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Article

Physicochemical Characteristics, Selected Lipid Content and Protein Bioactive Compounds of Lamb Meat Depending on Aging Time and Muscle Type

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Simple Summary: Many controversies about the presence of red meat in the human diet result from insufficient knowledge of consumers. The physicochemical characteristics of meat and the content of bioactive ingredients in it are affected by many factors. In addition to the breed, age at slaughter or the animal feeding system, the quality of meat and its health benefits are affected by the process of its aged and the type of muscle. The conducted research confirmed changes in the physicochemical characteristics of meat and the content of taurine, carnosine and carnitine, components related to the proper functioning of the human body under the influence of the time of aged and the type of muscle.

Abstract: Many factors affect the quality of red meat. The aim of the study, carried out on 44 Polish Merino lambs, was analysis of physicochemical traits (pH, meat color, expressed juice, content of moisture, protein, fat, total collagen and fatty acid) and content of carnosine, taurine, L-carnitine on fresh and meat aged for 7 and 14 d in the *longissimus lumborum* (LL) and *gluteus medius* (GM) muscles., Higher (p<0.05) redness value (a*), lower yellowness (b*) were recorded in meat after of aging in *gluteus medius* muscle. A lower value (p<0.05) of expressed juice was found in both LL and GM after 7 days of aging. The increase (p<0.05) in protein and fat content in both muscle and collagen content in LL was observed in aged meat. There was no difference in fatty acid groups and C18:2 c9, t11 content between GM and LL muscle and fresh and aging meat. A higher TBARS content (p<0.05) was recorded in meat after aging in both GM and LL. The meat aging process increased (p<0.05) the content of carnitine and taurine, while the content of carnosine decreased. In summary the processes that turn muscles into meat in different types of muscles affect the physicochemical characteristics and the content of bioactive ingredients.

Keywords: lambs; meat; CLA; carnosine L-carnitine; taurine

1. Introduction

Consumer demands on the meat industry are increasing. In addition, the controversies that have arisen in recent years in connection with red meat indicate that there is still a need to understand the influence of various factors on its quality as well as its health value [1,2]. In addition to beef or pork, this also applies to lamb meat, which, due to its low production, has to comply more with quality standards in order to remain competitive in the market.

Many studies have shown that breed, age at slaughter, the feeding system and related muscle development and the proportion of different types of muscle fibers determine important meat characteristics for the consumer, such as color, tenderness, juiciness or intramuscular fat content, as well as the presence of biologically active ingredients [3–11]. The quality of the meat is also affected by physiological, biochemical and metabolic changes that occur during meat aging. These changes mainly involve a drop in pH, degradation and oxidation of myofibrillar proteins, the chemical state of myoglobin, production of heat shock proteins and apoptosis, which eventually affect tenderness, color or water holding capacity (WHC) [12–14]

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The basic components of skeletal muscle are different types of muscle fibers, the conversion of which can affect both the quality of meat and the composition of bioactive compounds [9]. To the bioactive compounds found particularly in red meat, especially in ruminants, carnosine, anserine, taurine, L-carnitine, omega-3 polyunsaturated fatty acids as well as conjugated linoleic acid isomers (CLA) are included. These compounds which are characterized by their properties that inhibit oxidative stress, inflammation as well as cancer processes, play a key role in the human body by ensuring health and proper metabolic processes. They are not always synthesized in sufficient quantities, and could be supplemented by a proper diet including red meat [15,16].

It has been established that in mammals, approximately 99% of carnosine is found in skeletal muscles and more in white muscles than in red ones [17,18]. Joo et al. [19] found that intramuscular fat content (IMF) and the proportions of saturated fatty acids (SFA) and monounsaturated fatty acids (MUFA) in steers were correlated with the proportion of different muscle fibers. Taurine, which is now recognized as an ingredient that plays a major role in human physiology and nutrition, is found in 70% of skeletal muscle. The ability to synthetize this β-amino acid by humans is very low compared to livestock like cattle or sheep [15]. Providing this component through the diet and sometimes even its supplementation can effectively counteract the occurrence of cardiovascular, digestive, endocrine, immune, muscular or neurological disorders [20–22]. The L-carnitine content of lamb meat, which is involved in energy metabolism, can also depend on the type of muscle and the proportion of different muscles fibers. According to Shimada et al. [23] in their studies conducted on hens, muscles with a higher content of oxidative and oxidative-glycolytic fibers had a higher L-carnitine content.

