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Changes in the physicochemical properties of skeletal muscles from four slaughter cattle categories during 12 days of ageing under vacuum*

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The aim of the study was to determine the effect of the ageing period (12-day vacuum storage) and category of cattle (milk-fed calves n=20, heavy calves n=20, young slaughter cattle n=71 and cows n=10) on the physicochemical properties of two skeletal muscles. The pH, electrical conductivity (EC), TBARS index, colour according to CIE L*a*b* and water-holding capacity of the longissimus lumborum (ML) and semitendinosus (ST) muscles were determined. The category of cattle had a significant (p≤0.01) effect on all the evaluated physicochemical properties of the ML and ST muscles (except EC in ST). Of the cattle categories studied, the highest lightness (the highest value of L*) and the lowest proportion of redness (a*) and yellowness (b* in the ST muscle) was found in the meat of the milk-fed calves. The highest drip loss was found in the ST and ML muscles of the heavy calves, and the lowest in those of the milk-fed calves. The highest cooking loss was also found in the ML muscle of the heavy calves. The lowest oxidative stability of intramuscular fat (higher TBARS value) was determined in the meat of the young slaughter cattle and cows. In the muscles of all evaluated categories of cattle, post mortem changes were observed to progress normally during the 12-day period of ageing under vacuum. The meat became lighter in colour (higher value for L*), redder (higher a*) and yellower (higher b*) over the duration of the ageing period. During the 12-day cold storage an increase in drip loss and cooking loss as well as a decrease in free water (measured by the Grau-Hamm method) were noted.

KEY WORDS: beef / ageing / physicochemical properties / meat quality

The term 'beef' in production and trade customarily refers to meat derived from young slaughter cattle in various age ranges and of either sex or from adult cattle after culling, whereas 'veal' most often comes from juvenile (immature) animals aged from a few weeks to up to about 20 weeks [22, 31]. In Poland, calves are most often slaughtered at a weight

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***Abridged doctoral thesis**

of about 80 kg, which they reach at the age of 50-60 days. However, in accordance with regulations [29], the term 'veal' may refer to meat from the slaughter of animals up to the age of 8 months. If slaughter takes places between 8 and 12 months of age, the meat is called 'young beef', while meat from animals over 12 months of age should be called 'beef'. In some countries, with a large population of cattle of meat breeds, calves are slaughtered after being reared with their mothers in pasture up to the age of 7-8 months. Depending on the breed, they gain a body weight of 200-300 kg. According to researchers [8, 12, 21], although this category of cattle is not yet well known in Poland, it should be of interest to the meat industry.

Immediately after slaughter, the meat of the slaughtered animals is not a food product of full value, due to a number of features which clearly reduce its value. This meat is hard, rubbery, and not juicy; it is difficult to cook properly, it is not easily digestible and its nutrients are not sufficiently assimilated [18]. An important element to remember in acquiring culinary beef is ageing of the meat for a sufficiently long period. This process takes place when the meat is stored after rigor mortis at a low temperature but above the freezing point [25]. Among all available methods, ageing seems to be one of the least complicated procedures for improving the suitability of meat for consumption and processing.

The most commonly evaluated quality parameters of meat are pH, drip loss and cooking loss, water-holding capacity, colour (lightness and red and yellow colour), shear force (WB-SF), length of sarcomeres, and proximate chemical composition [4]. Among physicochemical properties, acidity, determined by pH measurement, has a decisive role. This parameter is easy to determine and is a good indicator of the technological and culinary suitability of the meat [2, 34]. The colour of beef during purchase is the most important criterion in visual assessment. Valued by consumers ahead of tenderness and palatability, it is a visible indicator of the quality and freshness of the meat [3].

The aim of the study was to determine the effect of ageing time (during 12-day vacuum storage) and cattle category on the pH, conductivity, colour, water-holding capacity and oxidative stability of two skeletal muscles: the *longissimus lumborum* and the *m. semitendinosus*.

