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EFFECT OF THE GENOTYPE AND AGEING TIME ON PHYSICOCHEMICAL PARAMETERS OF SKELETAL MUSCLES IN YOUNG BULLS FATTENED IN A SEMI INTENSIVE SYSTEM

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ABSTRACT

The aim of the study was to determine the effect of the genotype and ageing time on pH, water holding capacity, shear force and energy, and the myofibrillar index of *m. longissimus lumborum* and *m. semitendinosus* muscles in semi-intensively fed bulls. Carcass value indices and the chemical composition of the muscles depending on the genetic group were assessed as well. The study involved 46 young bulls from four genetic groups, i.e. the Hereford breed (HER, 8 bulls), the Limousin breed (LIM, 8 bulls), commercial cross-breeds (MT, 14 bulls), and the Polish Black-and-White Holstein-Friesian breed (PHF, 16 bulls). The analyses showed that the semi-intensive fattening system ensures production of carcasses with satisfactory slaughter yield and quality parameters (good musculature and moderate fatness). The best quality parameters were determined in the meat from the LIM and MT young bulls, whereas the poorest results were exhibited by the PHF beef. The ageing time had a positive effect on the meat quality parameters (especially tenderness and color), contributing to a significant reduction in the differences between the genotypes observed in the initial *postmortem* period. The results of the shear force and myofibrillar index, i.e. parameters of meat tenderness, suggest that a 14-day ageing period seems to be the necessary minimum. This period should even be extended in the case of the LL muscle of HER and PHF young bulls or the ST muscle of HER, MT, and PHF young bulls. Further research with consumer assessment is therefore advisable to determine the optimal ageing time of beef produced in the country.

Key words: semi-intensive fattening system, fattening performance, slaughter yield, beef quality, meat ageing

INTRODUCTION

Consumers are increasingly looking for food with special dietary and pro-health properties, and beef is one of the most valuable types of meat meeting these criteria [Gotoh and Joo 2016, Henchion et al. 2017]. As indicated by consumers, the quality of beef is determined by a number of distinguishing traits that are initially assessed at the time of purchase and then during consumption. During purchase, the consumer primarily focuses on the color, marbling, texture, and aroma of meat. In turn, tenderness, palatability, and juiciness are the most important traits after thermal treatment [Kerth and Miller 2015, O'Quinn et al. 2018].

The quality of beef is influenced by many interrelated genetic and environmental factors. Among the genetic factors, the most important role is played by the cattle breed, which is associated with the genetic variability and use (dairy, meat) of these animals [Mach et al. 2008, Ripoll et al. 2013]. It is assumed that culinary beef should come from young meat-type animals (aged up to 2 years). However, some authors have argued that dairy cattle meat can be an equally valuable raw material for culinary use [Modzelewska-Kapituła et al. 2019], as it

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is characterized by a similar or sometimes higher quality than beef from meat breeds [Devlin et al. 2017]. High indicators of fattening performance and slaughter yield can also be achieved by crossing commercial dairy cattle with bulls of meat breeds [Nogalski et al. 2013, Momot et al. 2020].

In Poland and other European countries, the basic fodder in the nutrition of cattle fatteners is maize silage supplemented with soybean meal-based concentrates [Łozicki et al. 2012, Avilés et al. 2015]. However, this intensive nutrition system has an adverse effect on the oxidative stability [Fruet et al. 2018], color [Salim et al. 2022], and nutritional value [Nogoy et al. 2022] of meat. Additionally, such a raw material contains low amounts of vitamin E but high levels of linoleic acid (18:2n-6), which unfavorably increases the ratio of n-6 to n-3 fatty acids [Cama-Moncunill et al. 2021]. Thus, from the dietary point of view, extensive or semi-intensive fattening systems with the use of green pasture and/or silage and grass haylage are advisable [Łozicki et al. 2012]. Equally important is the fact that this feeding system ensures satisfactory economic outcomes [Siphambili et al. 2020].

Immediately after slaughter, beef meat is not a wholesome raw material for consumption. Its organoleptic properties, especially tenderness and palatability, are improved during the ageing process, i.e. storage after the end of the *rigor mortis* phase in refrigerated conditions, during which the raw material acquires the characteristics of culinary meat. During storage, complex processes take place in the structure of muscle fibers and connective tissue as a result of endogenous proteolysis [Kim et al. 2015, Xu et al. 2023]. The AMSA [2015] recommends a 14-day ageing period for meat to achieve acceptable tenderness and palatability [Goñi et al. 2007]. In contrast, Resconi et al. [2018] suggest that the process of beef ageing may last from 7 to 21 days. As reported by Modzelewska-Kapituła et al. [2019], a longer ageing time generates higher costs for beef producers; hence, a 9-day rather than 14-day ageing period is more advantageous in the production of high-quality culinary beef.

The aim of the study was to determine the effect of the genotype and ageing time on pH, water holding capacity, shear force and energy, and myofibrillar index of two skeletal muscles, i.e. *m. longissimus lumborum* and *m. semitendinosus*, in young bulls fed semi-intensively with fodder from permanent grasslands supplemented with grain meal. The slaughter yield indices and the chemical composition of these muscles associated with the genetic group were assessed as well.

MATERIAL AND METHODS

Animals, feeds, housing, and diets

The study involved 46 young bulls from four genetic groups, i.e. the Hereford breed (HER, 8 bulls), the Limousin breed (LIM, 8 bulls), commercial cross-breeds (MT, 14 bulls), and the Polish Black-and-White Holstein-Friesian breed (PHF, 16 bulls). The HER and LIM bulls (with known origin) were purchased at the age of ca. 6 months, while the MT and PHF animals were reared on the experimental farm. The animals were kept in breed groups in deep-litter pens with year-round access to pastures in order to comply with the requirements for cattle welfare. From the age of 6 months and approx. 220 kg body weight to slaughter (20 months ±2 months), the animals were fed *ad libitum* in a semi-intensive system. The feed ration was designed according to the INRA cattle feeding system [IZ-PIB INRA 2009] corrected after each gain of 100 kg of body weight. The animals received grass haylage (natural meadows), hay (natural meadows), and cereal meal (triticale, oats, and barley at the dose of 30% each and 10% of post-extraction rapeseed meal) with the addition of mineral and vitamin preparations for fattening animals (Taurus Standard 2.5%). The animals had constant access to water and licks (NaCl).

The chemical composition of the feeds was determined with reference methods, i.e. dry matter content with the drying method PN-88/R-04013, total protein with the Kjeldahl method PN-75/A-04018, fat with the Soxhlet method PN-76/R-64753, crude fiber with PN-76 /R-64814, ash with PN-76/R-64795, NDF with the gravimetric method PN-EN ISO 16472:2007, and ADF with the gravimetric method PN-EN ISO 13906:2009. The nutritional value of the feeds was calculated in INRA units using the INRAtion-PrevAlim 3.3 program and taking into account PDIN, PDIE, and JPM. These analyses showed that the chemical composition and nutritional value of the feeds used in the experimental fattening scheme did not differ from the values reported in the literature [IZ-PIB INRA 2009]. Concurrently, the composition of the complete ration fully covered the energy and protein requirements at each stage of rearing of the young bulls.

Sampling and analyses

The animals were transported to the slaughterhouse in accordance with the requirements of Regulation (EC) 1/2005 [European Commission 2005] and placed in a livestock warehouse with access to water. The following day, they were weighed and slaughtered in accordance with European Council (EC) Regulation No 1099/2009 on the protection of animals at the time of killing [European Commission 2009]. After slaughter, the weight of carcasses before cooling, their percentage yield, and the commercial quality class according to the EUROP system were determined. For the statistical analysis, the results of the conformation (P– ÷ E+) and fatness (1– ÷ 5+) classification were converted into a numerical 1–15 point scale (Table 1) [Klont et al. 1999].

Table 1. EUROP carcass conformation classes and scores; fatness classes and scores [Klont et al. 1999]

Carcass conformation classes (EUROP)	E+	E	E–	U+	U	U–	R+	R	R–	O+	O	O–	P+	P	P–
Carcass conformation (pts)	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
Carcass fatness classes (EUROP)	1–	1	1+	2–	2	2+	3–	3	3+	4–	4	4+	5–	5	5+
Carcass fatness (pts)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15

Physicochemical analyses of meat

After 24-hour cooling, right half-carcasses were subjected to technological dissection, during which samples of *m. longissimus lumborum* (LL) and *m. semitendinosus* (ST) with a an approx. 500-g unit weight were collected, vacuum packed in PA/PE film bags, and stored at 2°C (±1°C) until assays.

