.21 gPa. Overall, the Akbas samples demonstrated greater structural stability and elasticity. Thus, the Akbas minced beef samples exhibited greater structural strength than the Angus samples.

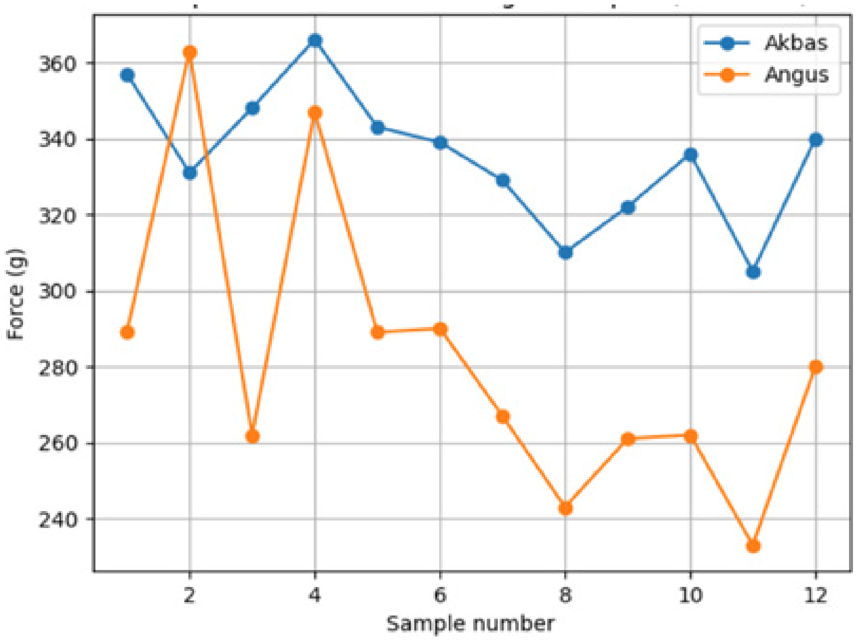


Figure 5. Comparison of Meat Hardness Between Akbas and Angus Beef Samples

The Figure 5 shows a comparison of the hardness (usilie) indicators of minced meat samples Akbas and Angus. It has been shown that the Akbas samples have higher overall values, which indicates that their structure is denser and more durable.

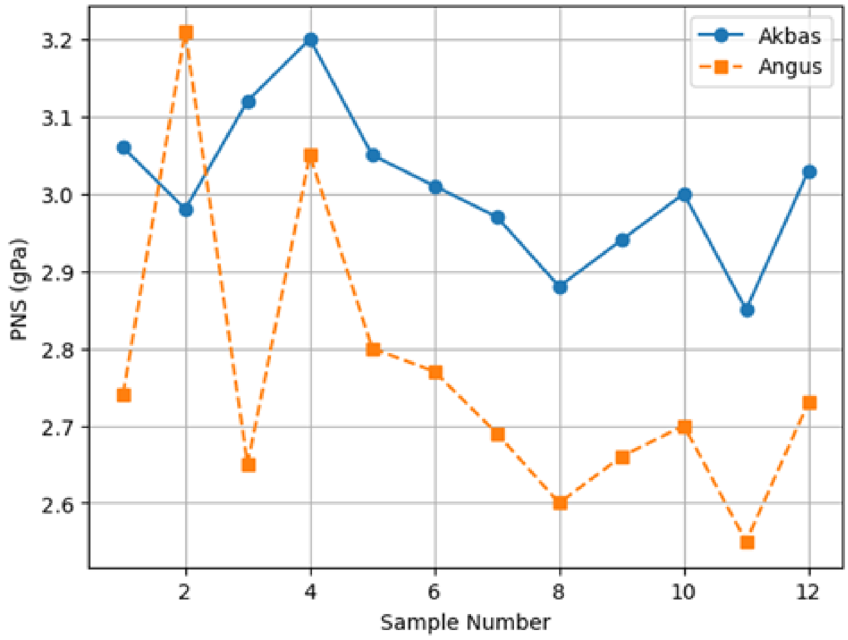


Figure 6. Comparison of Texture Strength (PNS) in Beef Samples from Akbas and Angus Breeds
As shown in Figure 6, the Akbas samples demonstrate relatively high PNS values, indicating enhanced structural stability and mechanical strength

Discussion

The results of this study demonstrate that beef from the Angus breed exhibits significantly lower structural resistance compared to Akbas, indicating greatertenderness. This finding is consistent with the general understanding in meat science that tenderness is one of the most important determinants of consumer acceptance and overall eating quality. The statistically significant difference observed between the two groups ($p = 0.028$) confirms that breed-related factors have a measurable effect on the mechanical behavior of minced beef systems.

