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Article

Analysis of chemical properties and nutritional composition of mutton from Erdenedalai soum, Dundgovi province

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Abstract

This study evaluated the effect of animal age, sex, and muscle type on mutton. Analysed the proximate analysis, fatty acid composition, amino acid profile, and mineral content of mutton from Erdenedalai soum in Dundgovi Province, Mongolia. The results showed that the samples exhibited adequate moisture, relatively high protein content, and moderate fat levels, with notable differences among muscle type. Among the three muscles, the thigh exhibited the highest ($p<0.05$) moisture content (69.67%) and the lowest ($p<0.05$) fat level (8.27%), resulting in a lower energy value (154.58 kcal/100 g). The loin had the highest protein content (20.75%), and fat (10.58%), and the greatest ($p<0.05$) energy value (178.20 kcal/100 g). Monounsaturated fatty acids (MUFA) were the predominant lipid components, and the n-6/n-3 ratio remained within a nutritionally desirable range. The amino acid composition was stable, with the proportion of essential amino acids (EAA/TAA ≈ 43%) meeting the criteria for high-quality protein. Among flavor-related amino acids, glutamic acid (3.06–4.18 g/100 g) and aspartic acid (1.48–2.13 g/100 g). Mineral element contents were also stable, and no heavy metals were detected, indicating excellent nutritional value and food safety.

Keywords: mutton; amino acids; fatty acids; nutritional evaluation; geographical indication certification

Introduction

With the continuous development of Mongolia's economy and the rising income levels of urban and rural residents, consumers are paying increasing attention to dietary structure and nutritional balance [1]. This shift has placed higher demands on nutritional safety, health value, and quality differentiation of meat products. As a traditional and dominant meat type in Mongolia, mutton plays an essential role in both the national diet and the pastoral economy. High-quality mutton is not only an important source of high-quality protein and low fat but also a key agricultural product that reflects the ecological environment, feeding systems, and regional culture. In recent years, driven by global trends toward healthy consumption, competition in the meat industry has increasingly shifted from quantity-oriented growth to quality- and brand-oriented development [2]. As a result, nutritional characteristics and regional distinctiveness have become core determinants of market competitiveness [3].

Geographical Indication (GI) certification, as an institutional mechanism linking product origin with unique quality attributes, has emerged as an important tool for promoting high-quality agricultural and pastoral development and enhancing regional branding [4]. Systems such as the Protected Designation of Origin (PDO) and Protected Geographical Indication (PGI) in Europe, as well as China's Geographical Indication Agricultural Product Certification, have demonstrated that GI products can significantly enhance added value and international competitiveness [5].

For example, the Inner Mongolia Autonomous Region of China has established a comprehensive

GI-based mutton quality evaluation system, including standardized physicochemical and nutritional benchmarks for premium breeds such as Sunit sheep, Ujimqin sheep, and Chahar sheep, thereby forming an industrial pathway centered on "standards–testing–branding" [6]. Although Mongolia is a traditional pastoral livestock country with vast grassland ecosystems and abundant high-quality Mongolian sheep resources, it still lacks a scientific and systematic evaluation system for mutton quality and a GI-oriented branding framework. This scientific data gap has constrained the marketization and internationalization of Mongolian mutton to a certain extent.

From a scientific perspective, the core of meat quality lies in its physicochemical composition and nutritional profile. Protein content and amino acid composition determine the nutritional value and flavor foundation of meat, serving as key indicators for evaluating the quality of animal products. Fatty acid composition reflects feeding systems and ecological environments, carrying important implications for human health as well as the regional characteristics of livestock products. In addition, the concentration of mineral elements affects nutritional balance and food safety, forming an essential component of the physicochemical "fingerprint" of Geographical Indication (GI) products. In recent years, systematic studies on GI-certified mutton in regions of China, such as Ningxia's Tan sheep and Inner Mongolia's Sunit sheep, have revealed clear relationships between nutritional composition and ecological environments. However, similar research in Mongolia remains limited, and international comparative studies are still lacking [7].

