Scifood
vol. 20, 2026, p. 210-226
https://doi.org/10.5219/scifood.112
ISSN: 2989-4034 online
https://scifood.eu

Received: **18.1.2026**
Revised: 20.3.2026
Accepted: 22.3.2026
Published: 25.3.2026

Carcass characteristics, physicochemical properties, amino acid composition, and fatty acid profile of European brown hare (*Lepus europaeus*) meat

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ABSTRACT

This study examined carcass characteristics and selected nutritional quality parameters of meat derived from European brown hares (*Lepus europaeus*). Biological material was collected from free-living animals legally harvested during the regular hunting season in western Slovakia. In total, 40 hares (17 males and 23 females) were included in the investigation. Samples of three muscles (*longissimus dorsi*, *semimembranosus*, and *brachialis* muscles) were analysed to determine proximate composition, amino acid profile, fatty acid composition, lipid nutritional indices, and instrumental colour parameters. The analysed hare meat was characterised by a high protein content ranging from approximately 22.0 to 23.8 g.100 g^{-1} and very low intramuscular fat levels (0.61–0.91 g.100 g^{-1}). The amino acid profile showed a balanced distribution of essential amino acids, with lysine and leucine as the most abundant. Among individual fatty acids, oleic acid (C18:1 n-9), palmitic acid (C16:0), and linoleic acid (C18:2 n-6) were predominant. Monounsaturated fatty acids constituted the dominant fraction of the total lipid content (44–47%), followed by saturated fatty acids (34–36%) and polyunsaturated fatty acids (17–23%). Calculated lipid quality indices indicated a relatively favourable balance between saturated and unsaturated fatty acids. Instrumental colour measurements confirmed the typical dark red appearance of hare meat, reflecting the higher myoglobin content characteristic of physically active wild animals. The results confirm the lean character of hare meat, particularly due to its low fat content and relatively high protein content. The fatty acid profile further supports its nutritional relevance, although some variation between muscles was observed. These findings contribute to a better understanding of the nutritional characteristics of game meat and highlight the potential of hare meat as part of a more diverse human diet.

Keywords: *Lepus europaeus*, meat, fatty acid, amino acid, meat colour

INTRODUCTION

In recent years, increasing attention has been directed towards alternative sources of animal protein, including game meat, primarily due to its distinct nutritional characteristics. Compared with conventional livestock species, meat from wild animals is generally characterised by lower fat content, higher protein concentration, and a more favourable fatty acid composition. These attributes are largely associated with natural feeding behaviour and higher levels of physical activity typical of free-living species **[1]**, and **[2]**. Nevertheless, the composition of game meat is not uniform and may vary depending on environmental conditions, diet, and biological factors.

The European brown hare (*Lepus europaeus*) represents an important free-living herbivorous species widely distributed across agricultural landscapes in Europe. Its diet consists of a broad spectrum of plant material, the availability of which changes seasonally and spatially. Such variation in feeding conditions may influence nutrient intake and, in turn, affect the chemical composition of muscle tissue, particularly lipid fractions and fatty acid

profiles **[3]**, and **[4]**. In addition, the high level of locomotor activity characteristic of wild species is associated with increased myoglobin content and a predominance of oxidative muscle fibres, which contribute to specific differences in meat colour and technological properties **[5]**, and **[1]**.

Meat from lagomorph species, including hares, is generally described as lean, with high protein content and low intramuscular fat levels. Previous studies have reported protein contents exceeding 22–23 g.100 g^{-1} and fat levels typically below 2 g.100 g^{-1}, confirming its high nutritional value and dietetic character **[6]**, and **[7]**. In addition to its favourable macronutrient composition, hare meat is also considered a valuable source of essential amino acids and other nutrients important for human nutrition **[8]**, and **[9]**.

From a lipid perspective, hare meat is typically characterised by a relatively high proportion of unsaturated fatty acids, particularly polyunsaturated fatty acids (PUFA), which are associated with beneficial effects on human health. This pattern is closely linked to the natural plant-based diet of wild herbivores and has been confirmed in studies reporting elevated PUFA levels in hare muscle tissues **[5]**, and **[2]**. However, fatty acid composition and related lipid indices may vary depending on several factors, including sex, muscle type and environmental conditions **[10]**.

Meat colour represents another important quality attribute that directly influences consumer acceptance. It is primarily determined by myoglobin content and muscle metabolism. Due to higher levels of physical activity and oxidative metabolism, meat from wild species, including hares, typically exhibits a darker red colour compared with meat from intensively reared animals **[11]**, and **[12]**. These characteristics are considered typical for game meat and reflect physiological adaptations to free-living conditions.

Therefore, the aim of the present study was to evaluate selected carcass characteristics and quality parameters of meat obtained from the European brown hare (*Lepus europaeus*), with particular emphasis on chemical composition, amino acid profile, fatty acid composition, lipid nutritional indices, and instrumental colour characteristics, and to assess the influence of muscle type and sex on these parameters.

Scientific Hypothesis

Based on previous studies describing the nutritional characteristics of game meat and the physiological differences among skeletal muscles, it was hypothesised that meat from the European brown hare (*Lepus europaeus*) exhibits favourable nutritional characteristics, including high protein content, low intramuscular fat levels, and a balanced fatty acid profile. Furthermore, it was assumed that selected meat quality parameters, including chemical composition, amino acid profile, fatty acid composition, and instrumental colour characteristics, vary by muscle type and animal sex. These differences were statistically evaluated to determine whether muscle location and sex represent significant sources of variability in the nutritional and technological properties of hare meat.

Objectives

The primary objective of this study was to comprehensively evaluate selected quality characteristics of meat obtained from the European brown hare (*Lepus europaeus*). The study aimed to assess carcass performance and the nutritional composition of hare meat obtained from wild animals harvested under natural environmental conditions.

The secondary objectives of the study were:

- to determine the basic chemical composition of selected muscles, including moisture, protein, fat, and cholesterol content;
- to analyse the amino acid profile of hare meat and evaluate the proportion of essential amino acids and branched-chain amino acids;
- to determine the fatty acid composition of intramuscular lipids and calculate selected lipid nutritional indices, including the atherogenic index, thrombogenic index, hypocholesterolemic/hypercholesterolemic ratio, and PUFA/SFA ratio;
- to evaluate instrumental colour parameters of selected muscles using the CIE *Lab** colour system and derived colour indices; and
- to investigate potential differences in the analysed parameters between individual muscles and between sexes.

Through this integrated approach, the study aimed to provide a comprehensive assessment of the nutritional and technological quality of meat from the European brown hare.

MATERIAL AND METHODS

Samples

Samples description: Biological material consisted of meat obtained from European brown hares (*Lepus europaeus*). The analysed animals originated from free-living populations inhabiting agricultural habitats typical of western Slovak landscapes. A total of 40 animals were included in the study, comprising 17 males and 23 females.

