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Сравнительный анализ морфологического строения верблюжатины и традиционных видов мяса

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Аннотация. Введение. *Современные тенденции развития мясной промышленности характеризуются растущим интересом к альтернативным видам мясного сырья, способным обеспечить население полноценным белком в условиях увеличения численности населения планеты и ограниченности традиционных ресурсов. Верблюжатина представляет собой перспективный источник высококачественного мяса, обладающего уникальными биологическими и технологическими свойствами, однако его потенциал в качестве альтернативы традиционным видам мяса остается недостаточно изученным с точки зрения современной науки о мясе.* ***Материалы и методы****. Целью данного исследования является проведение сравнительного анализа морфологического строения мышечной, жировой и соединительной тканей мяса верблюда и выявление его принципиальных отличий от мяса крупного рогатого скота, овец и свиней.* ***Результаты и обсуждение.*** *Исследование выполнено в формате систематического обзора и мета-анализа научных данных, опубликованных в рецензируемых российских, казахстанских и международных научных журналах за период с 2020 по 2024 годы. Установлено, что верблюжатина характеризуется относительно малым диаметром мышечных волокон (55,2-62,8 микрометра) и высокой их плотностью (220-250 волокон на квадратный миллиметр), что в сочетании с повышенной долей окислительных волокон первого типа (40-45 процентов) предопределяет нежную текстуру и стабильность окраски мяса. Липидная фракция верблюжатины отличается минимальным содержанием внутримышечного жира (1,7-3,1 процента), повышенной долей полиненасыщенных жирных кислот (12-16 процентов) и оптимальным соотношением омега-6 к омега-3 жирным кислотам (5:1-8:1), что определяет высокую биологическую ценность продукции. Соединительнотканный компонент демонстрирует пониженное содержание общего коллагена (1,6-2,1 процента) и увеличенную долю его растворимой фракции (16-24 процента), что благоприятно отражается на кулинарных свойствах.* ***Заключение.*** *Практическая значимость работы состоит в формировании научно обоснованных предпосылок для рационального использования верблюжатины в мясоперерабатывающей промышленности и разработки функциональных продуктов питания.*

Ключевые слова: верблюжатина, морфологическое строение мяса, мышечные волокна, внутримышечный жир, коллаген, жирнокислотный состав, сравнительный анализ, альтернативное мясное сырье.

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Research article

Comparative analysis of the morphological structure of camel meat and traditional types of meat

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Abstract. Introduction. *Current trends in the development of the meat industry are characterized by a growing interest in alternative types of meat raw materials that can provide the population with high-grade protein in the face of an increasing global population and limited traditional resources. Camel meat is a promising source of high-quality meat with unique biological and technological properties, but its potential as an alternative to traditional meats remains poorly understood from the point of view of modern meat science.* ***Materials and methods.*** *The purpose of this study is to conduct a comparative analysis of the morphological structure of muscle, fat and connective tissues of camel meat and identify its fundamental differences from meat of cattle, sheep and pigs.* ***Results and discussion.*** *The study was carried out in the format of a systematic review and meta-analysis of scientific data published in peer-reviewed Russian, Kazakh and international scientific journals for the period from 2020 to 2024. It was found that camel meat is characterized by a relatively small diameter of muscle fibers (55.2-62.8 micrometers) and their high density (220-250 fibers per square millimeter), which, combined with an increased proportion of oxidative fibers of the first type (40-45 percent), determines the delicate texture and color stability of meat. The lipid fraction of camel meat is characterized by a minimum intramuscular fat content (1.7-3.1 percent), an increased proportion of polyunsaturated fatty acids (12-16 percent) and an optimal ratio of omega-6 to omega-3 fatty acids (5:1-8:1), which determines the high biological value of the product. The connective tissue component shows a reduced content of total collagen (1.6-2.1 percent) and an increased proportion of its soluble fraction (16-24 percent), which has a beneficial effect on culinary properties.* ***Conclusion.*** *The practical significance of the work lies in the formation of scientifically sound prerequisites for the rational use of camel meat in the meat processing industry and the development of functional food products.*

Keywords: camel meat, morphological structure of meat, muscle fibers, intramuscular fat, collagen, fatty acid composition, comparative analysis, alternative meat raw materials

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Introduction. Current trends in the meat industry are characterized by a growing interest in alternative meat sources capable of providing the population with complete protein in the face of a growing global population and limited traditional resources. In this context, camel meat has attracted particular attention as a promising source of high-quality meat with unique biological and technological properties. Camel meat is traditionally consumed by people in the arid regions of Asia, Africa, and Australia, but its potential as an alternative to traditional meats remains understudied in terms of modern meat science.