Dundgovi province is located in the central part of the Gobi grassland region of Mongolia and is characterized by a typical continental arid climate. The province can be divided into three major climatic zones: a dry and cool mountain steppe zone, an extremely arid and warm desert-steppe zone, and an intensely arid and hot desert-steppe zone. Average temperatures range from –16 °C to –19 °C in winter and +17 °C to +21 °C in summer, with annual precipitation of only 95–150 mm [8]. Overall, the region experiences cold, dry winters and warm, low-rainfall summers, representing the typical climatic pattern of the Gobi steppe. Sheep in this region are primarily raised under natural grazing conditions, producing meat with a fine texture, pure flavor, and distinctive lipid characteristics, making it a representative example of Mongolian mutton. Against this background, the present study focuses on mutton from Erdenedalai soum in Dundgovi Province. By systematically determining chemical properties and evaluating the nutritional characteristics and regional stability of Erdenedalai mutton. The objectives are to provide fundamental data for the nutritional evaluation of Mongolian mutton; to compare its physicochemical characteristics with those of Chinese Geographical Indication (GI) mutton; and, by integrating regional ecological features, to infer the potential mechanisms through which ecological conditions influence meat quality. From the perspective of GI product development, this study aims to offer a scientific basis and policy reference for the branding and industrialization of Mongolian mutton.

Materials and methods

Sampling

Mutton samples were collected from sheep in Erdenedalai soum, Dundgovi Province. Four animal groups included: rams, ewes, ram lamb, and ewe lamb. Healthy individuals were selected, and samples were taken from three representative muscle parts-the shoulder, loin, and leg-under standardized slaughtering and processing conditions. Approximately 300 g of tissue was collected from each anatomical site. All samples were immediately sealed, stored at low temperature, and transported to the laboratory using a cold-chain system for subsequent analyses [9].

Determination of chemical properties

Moisture, protein, fat, ash, and energy contents were determined according to the Mongolian National Standard MNS 6958:2021. Moisture was analyzed by oven drying, protein by the Kjeldahl method, fat by the Soxhlet extraction method, and ash by high-temperature incineration. Energy values were calculated from the proximate composition using standard physiological conversion coefficients [10].

Determination of amino acid composition

Amino acid composition was analyzed as a key indicator of protein quality. Following acid hydrolysis, seventeen amino acids—including aspartic acid, glutamic acid, lysine, leucine, threonine, and tryptophan—were quantified using an automatic amino acid analyzer.

The analysis followed internationally recognized HPLC procedures with pre-column derivatization using OPA and FMOC, based on the analytical principles of ISO 13903 and AOAC Official Methods. Results were expressed in g/100 g, and total amino acids (TAA), essential amino acids (EAA), non-essential amino acids (NEAA), and their ratios (EAA/TAA and EAA/NEAA) were calculated [11].

Determination of fatty acid composition

Fatty acids were analyzed using gas chromatography (GC) in accordance with AOAC Official Method 963.22 and CA318:2016. A total of 35 fatty acids were identified, including saturated (SFA), monounsaturated (MUFA), and polyunsaturated fatty acids (PUFA). Particular emphasis was placed on nutritionally relevant fatty acids, such as oleic acid (C18:1 n-9), linoleic acid (C18:2 n-6), and n-3 fatty acids. Results were expressed as the relative percentage of each fatty acid to total fatty acids [12].

Data analysis

All analytical results were expressed as mean ± standard deviation (Mean ± SD). Due to the limited sample size, descriptive statistical methods were used to compare differences and distribution patterns among age and sex groups. The purpose of this method is to evaluate the nutritional characteristics and potential industrial value of Mongolian mutton.

Results and Discussion

As shown in Table 1, the chemical properties of mutton from different anatomical parts in Dundgovi Province exhibited noticeable variation. Overall, moisture content ranged from 64.17% to 72.68%. Protein content varied between 17.06% and 22.67% (mean ≈ 20.2%), whereas fat content showed greater fluctuation, ranging from 6.04% to 17.05% (mean ≈ 9.9%). Ash content remained relatively stable (0.70%–1.07%, mean ≈ 0.93%). Energy values ranged from 128.2 to 225 kcal/100 g, closely corresponding to the variation in fat content.

Table 1.

