THE EFFECT OF VACUUM COLD STORAGE ON THE QUALITY OF MEAT FROM POLISH HOLSTEIN-FRIESIAN BLACK-AND-WHITE HEIFERS AND LIMOUSIN CROSSES

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Abstract. The aims of this study were to determine changes in the physicochemical and sensory properties of vacuum-packaged cold-stored beef, and to compare the quality of meat from 11 Polish Holstein-Friesian Black-and-White (PHF BW) heifers and 11 crossbred heifers produced by mating PHF BW cows to Limousin (LIM) bulls (PHF BW x LIM). The experimental materials comprised samples of *m. longissimus lumborum* (MLL). Three samples of similar weight were collected from chilled right half-carcasses. The first sample was analyzed approximately 72 post mortem (before storage), the second and third samples were analyzed after 7 and 14 days of cold storage (0-2°C), respectively (counting from the day of slaughter). The samples were vacuum-packaged before storage.

During cold storage, muscle samples from PHF BW heifers and LIM crosses did not differ significantly with respect to chemical composition, physicochemical properties and sensory properties. Cold storage time affected the functional properties and eating quality of meat. Prolonged storage contributed to increased weight loss and water-holding capacity (shear force), an increase in color lightness (L^*) and a decrease in redness (a^*). Meat stored for 7 days was characterized by lower yellowness (b^*), compared with meat evaluated 72 hours post mortem and meat stored for 14 days. No significant changes in the pH of meat and no significant increase in TBARS values were noted. The taste, aroma, juiciness and tenderness of meat improved, and shear force values decreased throughout storage.

Keywords: beef, heifers, meat quality, cold storage, vacuum packaging

Introduction. Modern consumers demand food products of premium quality. Beef quality is determined by numerous pre-slaughter (breed, feeding regime, sex, age, and pre-slaughter handling) and post-slaughter factors (carcass processing, post mortem aging). The biochemical processes that occur in muscles post mortem significantly affect the processing suitability and eating quality of meat. Post mortem changes influence the sensory properties of beef such as tenderness and palatability (Miller et al., 2001) as well as color that is considered as the most important quality attribute by consumers (Mancini and Hunt, 2005). The course and rate of post mortem changes in meat quality are influenced by storage time and temperature, and packaging method (Gök et al., 2008). Therefore, proper storage conditions can contribute to improving overall meat quality attributes so as to satisfy the expectations of consumers and meat processing plants.

Adequate packaging helps maintain beef quality, protects meat products from undesirable changes during storage, has a color-stabilizing effect, prevents lipid oxidation and ensures microbiological safety (Lavieri and Williams, 2014). Cold storage time should be appropriately adjusted based on meat type and packaging method to protect meat from undesirable impacts on quality (Lindahl, 2011). The simplest method of extending the shelf-life of meat involves cold storage at a temperature above the freezing point of cell sap, which enables to maintain the texture and appearance of fresh meat and prevent loss of nutrients. Selected meat attributes, including tenderness and palatability, can improve during the cold storage aging process (Stenström et al., 2014).

Scientists and producers have long searched for optimal packaging solutions that would ensure microbiological safety and help beef retain its attractive red color. In many countries, vacuum packaging is the most common method of packaging fresh meat. However, vacuum-packaged red meat has a dark purple color due to the removal of oxygen from the package which increases the myoglobin (deoxymyoglobin) content of muscle, and this is a potential disadvantage from the consumer's point of view (Mancini and Ramanathan, 2014). On the other hand, oxygen present in the package can accelerate lipid oxidation and rancidity, promote the growth of aerobic bacteria and lead to undesirable changes in aroma (Rogers et al., 2014). In some cases, high oxygen concentrations are desirable because oxygenated myoglobin (oxymeoglobin) gives beef its bright red color that consumers associate with freshness. However, longer exposure to oxygen, in particular under low pressure conditions, leads to the formation of metmyoglobin from oxymyoglobion (the process is delayed by high oxygen concentrations). Metmyoglobin formation should be avoided because this pigment is brown and considered unattractive by consumers (Mancini et al., 2008). Thus, meat can be stored under aerobic conditions for short periods of time, but long-term storage requires the removal of oxygen from the package.

Beef packaging and cold storage have been widely investigated in order to optimize the shelf-life and quality of the product (Li et al., 2013, 2012; Lindahl, 2011).

However, most studies conducted to date have used meat from young bulls, whereas changes in the quality of cold-stored beef coming from heifers remains scarcely researched. In addition to the post-mortem factors described above, beef quality is also affected by the gender and genotype of animals as well as commercial crossbreeding aimed at improving meat quality (Litwińczuk et al., 2006; Węglarz et al., 2010).

In view of the above, the objectives of this study were to determine changes in the quality of vacuum-packaged beef stored over 14 days, and to compare the quality of meat from Polish Holstein-Friesian Black-and-White (PHF BW) heifers and crossbred heifers produced by mating PHF BW cows to Limousin (LIM) bulls.