The aim of this study was to analyze the physicochemical characteristics and content of selected bioactive compounds (carnosine, taurine and L-carnitine, CLA) in fresh and at 7 and 14 days post-slaughtered aged lamb meat with regard to muscle type.

2. Materials and Methods

The study have been carried out on 44 Polish Merino rams, which were fattened to a weight of 40 kg (± 1.5 kg). The animals were kept in identical conditions under constant zootechnical and veterinary supervision, and were fed in accordance with the requirements for fattened animals [24]. The ration consisted of grass hay; steamed potatoes and concentrate with the following composition: 23.5% rapeseed meal, 57.8% oatmeal, 17.6% wheat bran, and 1% mineral mixture. Feeds were given twice a day. Lambs were given grass hay separately, while potatoes and concentrate were mixed before each feeding. The animals were provided with constant access to water.

When the lambs reached the desired body weight, they were slaughtered. Slaughter was carried out in accordance with Council Regulation (EC) no. 1099/2009 of 24 September 2009 [25]. The carcasses, which were suspended on the Achilles tendon, were chilled at 4°C. The cooling period lasted 24 hours.

2.1. Sample Preparation

Longissimus lumborum (LL; n = 88) and *gluteus medius* (GM; n = 88) muscle samples were taken from both sides of the carcass, which were vacuum packed. Then, for qualitative analysis of not aged (fresh) meat, 44 LL and 44 GM samples were transported in a refrigerator to the laboratory. In turn, 22 LL and 22 GM muscles were aged at a constant temperature of 2°C and 68% humidity for 7 days, and then 22 LL and 22 GM for 14 days. After 7 and 14 days, the samples were analyzed for meat quality.

In order to analyze the concentration of taurine, carnosine and L-carnitine, samples weighing about 700 mg, taken from the central part of the muscle, were fixed in liquid nitrogen and then stored at −80 ◦C. The residue of the LL and GM muscle samples was used to determine the physicochemical parameters of the meat.

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2.2. Analysis of Physical Traits of Meat

Meat pH was measured using the Elmetron CP-411 pH meter with a dagger electrode calibrated at pH 4.0, 7.0 and 9.0. After 30 minutes of blooming, the color of the LL and GM samples was measured on the meat surface using a Minolta CR410 colorimeter (Konica-Minolta). Color coordinates were determined three times for each sample: lightness (L*), redness (a*) and yellowness (b*), color saturation (C*) and hue angle (H*). According to the method of Grau and Hamm [26] samples (0.3 g) of meat placed on Whatman No. 1 filter paper and held under a pressure of 2 kg for 5 min were used to determine the expressed juice. The expressible juice outline area and the meat film were measured with a planimeter and the results were calculated in units of square centimeters per gram of meat.

2.3. Chemical Composition of Meat

Using the spectrometric technique with near infrared transmission (NIR) (PNA-82109), the content of moisture, crude protein, intramuscular fat and collagen was determined. For this purpose, meat samples were homogenized in the Electrolux DITO K35 apparatus, which were then placed in the measuring cell of the FoodScan analyzer. This device uses the near infrared transmission method in the range of 850-1050 nm. It is equipped with an ANN calibration developed using a model of artificial neural networks, and the analysis is carried out by indicating the number of 16 measurements in the sample in the computer program. Then the program automatically calculates the average and presents the result.

2.4. Fatty Acid Determination

Fat extraction from fresh and aged meat samples was carried out according to the method of Folch et al. [27]. Fat saponification was carried out in 0.5 M potassium hydroxide (KOH) in methanol and esterification in 10% BF3 in methanol. The fatty acid methyl esters were extracted with hexane. Fatty acid composition analysis was performed by gas chromatography, using an Agilent Technologies GC 6890 N chromatograph equipped with a BP × 70 capillary column (length 60 m, internal diameter 0.22 mm, film thickness 0.25 μm). The conditions of analysis were helium gas (41 psi) and FID (flame ionization detector) at 240°C. The temperature program included 3 min at 130 ◦C, an increase to 235 ◦C by +2 ◦C min−1 and 4 min at 235°C. The fatty acids were identified using the reference material BCR 163 (a mixture of beef and pork fat). The standard cis-9, trans-11 octadecadienoic acid (Larodon AB, Sweden) was used to determine the isomer of linoleic acid (CLA).