Material and methods

The study was conducted on samples of two skeletal muscles, the *longissimus lumborum* (ML) and the *semitendinosus* (ST), taken from 121 carcasses of cattle of various breeds from the mass population. The following categories of cattle were distinguished:

– milk-fed calves (8-12 weeks of age, average pre-slaughter weight 92.3 ±10.6 kg, fed milk or milk replacers) – 20 animals

– heavy calves (7-8 months of age, average pre-slaughter weight 285.6 ±41.2 kg, reared with their mothers on pasture) – 20 animals

– young slaughter cattle (18-24 months of age, average pre-slaughter weight 537.6 ±56.2 kg, fattened in semi-intensive system) – 71 animals

– cows (over 5 years, average pre-slaughter weight 503.6 ±21.4 kg) – 10 animals

Slaughter and post-slaughter handling of cattle were conducted in accordance with meat industry regulations and under veterinary inspection. After 24-hour cooling of the right half-carcasses, they were dissected and samples of the ML and ST (approximately 500 g each) were collected. The samples were weighed, vacuum-packed and refrigerated (4°C ± 1°C) for 2, 7 and 12 days until analysis.

The pH and electrical conductivity (EC – mS/cm) were measured directly in the muscle tissue, with a PQM I-KOMBI from INTEK GmbH at 45 min, 24 h, 48 h, 7 days and 12 days after slaughter. The colour of the freshly exposed meat surface after 30 min exposure to oxygen at 4°C (blooming) was assessed using a Minolta CR-310 colour saturation meter. Measurements were made on the first, second, seventh and twelfth days. Results are given in the CIE colour space (CIE, 1976), where: L * – lightness; a * – red; b * – yellow. The result for the sample was calculated as the arithmetic mean of three measurements. Water-holding capacity (based on 3 indicators) and lipid oxidation stability were assessed after 48 h, 7 days and 12 days. Drip loss (in %) was determined with respect to the initial weight of the sample (before packaging). Cooking loss (in %) was determined on the basis of the difference in sample weight before and after 60 minutes of heat treatment in a water bath at 70°C. The percentage of free water (%) was determined by the filter paper method [9], on the basis of measurements (in cm^2) of image scans – area of the meat sample and total area of wetted paper – using MultiScan Base ver. 14 image analysis software. Lipid oxidation stability, based on the TBARS index, was determined according to the method described by Witte et al. [36], using a Varian Cary BIO spectrophotometer (wavelength 530 nm). The results were expressed in mg of malondialdehyde (MDA) per kg of meat.

The results were analysed statistically using StatSoft, Inc. (2003) STATISTICA version 6, based on a two-way analysis of variance with interaction, evaluating the effect of the cattle category and ageing time. Means and standard deviations were calculated for each characteristic.

Results and discussion

The results of pH measurements presented in Table 1 and 2 indicate proper post-mortem transformations in the muscles of the four categories of cattle during 12-day ageing. This demonstrates proper acidification of the muscle tissue in the first hours post mortem, as well as appropriate refrigeration conditions and the protective role of vacuum packing. It is commonly believed that the pH of beef intended for the production of culinary meat evaluated 48 hours after slaughter (called final pH) should not exceed 5.8 [11, 33]. In the present study, the mean final pH (48 h) was similar in the two muscles analysed: 5.57 for ML and 5.56 for ST. Grześkowiak et al. [13], in their analysis of the quality of the basic cuts of young cattle, with the exception of the shoulder muscles, found no significant differences between them. The final pH (48 h) of the cuts was higher (5.71-5.98) than in the present study.

The category, ageing time and interaction of category x ageing time were found to significantly ($p \leq 0.01$ and $p \leq 0.05$) affect the pH of the two cattle muscles (Tables 1 and 2). The pH values coincide with the results of other authors [11, 16, 30]. A study by Jelníkova et al. [17] showed that pre-slaughter treatment affects the pH of the ML muscle of young bulls and cows. Very different results were obtained for the pH_{48} of the meat of animals kept in groups. The value of this measurement was 6.03 for bulls and 5.81 for cows. According to the authors, these differences were the result of the bulls' greater susceptibility to stress, resulting in a decrease in glycogen levels in the muscle tissue prior to slaughter and the absence of post-mortem acidity. Toohey et al. [30] showed a significant effect of the ageing period on the pH of the *semimembranosus* muscle (SM) of cows. The initial pH (2 hours after slaughter) of 6.13 decreased to 5.57 (after 48 hours), to finally stabilize at 5.62 (after 14 days post mortem).