Chemical properties of mutton from different muscles of sheep in Dundgovi Province

Animal age and sex	Muscles	Moisture, %	Protein, %	Fat, %	Ash, %	Energy, **(kcal)**
Ram	Foreleg	68.38^b	19.09	11.07^a	0.92	176.0^a
	Loin	67.13^b	21.55	10.03^a	1.05	176.5^a
	Thigh	70.28^a	20.96	6.98^b	0.98	146.6^b
Ewe	Foreleg	71.86	20.65	6.53^b	0.96	141.4^b
	Loin	70.42	19.45	9.09^a	1.04	159.6^a
	Thigh	71.60	21.36	6.08^c	0.96	140.2^b
Ram lamb	Foreleg	72.68^a	18.46	6.04^c	0.88	128.2^c
	Loin	64.17^b	17.89	17.05^a	0.89	225^a
	Thigh	68.6^a	17.06	10.25^b	0.89	160.5^b
Ewe lamb	Foreleg	64.27^c	19.19	15.84^a	0.70^b	219.3a
	Loin	67.76^b	22.20	9.15^b	0.87^b	171.1^a
	Thigh	69.37^a	22.67	6.77^c	1.07^a	151.6^b

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Among the three muscles, the thigh exhibited the highest mean ($p<0.05$) moisture content (69.67%) and the lowest ($p<0.05$) fat level (8.27%), resulting in a lower energy value (154.58 kcal/100 g) and a leaner nutritional profile. The loin had the highest protein content (20.75%), and fat (10.58%), and the greatest ($p<0.05$) energy value (178.20 kcal/100 g), indicating greater nutritional density and stronger flavor potential. The foreleg presented intermediate values but exhibited higher inter-individual variability, especially in fat content (SD = 4.6), suggesting that this cut is more suggesting that this cut is more affected by individual physiological differences. The physicochemical properties of Dundgovi mutton generally fell within the typical range of high-quality meat, and the differences among muscles were consistent with muscular physiology [13]. The hind leg, as a major locomotive muscle group, had higher moisture and lower fat content due to coarser muscle fibers and lower lipid deposition. The longissimus dorsi, located along the dorsal region, showed fine texture and well-distributed intramuscular fat, resulting in higher protein and energy levels—consistent with its use as a key indicator in meat quality evaluation. In contrast, the foreleg, which performs both support and movement, showed greater variability, and its fat content appeared to be more influenced by individual biological differences. When compared with Chinese Geographical Indication (GI) mutton—such as Ningxia Tan sheep and Inner Mongolian grassland sheep (which typically contain 68–72% moisture, 18–22% protein, and 6–15% fat)—the mutton samples from Dundgovi exhibited comparable or slightly higher moisture and protein levels, indicating high-quality meat with favorable nutritional characteristics [14]. Furthermore, correlation analysis revealed a strong positive relationship between fat content and energy value (r = 0.95), while moisture was negatively correlated with fat content (r = −0.97). These results suggest that energy density is largely determined by fat levels, and that an inverse relationship between moisture and fat is consistent with previous studies on mutton quality.

Fatty acid composition

A total of 28 fatty acids were identified in the mutton samples from Erdenedalai soum, Dundgovi Province (Table 2). Saturated fatty acids (SFA) accounted for 45.17 ± 2.26%, while monounsaturated fatty acids (MUFA) constituted 41.58 ± 2.63%, representing the major portion of total fatty acids. The mean proportion of polyunsaturated fatty acids (PUFA) was 13.61 ± 0.91%, including 7.99 ± 0.89% n-6 PUFA and 5.28 ± 0.68% n-3 PUFA, resulting in an average n-6/n-3 ratio of 1.52 ± 0.15. These indices fall within the range generally considered favorable for ruminant meat nutrition.

Table 2.