2.5. Peroxidation of Lipids

In the extracts from the tested meat samples, according to the method of Uchiyama and Mihara [28], lipid peroxidation was assessed by substances reacting with thiobarbituric acid (TBARS). These extracts were obtained after homogenization of tissue lyophilisates in radioimmunoprecipitation assay (RIPA) buffer and centrifugation (1600 x g, 10 min). As a standard to express TBARS as malondialdehyde (MDA) equivalents, the MDA precursor 1.2.3.3-tetraethoxypropane (TEP) was used. At 532 nm, the absorbance was measured using a microplate reader (Infinite M200, Tecan, Männedorf, Switzerland).

2.6. L-Carnitine, Carnosine and Taurine Analysis

The ELISA immunoassay was used to determine the concentration of L-carnitine, carnosine and taurine. Triplicate 250 mg samples taken from all meat samples were homogenized in 25 mL of PBS, previously stored at -80°C. The resulting homogenates were then centrifuged for 5 min at 5000 x g on ice to obtain supernatants, which were assayed using enzyme-linked Immunosorbent Assays Kits according to manufacturer's protocols (CLOUD-CLONE Corp., USA). Using the WHY101TX microplate reader (Novazym Poland Ltd.), spectrophotometric reading of the results was made. The concentration of L-carnitine, carnosine and taurine was calculated from the determined curves.

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2.7. Statistical Analysis

A statistical analysis of the data was performed using the SPSS 23.0 packet software [29] based on a linear model that included the effect of aging time and type of muscle. All effects were tested against residual middle squares to determine the level of significance. Tukey's test was used for comparing mean values when an F test for main effect was significant. The results are presented as the means for each trait and standard deviation (SD).

3. Results

3.1. Physical Traits of Meat

There were no statistical differences in the pH value between analyzed muscles. Among the types of studied muscle, meat after a 14-day of aging had a higher pH (p<0.05) compared to fresh meat but only for the GM muscle (Table 1).

The aging time and the type of muscle has an effect on the color changes in meat. Higher (p<0.05) redness value (a*), higher Chroma value but lower Hue value and lower (p<0.05) yellowness (b*) were recorded in meat after 7d and especially after 14d of aging compared to fresh meat in *gluteus medius* muscle. In LL muscle, differences (p<0.05) between fresh meat and after 7d and 14d of aging were found for yellowness (b*) and Hue angle. The values of these parameters were as in GM muscle lower in aged meat (Table 1). In both muscles L* parameter decreased in aged meat but the differences with respect to fresh meat were not statistically confirmed.

A higher lightness (L*) in both fresh meat and after 7 days of aging (p<0.05) was registered in GM muscle compared to LL muscle. On the other hand, fresh *longissimus lumborum* muscle had a higher (p<0.05) yellowness value (b*) and H*. Analysis of the expressed juice showed no differences in this parameter between the studied muscles, although meat that was aged 7 and 14d had a better value for this trait. A lower value (p<0.05) of expressed juice was found in both LL and GM after 7 days of aging compared to fresh meat, in GM muscle the value was even lower after 14 days of aging, but the differences between 7 and 14 days were not statistically confirmed. Whereas, in LL muscle, expressed juice after 14 days of aging was lower (p<0.05) compared both to fresh meat and after 7 days of aging. (Table 1).

Table 1. The mean values ±SD for meat quality properties for different muscles and aging time.

Item	Muscle	Aging time		
		Fresh meat	Meat aged 7d	Meat aged 14d
pH	GM	5.53^{a} 0.17	5.60 0.11	5.68^{b} 0.18
	LL	5.55 0.23	5.60 0.15	5.65 0.23
L*	GM	33.68* 2.00	33.60* 2.07	32.31 3.06
	LL	31.48* 2.39	31.54* 2.83	30.72 3.01
a*	GM	11.72^{a} 0.74	12.33 0.86	12.70^{b} 0.99
	LL	11.70 1.18	12.30 0.87	12.26 1.28
b*	GM	2.82^{a*} 1.46	1.65^{b} 0.43	1.97^{b} 0.79
	LL	3.86^{a*} 0.90	1.87^{b} 1.07	1.80^{b} 1.02
C*	GM	12.12^{a} 0.94	12.45 0.87	12.87^{b} 1.06
	LL	12.33 1.33	12.49 0.90	12.44 1.19
H*	GM	13.21^{a*} 6.29	7.61^{b} 1.92	8.69^{b} 3.04
	LL	18.10^{a*} 3.12	8.61^{b} 4.80	8.44^{b} 5.41
Expressed juice (cm^2/g^{-1})	GM	24.07^{a} 4.47	18.32^{b} 5.32	15.40^{b} 3.00
	LL	24.27^{a} 2.69	19.01^{b} 2.97	15.54^{c} 2.22