Basic chemical composition and collagen content

On day 14 of meat ageing, water content was determined using the PN-ISO 1442:2000 drying method [Polish Committee for Standardization 2000a], the total protein content was determined with the Kjeldahl method using the Büchi B-324 apparatus according to PN-75/A-04018 [Polish Committee for Standardization 2002], the free fat content was determined with the Soxhlet method (solvent – n-hexane) in a Büchi B-811 device in accordance with PN-ISO 1444:2000 [Polish Committee for Standardization 2000b], and the collagen protein content was determined based on the content of hydroxyproline (PN-ISO 3496–2000; conversion factor 8) [Polish Committee for Standardization 2000c] using a Varian Cary 300 Bio spectrophotometer. The Feder number, i.e. the proportion of water to protein, which expresses the degree of hydration of muscle proteins, was calculated based on the water and protein content.

Soluble collagen was determined as in Palka [1999] with modifications. Meat samples (approx. 5 g) were homogenized with 24 cm^3 of Ringer's solution diluted with distilled water (1:4). The homogenate was heated in a water bath at 77°C for 70 min and then centrifuged in a Universal 320R Hettich Zentrifugen centrifuge (4000×g for 15 min). The supernatant was collected and the precipitate was washed with Ringer's solution (1:4) and centrifuged again. Next, the precipitate was hydrolyzed in 30 cm^3 of an H_2SO_4 solution (3 M). The procedure used for the determination of total collagen was followed in the subsequent stages. The content of soluble collagen was calculated by subtracting the insoluble collagen content from the total collagen and expressed as a percentage of total collagen.

pH value

The values of pH_{45min}, pH_{24h}, pH_{2d}, pH_{7d}, and pH_{14d} were determined directly in the muscle tissue after slaughter with the use of a CP-401 pH-meter and an ERH-12-6 combined electrode.

Color

Meat color indices were assessed using a Minolta CR-310 color saturation meter (illumination/projection D65/10°) by recording L* (brightness) and a* (redness) on an exposed surface of the muscle cross-section (after 30-min blooming in refrigeration conditions at –2°C) [CIE 2004].

Water holding capacity

Drip loss (DL) and cooking loss (CL) were determined as in Honikel [1998]. The amount of expressible water (EW, %) was determined with the blotting method [Grau and Hamm 1953] using Whatman No 1 filter paper, 300-mg aliquots, and constant mass of 2 kg for 5 min.

Shear force

Shear force (N) and energy (J) were measured using a Zwick/Roell Proline B0.5 device (Zwick GmbH & Co, Ulm, Germany) and a Warner-Bratzler (V-blade) shear blade. The tested muscle fragments (cut out from thermally treated samples) were 5 cm long and had a shear surface cross-section of 1 cm^2. The mean value for each sample was calculated from 6 replicates. The shear force measurement results were analyzed using the TestXpert II program.

MFI

The myofibrillar index (MFI) was determined as in Hopkins et al. [2000] using a Büchler HO-4A knife homogenizer (speed 15,000 rpm), a Universal 320R Hettich Zentrifugen centrifuge (speed 1000 g, time 15 min, temperature 2°C), and a Varian Cary BIO spectrophotometer (Varian Australia PTY, Ltd., Mulgrave, Australia) at a wavelength of 540 nm. The protein content in the mixture was determined using the biuret method. A conversion factor of 150 was used to calculate the myofibrillar index (MFI).

TBARS

Lipid oxidative stability (TBARS value) was determined with the method proposed by Witte et al. [1970] with the use of a Varian Cary 300 Bio spectrophotometer at

a 530-nm wavelength. The results were expressed in mg of malondialdehyde (MDA) in 1 kg of meat.

Statistical analysis

Statistical analysis of the results was performed in Statistica ver. 13.1 [TIBCO Software Inc. 2016]. The effect of the bull genotype on the slaughter yield and chemical composition of the LL and ST muscles was determined using a one-way analysis of variance. The two-way analysis of variance model taking into account the effect of the bull genotype (g), the ageing time (t), and their interaction (g * t) was used to analyze the pH value, texture indicators (shear force, SF and energy, En), water holding capacity parameters (DL, CL, EW), color parameters (L*, a*), TBARS value, and myofibrillar index values, MFI, for the individual muscles. Statistical differences of experimental factors were determined by the least squares method using the formulas:
– for pH value:

$$pH_{ijk} = \mu + g_i + t_j + (gt)_{ij} + e_{ijk}$$
$$(i = 1, \ldots, 4; j = 1, \ldots, 5)$$

– for SF, En, DL, CL, EW, L*, a*, TBARS and MFI value:

$$Y_{ijk} = g_i + t_j + (gt)_{ij} + e_{ijk}$$
$$(i = 1, \ldots, 4; j = 1, \ldots, 3)$$

where:

pH_{ijk}, Y_{ijk} – the value of the analyzed parameter;
μ – population mean;
g_i – the effect of genetic group;
t_j – the effect of ageing time;
$(gt)_{ij}$ – genetic group × ageing time interaction;
e_{ijk} – random error.

The significance of the differences between the mean values in the groups was determined using Tukey's test at $P \leq 0.01$ and $P \leq 0.05$. The mean values of individual traits and the standard error are shown in tables.

RESULTS AND DISCUSSION

Slaughter yield

Carcass weight is an important parameter according to which meat processing plants settle accounts with breeders. The highest mean carcass weight ($P \leq 0.01$) was determined in the group of the commercial cross-breeds (MT) compared to the bulls from the other genetic groups, where the mean weight did not differ significantly (Table 2). As reported by Şenyüz et al. [2020] in a study conducted on intensively fed bulls representing four breeds, the highest (but statistically insignificant) carcass weight was found in the Limousin breed (385.15 kg), followed by Simmental (368.98 kg), Charolais (362.76 kg), and Angus (355.45 kg). It was shown by Avilés et al. [2015] that the carcass weight of LIM bulls was influenced by the intensity of feeding and reached 332.1 kg in the traditional fattening system (concentrate and wheat straw) and 307.4 kg in the TMR system (concentrate, maize silage, and wheat straw). In comparison with the animals in the present study, young bulls of the PHF breed analyzed by Wajda et al. [2011] had higher carcass weight in the range from 296.3 kg (class O) to 315.5 kg (class R), depending on the EUROP conformation class.

Table 2. Slaughter yield and EUROP classification results

Parameter	Statistical measures	Genetic group				Mean
		HER	LIM	MT	PHF	
	n	8	8	14	16	46
Carcass weight, kg	x̄	287.7^{B}	305.2^{B}	373.8^{A}	286.9^{B}	319.8
	SD	35.4	26.7	54.8	18.11	52.0
Slaughter yield, %	x̄	54.02^{ab}	57.99^{a}	58.22^{a}	51.96^{b}	55.27
	SD	1.92	1.24	2.96	2.13	3.61
Carcass conformation (pts/ EUROP)	x̄	9.00^{B} / R+	11.63^{A} / U+	7.64^{C} / R	4.88^{D} / O	7.61 / R
	SD	0.02	1.06	1.50	0.72	2.62
Carcass fatness (pts / EUROP)	x̄	7.00^{BA} / 3–	2.5^{C} / 1+	8.07^{A} / 3	6.06^{B} / 2+	6.22 / 2+
	SD	0.02	0.53	1.38	1.24	2.18

A, B, C, D – $P \leq 0.01$; a, b – $P \leq 0.05$.

The slaughter yield is an important indicator of meat production performance. It had the lowest value ($P \leq 0.05$) in the case of the PHF bulls and the highest value in the group of the MT and LIM bulls. Nogalski et al. [2014] reported a higher slaughter yield than that in the present study, i.e. 54.25% and 55.41% in PHF bulls reared in semi-intensive and intensive systems, respectively. Similar slaughter yield to that obtained in the present study was reported by Ünlü and İpçak [2021] in a study on HF bulls and by Avilés et al. [2015], who analyzed LIM bulls. Şenyüz et al. [2020] determined the highest slaughter yield in LIM (60.64%), SIM (58.48%), CH (58.09%), and ANG (57.47%) bulls. Similar results in the range of 58–59% were obtained by Duru and Sak [2017] in their study on the LIM, ANG, CH, SIM, and HER breeds. Given the aforementioned data, it should be emphasized that breeds of meat cattle fattened in similar conditions are characterized by similar fattening and slaughter yields.

The carcasses of the LIM bulls exhibited the best conformation and the lowest fatness level ($P \leq 0.01$). The lowest EUROP classification scores were assigned to the carcasses of the PHF bulls, which is in agreement with the results reported by Alberti et al. [2008]. As shown by Vestergaard et al. [2019], the crossing of the Danish Holstein-Friesian cattle with the Limousin breed significantly improved the conformation of carcasses in cross-breed young bulls and heifers (3.0 points vs. 7.0 and 5.3 points). Similar carcass conformation values to those obtained in the present study were reported by Momot et al. [2020]. Concurrently, the authors found that the fat content in the carcasses of PHF×HH cross-breeds was significantly higher than in PHF×LIM cross-breeds (5.5 points vs. 4.2 points). In turn, Bittante et al. [2020] found no differences in the carcass conformation in commercial cross-breed bulls originating from different meat breeds in the paternal line, despite statistically significant differences in slaughter yield.