Samples collection: The hares were harvested during the regular hunting season (November–December) in the Piešťany hunting area (Slovak Republic). Hunting activities were conducted in accordance with the legislation of the Slovak Republic governing wildlife management and hunting practices (Act No. 274/2009 Coll.). Immediately after harvesting, the live body weight of each animal was recorded using a digital laboratory scale (WTC 2000, RADWAG, Poland). Following harvesting, carcasses were transported under chilled conditions (approximately 4 °C) to the laboratory facilities at the Institute of Food Sciences, Slovak University of Agriculture in Nitra (Slovakia), where further analyses were performed.

Samples preparation: After transport, carcasses were stored under chilled conditions (4 °C) for 4–5 days to allow *post-mortem* ageing. Subsequently, carcasses were dissected, and three major muscle groups were sampled for laboratory analyses: *longissimus dorsi* (back muscle), *semimembranosus* (thigh muscle), and *brachialis* (shoulder muscles). The collected muscle samples were trimmed of visible connective tissue and homogenised prior to analytical determinations.

Number of samples analysed: A total of 120 muscle samples were analysed (3 muscles from each of 40 animals).

Chemicals

All chemicals used in laboratory analyses were of analytical grade quality. Hydrochloric acid (6 N HCl) used for amino acid hydrolysis and other reagents were purchased from Sigma-Aldrich (Germany). Petroleum ether used for lipid extraction was obtained from Merck (Germany). Standard mixtures of fatty acid methyl esters (Supelco 37 Component FAME Mix) used for chromatographic identification were purchased from Sigma-Aldrich (Germany).

Animals, Plants and Biological Materials

The analysed biological material consisted of the European brown hare (*Lepus europaeus*), a wild lagomorph species widely distributed throughout European agricultural landscapes. The animals originated from natural populations inhabiting farmland habitats and fed exclusively on natural vegetation available within their habitat.

Instruments

Basic chemical composition of meat samples was determined using an INFRATEC 1265 analyser (FOSS, Germany) operating in near-infrared transmittance mode. Amino acid composition was determined using an automatic amino acid analyser AAA 400 (Ingos, Prague, Czech Republic). Fatty acid composition was analysed using gas chromatography after preparation of fatty acid methyl esters. Instrumental colour parameters were measured using a Konica Minolta CM-2600d spectrophotometer (Konica Minolta, Osaka, Japan).

Laboratory Methods

Chemical composition

Basic chemical composition of the muscle samples, including moisture, crude protein, crude fat, and cholesterol content, was determined using near-infrared spectroscopy with an INFRATEC 1265 analyser (FOSS, Germany). Approximately 50 g of homogenised meat sample was placed into a glass sample cup and analysed according to the manufacturer's instructions. Each sample was scanned twice, and each spectrum represented the average of five scanning positions.

Amino acid analysis

The amino acid composition of muscle samples was determined using an automatic amino acid analyser (AAA 400, Ingos, Czech Republic) following acid hydrolysis. Approximately 5 g of homogenised sample was hydrolysed in 6 N hydrochloric acid at 110 °C for 24 h. Amino acids were separated by ion-exchange chromatography and detected after post-column derivatisation with ninhydrin. Amino acids were quantified using external calibration standards.

Fatty acid composition

Total lipids were extracted from the samples using Soxhlet extraction with petroleum ether. Fatty acid methyl esters (FAME) were prepared according to ISO 12966-2 methodology. The methyl esters were subsequently analysed using gas chromatography. Fatty acids were identified by comparing retention times with those of standard mixtures (Supelco 37 Component FAME Mix).

Calculation of lipid nutritional indices

Based on the fatty acid composition, several lipid nutritional indices were calculated to evaluate the nutritional quality of intramuscular lipids. The following indices were calculated: atherogenic index (AI), thrombogenic

index (TI), hypocholesterolemic/hypercholesterolemic ratio (h/H), PUFA/SFA ratio, and n-6/n-3 ratio. The indices were calculated according to equations proposed by **[13]**.

Meat colour measurement

Instrumental colour of meat samples was measured using a Konica Minolta CM-2600d spectrophotometer (Konica Minolta, Osaka, Japan) with a D65 light source and a 10° standard observer, using an 8 mm measuring aperture. Before measurement, samples were allowed to bloom for approximately 30 minutes at 4 °C. Colour parameters were expressed in the CIE *Lab** colour space, where *L** represents lightness, *a** redness, and *b** yellowness. Additional colour indices, including chroma (C*), hue angle (h°), browning index (BI), and total colour difference (ΔE), were calculated from the measured colour coordinates.

Description of the Experiment

Study flow: The experimental procedure consisted of several consecutive stages. In the first stage, carcass characteristics including live body weight, carcass weight, and distribution of carcass parts were recorded. In the second stage, muscle samples were collected and prepared for laboratory analyses. Chemical composition, amino acid profile, fatty acid composition, and colour parameters were subsequently determined using appropriate analytical methods. In the final stage, the obtained analytical data were processed and subjected to statistical analysis to evaluate potential differences between sexes and among muscle types.

Quality Assurance

Number of repeated analyses: Each analytical determination was performed in replicate to ensure the reliability of the obtained results. Basic chemical composition analyses were carried out in triplicate for each sample. Amino acid analyses were performed in duplicate after independent hydrolysis of the samples. Fatty acid composition analyses were also performed in duplicate, including independent preparation of fatty acid methyl esters. Instrumental colour measurements were conducted in five repeated measurements at different locations on the muscle surface, and the mean value was used for further statistical evaluation.

Number of experiment replication: The experiment was conducted on biological samples obtained from 40 animals (17 males and 23 females). For each animal, three different muscle groups (back muscle, thigh muscle, and shoulder muscle) were analysed. This resulted in a total of 120 muscle samples included in the experimental design. Each laboratory determination was performed independently for each sample.

Reference materials: For chromatographic analyses of fatty acids, standard mixtures of fatty acid methyl esters (Supelco 37 Component FAME Mix, Sigma-Aldrich, Germany) were used for identification and retention-time verification. Calibration standards supplied by the manufacturers of the analytical instruments were used to verify the accuracy of the amino acid analyser and near-infrared analyser. In addition, certified analytical standards were used for routine quality control of chromatographic measurements.

Calibration: All analytical instruments were calibrated prior to the start of each analytical series according to the manufacturer's instructions. The spectrophotometer used for colour measurement was calibrated using a certified white calibration tile supplied by the manufacturer. The amino acid analyser was calibrated using standard amino acid mixtures before each analytical batch. Gas chromatographic analyses of fatty acid methyl esters were verified using standard reference mixtures to confirm retention time stability and detector response.

Laboratory accreditation: The analyses were performed in the research laboratories of the Slovak University of Agriculture in Nitra. The experiments were conducted in accordance with standard laboratory procedures and internal quality control protocols.

Data Access

The datasets generated and analysed during the current study are available from the corresponding author upon reasonable request.

Statistical Analysis

Statistical analysis was performed using Statistica software (StatSoft Inc., USA). The normality of the data distribution was verified using the Shapiro–Wilk test. Differences in meat quality parameters among muscles and between sexes were evaluated using two-way analysis of variance (ANOVA) with sex and muscle type as fixed factors. When significant effects were detected, Tukey's post-hoc test was applied for pairwise comparisons. Results are presented as mean ± standard deviation (SD). Statistical significance was considered at $p \leq 0.05$.