GM - *M. gluteus medius;* LL - *M. longissimus lumborum;* ^{a,b,c} - different superscripts in the same row represents significant differences between aging time within individual muscle (p<0.05); *- in columns represents significant differences between muscles within item and aging time (p<0.05.

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3.2. Chemical Composition of Meat and Peroxidation of Lipids

An analysis of the basic chemical composition of fresh and aged meat in both tested muscles is shown in Table 2.

Table 2. The mean values ±SD for meat chemical composition for different muscles and aging time (%).

Item	Muscle	Aging time		
		Fresh meat	Meat aged 7d	Meat aged 14d
Moisture	GM	75.68 ±0.81	75.56* ±1.23	75.06 ±1.04
	LL	75.41a ±0.66	74.26b* ±1.69	74.79 ±1.18
Fat	GM	3.15a ±0.79	4.20b* ±1.86	3.46 ±1.07
	LL	3.02 ±0.84	2.78* ±0.99	3.03 ±0.87
Protein	GM	20.61a ±0.46	20.94 ±0.45	21.12b ±0.33
	LL	20.71a ±0.46	20.87 ±0.68	21.10b ±0.45
Total collagen	GM	1.14 ±0.14	1.23* ±0.19	1.24* ±0.22
	LL	1.26a ±0.15	1.41b* ±0.19	1.40b* ±0.22

GM - *M. gluteus medius;* LL - *M. longissimus lumborum;* a,b,c - different superscripts in the same row represents significant differences between aging time within individual muscle ($p<0.05$); *- in columns represents significant differences between muscles within item and aging time ($p<0.05$).

There were no differences in water content between fresh meat and meat aged for 7 and 14 days in GM muscle. The fat content of this muscle was higher ($p<0.05$) after 7 days of aging compared to fresh meat. LL muscle after 7 days of aging had a lower ($p<0.05$) water content and there were no differences in fat content between fresh and aged meat. Whereas the protein content increased ($p<0.05$) after 14 days of aging compared to fresh meat in both GM and LL muscle. Collagen content increased with aging of meat but a significant increase ($p<0.05$) of this component in meat after 7 and 14 days of aging was recorded only in LL muscle. The *longissimus lumborum* muscle was also characterized by a higher ($p<0.05$) collagen content in the meat in both periods of aging compared to the GM muscle (Table 2).

Analysis of fatty acid composition showed no effect of either aging or muscle type on the proportion of particular fatty acid groups and the content of the main linoleic acid isomer C18:2 c9,t11 (Table 3).

Table 3. The mean values and ±SD for the groups and chosen fatty acid for different muscles and aging time (g/100g total fatty acid).

Item	Muscle	Aging time		
		Fresh meat	Meat aged 7d	Meat aged 14d
Σ SFA	GM	46.92 ±2.20	47.40 ±2.09	48.27 ±2.14
	LL	46.96 ±1.91	47.62 ±2.87	47.48 ±1.63
Σ MUFA	GM	46.01 ±2.03	45.84 ±1.80	44.95 ±1.51
	LL	46.70 ±1.33	46.43 ±1.46	46.41 ±1.89
Σ PUFA	GM	6.59 ±1.14	6.23 ±1.55	6.22 ±1.40
	LL	6.04 ±1.89	5.82 ±1.54	5.42 ±0.91
Σ n6	GM	4.53 ±0.99	4.06 ±1.40	4.14 ±1.30
	LL	3.98 ±1.31	3.77 ±1.25	3.49 ±0.72
Σ n3	GM	1.29 ±0.26	1.28 ±0.19	1.32 ±0.33
	LL	1.33 ±0.33	1.26 ±0.26	1.25 ±0.31
n6/n3	GM	3.55 ±0.60	3.15 ±0.89	3.20 ±0.93
	LL	2.99 ±0.61	2.97 ±0.62	2.86 ±0.63
C18:2c9t11	GM	0.63 ±0.17	0.58 ±0.18	0.57 ±0.13
	LL	0.54 ±0.09	0.59 ±0.14	0.48 ±0.05