Basic chemical composition and characteristics of the collagen fraction

A significant effect of the genetic group on the chemical composition of the LL muscle was demonstrated in this study (Table 3). The MT bulls had two-fold lower content of intramuscular fat ($P \leq 0.01$) and the lowest ($P \leq 0.01$) water content. In turn, the LL muscle of the HER bulls contained the lowest amounts of total protein ($P \leq 0.05$) and, consequently, the highest degree of hydration of muscle proteins (so-called Feder number). The content of basic chemical components and the degree of

Table 3. Content of fat, protein, water, total and soluble collagen (as % of total collagen), Feder number, and proportion of connective tissue proteins in total protein (C:P) in *m. longissimus lumborum* and *m. semitendinosus* of the analyzed bulls

Parameter	Genetic group				SEM	*p*-value
	HER	LIM	MT	PHF		
			m. longissimus lumborum			
Water, %	75.34^{B}	74.43^{B}	72.46^{A}	74.56^{B}	0.22	<0.0001
Total protein, %	21.31^{a}	22.65^{b}	22.87^{b}	22.68^{b}	0.19	0.0454
Fat, %	1.77^{A}	1.48^{A}	3.59^{B}	1.50^{A}	0.22	0.0009
Feder number	3.58^{b}	3.29^{a}	3.17^{a}	3.29^{a}	0.04	0.0155
Total collagen, mg · g^{-1}	7.62^{A}	11.30^{B}	8.09^{A}	10.19^{AB}	0.41	0.0028
Soluble collagen, %	21.26^{A}	29.30^{B}	24.57^{A}	24.08^{A}	0.67	0.0002
C:P, %	3.51^{A}	4.82^{B}	3.43^{A}	4.49^{B}	0.18	0.0075
			m. semitendinosus			
Water, %	74.70	74.99	74.85	75.33	0.16	0.4963
Total protein, %	23.04	22.37	22.45	22.25	0.16	0.3635
Fat, %	0.93	1.15	1.56	1.03	0.09	0.1337
Feder number	3.24	3.36	3.34	3.39	0.03	0.3361
Total collagen, mg · g^{-1}	11.45^{A}	11.65^{A}	12.78^{A}	15.10^{B}	0.38	0.0001
Soluble collagen, %	18.30^{A}	24.79^{B}	23.04^{B}	22.11^{AB}	0.63	0.0020
C:P, %	5.06^{A}	5.30^{A}	5.62^{A}	6.99^{B}	0.19	<0.0001

A, B – $P \leq 0.01$; a, b – $P \leq 0.05$.

hydration of muscle proteins in the ST muscle did not differ significantly between the genetic groups.

As indicated by literature data, the greatest differences between genotypes are exhibited by the fat content, as they may reach over 100% between breed groups. Substantially smaller differences between genotypes are recorded in the content of total protein, water, or ash, as they account for only several percent [Prado et al. 2008a, Prado et al. 2008b]. Nogalski et al. [2013] analyzed the composition of the *longissimus dorsi* muscle of PHF×LIM hybrid steers reared in intensive and semi-intensive systems and showed that the protein content ranged from 21.19 to 21.80%, and the fat content was estimated at 4.71 and 3.60%, respectively. A significant effect of the genotype on the chemical composition of the *longissimus dorsi* (MLD) muscle was demonstrated by Jukna et al. [2017] in bulls fed high-energy feed. In their study, the highest content of intramuscular fat was found in HER bulls (2.51%), compared to CH (2.19%), SIM (1.83%), and LIM (1.24%). Similar to the present study, the lowest total protein content was determined in the HER breed (21.44%).

Significant differences in the content of collagen fractions and the percentage of connective tissue proteins in total protein (C:P) in both skeletal muscles were observed between the breeds analyzed in the present study (Table 3). The highest values of these traits ($P \leq 0.01$) were found in the LL muscle of the LIM bulls. The highest amount of total collagen and its highest proportion in the protein in the ST muscle were determined in the PHF breed. Similar to the LL muscle, the highest content of the soluble collagen fraction was found in the LIM bulls, although significant differences were confirmed only in the HER breed.

The amount of soluble collagen increases during post-slaughter ageing and is strongly dependent on the animal breed, age, sex, diet, and condition, and its content has a significant impact on the water holding capacity and texture of the meat after thermal treatment [Zając et al. 2011]. It has been shown that intensive feeding contributes to reduction of the content of total collagen and its insoluble fraction in meat and to an increase in the percentage of the soluble fraction [Shiba et al. 2004]. In the present study, the amount of soluble collagen determined after 14 days of meat ageing did not exceed 25%, with the exception of the LL muscle of the LIM bulls, where it reached a level of almost 30% ($P \leq 0.01$). These results agree with other literature data, as similar content of the soluble collagen fraction in meat ageing for 12–14 days has been reported by Palka [2003] and Zając et al. [2011].

pH value

Although the results of the pH measurements (Table 4) indicated a correct course of post-slaughter glycogenolysis (typical for normal meat) in both muscles of the young bulls representing the four genotypes, the ageing time and the interactions between these factors were shown to have a significant effect on this trait. Regardless of the genetic group, the greatest decrease in pH in the LL muscle was found in the initial *postmortem* period, i.e. between 45 min and 24 h. In general, the level of acidification of the LL muscle assessed after one day remained stable ($P \leq 0.05$) until *postmortem* day 14. Similar relationships were observed in the analyses of the ST muscle.

It was also found that both muscles of the LIM and HER bulls were characterized by significantly higher initial pH (i.e. >6.80 after 45 min), compared to the meat from the MT (6.32–6.51) and PHF (6.46–6.51) breeds. During the entire ageing period, the highest pH was found in the muscles of the LIM bulls, but it was not higher than 5.75 in the period between 24 h and 14 days. Proper pH is one of the most important determinants of meat quality, as it has an impact on many beef technological parameters and culinary traits e.g. tenderness, water holding capacity, color, flavor, and durability or stability of collagen cross-linking bonds [Domaradzki et al. 2017, Gagaoua et al. 2017, Gagaoua et al. 2018]. It is assumed that the ultimate pH (pHu) of culinary beef, usually assessed between 24 h and 48 h after slaughter, should not exceed 5.8 [Mach et al. 2008]. In DFD-free beef, a decrease in pH to a range of 5.5 to 5.7 has been observed in the initial period (typically up to 48 h *postmortem*), followed by a slight but constant increase on the subsequent days of ageing [Domaradzki et al. 2017]. The initial decrease in pH indicates the accumulation of lactic acid in the process of post-slaughter glycolysis and a correct course of meat acidification. In turn, the subsequent increase in pH is a result of progressive alkalization caused by the release of alkaline protein breakdown products during post-slaughter meat ageing [Florek et al. 2007].

Water holding capacity

The analyses revealed a significant effect of the genetic group and ageing on the water holding capacity of both skeletal muscles (Table 5). In the case of cooking loss and water holding capacity determined with the EW method, a significant interaction of the main effects (genetic group × ageing) was found. With the ageing time, the level of drip loss from both assessed muscles increased steadily. Similar relationships were reported previously by other authors [Florek et al. 2007, Domaradzki et al. 2017]. The highest ($P \leq 0.05$) levels of drip loss from the LL and ST muscles were found in the meat of the HER bulls (except for day 14 in ST). In turn, the lowest values ($P \leq 0.05$) of this parameter were determined in the LL muscle of the LIM bulls on ageing days 2 and 7 and in the MT bulls on day 14. The latter group was also characterized by the lowest losses of the ST muscle throughout the ageing period.