Reporting and transparency statement

This study was observational and used biological material obtained from legally hunted animals. Randomisation and blinding procedures were not applicable. All collected samples were included in the analysis and no data were excluded. The sample size was determined based on the availability of animals harvested during the hunting season.

RESULTS AND DISCUSSION

Carcass characteristics

Carcass characteristics are commonly used to describe biological performance and meat yield in wild game species. The results obtained for *Lepus europaeus* are summarised in Table 1. In the present study, the average live body weight reached 3729.15 g in males and 4239.93 g in females, although the difference was not statistically significant (p=0.203). These values correspond to those reported for free-living populations in Central Europe, where body weight typically ranges from approximately 3.5 to 5 kg, depending on environmental conditions and seasonal factors **[3]**, and **[10]**. Comparable body weight ranges have also been reported in earlier field studies on European hare populations, where variation was primarily associated with habitat conditions and food availability **[1]**. The slightly higher body weight recorded in females may reflect differences in feeding conditions prior to harvesting or natural individual variability.

Carcass weight without head averaged 2381.85 g in males and 2580.70 g in females, with no significant differences between sexes (p=0.424). A similar pattern was observed for carcass weight with head (p=0.419), indicating a limited effect of sex on overall carcass yield. This is consistent with previous studies reporting a relatively minor influence of sex on carcass traits in hares and other lagomorph species **[10]**, **[14]**, and **[15]**. In general, carcass yield in wild animals is more strongly influenced by environmental factors and physiological condition than by intrinsic factors such as sex **[1]**, and **[16]**.

The distribution of carcass components followed the expected anatomical pattern. Hind limbs represented the largest portion of the carcass, reaching 819.60 g in males and 945.42 g in females (p=0.138). The back muscle accounted for 593.15 g in males and 700.58 g in females (p=0.397), while forelimb weights were comparable between sexes (p=0.820). This pattern is associated with locomotor demands, as hares rely on well-developed hind limbs for rapid movement and escape behaviour **[10]**. The predominance of hind limb musculature is a typical adaptation in cursorial species and reflects the functional requirements for sustained locomotor performance **[5]**. Slaughter yield without head ranged from 67.20% in females to 70.23% in males (p=0.131), whereas slaughter yield with head ranged from 70.83% to 73.92% (p=0.137). These values are comparable with previously reported dressing percentages for wild hares **[10]**, and **[17]**. Similar ranges have also been reported in earlier carcass evaluation studies on hares, although variability may occur depending on carcass processing and definition **[1]**. Among edible offal components, a statistically significant difference between sexes was found only for heart weight (p=0.010), with higher values in females (50.38 g) compared with males (35.55 g). No significant differences were detected for liver, kidneys, lungs or gastrointestinal tract components (p>0.05), suggesting that this finding is more likely related to individual variability than to a consistent sex effect. Similar observations were reported by **[10]**, who found limited sex-related differences in most carcass and organ parameters.

Overall, sex-related differences were limited across most carcass parameters, indicating that carcass composition in *Lepus europaeus* is influenced more strongly by environmental conditions, nutritional availability and physiological status than by sex alone. In wild animals, variability in carcass traits is commonly associated with seasonal fluctuations in feed resources and habitat conditions, which directly affect body condition and energy reserves **[1]**, and **[3]**.

From a production perspective, the relatively high proportion of lean muscle tissue combined with low fat deposition represents a typical feature of hare carcasses. This is consistent with the biology of wild herbivores and their high level of physical activity, which limits fat accumulation and promotes muscle development **[6]**. Compared with conventional livestock species, hare meat generally contains higher protein levels and lower fat content, which contributes to its favourable nutritional profile **[6]**, **[7]**, and **[8]**.

Taken together, the carcass characteristics observed in this study confirm that the European brown hare is a lean game species with favourable meat yield and well-developed locomotor musculature. The limited influence of sex and the characteristic distribution of muscle mass reflect both ecological adaptation and physiological demands under natural conditions, while observed variability is primarily driven by environmental and nutritional factors rather than intrinsic biological differences. These findings are consistent with the general perception of game meat as a nutritionally valuable and biologically distinct product compared with conventional livestock **[1]**, **[19]**.

Table 1 presents the meat performance traits of *Lepus europaeus*, including live weight, fur with paws, head, carcass weight with and without head, hind limbs, back, fore limbs, slaughter yield with and without head, edible offal, heart, kidneys, lungs, liver, stomach, GIT, and chest with neck, expressed as mean ± SD for males and females, together with p-values.

Table 1 Meat performance of *Lepus europaeus* meat (g).

Sex	Mean ± *SD*	*p*-value
	Live weight	
Male	3729.15±283.65	0.203
Female	4239.93±406.50	
	Fur with paws	
Male	481.95±56.25	0.236
Female	576.85±82.20	
	Head	
Male	137.45±9.75	0.401
Female	154.13±21.94	
	Carcass + Head	
Male	2519.30±282.10	0.419
Female	2734.87±257.02	
	Carcass without Head	
Male	2381.85±272.35	0.424
Female	2580.70±236.24	
	Hind limbs	
Male	819.60±44.80	0.138
Female	945.42±86.40	
	Back	
Male	593.15±71.45	0.397
Female	700.58±138.28	
	Fore limbs	
Male	402.55±41.15	0.820
Female	394.28±35.25	
	Slaughter yield with head (%)	
Male	73.92±1.84	0.137
Female	70.83±1.93	
	Slaughter yield without head (%)	
Male	70.23±1.86	0.131
Female	67.20±1.83	
	Edible offal	
Male	242.30±3.90	0.547
Female	265.42±44.32	
	Heart	
Male	35.55±3.25^{b}	0.010
Female	50.38±4.55^{a}	
	Kidneys	
Male	37.55±4.25	0.988
Female	37.75±14.89	
	Lungs	
Male	54.85±2.55	0.231
Female	78.63±21.79	
	Liver	
Male	114.35±7.45	0.295
Female	98.65±16.22	
	Stomach	
Male	97.80±0.50	0.323
Female	113.55±32.13	
	GIT	
Male	342.85±35.55	0.124
Female	456.52±74.97	
	Chest with neck	
Male	534.35±84.05	0.683
Female	562.23±63.13	

Notes: Mean ± *SD* (standard deviation); Different superscript letter in column (a-b) indicate statistically significant differences ($p \leq 0.05$).

Chemical composition of muscle tissue

The chemical composition of *Lepus europaeus* muscle tissue (Table 2) represents a key indicator of both nutritional value and technological quality. In the present study, all analysed muscles were characterised by high protein content, low intramuscular fat levels and relatively stable moisture content, which are typical features of game meat species. Similar compositional patterns have been reported for wild ungulates and lagomorphs, where lean tissue predominates because of natural feeding conditions and sustained physical activity **[1]**, **[19]**, **[20]**.