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TBARS	GM	$0.28^{a*} \pm 0.08$	$0.51^{b*} \pm 0.07$	$0.60^{c} \pm 0.24$
	LL	$0.19^{a*} \pm 0.08$	$0.43^{b*} \pm 0.08$	$0.46^{b} \pm 0.08$

GM - *M. gluteus medius;* LL - *M. longissimus lumborum;* ^{a,b,c} - different superscripts in the same row represents significant differences between aging time within individual muscle ($p<0.05$); *- in columns represents significant differences between muscles within item and aging time ($p<0.05$).

Although a slight increase in the content of total saturated fatty acids (SFA) and a decrease in total monounsaturated (MUFA) and polyunsaturated (PUFA) acids were observed with the aging of the meat in both tested muscles, but the differences in the content of these acid groups between fresh and aged meat were not statistically confirmed. There was also no difference in fatty acid groups between GM and LL muscle. However, aging time and muscle type affected the degree of lipid peroxidation expressed as TBARS (Table 3). A higher content of thiobarbituric acid reactive substances ($p<0.05$) was recorded in meat after 7 and 14 days of aging in both GM and LL. A higher TBARS content ($p<0.05$) in fresh meat and in meat after 7 days of aging was recorded in GM muscle compared to *longissimus lumborum* muscle. GM muscle aged for 14 days also had a higher thiobarbituric acid reactive content than LL, but the differences were not statistically confirmed (Table 3).

3.3. L-Carnitine, Carnosine and Taurine Contents

In the conducted study, the effect of aging, as well as muscle type, on taurine, carnosine and L-carnitine content was observed (Table 4). Among the tested muscles, the L-carnitine content was higher ($p<0.05$) in meat aged for either 7 or 14 days compared to fresh meat. While the carnosine content was higher ($p<0.05$) in fresh meat, the content of this component decreased in aged meat. As for taurine, its amount was lower ($p<0.05$) in meat after 7 days of aging compared to meat aged for 14 days in GM and LL. The content of this bioactive amino acid in meat after 7 days of aging was also lower compared to fresh meat but the differences were not statistically significant (Table 4).

The proportion of the aforementioned bioactive compounds also differed according to the type of tested muscle. In *longissimus lumborum*, taurine content was lower ($p<0.05$) compared to *gluteus medius* muscle in fresh meat and after 7 and 14 days of aging, while conversely carnosine was characterized by higher content ($p<0.05$) in LL and lower in GM but only in fresh meat. In meat after 14 days of aging, the content of this dipeptide was lower in LL than in GM. Differences in L-carnitine content between the tested muscles were registered in meat aged for 14 days. In *gluteus medius* muscle, the amount of L-carnitine was higher ($p<0.05$) than in LL (Table 4).

Table 4. The mean values and ±SD for L-carnitine, carnosine and taurine concentration for different muscles and aging time (mg/100g meat).

Item	Muscle	Aging time		
		Fresh meat	**Meat aged 7d**	**Meat aged 14d**
L-carnitine	GM	$169.32^{a} \pm 5.88$	$192.01^{b} \pm 6.40$	$224.70^{c*} \pm 9.91$
	LL	$165.16^{a} \pm 4.10$	$191.14^{b} \pm 7.57$	$204.15^{c*} \pm 9.30$
Carnosine	GM	$206.28^{a*} \pm 9.97$	$103.71^{b} \pm 10.12$	$111.80^{b*} \pm 9.04$
	LL	$226.15^{a*} \pm 13.42$	$101.99^{b} \pm 9.10$	$96.26^{b*} \pm 13.13$
Taurine	GM	$75.10^{*} \pm 8.87$	$70.92^{a*} \pm 9.69$	$80.71^{b*} \pm 8.38$
	LL	$61.63^{*} \pm 11.87$	$56.22^{a*} \pm 5.75$	$67.01^{b*} \pm 11.16$

GM - *M. gluteus medius;* LL - *M. longissimus lumborum;* ^{a,b,c} - different superscripts in the same row represents significant differences between aging time within individual muscle ($p<0.05$); *- in columns represents significant differences between muscles within item and aging time ($p<0.05$).