Table 4. Changes in the pH value in *m. longissimus lumborum* and *m. semitendinosus* during 14 days of ageing

Parameter	Genetic group				SEM	*p*-value		
	HER	LIM	MT	PHF		Genotype	Ageing	Genotype × Ageing
			m. longissimus lumborum					
pH_{45min}	$6.82^{b, x}$	$6.88^{b, x}$	$6.32^{a, x}$	$6.46^{a, x}$	0.05			
pH_{24h}	$5.58^{a, y}$	$5.75^{a, y}$	$5.66^{a, y}$	$5.67^{a, y}$	0.03			
pH_{2d}	$5.56^{ab, y}$	$5.66^{b, y}$	$5.46^{a, y}$	$5.58^{b, y}$	0.02	<0.0001	<0.0001	<0.0001
pH_{7d}	$5.59^{a, y}$	$5.61^{a, y}$	$5.55^{a, y}$	$5.55^{a, y}$	0.01			
pH_{14d}	$5.61^{a, y}$	$5.70^{b, y}$	$5.57^{a, y}$	$5.63^{ab, y}$	0.01			
			m. semitendinosus					
pH_{45min}	$6.85^{b, x}$	$6.89^{b, x}$	$6.51^{a, x}$	$6.51^{a, x}$	0.04			
pH_{24h}	$5.41^{a, y}$	$5.54^{ab, y}$	$5.60^{ab, y}$	$5.62^{b, y}$	0.02			
pH_{2d}	$5.55^{a, z}$	$5.69^{a, z}$	$5.55^{a, y}$	$5.57^{a, y}$	0.02	0.0002	<0.0001	<0.0001
pH_{7d}	$5.63^{a, z}$	$5.70^{a, z}$	$5.61^{a, y}$	$5.56^{a, y}$	0.02			
pH_{14d}	$5.64^{a, z}$	$5.70^{a, z}$	$5.63^{a, y}$	$5.62^{a, y}$	0.01			

a, b, c – P ≤ 0.05 in the row (genotype effect); x, y, z – P ≤ 0.05 in the column (ageing effect).

Table 5. Effect of ageing time and cattle breed on the water holding capacity of *m. longissimus lumborum* and *m. semitendinosus*

Parameter	Ageing (days)	Genetic group				SEM	*p*-value		
		HER	LIM	MT	PHF		Genotype	Ageing	Genotype × Ageing
				m. longissimus lumborum					
	2	$2.44^{c, x}$	$1.09^{a, x}$	$1.84^{bc, x}$	$1.68^{ab, x}$	0.12			
Drip loss, %	7	$4.04^{b, xy}$	$2.31^{a, x}$	$2.60^{ab, xy}$	$3.53^{ab, y}$	0.23	0.0001	<0.0001	0.4667
	14	$6.05^{b, y}$	$3.95^{ab, y}$	$3.57^{a, y}$	$4.57^{ab, z}$	0.26			
	2	26.62^{b}	26.91^{b}	$20.61^{a, x}$	27.72^{b}	0.68			
Cooking loss, %	7	30.26	27.38	27.62^{y}	29.21	0.44	0.0069	0.0003	0.0089
	14	28.30	28.00	27.91^{y}	28.28	0.50			
	2	$25.12^{b, xy}$	$26.71^{b, y}$	21.25^{a}	$25.80^{b, z}$	0.50			
Expressible water, %	7	$27.83^{b, y}$	$21.54^{a, x}$	20.86^{a}	$22.08^{a, y}$	0.60	<0.0001	<0.0001	<0.0001
	14	$24.35^{b, x}$	$21.52^{ab, x}$	20.87^{ab}	$19.30^{a, x}$	0.51			
				m. semitendinosus					
	2	$4.08^{b, x}$	$2.58^{a, x}$	$2.41^{a, x}$	$2.68^{a, x}$	0.20			
Drip loss, %	7	$6.97^{b, y}$	$5.18^{ab, x}$	$4.01^{a, xy}$	$5.90^{ab, y}$	0.36	0.0001	<0.0001	0.2476
	14	$7.16^{b, y}$	$7.29^{b, y}$	$5.59^{a, y}$	$7.59^{b, y}$	0.27			
	2	30.53^{b}	31.64^{b}	$24.38^{a, x}$	32.00^{b}	0.77			
Cooking loss, %	7	31.28	31.51	32.66^{y}	31.83	0.42	0.0084	0.0001	<0.0001
	14	31.01	32.98	32.73^{y}	31.28	0.34			
	2	$24.00^{a, x}$	$28.28^{b, x}$	26.25^{ab}	$26.12^{ab, x}$	0.47			
Expressible water, %	7	$30.45^{b, y}$	$24.07^{a, y}$	24.05^{a}	$25.54^{a, x}$	0.59	0.0036	0.1178	<0.0001
	14	$28.42^{b, xy}$	$22.89^{a, y}$	25.17^{ab}	$22.56^{a, y}$	0.64			

a, b, c – P ≤ 0.05 in the row (genotype effect); x, y, z – P ≤ 0.05 in the column (ageing effect).

The water holding capacity of muscle tissue plays an important role for meat processing or culinary purposes and is an important indicator of meat processing suitability. The present study showed a significant variability of the muscle tissue of the MT bulls in terms of the level of cooking loss. Although the meat of these animals exhibited lower losses ($P \leq 0.05$) after thermal treatment on ageing day 2, the cooking loss increased significantly to approx. 30% on the subsequent days, i.e. to a level comparable to that exhibited by the other groups of young bulls ($P \leq 0.05$). These values are higher (by 4.0–7.2 p.p.) than those reported by Młynek [2011], who analyzed meat of black and white cattle and hybrids of various breeds.

The LL and ST muscles of the LIM and PHF bulls exhibited a significant improvement in the water holding capacity (EW), i.e. a decrease in the amount of expressible water was observed on days 7 and 14, compared to *postmortem* day 2 ($P \leq 0.05$). No such relationship was exhibited by the meat of the MT bulls, and the opposite trend (i.e. lower water holding capacity) was observed in the ST muscle of the HER bulls. In the LL muscle of five breeds of bulls, Domaradzki et al. [2017] found a significant improvement in water holding capacity during meat ageing, i.e. a decrease in the amount of expressible water (compared to *postmortem* day 2) by an average of 6.79 mg on day 7 and 13.41 mg on day 14. Modzelewska-Kapituła et al. [2015] reported an increase in the water holding capacity of *m. infraspinatus* in the initial period of ageing (before day 10) followed by a decrease on days 15 and 20.

Shear force and energy

The statistical analysis showed a significant effect of the ageing time and genetic group on the shear force and energy (except for shear force in LL) of the analyzed muscles (Table 6). Regardless of the genotype of the young bulls, a significant improvement in the tenderness of the meat (LL and ST), expressed by the decrease in the shearing force and energy value, was observed during ageing ($P \leq 0.05$). The LL muscle of the HER and PHF bulls required greater shear force and energy on the subsequent days than the same muscle of the MT and LIM bulls. In the case of the ST muscle, a similar relationship was observed only on *postmortem* day 2, and the shear force and energy values on the subsequent days did not differ significantly between the groups.

As reported by Muchenje et al. [2009], the tenderness of beef improves significantly during ageing through changes in the myofibrillar structure induced by the activity of the endogenous proteolytic complex. The improvement of meat tenderness on the first 4–6 post-slaughter days is associated with fragmentation of myofibrils and disintegration of costameres and other intermyofibrillar cytoskeletal links [Kemp et al. 2010, Boudida et al. 2016]. Differences in the rate of ageing are dependent on the animal species, the breed, and the structure and physiological activity of the muscle [Coria et al. 2018]. Niedźwiedź et al. [2011] reported that the muscle type and ageing time had a significant effect on the value of the maximum shear force in bovine hindquarter muscles. In a study conducted by Modzelewska-Kapituła et al. [2019], the value of shear force in the LL muscle of Holstein-Friesian bulls was dependent on the feeding system (TMR with maize silage and concentrates vs. TMR with the addition of herbal preparations: 66.93 and 51.95 N, respectively) and on the duration of ageing (68.98 N on *postmortem* day 9 and 59.36 N on day 14). Bureš and Bartoň [2018] reported a significant effect of the breed on the shear force of the LL muscle of Holstein bulls (58.6 N), in comparison with the value of this parameter in Aberdeen Angus meat (36.0 N). In turn, Domaradzki et al. [2017] found a decrease in shear force along with the post-slaughter ageing of meat, and the initial differences between the breeds declined, thus contributing to an equal value of the beef tenderness parameter.

The disintegration of myofibrils into shorter segments (in controlled homogenization conditions) is used for determination of the so-called myofibril fragmentation index (MFI), which is a measure of their average length. MFI is highly correlated with meat tenderness, i.e. a higher MFI value is associated with shorter myofibrils and greater tenderness of muscle tissue. It has been found that the numerical MFI index reflects the progression of the degradation of key structural proteins located in band I of the sarcomere [Hopkins et al. 2000]. The myofibrillar index value determined in the LL and ST muscles was significantly correlated with the genetic group and the ageing time and with the interactions between these factors ($P \leq 0.01$) (Table 6). Regardless of the genetic group, the MFI increased significantly during muscle ageing ($P \leq 0.05$).