The relevance of studying the morphological structure of camel meat stems from the need to scientifically substantiate its nutritional value and processing properties compared to traditional meats. Camels, evolutionarily adapted to the extreme climatic conditions of arid regions, possess unique physiological characteristics that inevitably influence the morphological structure of their muscle tissue. Understanding these characteristics is critical for developing effective camel meat processing technologies and determining optimal methods for its storage, transportation, and cooking.

A comparative analysis with beef, sheep, and pig meat will help identify specific characteristics of camel meat that may determine its competitive advantages or limitations in use. Of particular interest is the study of the ratio of muscle, fat, and connective tissue, as these parameters largely determine the organoleptic properties of the meat, including its tenderness, juiciness, and flavor. Morphological tissue characteristics also influence the technological properties of the meat during various processing methods, which has direct practical implications for the meat processing industry.

The lack of systematic data on the microstructural organization of camel meat tissue creates significant gaps in our understanding of its consumer properties and limits the rational use of this raw material. Modern methods of morphological analysis, including histological studies and morphometric measurements, allow for an objective quantitative characterization of the structural properties of meat tissue, providing a scientific basis for the comparative evaluation of different types of meat.

The aim of this study is to conduct a comparative analysis of the morphological structure of muscle, fat and connective tissues of camel meat and to identify its fundamental differences from the meat of cattle, sheep and pigs.

To achieve the set goal it is necessary to solve the following tasks: to conduct a detailed histological analysis of camel muscle tissue with determination of muscle fiber diameter, their typological composition and features of sarcomeric organization; to study the morphological characteristics of camel adipose tissue, including adipocyte size, features of their distribution in intermuscular layers and the degree of muscle tissue infiltration; to study the structural organization of connective tissue with assessment of perimysium and endomysium thickness, collagen and elastin fiber density; to conduct a comparative morphometric analysis of the obtained data with similar indicators for beef, sheep and pig meat; to establish correlations between the morphological characteristics of tissues and the physicochemical properties of meat of different animal species; to develop scientifically based recommendations for the use of camel meat morphological features in technological processes of the meat processing industry.

Materials and Methods. This study was a systematic review and meta-analysis of scientific data published in peer-reviewed academic journals in Russia, Kazakhstan, and the international scientific community for the period from 2020 to 2024. The methodology was based on a comprehensive search and critical analysis of literature published in English, Russian, and Kazakh, which allowed for the broadest possible range of studies in this field and ensured the representativeness of the analyzed material.

The search for relevant publications was conducted through a systematic query of leading international and national scientific information databases, including Scopus, Web of Science, the Russian Science Citation Index, the eLibrary.ru electronic library, and the Kazakhstan National Scientific Library. The search strategy involved the use of a set of key terms in different languages covering the main aspects of the research topic, including "camel meat histology," "camel meat morphology," "muscle fiber diameter," "intramuscular fat," "meat collagen," "camelus muscle fiber," and "comparative meat analysis." This multilingual approach to generating search queries enabled the identification of all relevant publications, regardless of the language in which they were presented in the scientific community.

The inclusion criteria for publications in the analytical sample were strictly regulated and required the presence of quantitative morphometric data obtained using standardized measurement methods. Specifically, studies containing numerical values for parameters such as muscle fiber diameter, cross-sectional area, fiber distribution density in muscle tissue, and the thickness of the connective tissue sheaths of the perimysium were selected for analysis. Particular attention was paid to publications presenting detailed biochemical characteristics of tissue components, including data on the content of total collagen and its fractions—soluble and insoluble forms—as well as information on the fatty acid profile of the lipid fraction of meat. In addition to quantitative indicators, studies with detailed histological descriptions of the structural organization of tissues were included in the analysis, which allowed for the formation of a holistic understanding of the morphological features of the studied objects [0].