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4. Discussion

The acceptable pH range for sheep meat should have a range between 5.5 - 5.8 [30]. In this study, such pH values were not exceeded by both fresh and aging meat in GM and LL muscle (Table 1). No differences in pH values between fresh meat and meat after 7 days of aging, as in the present study, were reported by Abdullah and Qudsieh [7] in *semitendinosus, semimembranosus, biceps femoris* and *longissimus* muscles in Awassi sheep meat. Conversely to the obtained results, a marked decrease of pH at 7 days post-slaughter in muscle *longissimus dorsi* and *semimembranosus* in adult sheep was recorded by Yaner and Yetim [31]. Decreasing pH values in lamb meat with aging up to 35 days were recorded by Gramatina et al. [13] in a study comparing the quality of beef, lamb and pig meat. A significant reduction of this parameter, but during 0 and 24 hours after slaughter, was recorded by Yang et al. [11] in LT muscle of Sunit sheep, which the authors explained by the accumulation of lactic acid during the process of anaerobic glycolysis. In this studies, there was no effect of muscle on the pH value either in fresh meat and after 7 and 14 days of aging. Similarly, no differences in the value of this parameter between muscles were recorded by Purchas and Zou [32] when examining *longissimus* and *infraspiratus* muscle in fresh meat in cattle.

Color is a key indicator of meat quality for consumers, who consider meat color to be the main criteria for judging whether meat is fresh or not, which does not go unchallenged in the decision to buy it [33]. One of the factors influencing changes in meat color may be the storage method and aging period [11] The darkening of meat expressed by a higher saturation of readness and an increase in Chroma values in *gluteus medius* muscle along the aging period obtained in the present study was confirmed by Yang et al. [11] analyzing changes in quality parameters in lamb meat from 0 to 96 hours. Likewise, Abdullach and Qudsieh [7] reported a significant increase in a* value with a slight decrease in L* value after 7 days aging of meat compared to fresh meat in Awassi lambs. The aging of meat after slaughter can increase the conversion of myoglobin to oxymyoglobin and make the muscles acquire oxygen more easily, making them redder. The observed small changes in the L* value representing the lightness of color in the conducted studies, according to McKenna et al. [34] and Suman and Joseph [35], do not have a great significance in stabilizing the color of red meat.

The concentration of myoglobin in skeletal muscle, which is responsible for changes in meat color, can also be affected by the type of muscle fiber [33]. In muscle with a higher proportion of oxidative slow-contracting fibers, myoglobin content is higher than in muscle with a predominance of glycolytic fast-contracting fibers [36]. According to Ithurralde et al. [37], the Type I fiber content of the *gluteus medius* muscle is higher than in the *longissimus lumborum.* Whereas, Joo et al. [19] determined a similar proportion of Type I fibers in GM and LL, but also indicated a significantly higher proportion of oxidative-glycolytic fast-contracting fibers (Type IIA) in *gluteus medius* muscle than in LL muscle. The differences in L*, b* and Hue values between fresh muscle and in L* values after 7 days of aging can be explained by the different proportion of muscle fibers in the studied muscle types (Table 1).

The effect of muscle type on meat color was not recorded by the authors in their previous study on Polish Merino lambs in fresh meat, while after 14 days of aging, the L* value in *longissimus lumborum* muscle was significantly higher compared to GM muscle [38]. However, in another study conducted by the authors on fresh meat from Polish Merino lambs and Polish Merino x Berrichone du Cher crossbred lambs, higher L*, lower b* and H* values were determined in the GM muscle of both tested genotypes [5]. The variation in the values of parameters determining meat color was also indicated by Realini et al. [39] when analyzing the relationship between meat quality and muscle type and their morphological structure in pigs.

The water holding capacity, referred to as free water, is an important indicator for assessing meat quality, as it can directly affect the juiciness, tenderness or color of meat [40]. The lower expressed juice value in aging meat in both muscles obtained in the present study was also found by the authors in their earlier study comparing fresh meat and after 14 days of aging [38]. A lower value for this parameter in *semitendinosus, semimembranosus, biceps femoris* and *longissimus muscles* in Awassi sheep after 7 days of aging was also determined by Abdullah and Qudsieh [7]. Many factors can affect water loss including hydrolysis and oxidation of cytoskeletal proteins or cell membrane

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permeability. During aging, contraction of the myofibrillar reticulum and myocytes and degradation of proteins leads to relaxation of the sarcomere structure so that water retention in muscle may increase [14,41]

In this study, no differences in water loss were registered between muscles (Table 1). Different results were obtained by Purchas and Zou [32] comparing the quality of beef in the two muscle types, where the *infraspinatus* muscle had a significantly higher water loss than the *longissimus* muscle.