Electrical conductivity (EC) generally increased during storage of meat samples (Table 1 and 2). Only in the case of the ST muscle on day 12 of cold ageing was a slight decrease in EC observed as compared with 7 days of ageing (Table 2). For the ML muscle, category, ageing time and the interaction of category x ageing time (Tab. 1) significant ($p \leq 0.01$) were shown to have a significant effect. In the case of the ST muscle, only the effect of ageing time and interaction of category x ageing time were significant ($p \leq 0.01$). Grodzicki [10], evaluating the quality of the meat of four categories of cattle (calves, young bulls, heifers and cows), also showed that the category significantly influenced the EC and pH of the muscles at 45 min, 24 h and 48 h after slaughter. A successive increase in conductivity was observed, with the highest values noted in the final measurement period, i.e. after 48 h. In addition, as in the present study, the highest pH values for both muscles (ML and ST) were obtained in calves. Electrical conductivity (EC) is an important indicator of cell membrane integrity in muscle tissue [14]. When structural membranes are impaired, electrical conductivity increases, which is linked to the increase in water content within the muscle and the movement of fluid in intracellular and intercellular spaces.

The lowest oxidative stability of muscle fat, expressed as a significantly higher TBARS value, was noted in the ML of young slaughter cattle and cows (0.37 mg MDA/kg, mean value from three measurements) – Table 1. In the ST muscle, the highest TBARS values were also noted for these two categories: 0.34 and 0.36 mg MDA/kg, respectively (Table 2). Insausti et al. [15] report that meat with a higher content of pigments is more oxidative and its colour is less stable. According to O'Grady et al. [26], lower pH of meat accelerates oxidation of oxymyoglobin. Similar trends were observed in the present study, as the meat of young slaughter cattle and cows had the lowest average pH (especially that of cows) – Tables 1 and 2, as well as the most red colour (a *) – Tables 3 and 4. According to McKenna [23], lipid oxidation in beef is closely linked to oxidation of muscle pigments.

The mechanism responsible for this system, however, is not fully understood. Direct oxidation of the pigments or impairment of the redox system is probably linked to the effect of free radicals produced during lipid oxidation.

The present study showed that the ageing time did not significantly affect the TBARS value (despite a slight increase on successive days of ageing), which shows that the cold ageing conditions were suitable and that vacuum packaging plays a protective role. This opinion is consistent with previous reports by Vieira et al. [32] and by Domaradzki et al. [5].

The cattle category and the ageing time were found to have a significant ($p \leq 0.01$) effect on all evaluated colour indices (L^*, a^* and b^*) in the muscles analysed. In addition, a significant ($p \leq 0.01$) interaction of these factors (category x time) was noted for red (a^*) in the ML and L^* and a^* in the ST. The colour of beef, which is an important indicator of its quality, is of particular interest not only to food producers but especially to consumers. It is a fundamental characteristic determining the choice of meat at the time of purchase.

In the present study, an increasing tendency was observed in the L^*, a^* and b^* parameters during cold ageing of meat (Tab. 3 and 4). Similarly, Oliete et al. [27] showed that increasing the duration of vacuum storage (1, 7 and 14 days) of the *longissimus thoracis* muscle of calves at the age of 7-12 months, slaughtered at a body weight of 330-350 kg, caused an increase in a^* and b^* values, i.e. the meat became redder and yellower, while the hue was more pink (higher h^o) and the colour saturation was more intense (higher C^*). Another study by Oliete et al. [28], evaluating the *longissimus thoracis* muscle of cattle at the age of 12-17 months, also showed that ageing time significantly increased all colour coordinates tested, L^*, a^* and b^*, as well as h^o and C^*. On the last (21st) day of evaluation (as compared to day 1), the authors noted an increase in L^* from 37.0 to 37.8; in a^* from 15.9 to 17.2; and in b^* from 9.0 to 11.3. Insausti et al. [15], assessing colour stability in relation to the packaging system of meat of various Spanish cattle breeds, observed a marked increase in L^*, a^*, b^*, C^* and h^o within the first 5 days in vacuum-packed meat, which remained at the same level up to the 15th day. Furthermore, they reported that the colour of meat packed in the MAP system was only acceptable until the 10th day of refrigeration. The meat was not acceptable after this time due to a high concentration of metmyoglobin and browning of the meat.