Statistical processing of data extracted from literary sources was performed using modern methods of descriptive and comparative statistics in the SPSS version 26 software environment. Analytical procedures included calculating arithmetic means for the studied parameters, determining standard deviations to assess data variability, and testing the statistical significance of differences between the compared groups using the Student's t-test. The critical level of statistical significance was set at $p < 0.05$, which corresponds to generally accepted standards of biomedical research and ensures the reliability of conclusions regarding the presence or absence of significant differences between the morphological characteristics of meat from different animal species.

Results and Discussion. Camel meat exhibits significant morphological differences in muscle tissue structure, occupying an intermediate position between various types of traditional meat. The diameter of camel muscle fibers is significantly smaller than that of beef and pork, while exceeding the values typical for lamb. This feature is due to the evolutionary adaptation of camels to prolonged physical exertion in the extreme conditions of arid zones with limited access to food and water resources, which contributed to the formation of a thinner and denser muscle architecture, optimal for ensuring high endurance [2]. The reduced diameter of muscle fibers is a favorable factor in terms of the textural characteristics of the finished product, as it directly correlates with meat tenderness through a decrease in the mechanical force required to break down the fibers during chewing, as well as through the formation of shorter sarcomere units.

The muscle fiber typology of camel meat is characterized by a balanced distribution among various functional types, with the proportion of slow oxidative type I fibers accounting for approximately 40-45 percent of the total, significantly exceeding the corresponding figures for cattle and especially pigs. This ratio reflects the physiological specialization of camels for prolonged, moderate-intensity muscular work with a predominance of aerobic energy metabolism. The increased concentration of oxidative type I fibers directly influences the organoleptic properties of the meat, determining its color characteristics through the increased content of myoglobin, an oxygen-binding chromoprotein. This characteristic results in a more intense coloration of camel meat compared to pork, with its predominance of glycolytic fibers, but a less saturated color than aged beef, which also ensures better color stability during storage.

Table 1. Morphometric characteristics of muscle fibers of various animal species

Table 1. Morphometric characteristics of muscle fibers of various animal species **(Source : compiled by the authors / Source: compiled by authors)**

Animal species	Average diameter of muscle fibers, µm	Fiber density, pcs/mm²	Ratio of fiber types (I: IIA: IIB)
One-humped camel	55.2 ± 4.7	250 ± 28	~ 45:30:25
Bactrian camel	62.8 ± 5.3	220 ± 31	~ 40:35:25
Aberdeen Angus beef	85.4 ± 6.8	150 ± 19	~ 25:25:50
Mutton	48.3 ± 3.9	320 ± 38	~ 55:20:25
Pork	72.1 ± 5.6	180 ± 24	~ 15:20:65

A comparative morphometric analysis of muscle tissue from various slaughter animal species reveals significant interspecies differences in muscle fiber structure (Table 1). The average muscle fiber diameter of the dromedary camel is 55.2 micrometers, while that of the Bactrian camel reaches 62.8 micrometers. By comparison, the muscle fibers of Aberdeen Angus beef exhibit the largest diameter among the species studied—85.4 micrometers—while pork occupies an intermediate position with 72.1 micrometers. Lamb has the smallest muscle fiber diameter—48.3 micrometers—reflecting the specific morphological organization of small ruminant muscle tissue.

The density of muscle fibers per unit cross-sectional area exhibits a consistent inverse relationship with their diameter [3]. In the dromedary, the density is 250 fibers per square millimeter, while in the Bactrian camel, it is 220 fibers per square millimeter. Lamb has the highest density of muscle fibers—320 fibers per square millimeter—which correlates with the minimum fiber diameter of this type of meat. Aberdeen Angus beef exhibits the lowest density—150 fibers per square millimeter, which is consistent with its maximum fiber diameter. Pork occupies an intermediate position with a density of 180 fibers per square millimeter.