The lowest levels of MFI in the LL and ST muscles were observed in the HER bulls, whereas the meat from the LIM and MT breeds exhibited the highest value of this parameter, which corresponded well with the muscle shear force discussed above. As shown by the comparison of the changes in MFI between ageing days 2 and 14, the greatest degree of fragmentation of myofibrils in the LL muscle was observed in the MT hybrids (a 57% increase), the HER bulls (48%), and the PHF breed (44%), whereas the meat from the LIM bulls exhibited the lowest value of this parameter (38%). In the case of the ST muscle, the greatest changes were observed in the HER breed (a 115% increase), and a similar level in the range of 46–49% was recorded in the other groups. As highlighted by many researchers, post-slaughter ageing, usually proceeding in anaerobic conditions (so-called wet ageing), is one of the most popular procedures improving the con-

Table 6. Shear force and energy and MFI of *m. longissimus lumborum* and *m. semitendinosus* during 14 days of ageing

Parameter	Ageing (days)	Genetic group				SEM	*p*-value		
		HER	LIM	MT	PHF		Genotype	Ageing	Genotype × Ageing
m. longissimus lumborum									
Shear force (N)	2	$155.83^{c, y}$	$106.09^{ab, y}$	$86.66^{a, y}$	$137.30^{bc, y}$	7.29	<0.0001	<0.0001	0.4059
	7	$110.25^{b, x}$	$70.35^{a, x}$	$55.44^{a, x}$	$78.53^{ab, x}$	5.22			
	14	$85.28^{b, x}$	$55.75^{a, x}$	$49.70^{a, x}$	$62.34^{ab, x}$	3.89			
Shear energy (J)	2	$0.59^{b, y}$	0.40^{a}	0.33^{a}	$0.56^{b, y}$	0.03	0.0001	<0.0001	0.0923
	7	0.41^{x}	0.30	0.29	0.31^{x}	0.02			
	14	0.38^{x}	0.27	0.26	0.29^{x}	0.02			
MFI	2	$68.64^{a, x}$	$83.14^{b, x}$	$76.96^{ab, x}$	$77.02^{ab, x}$	1.75	<0.0001	<0.0001	0.0082
	7	$82.62^{a, y}$	$108.03^{b, y}$	$109.96^{b, y}$	$100.25^{b, y}$	2.48			
	14	$101.49^{a, z}$	$115.19^{bc, z}$	$121.14^{c, z}$	$110.70^{b, y}$	1.73			
m. semitendinosus									
Shear force (N)	2	$130.73^{b, y}$	$90.02^{a, y}$	$90.74^{a, y}$	$101.58^{ab, z}$	4.53	0.0655	<0.0001	0.0412
	7	70.05^{x}	71.72^{xy}	77.77^{xy}	76.64^{y}	2.86			
	14	$63.98^{b, x}$	$54.90^{a, x}$	$60.10^{ab, x}$	$60.48^{ab, x}$	2.05			
Shear force (J)	2	$0.50^{b, y}$	$0.34^{a, y}$	0.34^{a}	$0.37^{a, y}$	0.02	0.0046	<0.0001	0.0987
	7	0.36^{xy}	0.27^{xy}	0.29	0.29^{x}	0.01			
	14	0.24^{x}	0.20^{x}	0.25	0.27^{x}	0.01			
MFI	2	$53.20^{a, x}$	$82.15^{b, x}$	$81.37^{b, x}$	$81.03^{b, x}$	3.23	<0.0001	<0.0001	0.0126
	7	102.66^{y}	110.39^{y}	110.24^{y}	106.45^{y}	1.29			
	14	$114.15^{a, y}$	$119.81^{ab, y}$	$121.62^{b, y}$	$118.69^{ab, z}$	0.94			

a, b, c – $P \leq 0.05$ in the row (genotype effect); x, y, z – $P \leq 0.05$ in the column (ageing effect).

sumption quality of beef. White et al. [2006] reported a significant effect of the conditions of slaughtering and chilling of carcasses as well as meat storage and ageing on the mechanical resistance of meat. As shown by Rajagopal and Oommen [2015], the tenderness of meat after thermal treatment can be predicted with high accuracy based on the MFI index (determined in raw meat), as this parameter is strongly correlated with overall tenderness.

Color and TBARS

The meat brightness (L*) and redness (a*) parameters in both analyzed muscles were significantly ($P \leq 0.05$) correlated with both the genetic group and the duration of muscle ageing; in the case of the LL muscle, they were also dependent on the interaction between these factors (Table 7). The analysis of the ageing-related changes in the values of the color parameters revealed a significant increase in the brightness (a higher L* value) of the LL muscle of the LIM and PHF bulls and in the brightness of the ST muscle of the LIM and HER bulls ($P \leq 0.05$). In terms of redness (a*), both muscles exhibited a significant increase in all the genetic groups of bulls ($P \leq 0.05$). The highest brightness of the LL muscle surface ($P \leq 0.05$) was noted in the meat from the LIM bulls on *postmortem* day 14, whereas the lowest value of the parameter was exhibited by the meat from the MT hybrids. The darkest color of the ST muscle ($P \leq 0.05$) was found in the HER bulls on *postmortem* day 2. On the subsequent ageing days, the L* value was similar in all the genotypes and did not differ significantly.

Papaleo Mazzucco et al. [2016] reported no significant effect of the breed (Angus vs. Hereford) on the L*, a*, and b* parameter in *m. longissimus dorsi*. In turn, Cuvelier et al. [2006] confirmed the relationship between the breed (AA – Aberdeen Angus, BB – Belgian White and Blue, and LM – Limousin) and the L* and a* values; the MLT muscle of the BB bulls was brighter and less red, while the AA bulls were characterized by the highest brightness and redness parameters. Similarly, Domaradzki et al. [2017] reported a significant effect of breed on both color parameters and the content of heme pigments in the LL muscle.

Table 7. Color parameters and levels of TBARS in *m. longissimus lumborum* and *m. semitendinosus* during 14 days of ageing

Parameter	Ageing (days)	Genetic group				SEM	p-value		
		HER	LIM	MT	PHF		Genotype	Ageing	Genotype × Ageing
m. longissimus lumborum									
L*	2	36.90	36.19^{x}	35.76	35.71^{x}	0.31	0.0093	0.0061	0.0442
	7	37.15	36.61^{x}	35.95	37.16^{y}	0.21			
	14	37.42^{ab}	$39.80^{b, y}$	35.63^{a}	$37.36^{ab, y}$	0.37			
a*	2	22.57^{x}	22.44^{x}	22.28^{x}	22.75^{x}	0.16	0.0109	<0.0001	0.0073
	7	$26.13^{b, y}$	$23.59^{a, x}$	$24.93^{ab, y}$	$24.37^{a, y}$	0.22			
	14	26.26^{y}	26.11^{y}	24.56^{y}	25.01^{y}	0.23			
TBARS	2	0.28^{a}	0.22^{a}	0.37^{b}	0.34^{b}	0.02	<0.0001	0.0578	0.7666
	7	0.28^{a}	0.23^{a}	0.47^{b}	0.37^{ab}	0.02			
	14	0.32^{a}	0.26^{a}	0.50^{b}	0.38^{ab}	0.02			
m. semitendinosus									
L*	2	$36.63^{a, x}$	$39.40^{b, x}$	38.41^{ab}	39.56^{b}	0.38	0.0043	0.0085	0.7336
	7	39.00^{xy}	41.00^{xy}	38.27	40.62	0.43			
	14	40.00^{y}	41.87^{y}	39.28	40.60	0.37			
a*	2	$25.27^{b, x}$	$23.62^{a, x}$	$24.46^{ab, x}$	$24.89^{ab, x}$	0.20	<0.0001	<0.0001	0.0528
	7	$27.72^{b, y}$	$24.93^{a, x}$	$26.62^{ab, y}$	$26.02^{ab, y}$	0.25			
	14	$27.94^{b, y}$	$26.62^{ab, y}$	$26.01^{a, y}$	$26.06^{a, y}$	0.21			
TBARS	2	$0.24^{a, x}$	0.23^{a}	$0.32^{b, x}$	$0.30^{b, x}$	0.01	<0.0001	<0.0001	0.0131
	7	$0.25^{a, x}$	0.25^{a}	$0.46^{b, y}$	$0.32^{ab, xy}$	0.02			
	14	$0.31^{ab, y}$	0.27^{a}	$0.48^{c, y}$	$0.36^{b, y}$	0.02			

a, b, c – $P \leq 0.05$ in the row (genotype effect); x, y – $P \leq 0.05$ in the column (ageing effect).