According to Oliete et al. [28], an increase in the L^* parameter during cold ageing of meat is a consequence of the breakdown of Z-line proteins, which causes light to reflect better, giving the impression of lighter meat colour. An increase in the a^* parameter as meat ageing time increases is linked to a decrease in the respiratory activity of the mitochondrial system. This phenomenon results in an increase in the amount of oxygen released on the meat surface in the process of red oxymyoglobin formation.

Of the four cattle categories evaluated, the meat of milk-fed calves had the lightest colour. The mean L* (lightness) value from successive measurements was 43.88 for ML (Table 3) and 45.32 for ST (Table 4). The calf meat also had the least red colour a^* (19.23 for ML and 20.28 for ST) and yellow b^* (4.50) for ST (Tables 3 and 4).

Table 1
Values for pH, electrical conductivity (EC) and TBARS of the *longissimus lumborum* (ML) muscle in the assessed cattle categories, including the effect of ageing time

Specification	Category (K)	Ageing time (C)					Average	Influence		
		45 min	24 h	48 h	7 days	12 days		K	C	KxC interaction
pH	milk-fed calves	6.98 ±0.13	5.85 ±0.29	5.47 ±0.14	5.48 ±0.11	5.50 ±0.11	5.81 ±0.57	**	**	**
	heavy calves	6.79 ±0.17	5.78 ±0.16	5.63 ±0.08	5.65 ±0.06	5.61 ±0.09	5.76 ±0.34			
	young slaughter cattle	6.45 ±0.26	5.66 ±0.12	5.57 ±0.13	5.58 ±0.11	5.60 ±0.09	5.74 ±0.36			
	cows	–	–	5.58 ±0.25	5.50 ±0.31	5.53 ±0.31	5.54 ±0.28			
	average	6.56 ±0.31	5.72 ±0.18	5.57 ±0.14	5.58 ±0.13	5.59 ±0.12				
EC (mS/cm)	milk-fed calves	5.00 ±0.59	2.90 ±1.13	10.57 ±3.33	11.45 ±2.82	15.38 ±1.79	9.22 ±5.06	**	**	**
	heavy calves	3.51 ±0.27	4.20 ±1.68	6.47±2.38	12.85 ±3.01	13.89 ±2.13	8.81 ±4.81			
	young slaughter cattle	3.72 ±0.98	4.19 ±2.23	7.54 ±2.92	10.10 ±2.99	13.95 ±3.31	8.19 ±4.58			
	cows	–	–	4.50 ±2.64	11.29 ±2.49	12.49 ±1.61	9.42 ±4.21			
	average	3.87 ±0.98	4.03 ±2.02	7.43 ±3.12	10.86 ±3.12	13.99 ±2.89				
TBARS (mg MDA/kg)	milk-fed calves	–	–	0.26 ±0.02	0.29 ±0.06	0.31 ±0.03	0.29 ±0.04	**	ns	ns
	heavy calves	–	–	0.28 ±0.06	0.30 ±0.07	0.33 ±0.07	0.31 ±0.07			
	young slaughter cattle	–	–	0.36 ±0.12	0.38 ±0.14	0.38 ±0.12	0.37 ±0.13			
	cows	–	–	0.38 ±0.08	0.34 ±0.06	0.38 ±0.16	0.37 ±0.10			
	average	–	–	0.34 ±0.11	0.36 ±0.12	0.36 ±0.12				

*p≤0.05; **p≤0.01; ns – not found

Table 2
Values for pH, electrical conductivity (EC) and TBARS of the *semitendinosus* (ST) muscle in the assessed cattle categories, including the effect of ageing time