Table 2 Chemical composition of *Lepus europaeus* muscle (g.100 g^{-1})

Parameter	Sex	Mean ± *SD*	*p*-value
Water		Back muscle	
	male	75.76±2.46	0.815
	female	76.05±1.80	
		Thigh	
	male	74.05±1.26	0.770
	female	74.33±1.55	
		Shoulder	
	male	74.77±2.09	0.956
	female	74.67±2.95	
Total protein		Back muscle	
	male	23.35±0.91	0.585
	female	22.97±1.13	
		Thigh	
	male	23.52±0.35	0.405
	female	23.76±0.49	
		Shoulder	
	male	22.64±0.76	0.412
	female	22.01±1.32	
Total fat		Back muscle	
	male	0.61±0.10	0.491
	female	0.71±0.24	
		Thigh	
	male	0.77±0.22	0.330
	female	0.91±0.21	
		Shoulder	
	male	0.72±0.28	0.636
	female	0.79±0.24	
Cholesterol		Back muscle	
	male	0.043±0.01	0.645
	female	0.040±0.01	
		Thigh	
	male	0.040±0.02	0.349
	female	0.043±0.01	
		Shoulder	
	male	0.041±0.01	0.162
	female	0.045±0.01	

Note: Mean ± *SD* (standard deviation).

Moisture content ranged from 74.05 to 76.05 g.100 g^{-1}, with no significant differences between sexes ($p>0.05$). These values are consistent with those reported for hare meat **[6]** and reflect the well-established inverse relationship between water and lipid content in muscle tissue **[2]**, **[21]**. In lean meat, reduced lipid deposition is typically accompanied by higher water content, which may also influence technological properties such as water-holding capacity and perceived juiciness **[7]**. Nevertheless, slight variations in moisture cannot be excluded, particularly under different environmental or seasonal conditions **[19]**.

Protein content exceeded 22 g.100 g^{-1}in all analysed samples, ranging from 22.01 to 23.76 g.100 g^{-1}. These values agree with previously reported data for hare and rabbit meat **[3]**, **[6]** and confirm the high protein density typical of game species. From a nutritional standpoint, such levels are considered favourable, as they significantly contribute to essential amino acid intake **[8]**. At the same time, the relatively narrow range observed across

muscles suggests a degree of compositional stability, which may be associated with the continuous locomotion of wild animals and the resulting uniformity of muscle metabolism **[5]**.

Intramuscular fat content remained low across all muscles (0.61–0.91 g.100 g^{-1}), which is characteristic of wild herbivores. Comparable values have been reported in previous studies on hare meat **[6]**, although slightly higher fat levels may occur depending on feeding conditions and seasonal factors **[3]**. Low lipid deposition is generally attributed to high energy expenditure and natural feeding regimes **[1]**. In contrast to intensively reared livestock, where fat accumulation is often enhanced, game meat tends to retain a markedly lean composition **[2]**, and **[7]**.

Slightly higher fat values observed in females were not statistically significant, indicating that sex had only a limited effect on lipid deposition under the conditions of this study. This observation is in line with previous findings suggesting that environmental factors may override sex-related differences in wild populations **[10]**. Cholesterol content ranged from 0.040 to 0.045 g.100 g^{-1} (approximately 40–45 mg.100 g^{-1}) and did not differ significantly between sexes or muscles. These values are comparable with those reported for other lean meats and are generally considered moderate from a nutritional perspective **[18]**. When interpreted together with low fat content and a favourable fatty acid profile, such levels support the classification of hare meat as a dietetically suitable food **[7]**. However, it should be noted that cholesterol content alone does not fully determine the health impact of meat, as the overall lipid composition plays a more decisive role **[2]**.

Differences between muscle types were minimal and did not reach statistical significance. Although minor variations may reflect differences in muscle function and metabolic activity **[5]**, the relatively uniform composition observed here suggests that physiological demands associated with continuous movement may reduce heterogeneity among muscles.

Overall, the combination of high protein content, low fat levels, and moderate cholesterol concentration confirms the favourable nutritional profile of *Lepus europaeus* meat. At the same time, the limited variability observed between sexes and muscles indicates that its chemical composition remains relatively stable under natural conditions, although environmental influences such as diet and season may still contribute to some extent.

Amino acid composition

The amino acid composition of *Lepus europaeus* meat (Table 3) reflects the typical profile of skeletal muscle proteins and confirms its high nutritional value as a protein source. The analysed muscles showed a relatively balanced distribution of essential amino acids, with only minor differences between sexes. Similar amino acid patterns have been described for game meat and lagomorph species, where high-quality protein represents one of the main nutritional advantages **[1]**, **[7]**, and **[20]**.

Among essential amino acids, lysine was present at the highest concentrations across all muscles, ranging from approximately 2.03 to 2.50 g.100 g^{-1}. This finding is consistent with previously reported values for hare and rabbit meat **[3]**, and **[6]** and is nutritionally relevant, as lysine is often considered a limiting amino acid in cereal-based diets. The relatively high lysine content therefore increases the biological value of hare meat proteins and improves their complementarity with plant-derived protein sources **[8]**, and **[9]**.

Branched-chain amino acids (leucine, isoleucine and valine) were also present in considerable amounts. The total BCAA content ranged from approximately 3.7 to 4.5 g.100 g^{-1}, while the sum of essential amino acids (ΣEAA) varied between approximately 9.6 and 11.5 g.100 g^{-1}. These values indicate a nutritionally favourable amino acid profile and are in line with the physiological role of BCAA in protein synthesis, energy metabolism and muscle maintenance **[9]**. At the same time, the relatively narrow range observed suggests that the amino acid composition is not strongly affected by sex under natural conditions.

Sex-related differences were generally limited. No statistically significant differences ($p>0.05$) were observed for most amino acids, including ΣEAA and ΣBCAA, which supports the assumption that amino acid composition in skeletal muscle remains relatively stable. Similar observations have been reported in previous studies, where environmental and nutritional factors were identified as more important determinants than sex **[1]**, and **[10]**. A significant difference was detected only for threonine in the shoulder muscle ($p\leq0.05$), where higher values were observed in males. However, since this difference was not reflected in other muscles or amino acids, it likely represents local variability rather than a consistent biological effect.

Differences between muscle types were more evident than differences between sexes. Slightly higher concentrations of several amino acids were observed in the back and shoulder muscles compared with the thigh muscle. This may be associated with differences in muscle fibre composition and metabolic activity, as muscles with higher oxidative capacity can exhibit altered protein turnover and amino acid utilisation **[5]**. Nevertheless, these differences remained relatively small, suggesting a generally homogeneous protein composition across anatomical locations.

From a nutritional perspective, the amino acid profile of hare meat is comparable with that reported for other high-quality animal protein sources, including rabbit and lean red meat **[7]**, and **[18]**. In addition, game meat is

often characterised by high digestibility and a favourable balance of essential amino acids, which enhances its dietary value **[1]**, and **[8]**. It should be noted, however, that the overall nutritional impact of protein depends not only on amino acid composition but also on digestibility and bioavailability **[7]**, and **[22]**.

Table 3 Amino acid composition of *Lepus europaeus* muscles according to sex (g.100 g^{-1}).