Significantly ($P \leq 0.05$) lower oxidative stability of the LL and ST muscle (higher TBARS levels) throughout the post-slaughter ageing period was determined in the meat from the MT and PHF bulls, and the highest value of this parameter was exhibited by the muscles of the LIM and HER bulls (Table 7). It should be emphasized that, despite the gradual increase in TBARS during post-slaughter meat ageing, the values of this parameter were lower than 1 mg MDA · kg^{-1}, i.e. the threshold value above which sensory characteristics may deviate due to the occurrence of oxidative changes in muscle tissue components [McKenna et al. 2005]. It has been shown [Franco et al. 2009] that these processes can be limited with the use of vacuum packaging during ageing.

CONCLUSIONS

The study of the bulls of different genetic groups fed in a semi-intensive system with the use of farm feed, i.e. hay, grass haylage, grain meal (without corn silage), showed that this fattening system guarantees satisfactory slaughter yield and good quality parameters (good musculature and average fatness) of carcasses, with the poorest results obtained in the PHF breed.

Despite the differences in the effects of the genotype, ageing time, and often the interaction of these factors on the most important quality traits of muscles, the meat did not exhibit any deviations in quality. In the four genetic groups, the meat from the LIM and MT bulls had the best quality parameters (water holding capacity, soluble collagen content, shear force, and myofibrillar index) after the 14-day wet ageing process. The ageing time had a positive effect on the meat quality parameters (especially tenderness and color, which were determined instrumentally) and contributed to a significant reduction in the differences between the meat from the bull genotypes in the initial *postmortem* period. Taking into account one of the most important qualitative traits of culinary beef, i.e. tenderness, which was assessed in the present study based on the shear force and myofibrillar index, the 14-day ageing period seems to be a necessary minimum. The ageing period should even be extended in the case of the LL muscle of HER and PHF bulls and the ST muscle of HER, MT, and PHF bulls. Further research with consumer assess-

ment is therefore advisable to determine the optimal ageing time of beef obtained from the most popular breeds of cattle reared in Poland and fattened in the most common semi-intensive system.

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REFERENCES

Alberti, P., Panea, B., Sañudo, C., Olleta, J.L., Ripoll, G., Ertbjerg, P., Christensen, M., Gigli, S., Failla, S., Concetti, S., Hocquette, J.F., Jailler, R., Rudel, S., Renand, G., Nute, G.R., Richardson R.I., Williams, J.L. (2008). Live weight, body size and carcass characteristics of young bulls of fifteen European breeds. Livest. Sci., 114(1), 19–30. DOI: 10.1016/j.livsci.2007.04.010.

AMSA (2015). Research Guidelines for Cookery, Sensory Evaluation, and Instrumental Tenderness Measurements of Meat (Wheeler, T. L., Papadopoulos, L.S., Miller, R.K., Eds.), American Meat Science Association Educational Foundation. (2nd ed.). Champaign: American Meat Science Association. Retrieved from meatscience.org.

Avilés, C., Martinez A.L., Domenech V., Pena, F. (2015). Effect of feeding system and breed on growth performance, and carcass and meat quality traits in two continental beef breeds. Meat Sci., 107, 94–103. DOI: 10.1016/j.meatsci.2015.04.016.

Bittante, G., Negrini, R., Bergamaschi, M., Ni, Q., Patel, N., Toledo-Alvarado, H., Cecchinato A. (2020). Purebreeding with sexed semen and crossbreeding with semen from double-muscled sires to improve beef production from dairy herds: Live and slaughter performances of crossbred calves. J. Dairy Sci., 103(6), 5246–5257. DOI: 10.3168/jds.2019-17932.

Boudida, Y., Gagaoua, M., Becila, S., Picard, B., Boudjellal, A., Herrera-Mendez, C.H., Sentandreu, M., Ouali, A. (2016). Serine Protease Inhibitors as Good Predictors of Meat Tenderness: Which Are They and What Are Their Functions? Crit. Rev. Food Sci. Nutr., 56(6), 957–972. DOI: 10.1080/10408398.2012.741630.

Bureš, D., Bartoň, L. (2018). Performance, carcass traits and meat quality of Aberdeen Angus, Gascon, Holstein and Fleckvieh finishing bulls. Livest. Sci., 214, 231–237. DOI: 10.1016/j.livsci.2018.06.017.

Cama-Moncunill, R., Moloney, A.P., Röhrle, F.T., Luciano, G., Monahan, F.J. (2021). Canonical discriminant analysis of the fatty acid profile of muscle to authenticate beef from grass-fed and other beef production systems: Model development and validation. Food Contr., 122, 107820. DOI: 10.1016/j.foodcont.2020.107820.

CIE (2004). CIE 15: Technical Report: Colorimetry. Colorimetry, 3rd Edition, vol. 552, pp. 72.

Coria, M.S., Carranza, P.G., Palma, G.A. (2018). Calpain System in meat tenderization: A molecular approach. Rev. MVZ Córdoba 23(1):6523-6536 Rev. MVZ Córdoba 23(1), 6523–6536. DOI: 10.21897/rmvz.1247.

Cuvelier, C., Clinquart, A., Hocquette, J.F., Cabaraux, J.F., Dufrasne, I., Istasse, L., Hornick, J.L. (2006). Comparison of composition and quality traits of meat from young finishing bulls from Belgian Blue, Limousin and Aberdeen Angus breeds. Meat Sci., 74(3), 522–531. DOI: 10.1016/j.meatsci.2006.04.032.

Devlin, D.J., Gault, N.F.S., Moss, B.W., Tolland, E., Tollerton, J., Farmer, L.J., Gordon, A.W. (2017). Factors affecting eating quality of beef. Adv. Anim. Biosci., 8 (suppl. 1), s2–s5. DOI: 10.1017/S2040470017001583.

Domaradzki, P., Litwińczuk, Z., Florek, M., Żółkiewski, P. (2017). Wpływ okresu dojrzewania na właściwości fizykochemiczne mięśnia longissimus lumborum buhajków pięciu ras [Effect of ageing on the physicochemical properties of musculus longissimus lumborum of young bulls of five breeds]. Med. Weter., 73(12), 802–810 [in Polish]. DOI: 10.21521/mw.5816.

Duru, S., Sak, H. (2017). Türkiye'de Besiye Alınan Simmental, Aberdeen Angus, Hereford, Limousin ve Charolais Irkı Sığırların Besi Performansı ve Karkas Özellikleri [Fattening Performance and Carcass Characteristics of Simmental, Aberdeen Angus, Hereford, Limousin and Charolais Cattle Breeds in Turkey]. Turk. J. Agric.-Food Sci. Techn., 5(11), 1383–1388 [in Turkish]. DOI: 10.24925/turjaf.v5i11.1383-1388.1485.

European Commission (2005). Council Regulation (EC) No 1/2005 of 22 December 2004 on the Protection of Animals during Transport and Related Operations and Amending Directives 64/432/EEC and 93/119/EC and Regulation (EC) No 1255/97. Official Journal of the European Union. Available online: eur-lex.europa.eu [accessed on 15 May 2023].

European Commission (2009). Council Regulation (EC) No 1099/2009 of 24 September 2009 on the protection of animals at the time of killing. Official Journal of the European Union. Available online: eur-lex.europa.eu [accessed on 15 May 2023].

Florek, M., Litwińczuk, A., Skałecki, P., Ryszkowska-Siwko, M. (2007). Changes of physicochemical properties of bullocks and heifers meat during 14 days of ageing under vacuum. Pol. J. Food Nutr. Sci., 57(3), 281–288.

Franco, D., Bispo, E., González, L., Vázquez, J.A., Moreno, T. (2009). Effect of finishing and aging time on quality attributes of loin from the meat of Holstein-Fresian cull cows. Meat Sci., 83(3), 484–491. DOI: 10.1016/j.meatsci.2009.06.030.

Fruet, A.P.B., De Mello, A., Trombetta, F., Stefanello, F.S., Speroni, C.S., De Vargas, D.P., De Souza, A.N.M., Rosado Júnior, A.G., Tonetto, C.J., Nörnberg J.L. (2018). Oxidative stability of beef from steers finished exclusively with concentrate, supplemented, or on legume-grass pasture. Meat Sci., 145, 121–126. DOI: 10.1016/j.meatsci.2018.06.015.

Gagaoua, M., Couvreur, S., Le Bec, G., Aminot, G., Picard, B. (2017). Associations among Protein Biomarkers and pH and Color Traits in Longissimus thoracis and Rectus abdominis Muscles in Protected Designation of Origin Maine-Anjou Cull Cows. J. Agric. Food Chem., 65(17), 3569–3580. DOI: 10.1021/acs.jafc.7b00434.

Gagaoua, M., Picard, B., Monteils, V. (2018). Associations among animal, carcass, muscle characteristics, and fresh meat color traits in Charolais cattle. Meat Sci., 140, 145–156. DOI: 10.1016/j.meatsci.2018.03.004.