Specification	Category (K)	Ageing time (C)					Average	Influence		
		45 min	24 h	48 h	7 days	12 days		K	C	KxC interaction
pH	milk-fed calves	6.96 ±0.14	5.60 ±0.22	5.43 ±0.16	5.45 ±0.16	5.57 ±0.19	5.77 ±0.58	*	*	**
	heavy calves	6.66 ±0.19	5.58 ±0.16	5.61 ±0.12	5.64 ±0.11	5.61 ±0.16	5.70 ±0.33			
	young slaughter cattle	6.55 ±0.28	5.56 ±0.10	5.57 ±0.09	5.57 ±0.11	5.61±0.07	5.75 ±0.40			
	cows	–	–	5.50 ±0.12	5.51 ±0.17	5.48 ±0.10	5.50 ±0.12			
	average	6.62 ±0.29	5.57 ± 0.14	5.56 ±0.12	5.57 ±0.13	5.60 ±0.12				
EC (mS/cm)	milk-fed calves	4.51 ±0.53	3.64 ±2.04	14.20 ±3.27	18.71 ±2.98	17.93 ±1.97	12.03 ±6.96	ns	**	**
	heavy calves	3.39 ±0.51	10.50 ±5.45	11.79 ±4.13	16.03 ±2.83	15.48 ±2.53	12.61 ±5.15			
	young slaughter cattle	4.76 ±1.32	11.23 ±3.15	12.87 ±3.94	14.49 ±2.93	16.70 ±4.45	12.36 ±5.17			
	cows	–	–	9.83 ±5.73	17.43 ±3.66	16.91 ±1.92	14.59 ±5.29			
	average	4.56 ±1.24	10.00 ±4.55	12.53 ±4.13	15.39 ±3.23	16.58 ±3.77	.			
TBARS (mg MDA/kg)	milk-fed calves	–	–	0.26 ±0.01	0.28 ±0.03	0.28 ±0.04	0.27 ±0.06	**	ns	ns
	heavy calves	–	–	0.26 ±0.06	0.28 ±0.07	0.27 ±0.05	0.27 ±0.03			
	young slaughter cattle	–	–	0.31 ±0.08	0.34 ±0.10	0.38 ±0.12	0.34 ±0.10			
	cows	–	–	0.34 ±0.03	0.36 ±0.12	0.39 ±0.24	0.36 ±0.15			
	average	–	–	0.30 ±0.07	0.32 ±0.09	0.36 ±0.13				

*p≤0.05; **p≤0.01; ns – not found

Table 3
Colour parameters (CIE *L*a*b**) of the *longissimus lumborum* (ML) muscle in the assessed cattle categories, including the effect of ageing time

Specification	Category (K)	Ageing time (C)				Average	Influence		
		24 h	48 h	7 days	12 days		K	C	KxC interaction
L*	milk-fed calves	40.79 ±4.93	44.63 ±3.66	44.00 ±3.83	46.10 ±3.75	43.88 ±4.40	**	**	ns
	heavy calves	36.11 ±2.79	36.92 ±1.55	37.97 ±1.67	38.94 ±1.84	37.47 ±2.26			
	young slaughter cattle	34.26 ±1.76	35.97 ±1.65	36.75 ±1.45	37.24 ±2.09	36.23 ±2.01			
	cows	–	32.79 ±1.48	33.44 ±2.02	34.07 ±2.30	33.43 ±1.94			
	average	35.78 ±3.52	36.82 ±3.35	37.51 ±3.03	38.33 ±3.70				
a*	milk-fed calves	18.86 ±1.66	18.90 ±1.41	19.23 ±2.21	19.94 ±2.95	19.23 ±2.11	**	**	**
	heavy calves	20.32 ±1.28	21.38 ±0.81	22.73 ±1.05	23.46 ±1.45	21.95 ±1.67			
	young slaughter cattle	21.68 ±1.12	22.74 ±1.24	24.52 ±1.57	25.14 ±1.26	23.69 ±1.85			
	cows	–	20.47 ±2.29	22.52 ±2.87	24.32 ±3.02	22.43 ±3.06			
	average	20.86 ±1.61	21.94 ±1.76	23.50 ±2.31	24.18 ±2.33				
b*	milk-fed calves	2.61 ±1.13	3.27 ±0.55	3.75 ±0.88	5.13 ±1.05	3.69 ±1.30	**	**	ns
	heavy calves	2.44 ±1.21	2.73 ±0.92	3.95 ±1.26	5.00 ±1.27	3.51 ±1.54			
	young slaughter cattle	2.76 ±0.85	3.60 ±0.91	4.92 ±1.23	5.37 ±1.00	4.30 ±1.41			
	cows	–	2.36 ±0.76	3.78 ±1.55	5.13 ±1.91	3.76 ±1.80			
	average	2.64 ±1.01	3.31 ±0.96	4.54 ±1.32	5.26 ±1.13				

*$p \leq 0.05$; **$p \leq 0.01$; ns – not found

Table 4
Colour parameters (CIE *L*a*b**) of the *semitendinosus* (ST) muscle in the assessed cattle categories, including the effect of aging time