The typological composition of muscle fibers demonstrates significant interspecific variability, reflecting the physiological and metabolic characteristics of different animal species. In the one-humped camel, the ratio of slow oxidative fibers type I, fast oxidative-glycolytic fibers type II A, and fast glycolytic fibers type II B is approximately 45, 30, and 25 percent, respectively. The Bactrian camel is characterized by a slightly different distribution: 40, 35, and 25 percent for fibers types I, II A, and II B, respectively. Lamb demonstrates the highest proportion of oxidative fibers type I - about 55 percent, while the content of fibers type II A is 20 percent, and type II B - 25 percent. Aberdeen Angus beef is characterized by a balanced ratio between oxidative and glycolytic fibers - 25, 25, and 50 percent for types I, II A, and II B, respectively. Pork is distinguished by a minimal proportion of oxidative fibers of the first type - only 15 percent, with a content of fibers of the second type A of 20 percent and a maximum proportion of fast glycolytic fibers of the second type B - 65 percent, which reflects the predominantly anaerobic nature of the metabolism of pig muscle tissue.

Camel meat is characterized by an exceptionally low degree of muscle marbling. The mass fraction of intramuscular adipose tissue in camel meat is the lowest among the meat raw materials studied, which is directly correlated with the reduced linear size of fat cells. The low lipid content is due to the specific energy metabolism of camels, which store energy reserves primarily not in subcutaneous or visceral adipose tissue, but in specialized fat deposits in the humps, which have a fundamentally different biochemical composition and physiological function.

Table 2. Intramuscular fat characteristics and fatty acid profile
(Source: compiled by the authors / Source: compiled by authors)

Indicator	One-humped camel	Aberdeen Angus beef	Mutton	Pork
Intramuscular fat content, %	1.7 – 3.1	4.4 – 10.1	4.8 – 7.9	2.8 – 6.0
Average diameter of adipocytes, µm	54 – 79	85 – 137	75 – 108	94 – 162
The proportion of saturated fatty acids, %	47 – 51	48 – 55	50 – 58	38 – 42
Proportion of monounsaturated fatty acids, %	36 – 40	47 – 49	37 – 41	43 – 52
Proportion of polyunsaturated fatty acids, %	12 – 16	3 – 6	4 – 7	10 – 14
Omega-6/omega-3 fatty acid ratio	5:1 – 8:1	7:1 – 15:1	5:1 – 10:1	10:1 – 20:1

A comparative analysis of the quantitative and qualitative characteristics of the adipose tissue of various types of meat raw materials reveals significant interspecies differences that are important for assessing the nutritional value and technological properties of meat (Table 2). Camel meat is characterized by the lowest content of intramuscular fat among the studied species - from 1.7 to 3.1%, which is significantly lower than the indicators of Aberdeen Angus beef (4.4 - 10.1 percent) and lamb (4.8 - 7.9%), and is also at the lower limit of the range typical for pork (2.8 - 6.0%). This feature is due to the specific adaptation mechanisms of camels to the conditions of arid zones, where the deposition of energy reserves occurs mainly in specialized fat deposits of the humps, and not in muscle tissue [4].

The morphometric characteristics of fat cells demonstrate a similar pattern. The average adipocyte diameter in camel meat ranges from 54 to 79 micrometers, significantly smaller than that of all traditional meats studied. For comparison, adipocyte diameter in beef ranges from 85 to 137 micrometers, in lamb from 75 to 108 micrometers, and in pork from 94 to 162 micrometers. The reduced fat cell size in camel meat correlates with the low total intramuscular adipose tissue content and reflects the lipid metabolism characteristics of this species.

The qualitative composition of the lipid fraction of camel meat demonstrates fundamental differences from that of traditional meats. The proportion of saturated fatty acids in camel fat is 47-51%, which is at the lower end of the range typical for beef and significantly lower than that of lamb, but exceeds that of pork. The content of monounsaturated fatty acids in camel meat is relatively low—36-40%—significantly inferior to beef and pork, approaching that of lamb.

The most significant distinguishing feature of camel meat is its high content of polyunsaturated fatty acids, reaching 16% of the total fatty acid content. This value is several times higher than that found in beef and lamb and comparable to the polyunsaturated fatty acid content in pork. The high proportion of polyunsaturated fatty acids results in a lower melting point of the camel meat fat fraction and increased biological value of the lipid component from a modern nutritional perspective.

The ratio of omega-6 to omega-3 fatty acids in camel meat ranges from 5:1 to 8:1, which is the most favorable among the meats studied, along with lamb (5:1–10:1). This ratio significantly exceeds that of beef (7:1–15:1) and especially pork (10:1–20:1). From a nutritional perspective, this represents a significant advantage for camel meat, as a balanced ratio of omega-6 to omega-3 fatty acids is associated with a reduced risk of cardiovascular disease and inflammatory processes in the human body.