Goñi, M.V., Beriain, M.J., Indurain, G., Insausti, K. (2007). Predicting Longissimus dorsi texture characteristics in beef from bulls of the Pirenaica breed based on objective muscle colour measurements. Meat Sci., 76, 38–45. DOI: 10.1016/j.meatsci.2006.10.012.

Gotoh, T., Joo, S.T. (2016). Characteristics and health benefit of highly marbled wagyu and hanwoo beef. Korean J. Food Sci. Anim. Resour., 36(6), 709–718. DOI: 10.5851/kosfa.2016.36.6.709.

Grau, R., Hamm, R. (1953). Eine einfache Methode zur Bestimmung der Wasserbindung im Muskel. Die Naturwissenschaften, 40, 29–30. DOI: 10.1007/BF00595734.

Henchion, M.M., McCarthy, M., Resconi, V.C. (2017). Beef quality attributes: a systematic review of consumer perspectives. Meat Sci., 128, 1–7. DOI: 10.1016/j.meatsci.2017.01.006.

Honikel, K.O. (1998). Reference Methods for the Assessment of Physical Characteristics of Meat. Meat Sci., 49(4), 447–457. DOI: 10.1016/S0309-1740(98)00034-5.

Hopkins, D.L., Littlefield, P.J., Thompson, J.M. (2000). A research note on factors affecting the determination of myofibrillar fragmentation. Meat Sci., 56(1), 19–22. DOI: 10.1016/S0309-1740(00)00012-7.

IZ-PIB INRA (2009). Normy Żywienia Bydła, Owiec i Kóz – wartość pokarmowa pasz dla przeżuwaczy [Standards for the Nutrition of Cattle, Sheep and Goats – Nutritional value of feedingstuffs for ruminants]. Opracowanie według INRA, IZ-PIB, Kraków. Retrieved from books.google.pl [in Polish].

Jukna, V., Jukna, Č., Prusevičius, V., Meškinytė-Kaušilienė, E., Pečiulaitienė, N. (2017). Meat quality of different beef cattle breeds fed high energy forage. Zemdirbyste-Agriculture, 104(3), 277–282. DOI: 10.13080/z-a.2017.104.035.

Kemp, C.M., Sensky, P.L., Bardsley, R.G., Buttery, P.J., Parr, T. (2010). Tenderness – An enzymatic view. Meat. Sci., 84(2), 248–256. DOI: 10.1016/j.meatsci.2009.06.008.

Kerth, C.R., Miller, R.K. (2015). Beef flavor: A review from chemistry to consumer. J. Sci. Food Agric., 95(14), 2783–2798. DOI: 10.1002/jsfa.7204.

Kim, B.Y.H., Liesse, C., Kemp, R., Balan, P. (2015). Evaluation of combined effects of ageing period and freezing rate on quality attributes of loins. Meat Sci., 110, 40–45. DOI: 10.1016/j.meatsci.2015.06.015.

Klont, R.E., Barnier, V.M.H., Smulders, F.J.M., Van Dijk, A., Hovink-Bolink, A.H., Eikelenboom, G. (1999). Post-mortem variation in pH, temperature, and colour profiles of veal carcasses in relation to breed, blood hemoglobin content, and carcass characteristics. Meat Sci., 53(3), 195–202. DOI: 10.1016/S0309-1740(99)00048-0.

Łozicki, A., Dymnicka, M., Arkuszewska, E., Pustkowiak, H. (2012). Effect of pasture or maize silage feeding on the nutritional value of beef. Ann. Anim. Sci., 12(1), 81–93. DOI: 10.2478/v10220-012-0007-5.

Mach, N., Bach, A., Velarde, A., Devant, M. (2008). Association between animal, transportation, slaughterhouse practices, and meat pH in beef. Meat Sci., 78(3), 232–238. DOI: 10.1016/j.meatsci.2007.06.021.

McKenna, D.R., Mies, P.D., Baird, B.E., Pfeiffer, K.D., Ellebracht, J.W., Savell, J.W. (2005). Biochemical and physical factors affecting discoloration characteristics of 19 bovine muscles. Meat Sci., 70(4), 665–682. DOI: 10.1016/j.meatsci.2005.02.016.

Młynek, K. (2011). Wpływ intensywności wzrostu buhajów na zależności występujące pomiędzy otłuszczeniem tusz i jakością kulinarną mięsa [Effect of growth intensity of bulls on relationships between carcass fatness and culinary quality of meat]. Żywn. Nauka. Technol. Jakość, 3(76), 130–142 [in Polish].

Modzelewska-Kapituła, M., Kwiatkowska, A., Jankowska, B., Dąbrowska, E. (2015). Water holding capacity and collagen profile of bovine *m. infraspinatus* during *post-mortem* ageing. Meat Sci., 100, 209–216. DOI: 10.1016/j.meatsci.2014.10.023.

Modzelewska-Kapituła, M., Tkacz, K., Nogalski, Z., Karpińska-Tymoszczyk, M., Więk, A. (2019). Influence of ageing on *longissimus lumborum* quality from Holstein-Fresian young bulls fed different diets. J. Food Sci. Technol., 56(7), 3215–3224. DOI: 10.1007/s13197-019-03778-7.

Momot, M., Nogalski, Z., Pogorzelska-Przybyłek, P., Sobczuk-Szul, M. (2020). Influence of genotype and slaughter age on the content of selected minerals and fatty acids in the *longissimus thoracis* muscle of crossbred bulls. Animals, 10(11). DOI: 10.3390/ani10112004.

Muchenje, V., Dzama, K., Chimonyo, M., Strydom, P.E., Hugo, A., Raats, J.G. (2009). Some biochemical aspects pertaining to beef eating quality and consumer health: A review. Food Chem., 112(2), 279–289. DOI: 10.1016/j.foodchem.2008.05.103.

Niedźwiedź, J., Żmijewski, T., Ostoja, H., Cierach, M. (2011). Porównanie wartości maksymalnej siły cięcia wybranych mięśni z tylnej ćwierćtuszy wołowej [Comparison of maximum cutting force values of selected muscles from beef hindquarters]. Inż. Ap. Chem. 50(3), 57–58 [in Polish].

Nogalski, Z., Pogorzelska-Przybyłek, P., Wielgosz-Groth, Z., Sobczuk-Szul, M., Purwin, C., Winarski, R., Niedźwiedź, J. (2013). Wartość rzeźna wolców mieszańców mięsnych w zależności od intensywności opasu i wieku zwierząt w momencie uboju [Slaughter value of crossbred beef steers as depending on fattening intensity and slaughter age of animals]. Żywn. Nauka. Technol. Jakość, 3(88), 51–60 [in Polish]. DOI: 10.15193/zntj/2013/88/51-60.

Nogalski, Z., Wielgosz-Groth, Z., Purwin, C., Nogalska, A., Sobczuk-Szul, M., Winarski, R., Pogorzelska, P. (2014). The Effect of Slaughter Weight and Fattening Intensity on Changes in Carcass Fatness in Young Holstein-Friesian Bulls. Ital. J. Anim. Sci., 13, 66–72. DOI: 10.4081/ijas.2014.2824.

Nogoy, K.M.C., Sun, B., Shin, S., Lee, Y., Li, X.Z., Choi, S.H., Park, S. (2022). Fatty Acid Composition of Grain- And Grass-Fed Beef and Their Nutritional Value and Health Implication. Food Sci. Anim. Resour., 42(1), 18–33. DOI: 10.5851/kosfa.2021.e73.

O'Quinn, T.G., Legako, J.F., Brooks, J.C., Miller, M.F. (2018). Evaluation of the contribution of tenderness, juiciness,

and flavor to the overall consumer beef eating experience. Transl. Anim. Sci., 2(1), 26–36. DOI: 10.1093/tas/txx008.

Palka, K. (1999). Changes in intramuscular connective tissue and collagen solubility of bovine *m. semitendinosus* during retorting. Meat Sci., 53(3), 189–194. DOI: 10.1016/S0309-1740(99)00047-9.

Palka, K. (2003). The influence of post-mortem ageing and roasting on the microstructure, texture and collagen solubility of bovine semitendinosus muscle. Meat Sci., 64(2), 191–198. DOI: 10.1016/S0309-1740(02)00179-1.

Papaleo Mazzucco, J., Goszczynski, D.E., Ripoli, M.V., Melucci, L.M., Pardo, A.M., Colatto, E., Rogberg-Muñoz, A., Mezzadra, C.A., Depetris, G.J., Giovambattista, G., Villarreal, E.L. (2016). Growth, carcass and meat quality traits in beef from Angus, Hereford and cross-breed grazing steers, and their association with SNPs in genes related to fat deposition metabolism. Meat Sci., 114, 121–129. DOI: 10.1016/j.meatsci.2015.12.018.