Amino acid	Back ♂	Back ♀	*p*-value	Thigh ♂	Thigh ♀	*p*-value	Shoulder ♂	Shoulder ♀	*p*-value
Threonine	1.07 ± 0.22	1.13 ± 0.28	0.740	1.01 ± 0.11	0.99 ± 0.13	0.755	1.16 ± 0.20[a]	0.92 ± 0.13[b]	0.028
Valine	1.03 ± 0.18	1.09± 0.18	0.603	0.96 ± 0.06	0.96 ± 0.11	0.984	1.09 ± 0.14	0.99 ± 0.16	0.311
Methionine	0.95 ± 0.21	0.97 ± 0.19	0.820	0.78 ± 0.05	0.81 ± 0.13	0.723	0.91 ± 0.17	0.86 ± 0.27	0.771
Isoleucine	1.14 ± 0.26	1.17 ± 0.27	0.863	0.96 ± 0.06	0.95 ± 0.16	0.897	1.13 ± 0.22	1.00 ± 0.30	0.459
Leucine	2.14 ± 0.46	2.22 ± 0.51	0.807	1.88 ± 0.14	1.85 ± 0.28	0.889	2.19 ± 0.41	1.88 ± 0.46	0.289
Phenylalanine	1.09 ± 0.23	1.14 ± 0.25	0.746	0.95 ± 0.07	0.95 ± 0.14	0.989	1.11 ± 0.20	0.98 ± 0.24	0.385
Lysine	2.40 ± 0.54	2.50 ± 0.56	0.780	2.03 ± 0.13	2.04 ± 0.33	0.959	2.39 ± 0.44	2.14 ± 0.63	0.500
Cysteine	0.35 ± 0.07	0.31 ± 0.03	0.544	0.30 ± 0.04	0.32 ± 0.04	0.559	0.34 ± 0.06	0.29 ± 0.05	0.115
Histidine	1.18 ± 0.31	1.26 ± 0.30	0.680	1.05 ± 0.12	1.06 ± 0.17	0.915	1.25 ± 0.26	1.11 ± 0.29	0.447
Arginine	1.80 ± 0.40	1.86 ± 0.42	0.812	1.53 ± 0.10	1.52 ± 0.24	0.977	1.79 ± 0.33	1.59 ± 0.45	0.452
ΣEAA	11.00 ± 0.92	11.48 ± 0.97	NS	9.62 ± 0.28	9.61 ± 0.55	NS	11.23 ± 0.78	9.88 ± 0.98	NS
ΣBCAA	4.31 ± 0.56	4.48 ± 0.60	NS	3.80 ± 0.16	3.76 ± 0.34	NS	4.41 ± 0.49	3.87 ± 0.57	NS

Note: Values are expressed as mean ± standard deviation (SD), ΣEAA = sum of essential amino acids (Thr, Val, Met, Ile, Leu, Phe, Lys, His), ΣBCAA = sum of branched-chain amino acids (Val, Ile, Leu), Different superscripts (a–b) indicate statistically significant differences between sexes within the same muscle ($p \leq 0.05$), NS = not significant ($p > 0.05$)

Overall, the amino acid profile observed in this study confirms that *Lepus europaeus* meat represents a high-quality protein source with a balanced distribution of essential amino acids. The limited variability between sexes and muscles indicates a relatively stable composition under natural conditions, although minor variations related to muscle function and environmental factors cannot be excluded.

Fatty acid composition

The fatty acid composition of *Lepus europaeus* meat (Table 4) reflects the characteristic lipid profile of wild herbivorous species and represents an important determinant of its nutritional value. In the present study, monounsaturated fatty acids (MUFA) constituted the dominant fraction of total lipids, followed by saturated fatty acids (SFA) and polyunsaturated fatty acids (PUFA), with only minor differences observed between sexes. Similar fatty acid distributions have been described for game meat, which is generally characterised by a higher proportion of unsaturated fatty acids compared with meat from intensively reared animals **[1]**, and **[2]**.

Among individual fatty acids, oleic acid (C18:1 n-9) was the most abundant, followed by palmitic acid (C16:0) and linoleic acid (C18:2 n-6). This pattern is consistent with previously reported data for hare meat and other lagomorph species **[3]**, **[7]**, **[23]**, and **[24]**. The predominance of oleic acid is typical for muscle lipids, whereas the relatively high proportion of linoleic acid reflects the natural plant-based diet of hares, as herbivorous species incorporate dietary fatty acids directly into tissue lipids **[2]**, and **[3]**.

Table 4 Fatty acid classes and selected fatty acids of *Lepus europaeus* meat (%)

Parameter	Back ♂	Back ♀	*p*-value	Thigh ♂	Thigh ♀	*p*-value	Shoulder ♂	Shoulder ♀	*p*-value
Σ SFA	34.11 ± 2.09	35.35 ± 1.69	0.190	34.45 ± 1.56	35.86 ± 1.31	0.091	34.22 ± 2.19	35.38 ± 1.55	0.381
Σ MUFA	46.09 ± 1.56	46.65 ± 1.23	0.513	47.28 ± 1.07	47.61 ± 1.03	0.584	46.53 ± 0.16	44.66 ± 3.08	0.060
Σ PUFA	22.73 ± 3.35	20.68 ± 2.40	0.270	17.30 ± 1.87	16.95 ± 2.32	0.783	19.03 ± 3.00	19.34 ± 7.20	0.906
Σ n-3 PUFA	0.71 ± 0.13	0.73 ± 0.09	0.790	0.61 ± 0.06	0.62 ± 0.09	0.893	0.68 ± 0.11	0.69 ± 0.18	0.860
Σ n-6 PUFA	18.95 ± 3.06	16.80 ± 1.78	0.107	15.02 ± 1.35	14.56 ± 1.68	0.648	16.35 ± 3.99	16.05 ± 4.66	0.904
C18:1 cis-9 (oleic acid)	27.19 ± 2.64^{b}	31.61 ± 4.51^{a}	0.040	28.54 ± 4.65	32.72 ± 2.44	0.093	23.88 ± 10.08	30.67 ± 3.53	0.272
C18:2 n-6 (linoleic acid)	15.59 ± 3.52	14.47 ± 1.55	0.483	10.61 ± 1.63	11.42 ± 2.37	0.500	12.09 ± 4.40	14.77 ± 7.77	0.413
C20:4 n-6 (arachidonic acid)	1.70 ± 0.16	1.81 ± 0.29	0.406	1.65 ± 0.34	1.82 ± 0.18	0.336	1.77 ± 0.33	1.94 ± 0.21	0.405
C18:3 n-3 (α-linolenic acid)	0.37 ± 0.06	0.35 ± 0.09	0.717	0.30 ± 0.02	0.29 ± 0.04	0.717	0.30 ± 0.08	0.29 ± 0.08	0.902
C16:0 (palmitic acid)	24.50 ± 0.23	24.38 ± 0.25	0.395	24.44 ± 0.12	24.34 ± 0.24	0.360	24.47 ± 0.10	24.45 ± 0.24	0.821
C18:0 (stearic acid)	10.82 ± 0.23	10.95 ± 0.23	0.382	10.77 ± 0.11	10.95 ± 0.22	0.109	10.79 ± 0.09	10.87 ± 0.28	0.437
C14:0 (myristic acid)	1.37 ± 0.05^{a}	1.31 ± 0.04^{b}	0.027	1.36 ± 0.01^{a}	1.31 ± 0.03^{b}	0.003	1.35 ± 0.10	1.35 ± 0.04	0.969
CLA (9c,11t-C18:2) (conjugated linoleic acid)	0.13 ± 0.02	0.13 ± 0.02	0.620	0.14 ± 0.01	0.14 ± 0.01	0.902	0.13 ± 0.01^{b}	0.15 ± 0.01^{a}	0.041
C18:1 trans-11 (vaccenic acid)	4.78 ± 0.18	4.65 ± 0.17	0.199	4.72 ± 0.13	4.66 ± 0.11	0.411	4.71 ± 0.21	4.75 ± 0.12	0.783

Note: Mean ± *SD* (standard deviation); Different superscript letter in line (a-b) indicate statistically significant differences ($p \leq 0.05$).