Specification	Category (K)	Ageing time (C)				Average	Influence		
		24 h	48 h	7 days	12 days		K	C	KxC interaction
L*	milk-fed calves	43.82 ±3.32	43.87 ±3.52	45.50 ±3.62	47.96 ±3.22	45.32 ±3.72	**	**	*
	heavy calves	37.77 ±6.70	39.61 ±3.03	41.42 ±2.35	42.24 ±2.65	40.26 ±4.37			
	young slaughter cattle	39.59 ±2.12	39.41 ±2.09	40.45 ±2.35	40.62 ±2.58	40.05 ±2.35			
	cows	–	36.40 ±2.19	35.68 ±3.13	37.25 ±2.25	36.48 ±2.47			
	average	39.68 ±4.53	39.67 ±2.88	40.90 ±3.19	41.52 ±3.62				
a*	milk-fed calves	19.97 ±1.33	20.22 ±0.99	21.12 ±1.21	19.81 ±1.74	20.28 ±1.40	**	**	*
	heavy calves	22.94 ±1.48	22.94 ±0.80	23.81 ±1.81	23.96 ±1.89	23.41 ±1.60			
	young slaughter cattle	24.40 ±1.92	24.57 ±1.16	26.12 ±1.43	26.29 ±1.42	25.43 ±1.68			
	cows	–	24.26 ±1.37	25.59 ±1.80	26.53 ±1.41	25.45 ±1.74			
	average	23.31 ±2.30	23.8 ±11.70	25.11 ±2.21	25.12 ±2.59				
b*	milk-fed calves	3.74 ±0.93	3.58 ±1.26	5.37 ±1.52	5.21 ±1.10	4.50 ±1.44	**	**	ns
	heavy calves	4.57 ±1.51	4.68 ±1.27	6.11 ±1.93	6.68 ±1.69	5.51 ±1.83			
	young slaughter cattle	5.55 ±1.70	5.46 ±1.12	7.09 ±1.24	7.25 ±1.12	6.41 ±1.52			
	cows	–	5.10 ±0.86	6.02 ±1.60	7.28 ±1.40	6.14 ±1.55			
	average	4.99 ±1.68	5.10 ±1.27	6.66 ±1.56	6.91 ±1.41				

*$p \leq 0.05$; **$p \leq 0.01$; ns – not found

A study by Grodzicki [10] showed that the meat of the calves was lightest (L*=46.83 for ML and L*=49.23 for ST). The meat of the calves also had the lowest chromatic a* (16.59 for ML and 15.65 for ST), and the lowest b* for the ST (3.67). Lin-qiang et al. [20], evaluating the colour of the ML muscle (on day 12 of cold ageing) of young bulls slaughtered at the age of 3-15 months, showed a decrease in lightness (L*) and an increase in red colour (a*) as the age of the animals increased. McKenna et al. [23], evaluating the colour of 19 bovine muscles during 5-day storage, showed very minor changes in L*. However, significantly the highest L* value was noted in the *semitendinosus* and *tensor fasciae latae* muscles, and the lowest in the *longissimus lumborum*, *longissimus thoracis* and *triceps brachi*. The authors classified the ML and ST muscles (which in the present study were the basis for evaluating the quality of the meat of four cattle categories) as muscles with high colour stability.

Among the cattle evaluated in the present study, the cows had the darkest muscles. The mean L* in this category was 33.43 for the ML and 36.48 for the ST. Similar tendencies were reported by Węglarz [35], who also showed significantly the lowest value for L* in the ML of cows (36.81). The ML and ST of the young slaughter cattle on individual days of cold ageing had the highest content of yellow colour b* (4.30 and 6.41, respectively; mean values), and in the case of ML, red colour a* as well (on average 23.69).

Water, as one of the basic components of meat, plays an important role in the culinary process. The capacity of muscle tissue to retain water is an important indicator of suitability for processing. Analysis of the results for the ML muscle (Table 5) showed a significant ($p \leq 0.01$) effect of category and ageing time on all evaluated parameters of water-holding capacity. For cooking loss and free water content, determined by the Grau-Hamm method (G-H), there was also a significant interaction of these factors.