Polish Committee for Standardization (2000a). PN-ISO 1442:2000, Meat and meat products. Water contents determination. Warsaw.

Polish Committee for Standardization (2000b). PN-ISO 1444:2000, Meat and meat products. Free fat contents determination. Warsaw.

Polish Committee for Standardization (2000c). PN-ISO 3496-2000, Meat and meat products. Determination of hydroxyproline content. Warsaw.

Polish Committee for Standardization (2002). PN-75/A-04018:1975/Az3:2002, Agricultural food products. Nitrogen contents determination with Kjeldahl's method and recalculation into protein. Warsaw.

Prado, I.N., Ito, R.H., Prado, J.M., Prado, I.M., Rotta, P.P., Matsushita, M., Visentainer J.V., Silva, R.R. (2008a). The influence of dietary soyabean and linseed on the chemical composition and fatty acid profile of the Longissimus muscle of feedlot-finished bulls. J. Anim. Feed Sci., 17(3), 307–317. DOI: 10.22358/jafs/66610/2008.

Prado, I.N., Prado, R.M., Rotta, P.P., Visentainer, J.V., Moletta J.L., Perotto, D. (2008b). Carcass characteristics and chemical composition of the Longissimus muscle of crossbred bulls (Bos taurus indicus vs Bos taurus taurus) finished in feedlot. J. Anim. Feed Sci., 17(3), 295–306. DOI: 10.22358/jafs/66609/2008.

Rajagopal, K., Oommen, G.T. (2015). Myofibril Fragmentation Index as an Immediate *postmortem* Predictor of Buffalo Meat Tenderness. J. Food Proc. Preserv., 39(6), 1166–1171. DOI: 10.1111/jfpp.12331.

Resconi, V.C., Bueno, M., Escudero, A., Magalhaes, D., Ferreira, V., Campo, M.M. (2018). Ageing and retail display time in raw beef odour according to the degree of lipid oxidation. Food Chem., 242, 288–300. DOI: 10.1016/j.foodchem.2017.09.036.

Ripoll, G., Albertí, P., Casasús, I., Blanco, M. (2013). Instrumental meat quality of veal calves reared under three management systems and color evolution of meat stored in three packaging systems. Meat Sci., 93(2), 336–343. DOI: 10.1016/j.meatsci.2012.09.012.

Salim, A.P.A.A., Ferrari, R.G., Monteiro, M.L.G., Mano, S.B. (2022). Effect of different feeding systems on color of longissimus muscle from Bos cattle: A systematic review and meta-analysis. Meat Sci., 192, 1 08871. DOI: 10.1016/j.meatsci.2022.108871.

Şenyüz, H.H, Erat, S., Karslı, M.K., Soydemir, I. (2020). Comparison of fattening performance of Angus, Charolais, Limousine and Simmental cattle imported to Turkey. Livest. Stud., 60(1), 1–4. DOI: 10.46897/lahaed.779712.

Shiba, N., Matsuzaki, M., Tsuneishi, E. (2004). Effects of pre-slaughter nutritional condition on intramuscular collagen solubility, pyridinoline cross-links and meat tenderness in aged goats. Anim. Sci. J., 75(4), 319–324. DOI: 10.1111/j.1344-3941.2004.00192.x.

Siphambili, S., Monahan, F.J., O'Riordan, E.G., McGee, M., Moloney, A.P. (2020). Grass finishing and the residual effect of pasture prior to concentrate finishing on the shelf stability of late-maturing bull beef. Anim. Prod. Sci., 60(14), 1745–1758. DOI: 10.1071/AN19438.

TIBCO Software Inc. (2016). Statistica. Palo Alto, CA, USA.

Ünlü, H.B., İpçak, H.H. (2021). Fattening performance, carcass traits, and profitability of Aberdeen Angus and Holstein Friesian bulls in Turkey. S. Afr. J. Anim. Sci., 51(5), 613–621. DOI: 10.4314/sajas.v51i5.7.

Vestergaard, M., Jørgensen, K.F., Çakmakçı, C., Kargo, M., Therkildsen, M., Munk, A., Kristensen, T. (2019). Performance and carcass quality of crossbred beef × Holstein bull and heifer calves in comparison with purebred Holstein bull calves slaughtered at 17 months of age in an organic production system. Livest. Sci., 223, 184–192. DOI: 10.1016/j.livsci.2019.03.018.

Wajda, S., Burczyk, E., Winarski, R., Daszkiewicz, T. (2011). Wskaźniki wydajności rzeźnej buhajków i jego związek z wartością handlową tusz [Indicator of young bulls slaughter yield and its reference to the commercial value of carcasses]. Żywn. Nauka. Technol. Jakość, 4(77), 94–102 [in Polish].

White, A., O'Sullivan, A., Troy, D.J., O'Neill, E.E. (2006). Effects of electrical stimulation, chilling temperature of hot-boning on the tenderness of bovine muscles. Meat Sci., 73(2), 196–203. DOI: 10.1016/j.meatsci.2005.11.020.

Witte, V.C., Krause, G.F., Bailey, M.E. (1970). A new extraction method for determining 2-thiobarbituric acid values of pork and beef during storage. J. Food Sci., 35, 582–585. DOI: 10.1111/j.1365-2621.1970.tb04815.x.

Xu, L., Liu, S., Cheng, Y., Qian, H. (2023). The effect of aging on beef taste, aroma and texture, and the role of microorganisms: a review. Crit. Rev. Food Sci. Nutr., 63(14), 2129–2140. DOI: 10.1080/10408398.2021.1971156.

Zając, M., Midura, A., Pałka, K., Węgierska, E., Krzysztoporski, K., 2011. Skład chemiczny, rozpuszczalność kolagenu śródmięśniowego i tekstura wybranych mięśni wołowych [Chemical composition, solubility of intramuscular collagen, and texture of selected beef muscles]. Żywn. Nauka. Technol. Jakość, 4(77), 103-116 [in Polish].

Stanek, P., Domaradzki, P., Żółkiewski, P., Florek, M., Januś, E., Kowalczyk, M. (2023). Effect of the genotype and ageing time on physicochemical parameters of skeletal muscles in young bulls fattened in a semi intensive system. Acta Sci. Pol. Zootechnica, 22(2), 3–16. DOI: 10.21005/asp.2023.22.2.01

WPŁYW GENOTYPU I CZASU DOJRZEWANIA NA CECHY FIZYKOCHEMICZNE MIĘŚNI SZKIELETOWYCH BUHAJKÓW OPASANYCH W SYSTEMIE PÓŁINTENSYWNYM

STRESZCZENIE

Celem pracy było określenie wpływu genotypu i czasu dojrzewania na pH, wodochłonność, siłę i energię cięcia oraz indeks miofibrylarny dwóch mięśni longissimus lumborum i semitendinosus buhajków opasanych półintensywnie. Oceniono także wskaźniki wartości rzeźnej oraz skład chemiczny wymienionych mięśni w zależności od grupy genetycznej. Badaniami objęto 46 buhajków należących do czterech grup genetycznych, tj. rasy hereford (HER 8 szt.), rasy limousine (LIM 8 szt.), mieszańców towarowych (MT 14 szt.) oraz rasy polskiej holsztyńsko-fryzyjskiej odmiany czarno-białej (PHF 16 szt.). Przeprowadzone badania wykazały, że półintensywny system opasu gwarantuje uzyskanie tusz o zadowalającej wydajności rzeźnej i dobrych parametrach jakościowych (dobre umięśnienie i średnie otłuszczenie). Mięso o najlepszych parametrach jakościowych pochodziło od buhajków rasy LIM i mieszańców MT, a najsłabsze rezultaty uzyskano u buhajków rasy PHF. Czas dojrzewania korzystnie wpływał na parametry jakościowe mięsa (zwłaszcza na kruchość i barwę), przyczyniając się do istotnego zmniejszenia różnic między genotypami buhajków obserwowanych w początkowym okresie *postmortem*. Wyniki dotyczące siły cięcia i indeksu miofibrylarnego, czyli parametrów decydujących o kruchości mięsa sugerują, że 14-dniowy okres dojrzewania wydaje się być niezbędnym minimum. W przypadku mięśnia LL buhajków rasy HER i PHF czy mięśnia ST buhajków rasy HER, MT i PHF okres ten powinien zostać nawet wydłużony. Wskazane byłoby zatem prowadzenie dalszych badań, poszerzonych o ocenę konsumencką, które pozwolą ustalić optymalny czas dojrzewania mięsa wołowego pozyskiwanego w warunkach krajowych.

Słowa kluczowe: opas półintensywny, przydatność opasowa, wartość rzeźna, jakość wołowiny, dojrzewanie mięsa

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