Fatty acid composition and key nutritional indices of mutton, %

Fatty acid type and name				
Total saturated fatty acids (SFA)	46.13	45.67	47.03	41.86
Total unsaturated fatty acids (UFA)	53.83	54.17	52.73	58.04
Of which: total monounsaturated fatty acids (MUFA)	39.99	41.19	38.51	44.63
Palmitoleic acid (C16:1 n-7	2.43	1.81	1.82	1.96
Oleic acid (C18:1 n-9)	34.66	39.02	36.18	42.14
Of which: total polyunsaturated fatty acids (PUFA)	13.84	12.98	14.22	13.41
Linoleic acid (C18:2 n-6)	7.46	5.97	6.05	5.83
α-Linolenic acid (C18:3 n-3)	0.37	0.45	0.33	0.43
Total n-6 PUFA	9.35	7.56	7.66	7.38
Total n-3 PUFA	6.10	5.03	4.50	5.47
Key nutritional ratios				
PUFA / SFA ratio	0.30	0.28	0.30	0.32
n-6 / n-3 ratio	1.53	1.50	1.70	1.35

The predominant fatty acids were palmitic acid (C16:0, 16.15–17.69%), stearic acid (C18:0, 7.71–10.16%), oleic acid (C18:1 n-9, 34.66–42.14%), and linoleic acid (C18:2 n-6, 5.83–7.46%). Only trace levels of unidentified components (0.04–0.24%) were detected, indicating that the overall fatty acid profiles were chemically stable. The four samples showed minimal variation, demonstrating a consistent and regionally characteristic lipid structure. From a nutritional perspective, the samples exhibited moderate SFA, relatively high MUFA (~41%), and balanced PUFA, particularly with a substantial proportion of n-3 fatty acids.

This composition aligns with fatty acid patterns known to originate from grazing-based feeding systems [15]. The PUFA/SFA ratio (0.28–0.32) and n-6/n-3 ratio (1.35–1.70) observed in this study are indicative of healthier lipid characteristics compared with typical grain-fed sheep, which often show higher n-6/n-3 ratios.

When compared with Chinese Geographical Indication (GI) mutton—such as Ningxia Tan sheep and Inner Mongolian Sunit sheep—the Erdenedalai samples demonstrated a slightly higher MUFA proportion and a lower n-6/n-3 ratio (~1.5), both of which are typical signatures of pasture-fed ruminant meat. This pattern is largely attributed to the high α-linolenic acid (C18:3 n-3) content of natural steppe vegetation, which is metabolically converted in the rumen and deposited in muscle tissue, creating a region-specific lipid fingerprint**.** This fatty acid profile—marked by high levels of C18:1 n-9 and C18:2 n-6, together with a stable n-6/n-3 ratio—provides a distinctive biochemical marker for mutton produced in the Erdenedalai region. It suggests that the local grazing ecosystem exerts a measurable influence on muscle lipid metabolism and supports the establishment of quality standards for GI-labeled Mongolian mutton [16].

From the perspective of Geographical Indication (GI) certification, products must demonstrate regional specificity, compositional stability, and traceability. The minimal variation and structural consistency observed across the four samples meet the criteria of internal compositional stability. Additionally, the MUFA-enriched and grass-fed lipid characteristics offer a strong physicochemical basis for recognizing Erdenedalai mutton as a potential GI agricultural product**.**

Amino acid composition

A total of 17 amino acids were detected in the mutton samples collected from Erdenedalai soum in Dundgovi Province (Table 3). The total amino acid (TAA) content averaged 24.8 ± 2.8 g/100 g, while essential amino acids (EAA) averaged 10.7 ± 1.5 g/100 g, accounting for 43.2% of TAA. The EAA/NEAA ratio was 76.2%, indicating a well-balanced amino acid profile characteristic of high-quality animal protein.

Among flavor-related amino acids, glutamic acid (Glu: 3.06-4.18 g/100 g) and aspartic acid (Asp: 1.48-2.13 g/100 g**)** were the most abundant, jointly accounting for approximately 20% of total amino acids. Sweet-tasting amino acids-including Ala, Gly, Ser, Thr, and Pro contributed roughly 15% of total amino acids. The small variations among samples (SD < 0.3 g/100 g for most amino acids) indicate a highly stable amino acid pattern, suggesting regional consistency in protein composition shaped by the local grazing ecosystem [16]. The specific features are as follows:

Table 3.