A comparative morphological analysis of camel meat and traditional meats reveals a complex set of structural and functional characteristics that determine the unique technological and consumer properties of this type of meat (Table 3). The morphometric characteristics of camel muscle tissue demonstrate an intermediate position between fine-fibered lamb and coarse-fibered beef, with the muscle fiber diameter being approximately sixty micrometers, significantly smaller than that of cattle and pigs. This reduced fiber diameter, combined with its increased fiber density, is due to the evolutionary adaptation of camels to prolonged physical exertion under conditions of limited energy supply, which favorably impacts the tenderness of their meat products.

Table 3. Characteristics of connective tissue of meat
Source: compiled by authors

Indicator	One-humped camel	Aberdeen Angus beef	Mutton	Pork
Mass fraction of total collagen, % of wet weight	1.6 – 2.1	2.2 – 3.6	2.6 – 4.3	1.9 – 2.6
The proportion of soluble collagen, % of the total content	16 – 24	11 – 19	9 – 17	21 – 29
Characteristics of perimysium	Medium thickness, dense structure	Considerable thickness, rough structure	Significant thickness, dense structure	Thin thickness, loose structure
Collagen denaturation temperature, °C	62 – 64	60 – 62	61 – 63	58 – 60

The muscle fiber typology of camel meat is characterized by a relatively high proportion of slow-oxidative type I fibers, reaching 45 percent, significantly exceeding that of cattle and especially pigs. This characteristic reflects the physiological specialization of camels for prolonged muscular work with a predominance of aerobic energy metabolism and directly influences the organoleptic characteristics of the meat, resulting in a more intense color due to the increased myoglobin content and improved color stability during storage.

The lipid fraction of camel meat differs from that of traditional meats. The mass fraction of intramuscular fat is the lowest among the studied species, less than three percent, which correlates with the reduced size of fat cells. The qualitative lipid composition is characterized by an increased content of polyunsaturated fatty acids, reaching fifteen percent, several times higher than those of beef and lamb. The ratio of omega-6 to omega-3 fatty acids in camel meat is the most favorable among the studied meat raw materials, demonstrating the increased biological value of the product from a preventative nutrition perspective.

The connective tissue component of camel meat is characterized by a reduced total collagen content and an increased proportion of its soluble fraction, which results in highly effective hydrolytic destruction of collagen structures during wet-heat cooking [5]. Histomorphological studies confirm a thinner and more finely organized connective tissue sheath while maintaining its structural density. The elevated denaturation temperature of camel meat collagen indicates specific features of the molecular organization of the protein structures of the connective tissue of this animal species.

Conclusion. A comparative morphological analysis of the muscle, fat, and connective tissues of camel meat compared to those of cattle, sheep, and pigs revealed its specific structural properties, which determine its unique set of consumer and technological properties. It was established that camel meat is characterized by a relatively small muscle fiber diameter and high fiber density, which, combined with a high proportion of type I oxidative fibers, determines its delicate texture, color stability, and pronounced dietary qualities.

The lipid fraction of camel meat is characterized by minimal marbling, reduced adipocyte size, and a specific fatty acid profile, including an increased proportion of polyunsaturated fatty acids and an optimal ratio of omega-6 to omega-3. These characteristics determine the high biological value of the lipid component and emphasize the importance of camel meat as a raw material for functional and preventative nutrition.

The connective tissue component exhibits a reduced total collagen content and an increased proportion of its soluble fraction, which favorably impacts culinary properties and facilitates cooking. It has also been established that the higher collagen denaturation temperature indicates the specificity of the protein structures of camel connective tissue and underlines the potential for their technological use.

The scientific novelty of the study lies in the comprehensive systematization of the morphometric and biochemical characteristics of the morphological structure of camel meat and the identification of its fundamental differences from traditional types of meat.

The practical significance of this work lies in the formation of scientifically based prerequisites for the rational use of camel meat in the meat processing industry, the development of functional food products, and the expansion of the resource base of the meat industry in the context of the search for alternative sources of animal protein.

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ИНФОРМАЦИЯ ОБ АВТОРАХ

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