The aging time and type of muscle were not unaffected on the basic chemical composition of the meat (Table 2). The effect of meat aging on water content found in this study in LL muscle at 7 days after slaughter was also reported by Ablikim et al. [8] in meat from Chinese sheep breeds but after 15 days of freezing storage. In contrast, Abdullah and Qudsieh [7] found no effect of aging time on the water content of various muscles of Awassi lambs similarly to the GM muscle in the present study. The 14-day aging period had a significant effect on the total protein content of both tested muscles, while a higher fat content after aging was recorded only in the GM muscle, which also differs from the LL muscle in terms of this parameter in meat after 7 days of aging (Table 2). Abdullah and Qudsieh [7] did not confirm differences in protein content of different muscles according to aging and, inversely to the present study, they also did not show differences in fat content. The research of the above-mentioned authors was consistent with previous studies conducted on fresh meat and after 14 days of aging of Polish merino lambs by Rant et al. [38]. No differences regarding fat content between muscle types in fresh meat and after 14 days of aging, for fresh meat were also confirmed by Ablikim et al. [8] for *longissimus dorsi* and *gluteus medius* muscles and by Esenbuga et al. [4] comparing *longissimus dorsi, semitendinosus* and *triceps brachi* muscles in Awassi sheep. The effect of muscle type on water, protein and fat content in Blonde Galician cattle was also not observed by Franco et al. [42].

In this study, a 7-day aging period had an effect on increasing ($p<0.05$) the collagen content but only in the muscle *longissimus lumburum*, differences in the proportion of this component also related to the type of muscle. More collagen was recorded in LL muscle than GM muscle at both aging periods. In the authors' earlier study, higher collagen content in fresh meat was also found in the *longissimus dorsi* muscle of both Polish Merino lambs and Merino x Berrichone du Cher crossbreds lambs compared to GM muscle [5]. Similar to the present study, Ablikim et al. [8] observed a higher collagen content in the *longissimus dorsi* muscle compared to the GM muscle in Chinese sheep. In contrast, a higher proportion of collagen in goose breast muscle after 14 days of aging than in fresh meat was determined by Geldenhuys et al. [43]. Differences in the content of this component depending on the type of muscle may be influenced by differences in the amount of intramuscular fat. An increase in fat can decrease collagen content, which was also observed in the present study [44]

Although the study found no significant differences in the content of SFA, MUFA, PUFA fatty acid groups and in the content of the main isomer of C18:2 cis-9, trans-11 linoleic acid either between fresh and aging meat or between the muscles studied, it should be noted that meat after aging in both GM and LL muscles was characterized by an increase in SFA content and a decrease in MUFA and PUFA (Table 3). A similar variation in fatty acid content during aging was obtained by Yang et al. [11] in a study of *m.l.d.* muscle in Sunit sheep subjected to different feeding regimes. As reported by Han et al. [45] the increase in SFA may have been due to the destruction of long-chain PUFA. Due to the presence of double bonds in the structure of polyunsaturated fatty acids, they are the initiators of lipid oxidation. The oxidative stability of meat can be significantly affected by even small changes in the concentration of these acids [46]. Thus reduction in MUFA and PUFA which are precursors of flavor during the aging of meat in the present study may be due to their easier oxidation. This is consistent with the increase ($p<0.05$) in TBARS values with the aging period of the meat observed in both types of muscles (Table 3). The higher degree of lipid oxidation expressed by a higher TBARS value in *gluteus medius* muscle than in LL muscle could be explained by a higher intramuscular fat content in GM, although the differences in this component were not significant. Greater lipid oxidation was also observed in cattle meat with higher fat content [47,48]

The studied bioactive compounds L-carnitine, carnosine or taurine being substrates in chemical reactions occurring during thermal processing of meat, can be correlated, similarly to fatty acids, with its taste and aromatic qualities. In addition to its antioxidant, metal ion chelating or anti-glycation

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effects, carnosine has been attributed to its association with umami flavor [49]. In addition, the above-mentioned metabolites during meat aging are involved in processes such as glycolysis, the Krebs cycle, protein degradation or fatty acid metabolism, which can result in a change in their content.