In the case of the ST muscle, a significant ($p \leq 0.01$) effect of the category, ageing time and interaction of these two factors on all indicators of water-holding capacity was observed, except for the effect of ageing time on cooking loss (Table 6). In general, an increase in both drip loss and cooking loss was observed on successive days of cold ageing. The calf meat had the lowest drip loss. The average value of this indicator was 2.83% for ML and 2.36% for ST. According to Kołczak et al. [19], the amount of water bound in meat decreases during cold storage, but intense degradation of myofibrillar proteins results in an increase in capillary spaces available for water in the later post mortem period and an increase in water-holding capacity.

In the ST muscle of calves on the 12th day of ageing, a decrease in drip loss and cooking loss was observed as compared to previous measurements. Similar downward trends were observed in the measurement of electrical conductivity, which indicates that EC is linked to the amount of loss from muscle tissue. This is confirmed by a study by Florek [7], who showed a decrease in cooking loss and free water in calf meat during 7-day ageing, on average by 0.8% and 9.7 mg in the ML and 1.4% and 11.6 mg in the ST.

The highest drip loss was noted in the group of heavy calves (mean 3.80% for the ML muscle and 5.63% for ST), and in the ML muscle cooking loss was also the highest (28.08%) in this cattle category – Tables 5 and 6. Moreno et al. [24], evaluating the effect of ageing (for 5 days) of four commercial cuts of the meat of calves (age at slaughter 9.8 months) on parameters of water-holding capacity, reported drip loss in the range of 1.2--1.9% and cooking loss from 29.3% to 39.2%. They also showed a direct positive correlation between intramuscular fat content and tenderness and a negative correlation with drip loss, suggesting that low-fat veal should not be heated for too long, as this increases cooking loss and reduces the tenderness of the meat. Toohey et al. [30], determining the cooking loss of the *semimembranosus* muscle in cows, showed a significant increase in this parameter during cold storage. The cooking loss measured on meat samples taken about 4 h after slaughter was 21.7%, but after 14 days of ageing it was 23.6%. Anderson et al. [1], in their evaluation of the quality of seven skeletal muscles from English meat crossbreds at the age of 20 months, found no significant effect of post-slaughter ageing on cooking loss. Among the muscles evaluated, the lowest cooking loss was noted for ML (28-29%) and the highest for *m. adductor* (33% to 35%). Lin-qiang et al. [20] observed a decrease in cooking loss in the ML muscle of four age categories of Qinchuan cattle as the age of the animals increased. They noted the highest cooking loss in 3-month-old calves (39.19%) and the lowest in young bulls at the age of 15 months (32.88%).

The mean values for water-holding capacity measured by the G-H method from successive days showed that the ageing process improved the water-holding capacity of the muscle tissue. The decrease in the percentage of free water is indicative of the greater capacity (strength) with which the meat retains internal water, which is an important parameter both for processing and for the consumer. A slightly stronger positive effect of ageing time on the water-holding capacity of muscle tissue was observed in the ML muscle. On the 12th day of ageing, there was a 5.18% decrease in free water loss as compared to the first measurement (after 48 h), while for ST the decrease was 4.1%. Similar tendencies for the water-holding capacity of beef were reported by Farouk et al. [6], who observed a decrease in water loss measured gravimetrically, centrifugally, and by the G-H method during a 9-week ageing period. According to the authors, the increase in the WHC of the meat during post-slaughter ageing is due to structural changes in muscle tissue. Proteolytic changes in muscle (structural) proteins cause damage to the spaces (capillaries) through which, originally in the rigour state, water can be removed out of the muscle, leading to water loss. Degradation of protein structures, and thus of capillaries, leads to a ‘sponge effect’ whereby water is retained within the muscle tissue. At refrigeration temperatures, the ‘sponge effect’ is further enhanced by the increase in the potential viscosity of intramuscular water, which is associated with increased amounts of soluble substances (including proteins) and partial protein gelling. The authors also suggest that meat with a higher pH has a better WHC than meat with lower acidity.