The proportion of MUFA ranged from approximately 44 to 47%, confirming their dominance among total fatty acids. Saturated fatty acids accounted for approximately 34–36%, while PUFA ranged from 17 to 23%. These values are generally consistent with previous findings; however, higher PUFA proportions have been reported in studies focusing on phospholipid fractions, which are metabolically more active and structurally important in cell membranes **[2]**, and **[5]**. This distinction between neutral lipids and phospholipids is relevant, as phospholipids are naturally enriched in long-chain polyunsaturated fatty acids.

From a nutritional perspective, the relatively balanced distribution between SFA and unsaturated fatty acids observed in this study indicates a favourable lipid profile. Hare meat has consistently been described as containing a higher proportion of unsaturated fatty acids compared with conventional livestock meat **[1]**, **[14]**, and **[24]**. In particular, the presence of PUFA, including essential fatty acids such as linoleic and α-linolenic acids, contributes to improved lipid metabolism and cardiovascular health **[2]**, and **[25]**.

The fatty acid composition of hare meat is strongly influenced by natural feeding conditions. As herbivores, hares consume a wide variety of plants and cereals, and the fatty acid composition of their diet varies depending on season and habitat, which directly affects the lipid profile of muscle tissue **[1]**, and **[3]**. In addition, European hares exhibit selective feeding behaviour, with a preference for plant parts richer in lipids, which may further contribute to variation in fatty acid composition **[4]**. Seasonal variation in PUFA content has been reported, reflecting changes in diet composition and availability of plant resources **[10]**.

Sex-related differences in fatty acid composition were generally limited and did not reach statistical significance for most fatty acids. This is consistent with findings by **[10]**, who reported that sex has a relatively

minor effect on lipid composition compared with factors such as diet, season and habitat conditions. Minor differences observed in some fatty acids may therefore be attributed to individual variability rather than consistent biological effects.

Differences between muscle types were more evident than those between sexes. This may be related to variations in lipid class distribution and metabolic activity among muscles. Muscles with higher oxidative capacity tend to contain a greater proportion of phospholipids, which are enriched in polyunsaturated fatty acids, whereas less active muscles may contain higher proportions of neutral lipids **[2]**, and **[5]**. This physiological basis provides a plausible explanation for the observed variability in fatty acid composition between anatomical locations.

In addition, hare meat has been reported to exhibit favourable lipid quality indices, including relatively low atherogenic and thrombogenic indices and a beneficial PUFA/SFA ratio, further supporting its classification as a dietetically valuable meat **[13]**, and **[24]**. Compared with conventional livestock species, hare meat is generally characterised by lower fat content and a more favourable fatty acid profile, which enhances its nutritional value **[3]**, and **[6]**.

The fatty acid profile observed in this study confirms that Lepus europaeus meat is characterised by a favourable balance of saturated and unsaturated fatty acids, with a predominance of MUFA and a considerable proportion of PUFA. These characteristics, together with low total lipid content, contribute to its high nutritional value and support its inclusion as a healthy component of the human diet.

Lipid quality indices

Lipid quality indices calculated from the fatty acid composition (Table 5) provide an integrated assessment of the nutritional relevance of intramuscular lipids in *Lepus europaeus* meat. In the present study, all analysed indices indicated a generally favourable lipid profile, which corresponds with the predominance of unsaturated fatty acids. Similar characteristics have been reported for game meat, which is often considered nutritionally advantageous compared with conventional livestock products **[1]**, **[2]**, and **[26]**.

The PUFA/SFA ratio ranged from 0.47 to 0.66 across the analysed muscles. The highest values were observed in the back muscle, while lower values were recorded in the thigh muscle. Although these differences were not statistically significant ($p>0.05$), all values exceeded the recommended threshold of 0.40, indicating a favourable balance between polyunsaturated and saturated fatty acids. Comparable values have been reported for hare meat **[14]**, and **[24]**, suggesting that this species consistently exhibits a relatively beneficial lipid profile. Nevertheless, it should be noted that the PUFA/SFA ratio alone does not fully reflect the nutritional quality of fat, as it does not account for the distribution of individual fatty acids **[2]**.

The ratio of total unsaturated to saturated fatty acids ((MUFA+PUFA)/SFA) ranged from 1.80 to 2.02. A statistically significant difference between sexes was observed in the back muscle ($p=0.035$), with higher values in males. Although this finding indicates a slightly higher proportion of unsaturated fatty acids in male back muscle lipids, the absence of similar differences in other muscles suggests that this effect may be of limited biological relevance. Similar variability has been described in previous studies, where sex-related differences were often inconsistent and dependent on specific conditions **[10]**.

The n-6/n-3 PUFA ratio ranged from 23.02 to 26.90, with a significant difference detected in the back muscle ($p=0.004$). These values are relatively high and reflect the predominance of n-6 fatty acids in plant-based diets typical for terrestrial herbivores **[3]**. From a nutritional perspective, such ratios are generally considered less favourable, as lower n-6/n-3 ratios are associated with improved health outcomes **[26]**. However, it should be emphasised that the n-6/n-3 ratio in wild animals is strongly influenced by environmental conditions, particularly the availability and composition of natural feed resources, and may therefore vary considerably **[1]**.

The atherogenic index (AI) ranged from 0.44 to 0.48, while the thrombogenic index (TI) ranged from 1.06 to 1.13, with no significant differences between sexes. These relatively low values indicate a limited proportion of fatty acids associated with adverse cardiovascular effects. The AI and TI indices, originally proposed by **[13]**, are widely used to estimate the potential impact of dietary fats on cardiovascular risk. Lower values are generally considered favourable; however, their interpretation should be made in the context of the overall diet rather than as isolated indicators **[2]**.

The hypocholesterolemic/hypercholesterolemic ratio (h/H) ranged from 1.79 to 2.00, with no significant differences between sexes. Higher h/H values are associated with a greater proportion of fatty acids that may lower serum cholesterol levels, which is generally considered beneficial **[2]**. The values observed in this study therefore support the assumption of a favourable lipid profile, although their practical nutritional impact depends on total dietary intake.