Amino acid profile of mutton (g/100g)

no acids (n = 4)	Ram	Ewe	Ram lamb	Ewe lamb	Mean ± SD	Classification
Asp	1.76	2.06	1.48	2.13	1.86 ± 0.28	Flavor-related
Thr	1.01	1.20	0.84	1.24	1.07 ± 0.17	EAA
Ser	0.87	1.01	0.74	1.04	0.92 ± 0.14	NEAA
Glu	3.46	4.11	3.06	4.18	3.70 ± 0.47	Flavor-related
Pro	0.95	1.00	0.91	1.07	0.98 ± 0.07	Flavor-related
Gly	0.91	1.07	0.93	1.05	0.99 ± 0.07	Flavor-related
Ala	1.27	1.46	1.10	1.48	1.33 ± 0.17	Flavor-related
Val	1.04	1.12	0.86	1.25	1.07 ± 0.16	EAA
Met	0.55	0.55	0.45	0.52	0.52 ± 0.05	EAA
Ile	1.02	1.19	0.83	1.25	1.07 ± 0.18	EAA
Leu	1.76	2.06	1.48	2.13	1.86 ± 0.27	EAA
Tyr	0.78	0.93	0.66	0.94	0.83 ± 0.13	NEAA
Phe	1.09	1.19	0.73	0.98	1.00 ± 0.17	EAA
His	1.06	1.08	0.73	1.23	1.03 ± 0.19	EAA
Lys	2.00	2.30	1.64	2.33	2.07 ± 0.31	EAA
Arg	1.41	1.66	1.24	1.67	1.50 ± 0.20	NEAA

Trp	0.13	0.16	0.087	0.18	0.14 ± 0.04	EAA
Cys	0.23	0.24	0.22	0.22	0.23 ± 0.01	NEAA
TAA	23.3	27.1	20.9	27.8	24.8 ± 2.8	—
EAA	10.1	11.9	8.70	12.2	10.7 ± 1.5	—
EAA/TAA	43.4	43.9	41.6	43.9	43.2 ± 1.0	—
EAA/NEAA	76.6	78.3	71.3	78.4	76.2 ± 2.9	—

Amino Acid Structure and Geographical Indication Identifiability

The relatively stable EAA/TAA ratio (~43%) and EAA/NEAA ratio (~76%) across all samples demonstrate a consistent protein structure, whichtogether with the stable fatty acid patterns reported earlier-forms a regional physicochemical fingerprint. This compositional stability satisfies key requirements for Geographical Indication (GI) validation, namely: traceability, compositional uniqueness, and stability across samples [17].

Comparison with High-Quality Mutton and FAO/WHO Standards

The FAO/WHO standard for high-quality protein recommends an EAA/TAA ratio of 40–45%, and the Erdenedalai samples (43%) fall squarely within this optimal range. Among the EAA, Lys, Leu, and Val were present at relatively high levels, indicating an amino acid profile well aligned with human nutritional needs. Although Met levels were comparatively lower, they remained within an acceptable range. Overall, the amino acid composition is comparable to that reported for Chinese GI-certified mutton-such as Ningxia Tan sheep and Inner Mongolian Sunit sheep-indicating that Erdenedalai mutton possesses a protein quality consistent with internationally recognized high-quality mutton products [18].

Flavor Amino Acids and Sensory Potentia

The combined abundance of Glu and Asp (>15%) constitutes the biochemical basis of umami taste, while sweet-tasting amino acids (Ala, Gly, Ser, Pro) further enhance flavor complexity. This indicates that Erdenedalai mutton has a naturally rich and distinctive flavor profile, consistent with the sensory characteristics of pasture-raised livestock. The stable presence of these flavor-precursor amino acids provides strong physicochemical support for the "recognizable flavor" that GI products emphasize.

Potential Influence of Ecological Conditions

Pasture-based feeding, particularly on leguminous and gramineous plants common in the Gobi steppe, contributes high-quality protein and free amino acids that influence muscle amino acid deposition. The elevated levels of EAA and Glu observed in this study are therefore likely linked to ecosystem-specific nutritional inputs, reinforcing the concept that the ecological environment directly shapes the nitrogen metabolic profile of local mutton. This supports the argument that Erdenedalai mutton reflects ecological distinctiveness, a core requirement for GI certification.

Analysis of Mineral Composition

Table 4 summarizes the concentrations of major mineral elements (Ca, Fe, Zn, and Se) and heavy metals (As, Cd, Hg, Pb) in mutton samples collected from Erdenedalai soum of Dundgovi Province. Overall, the mineral profiles showed high stability and minimal inter-individual variation, consistent with the typical range reported for high-quality pasture-raised mutton.