To sum up, the cattle category significantly affected all evaluated physicochemical properties of the ML and ST muscles (except EC in the ST). In general, as the age of

Table 5

Water-holding capacity indices for the *longissimus lumborum* (ML) muscle in the assessed cattle categories, including the effect of aging time

Specification	Category (K)	Ageing time (C)			Average	Influence		
		48 h	7 days	12 days		K	C	KxC interaction
Drip loss (%)	milk-fed calves	1.56 ±0.43	3.21±0.79	3.73 ±1.59	2.83 ±1.39	**	**	ns
	heavy calves	2.17 ±1.03	4.58 ±1.86	4.69 ±2.64	3.80 ±2.25			
	young slaughter cattle	1.66 ±0.70	3.09 ±1.22	4.34 ±1.49	3.01 ±1.60			
	cows	2.53 ±0.35	2.65 ±1.18	4.33 ±1.41	3.43 ±1.49			
	average	1.77 ±0.79	3.38 ±1.46	4.34 ±1.78				
Cooking loss (%)	milk-fed calves	27.75 ±4.13	27.46 ±2.43	27.72 ±2.28	27.64 ±2.97	**	**	*
	heavy calves	27.98 ±4.42	26.50 ±2.79	29.86 ±2.81	28.08 ±3.65			
	young slaughter cattle	25.87 ±3.29	27.30 ±3.21	27.72 ±2.99	26.95 ±3.25			
	cows	21.35 ±3.80	22.85 ±2.40	26.05 ±4.12	24.17 ±3.67			
	average	26.48 ±3.78	26.86 ±3.17	28.04 ±3.10				
Free water G-H (%)	milk-fed calves	20.51 ±2.91	19.79 ±4.10	21.45 ±2.04	20.58 ±3.11	**	**	**
	heavy calves	25.90 ±5.40	20.24 ±3.43	16.88 ±3.59	21.08 ±5.64			
	young slaughter cattle	25.46 ±2.86	22.29 ±3.51	20.41 ±3.04	22.72 ±3.76			
	cows	24.07 ±4.85	19.91 ±6.22	20.07 ±7.18	21.21 ±6.20			
	average	24.92 ±3.99	21.43 ±3.88	19.74 ±3.77				

*p≤0.05; **p≤0.01; ns – not found

Table 6
Water-holding capacity indices for the *semitendinosus* (ST) muscle in the assessed cattle categories, including the effect of ageing time

Specification	Category (K)	Ageing time (C)			Average	Influence		
		48 h	7 days	12 days		K	C	KxC interaction
Drip loss (%)	milk-fed calves	1.73 ±0.70	3.40 ±1.85	1.89 ±1.00	2.36 ±1.47	**	**	**
	heavy calves	3.20 ±1.28	6.24 ±2.27	7.44 ±2.19	5.63 ±2.64			
	young slaughter cattle	2.68 ±0.93	5.27 ±1.93	7.21 ±1.79	5.03 ±2.45			
	cows	2.67 ±0.62	3.51 ±0.77	5.51 ±2.36	4.45 ±2.01			
	average	2.70 ±1.06	5.18 ±2.11	6.58 ±2.50				
Cooking loss (%)	milk-fed calves	27.17 ±1.53	29.85 ±1.50	25.65 ±4.30	27.57 ±3.25	**	ns	**
	heavy calves	27.97 ±3.08	28.65 ±3.40	30.85 ±3.48	29.15 ±3.50			
	young slaughter cattle	30.59 ±3.39	31.52 ±2.27	31.81 ±1.96	31.30 ±2.65			
	cows	27.44 ±1.67	26.59 ±1.88	28.44 ±1.60	27.57 ±1.84			
	average	29.62 ±3.43	30.48 ±2.87	30.72 ±3.27				
Woda wolna G-H (%) Free water G-H (%)	milk-fed calves	23.07 ±2.58	23.57 ±2.14	21.42 ±3.90	22.72 ±2.99	**	**	**
	heavy calves	26.96 ±5.72	21.36 ±4.37	19.22 ±4.45	22.51 ±5.83			
	young slaughter cattle	26.67 ±3.58	25.37 ±3.51	23.42 ±3.60	25.15 ±3.78			
	cows	27.80 ±4.81	19.95 ±3.17	23.90 ±2.93	23.42 ±4.48			
	average	26.41 ±4.25	24.01 ±4.02	22.31 ±4.14				

*p≤0.05; **p≤0.01; ns – not found

the animals increased, the meat was darker (lower L^*) and redder (higher a^* value) and had lower oxidative stability (higher TBARS value). The ageing time of the meat significantly affected pH, EC and colour parameters L^*, a^* and b^*, as well as most parameters of water-holding capacity of the ML and ST muscles. As the ageing period increased, the meat became lighter (higher L^*), redder (higher a^*) and yellower (higher b^*).

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