The content of long-chain n-3 polyunsaturated fatty acids (EPA + DPA + DHA) ranged from 0.25 to 0.29, with slightly higher values observed in females, although without statistical significance. These fatty acids are known for their anti-inflammatory and cardioprotective effects **[8]**, and **[25]**. Despite their relatively low absolute

levels in terrestrial animals, their presence still contributes to the overall nutritional value of hare meat. At the same time, the relatively high n-6/n-3 ratio suggests that their physiological effect may be moderated by the overall fatty acid balance.

Differences between muscles were more pronounced than differences between sexes. The back muscle tended to show more favourable lipid indices, particularly higher PUFA/SFA and (MUFA+PUFA)/SFA ratios. This may be associated with a higher proportion of membrane phospholipids, which are typically enriched in polyunsaturated fatty acids **[3]**, and **[5]**. Such muscle-specific differences highlight the importance of considering anatomical location when evaluating lipid quality.

Overall, the lipid quality indices observed in this study indicate a generally favourable fatty acid balance in *Lepus europaeus* meat. However, certain parameters, particularly the n-6/n-3 ratio, should be interpreted with caution, as they are strongly influenced by environmental factors and may not directly reflect intrinsic meat quality. These findings support the classification of hare meat as a nutritionally valuable food source, while also emphasising the importance of a broader dietary context when evaluating its health implications.

Table 5 Calculated lipid quality indices of *Lepus europaeus* meat

Parameter	Back ♂	Back ♀	*p*-value	Thigh ♂	Thigh ♀	*p*-value	Shoulder ♂	Shoulder ♀	*p*-value
PUFA/SFA	0.66 ± 0.07	0.59 ± 0.06	0.090	0.50 ± 0.06	0.47 ± 0.07	0.600	0.56 ± 0.08	0.55 ± 0.24	0.989
n-6/n-3	26.90 ± 1.38^{a}	23.02 ± 2.20^{b}	0.004	24.73 ± 2.63	23.67 ± 2.59	0.467	24.72 ± 4.25	23.11 ± 2.14	0.584
(MUFA+PUFA)/SFA	2.02 ± 0.07^{a}	1.91 ± 0.07^{b}	0.035	1.87 ± 0.06	1.80 ± 0.07	0.083	1.92 ± 0.08	1.82 ± 0.22	0.249
Atherogenic index (AI)	0.44 ± 0.02	0.46 ± 0.02	0.093	0.48 ± 0.01	0.47 ± 0.02	0.392	0.46 ± 0.04	0.47 ± 0.04	0.454
Thrombogenic index (TI)	1.06 ± 0.04	1.10 ± 0.04	0.153	1.09 ± 0.04	1.08 ± 0.05	0.882	1.09 ± 0.05	1.13 ± 0.06	0.453
h/H ratio	1.93 ± 0.15	2.00 ± 0.16	0.442	1.79 ± 0.08	1.85 ± 0.14	0.419	1.83 ± 0.20	1.94 ± 0.27	0.284
EPA+DPA+DHA	0.25 ± 0.02	0.29 ± 0.02	0.065	0.26 ± 0.01	0.28 ± 0.01	0.150	0.25 ± 0.04	0.29 ± 0.02	0.282

Note: Mean ± *SD* (standard deviation); Different superscript letter in line (a-b) indicate statistically significant differences ($p \leq 0.05$). SFA – saturated fatty acids; MUFA – monounsaturated fatty acids; PUFA – polyunsaturated fatty acids; AI – atherogenic index; TI – thrombogenic index; h/H – hypocholesterolemic/hypercholesterolemic ratio; EPA+DPA+DHA is eicosapentaenoic acid + docosapentaenoic acid +docosahexaenoic acid

Meat colour evaluation

Instrumental colour parameters of *Lepus europaeus* meat (Table 6) represent an important quality attribute related to muscle physiology, post-mortem metabolism and consumer perception. In the present study, all analysed muscles exhibited relatively low lightness (L^*) values, confirming the characteristic dark appearance of hare meat. Similar colour characteristics have been reported for game species, where darker meat is generally associated with higher myoglobin content and increased physical activity **[1]**, **[11]**, and **[20]**.

The L^* parameter ranged from 29.47 to 32.67. Significant differences between sexes were observed in the back (p=0.008) and thigh muscles (p=0.026), with females exhibiting higher L^* values than males. This suggests slightly lighter meat in females, which may be related to differences in muscle structure, water distribution or post-mortem biochemical processes. However, given the variability observed, a consistent sex-related effect cannot be clearly established. Low lightness values are typically associated with higher myoglobin concentration and reduced intramuscular fat content, both of which are characteristic of wild game species **[1]**, and **[27]**.

Redness (a^*), primarily associated with myoglobin content, ranged from 10.08 to 12.08. A significant difference was detected in the thigh muscle (p=0.028), with higher values observed in males. This may indicate a higher proportion of oxidative muscle fibres or differences in myoglobin concentration. Muscles with greater functional activity and oxygen demand generally contain higher levels of myoglobin, resulting in increased redness **[5]**. The biochemical basis of meat redness is closely related to the chemical state of myoglobin, particularly the presence of oxymyoglobin, which is responsible for the bright red colour of fresh meat **[11]**, and **[12]**. No significant differences were observed in the back and shoulder muscles, suggesting a relatively uniform distribution of pigment concentration across these anatomical locations.

Yellowness (b^*) ranged from 5.95 to 8.05. A significant difference was observed in the back muscle (p=0.006), where females showed higher values. This variation may be linked to lipid oxidation processes or interactions between lipids and muscle pigments. Oxidation products can promote the conversion of oxymyoglobin to

metmyoglobin, thereby affecting colour stability **[28]**. Nevertheless, as this effect was not consistently observed across all muscles, it is likely influenced by local muscle conditions or post-mortem handling rather than representing a systematic biological difference.

Chroma (C^*), representing colour intensity, ranged from 12.55 to 14.23 and did not differ significantly between sexes ($p>0.05$), indicating relatively stable colour saturation. The hue angle ($h°$) ranged from 26.79 to 36.44, with significant differences observed in both the back ($p=0.007$) and thigh muscles ($p=0.002$), where females exhibited higher values. This may suggest a shift towards less intense red tones, potentially associated with changes in myoglobin redox state during post-mortem storage **[12]**. The formation of metmyoglobin is a well-established factor contributing to colour deterioration and browning in meat **[11]**, and **[27]**.