Table 4.

Mineral composition of mutton

Element	Ram	Ewe	Ram lamb	1Ewe lamb	Mean ± SD
Ca (mg/100g)	4.37	7.43	6.20	5.03	5.76 ± 1.35
Fe (mg/100g)	2.39	2.43	1.51	1.81	2.04 ± 0.45
Zn (mg/100g)	2.04	2.17	3.08	2.09	2.35 ± 0.49
Se (mg/kg)	0.0805	0.0568	0.114	0.0571	0.077± 0.027
As (mg/kg)	ND	0.0109	ND	ND	—

Cd (mg/kg)	ND	ND	ND	ND	—
Hg (mg/kg)	ND	ND	ND	ND	—
Pb (mg/kg)	ND	ND	ND	ND	—

ND, not detected

For macro- and trace elements, the mean concentrations of Ca, Fe, and Zn were 5.76 ± 1.35 mg/100 g, 2.04 ± 0.45 mg/100 g, and 2.35 ± 0.49 mg/100 g, respectively. Among these, Zn levels were comparable to those reported for Chinese Geographical Indication (GI) mutton varieties such as Tan sheep and Sunit sheep, indicating a favorable trace-nutrient profile with potential health benefits. The stable Fe concentration (1.51–2.43 mg/100 g) also reflects a strong nutritional contribution to hematopoietic function. Selenium (Se), a key functional trace mineral associated with antioxidant activity and immune regulation, averaged 0.077 ± 0.027 mg/kg. This concentration aligns with the naturally high selenium background of Mongolian grassland soils, suggesting that local grazing ecosystems significantly influence Se deposition in muscle tissues [19].

Regarding food safety, heavy metals were either not detected or present at trace levels below analytical detection limits (As <0.005 mg/kg, Cd <0.005 mg/kg, Hg <0.003 mg/kg, Pb <0.05 mg/kg). All values are far below international and national safety standards, indicating exceptionally low contamination risk. This is consistent with the low industrial activity and pristine ecological conditions of the Middle Gobi region.

In summary, the mineral composition of Erdenedalai mutton is characterized by stable nutrient levels, adequate trace minerals, and excellent safety performance. These properties not only enhance its nutritional value but also provide strong physicochemical support for its potential qualification as a Geographical Indication (GI) product, embodying the characteristics of "eco-grazed, nutrient-rich, and highly safe" Mongolian mutton [20].

Conclusion

This study systematically evaluated the physicochemical properties, fatty acid composition, amino acid profile, and mineral elements of mutton from Erdenedalai soum in Dundgovi Province, Mongolia. The results demonstrate that mutton exhibits a balanced nutritional structure, stable physicochemical characteristics, and distinct ecological attributes shaped by the natural grazing environment. The amino acid and fatty acid profiles aligned closely with the quality benchmarks reported for Chinese Geographical Indication (GI) mutton, while mineral elements remained stable and heavy metals were undetected, reflecting both high nutritional value and excellent food safety. Overall, the integrated analysis indicates that Erdenedalai mutton possesses a recognizable and stable physicochemical "regional fingerprint", characterized by consistent macronutrient composition, favorable fatty acid distribution, and ecological specificity. These features strongly support its potential as a candidate for Geographical Indication (GI) certification, demonstrating clear traceability, regional uniqueness, and compositional stability key attributes of GI agricultural products [20].

Looking forward, this study provides essential scientific evidence and foundational data for the branding, premiumization, and international market development of Mongolian mutton. Further research may expand sampling coverage, incorporate environmental and seasonal variables, and explore sensory evaluation and consumer preference analysis, thereby establishing a more comprehensive quality evaluation framework and supporting the sustainable advancement of Mongolia's pastoral livestock industry.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Auhtors' contribution

NQ, D.D, T.A, R.Ch, and B.M conceived and planned the experiments. NQ, T.A, and B.M carried out the experiments. NQ and T.A contributed to sample preparation. R.Ch and NQ contributed to the interpretation of the results. NQ and D.D took the lead in writing the manuscript. All authors provided critical feedback and helped shape the research, analysis and manuscript.

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