A key factor underlyingthese differences is likely the variation in intramuscular fat (IMF) content between breeds. Angus cattle are known for higher marbling, which has been consistently associated with improved tenderness and palatability. Intramuscular fat disrupts the continuity of the muscle protein network, reducing mechanical resistance and increasing deformability. As a result, less force is required to penetrate the meat matrix, which explains the lower penetration force and PNS values observed in Angus samples. Previous studies have demonstrated that IMF contributes positively to tenderness by weakening structural cohesion and improving juiciness and mouthfeel [9]. In contrast, the higher resistance observed in Akbas samples suggests a denser protein structure, potentially linked to lower fat content and a relatively greater contribution of connective tissue.

The structural differences observed in this study can also be explained by fundamental mechanisms governing meat texture. Tenderness is influenced by the interaction between myofibrillar proteins, connective tissue (particularly collagen cross-linking), and postmortem proteolysis processes. Increased connective tissue content and stronger collagen cross-links typically lead to higher resistance to deformation and reduced tenderness, which may explain the higher penetration values recorded in Akbas meat [4, 10].

An important methodological aspectis the use of minced meat systems. Grinding disrupts muscle fiber orientation and eliminates anisotropic properties that are typically measured using shear force techniques such as Warner-Bratzler analysis. Under these conditions, penetration testing is more suitable, as it reflects the bulk mechanical resistance of the product rather than directional fiber strength. The consistency between penetration force and PNS values observed in this study supports the reliability of this approach for evaluating minced meat structure. Similar conclusions have been reported in texture research, where penetration methods are considered more appropriate for heterogeneous or processed systems [11].

The greater variability observed in Akbas samples is another important finding. The wider range and dispersion of penetration force values indicate a less uniform internal structure. This heterogeneity may be associated with uneven distribution of connective tissue or variability in muscle composition. In contrast, Angus samples showed a more consistent pattern, which may reflect more uniform fat distribution within the meat matrix. From an industrial perspective, such uniformity is highly desirable, as it ensures consistent processing performance and product quality. Variability in raw material properties can negatively affect technological processes such as grinding, mixing, and cooking, ultimately leading to inconsistent texture in the final products [12].

The application of the Rebinder equation to calculate structural strength (PNS) provides an additional level of interpretation beyond simple force measurements. While penetration force reflects resistance to deformation, PNS represents the intrinsic mechanical stability of the material. The fact that both parameters showed the same trend, with higher values in Akbas and lower values in Angus, confirms the robustness of the results. Although this approach is not widely used in meat science, it offers a valuable tool for standardizing mechanical measurements and improving comparability across studies.

Overall, the findings highlight clear breed-related differences in the structural and mechanical properties of minced beef. Angus meat appears more suitable for products where tenderness and uniformity are key quality attributes, whereas Akbas meat demonstrates higher structural strength, which may be advantageous in products requiring greater mechanical stability. However, it is important to note that meat texture is influenced by multiple factors beyond breed, including feeding system, animal age, and postmortem handling conditions. Future research combining instrumental analysis with microstructural and compositional studies would provide a more comprehensive understanding of the mechanisms underlying these differences.

Conclusions

Penetration-based analysis using the Structurometer ST-2 provides a reliable method for evaluating the structural properties of minced meat. Angus beef exhibited significantly lower structural resistance compared to Akbas, indicating superior tenderness. The integration of the Rebinder equation enhances the interpretation of mechanical data and supports its application in both scientific research and industrial quality control.

This study provides a comprehensive evaluation of the structural and mechanical properties of minced beef. The mass of minced meat affects its density, elasticity, and strength. The comparative evaluation of minced beef from Angus and Akbas cattle suggests that products from these breeds may be recommended for different applications according to their structural and mechanical characteristics. The work was performed at the Shakarim University in Semey, Abai region. The results of this study may contribute to future comprehensive research on improving the structural and mechanical properties of beef, thereby supporting agricultural development and providing consumers with high-quality domestically produced beef products.

Authors 'Contributions

GZh: conducted a comprehensive literature search, analyzed the gathered data and drafted the manuscript. GA, GA: contributed to data interpretation, manuscript editing, and overall study supervision. BB: conducted the final revision and proofreading of the manuscript. All authors have read, reviewed, and approved the final manuscript".

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Statement on Competing Interests

The authors declare that they have no competing interests.

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