Table 6 Instrumental colour parameters of *Lepus europaeus* meat

Parameter	Sex	Back muscle	Thigh muscle	Shoulder muscle
L^*	Male	29.47 ± 1.18^b	30.78 ± 0.51^b	32.29 ± 0.44
	Female	31.83 ± 1.26^a	32.67 ± 2.32^a	31.40 ± 4.22
	p-value	0.008	0.026	0.506
a^*	Male	11.81 ± 0.80	12.08 ± 1.25^a	11.61 ± 0.07
	Female	11.47 ± 1.48	10.08 ± 1.35^b	11.69 ± 1.99
	p-value	0.690	0.028	0.896
b^*	Male	5.95 ± 0.10^b	7.10 ± 0.34	7.76 ± 0.88
	Female	6.73 ± 0.76^a	7.43 ± 1.10	8.05 ± 1.91
	p-value	0.006	0.592	0.791
Chroma (C^*)	Male	13.22 ± 0.81	14.01 ± 1.27	13.99 ± 0.56
	Female	13.30 ± 1.66	12.55 ± 1.75	14.23 ± 2.74
	p-value	0.910	0.140	0.770
Hue angle ($h°$)	Male	26.79 ± 1.48^b	30.58 ± 1.63^b	33.66 ± 3.51
	Female	30.45 ± 1.51^a	36.44 ± 4.60^a	34.27 ± 4.38
	p-value	0.007	0.002	0.790
Browning index (BI)	Male	73.41 ± 3.62^b	79.56 ± 4.21	78.92 ± 6.40
	Female	79.28 ± 4.91^a	75.42 ± 6.08	83.61 ± 8.51
	p-value	0.013	0.180	0.310

Note: Mean ± *SD* (standard deviation); Different superscript letter in column (a-b) indicate statistically significant differences ($p\leq0.05$).

The browning index (BI) ranged from 73.41 to 83.61. A significant difference was observed in the back muscle ($p=0.013$), with higher values recorded in females, indicating a greater tendency towards pigment oxidation. No significant differences were detected in the thigh and shoulder muscles. Higher BI values are generally associated with increased oxidative processes, which may be influenced by oxygen exposure, lipid composition, and muscle metabolism **[28]**. The interaction between lipid oxidation and myoglobin oxidation is considered a key mechanism affecting colour stability in meat systems.

In general, differences between muscles were more pronounced than differences between sexes. The thigh muscle showed higher redness values, while the back muscle exhibited greater variability in lightness and browning index. These differences likely reflect variation in muscle fibre composition and metabolic activity. Muscles with a higher proportion of oxidative fibres typically exhibit a darker colour due to increased myoglobin content and mitochondrial density **[5]**, and **[12]**.

Overall, the relatively low L^* values and high a^* values confirm the typical dark-red appearance of hare meat, which is associated with high myoglobin content and the active lifestyle of wild animals. While some sex-related differences were observed, their biological significance appears limited. Muscle type and post-mortem processes appear to be the dominant factors influencing colour characteristics in Lepus europaeus meat, with variability driven primarily by muscle metabolism and oxidative changes rather than by intrinsic sex differences.

Limitations

Several limitations should be considered when interpreting the results of the present study. First, the analysed animals originated from wild populations harvested during the regular hunting season. As a result, key biological variables such as exact age, prior nutritional history and level of physical activity could not be controlled. These factors are known to influence carcass traits and muscle composition in wild mammals and may contribute to the

variability observed in the analysed parameters **[1]**, **[5]**, and **[19]**. Another limitation relates to the sample size. Although the number of animals included in this study is comparable to that of other investigations on wild game species, a larger dataset would allow for a more robust evaluation of potential sex-related differences and muscle-specific variation. At the same time, studies based on wildlife populations are inherently constrained by the availability of animals collected in the field, which limits experimental control.

In addition, all animals originated from a single geographical region in western Slovakia and were collected within a limited seasonal period. Seasonal variation in vegetation availability, environmental conditions and metabolic status may influence muscle composition and fatty acid profiles in wild herbivores. Previous studies have shown that these factors can significantly affect the nutritional characteristics of game meat **[1]**, **[3]**, and **[10]**.

From a methodological perspective, the analyses were performed under controlled laboratory conditions shortly after sampling. Despite the use of standardised procedures, post-mortem biochemical processes and storage conditions may still influence certain meat quality traits, particularly colour stability and lipid oxidation **[11]**, **[12]**, and **[28]**.

While these limitations should be considered, the study provides relevant data on the nutritional and technological characteristics of *Lepus europaeus* meat under natural conditions. The results may serve as a basis for further research focusing on seasonal variability, geographical differences and broader population-level patterns, where a more controlled assessment of environmental and biological factors would be desirable.

CONCLUSION

This study evaluated carcass traits and selected physicochemical characteristics of meat obtained from European brown hares (Lepus europaeus) harvested from wild populations in western Slovakia. Females showed higher mean live weight (4239.93 g) than males (3729.15 g), whereas slaughter yield was slightly higher in males, both with head (73.92 vs. 70.83%) and without head (70.23 vs. 67.20%). Among the carcass components, a significant sex-related difference was found only for heart weight, which was higher in females (50.38 vs. 35.55 g; $p = 0.010$).

The analysed muscles were characterised by high water content (74.05–76.05 g·100 g^{-1}), high protein content (22.01–23.76 g·100 g^{-1}), and very low intramuscular fat levels (0.61–0.91 g·100 g^{-1}), confirming the lean nature of hare meat. Cholesterol content remained relatively low and stable, ranging from 0.040 to 0.045 g·100 g^{-1} (approximately 40–45 mg·100 g^{-1}). The amino acid profile demonstrated high nutritional quality, with lysine as the predominant essential amino acid (2.03–2.50 g·100 g^{-1}), while the sum of essential amino acids ranged from 9.61 to 11.48 g·100 g^{-1} and the sum of branched-chain amino acids from 3.76 to 4.48 g·100 g^{-1}. Only threonine in the shoulder muscle differed significantly between sexes, with higher values in males (1.16 vs. 0.92 g·100 g^{-1}; $p = 0.028$).

The fatty acid profile was dominated by monounsaturated fatty acids (44.66–47.61%), followed by saturated fatty acids (34.11–35.86%) and polyunsaturated fatty acids (16.95–22.73%). Oleic acid was the predominant fatty acid (23.88–32.72%), followed by palmitic acid (24.34–24.50%) and linoleic acid (10.61–15.59%). Lipid quality indices were generally favourable, with PUFA/SFA ratios ranging from 0.47 to 0.66, exceeding the recommended nutritional threshold of 0.40, while the atherogenic index ranged from 0.44 to 0.48 and the thrombogenic index from 1.06 to 1.13. On the other hand, the n-6/n-3 ratio was relatively high (23.02–26.90), which should be considered when interpreting the nutritional value of the meat.

Instrumental colour measurements confirmed the typical dark-red appearance of hare meat, with lightness values ranging from 29.47 to 32.67 and redness from 10.08 to 12.08. Taken together, these results indicate that meat from the European brown hare represents a lean, protein-rich and nutritionally valuable source of animal protein with a favourable fatty acid composition. However, some variability related to environmental conditions and biological factors cannot be fully explained within the scope of the present study. Further research including larger sample sizes, multiple geographic regions and seasonal comparisons would help to better characterise the variability in carcass traits and meat quality of this species.

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Funds:

This work was supported by [APVV] under grant [no. 23-0077].

Competing Interests:

No potential conflict of interest was reported by the author(s).

Ethical Statement:

The research was conducted using biological material obtained from European brown hares (*Lepus europaeus*) legally harvested during the official hunting season. The animals were hunted by authorized hunters in accordance with applicable national hunting legislation and wildlife management regulations. The study did not involve experimental handling, housing, or euthanasia of animals for research purposes. Therefore, ethical approval from an animal ethics committee was not required.

AI Statement:

AI tools, such as Grammarly and DeepL, were used for performing English grammar proofreading.

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