The decrease in carnosine and increase in L-carnitine with aging of the meat obtained in their study (Table 4) was not confirmed by Bischof et al. [50] when examining non-aging and aging beef for 7 and 14 days. Carnosine content increased with aging of the beef, while L-carnitine remained at similar levels in both fresh and aged meat. On the other hand, in a study by [51] comparing metabolic changes in beef subjected to different aging treatments over a 4-week period, they observed in dry aging an initial increase in carnosine content, followed by a decrease after 14 days of aging and a renewed increase and decrease on days 21 and 28 of the study, respectively. The taurine content of the aforementioned studies decreased after 14 days of aging the meat, followed by an increase after 28 days. In present study, a decrease in taurine content occurred after 7 days of aging and increased after 14 days (Table 4). Carnitine, as in the present study, increased due to aging, but only up to the first week, thereafter the levels of this component were stable [51]. Carnitine, which is associated with utilizing fatty acids and facilitating their removal from the mitochondria, can be synthesized from lysine and methionine. Thus, its increase during meat aging can be linked to the release of amino acids during processes associated with protein degradation [52].

The differences in taurine, carnosine and L-carnitine content by muscle type recorded in this study can also be seen in other authors' studies. The lower content of taurine in the muscle of the *longissimus lumborum* and the higher content in the muscle of the GM and, conversely, the higher content of carnosine in the LL and the lower content of this compound in the GM obtained in the present study (Table 4) were confirmed in an earlier study by the authors conducted on fresh meat from Polish Merino lambs [5].

A higher carnosine and lower taurine content in LL muscle compared to GM was also reported in lamb meat by Purchas et al. [53]. Glycolytic fast-contracting muscle fibers (type IIB), which are more abundant in *longissimus* muscle, have a significantly higher carnosine content compared to oxidative slow-contracting fibers due to their susceptibility to acidification and higher buffering capacity, as confirmed in beef by Ruiz et al. [42] and in pork by Aristoy and Toldra [54]. Also, a higher carnosine content in breast muscle than in thigh muscle in the control group of broilers was determined by Kralik et al. [55] in a study of poultry meat quality in relation to the use in nutrition β-alanine and L-histidine supplementation.

A significantly higher L-carnitine content in muscle *gluteus medius* compared to LL was only registered in meat after 14 days of aging (Table 4). A higher L-carnitine content in GM also in fresh meat was determined by the authors in earlier study in Polish Merino x Berrichone du Cher crossbred lambs [5]. Muscles with more oxidative or oxidative-glycolytic fibers may have a higher content of this component due to its association with oxygen metabolism. The higher L-carnitine content in GM may be explained by the fact that there is a high concentration of lipid compounds in red muscle, in the metabolism of which L-carnitine is involved. A higher proportion of L-carnitine in the red muscle of m. soleus in laying hens was confirmed in their study by Shimada et al. [23].

5. Conclusions

The results of the study indicate that the aging process affected some of the physico-chemical characteristics of lamb meat. Meat after 7 and 14 days of aging was characterized by a more saturated red color, especially in muscle *gluteus medius*. Aged meat was also characterized by a better ability to hold own water. The aging process resulted in an increase in fat and protein content in GM muscle, while in LL muscle, in addition to an increase in protein content, collagen content also increased. After 7 days of aging the meat, the muscles differed in their basic chemical composition. In fresh meat, the chemical composition in both muscles was similar.

There were no differences in the content of SFAs, MUFAs and PUFAs and C18:2 cis-9, trans-11 according to either aging time or muscle type. The differences were in the degree of lipid oxidation. The TBARS value indicated higher levels of oxidation in aged meat and better oxidative stability in LL muscle.

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As the meat aged, the L-carnitine content increased in both muscles while the GM muscle showed a higher content of this component after 14 days of aging than LL. Carnosine content, after 7 days of aging, decreased in both GM and LL, while taurine content, after a periodic decrease during the later aging period, increased, whereby the level of this component increased in both muscles. The *gluteus medius* muscle contained more taurine in fresh and aged meat and L-carnitine in meat after 14 days of aging while the proportion of carnosine in fresh meat was significantly higher in *longissimus lumborum* muscle.

In summary, it can be concluded that, due to the processes involved in turning muscle into meat, both the aging time and the type of muscle have an impact on the physico-chemical characteristics and the content of bioactive compounds.

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