Materials and Methods. The experimental materials comprised 11 Polish Holstein-Friesian Black-and-White (PHF BW) heifers and 11 crossbred heifers produced by mating PHF BW cows to Limousin (LIM) bulls (PHF BW x LIM). All heifers were purchased from one farm where they were housed in group pens and fed an identical diet. At the end of fattening, i.e. at approx. 18 months of age, the animals were transported (1.5 h, approx. 60 km) to a meat plant, in accordance with the livestock transport guidelines. The heifers were kept in lairage, in individual pens, for 24 hours, after which time they were weighed and slaughtered. Slaughter and carcass dressing were carried out using standard procedures. Carcasses were chilled at 0–4ºC for approx. 48 hours. Three samples of similar weight were collected from chilled right half-carcasses, from the *longissimus lumborum* muscle (MLL). The samples were placed in isothermal containers and transported to the laboratory. The first sample was analyzed immediately (approx. 72 post mortem), and the second and third samples were weighed, placed in PA/PE vacuum packaging bags, and were chill stored at 4°C until analysis, for 7 and 14 days (counting from the day of slaughter). The analysis of the proximate chemical composition of meat, performed before storage, included the determination of dry matter content, total protein content by the Kjeldahl method, fat content by the Soxhlet method, and ash content (AOAC, 1990). The physicochemical and sensory properties of meat were determined before storage and after 7 and 14 days of storage. The pH (pH ultimate) of samples was measured in the water homogenates of meat, using a combination Double Pore electrode (Hamilton) and a 340i pH-meter equipped with a TFK 150/E temperature sensor (WTW). The water-holding capacity (forced drip loss) was determined by the Grau and Hamm method (Oeckel van et al., 1999). Meat color was determined based on the values of CIELAB coordinates L^* (lightness), a^* (redness), b^* (yellowness), C^* (chroma), h^o (hue angel) and ΔE (CIE, 1978). The color space parameters L^*, a^* and b^* were measured three times by the reflectance method using a HunterLab MiniScan XE Plus spectrocolorimeter (Hunter Associates Laboratory Inc., Reston, VA, USA) with an illuminant D65, a 10º standard observer angle and a 2.54 cm-diameter aperture, at different points over the muscle cross-section area. The apparatus was standardized using white and black standard plates. Prior to the measurement, samples wrapped in oxygen-permeable and water-impermeable foil were stored for 0.5 h at 4ºC. The values of C^*, h^o and ΔE were calculated from the following formulas: $C^* = (a^{*2} + b^{*2})^{1/2}$; $h^o = tan^{-1}(b^*/a^*)$; $\Delta E = (\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2})^{1/2}$. The rate of lipid oxidation was estimated based on TBARS values (Pikul et al., 1989). Absorbance was measured using a Specord 40 spectrophotometer (Analytik Jena AG), and TBARS values were expressed as mg malondialdehyde (MDA) per kg meat. The shear force of meat was determined using a Warner-Bratzler head (500 N, speed 100 mm/min.) attached to an Instron universal testing machine (model 5542). The preparation of the meat samples and the measurement of shear force were performed as described by Honikel (1998). The sensory properties of cooked meat were evaluated by five trained panelists, on a five-point scale (PN-ISO 4121:1998). Meat was cooked in a 0.6 % NaCl solution (meat to solution weight ratio of 1 : 2) until the temperature at the geometric centre of the sample reached 96 ºC (Baryłko-Pikielna et al., 1964). The ultimate temperature inside the sample was 80 ºC. Approximately 1 cm^3 cubes of meat were cut from the middle of each cooked sample and wrapped in aluminium foil. Coded meat samples were presented to the panelists under fluorescent light, at room temperature. Distilled water was made available to the panelists for mouth cleansing between samples. Weight loss after cold storage was calculated as the difference in sample weight before storage and after 7 and 14 days of storage, and was expressed as a percentage of initial sample weight.

The results were processed statistically using the STATISTICA data analysis software system ver. 9.0 (StatSoft Inc., 2009). Two-way ANOVA revealed no significant interaction between the experimental variables (heifer genotype and cold storage time). Thus, one-way ANOVA was performed to determine the effects of the experimental factors on meat quality. Least squares mean (LSM) and standard deviations (SD) were calculated. Statistical significance between means in groups was estimated by Duncan's test.

Results and Discussion. Commercial crossbreeding contributes to improving carcass traits and meat quality, and producing offspring that combine the desirable characteristics of both parents (Litwińczuk et al., 2006). In the present study, we analyzed and compared selected quality attributes of meat from Holstein-Friesian Black-and-White (PHF BW) heifers and crossbred heifers produced by mating PHF BW cows to Limousin (LIM) bulls.

Average hot carcass weight was by approximately 10 kg higher in crossbred heifers, compared with PHF BW heifers, but the noted difference was not statistically significant. The chemical composition of meat is an important determinant of its nutritional value, culinary uses and processing suitability. The proximate composition of meat from PHF BW and PHF BW x LIM heifers was compared before storage (Table 1). The

percentage content of dry matter, total protein, fat and ash in meat was similar in both groups (no significant differences were found in the mean values of the analyzed parameters). The average protein content of beef determined in our study was lower than that reported by Wajda et al., (2013) for the meat of young PHF BW bulls (23.36 %), similar to that noted by Węglarz (2010) (22.26 %) and higher than that reported by Daszkiewicz et al., (2009) (21.32 %).

Intramuscular fat content is an important component of the eating quality of beef. Intramuscular fat plays a key role in shaping the sensory properties of meat and is associated with superior tenderness and juiciness (Wood et al., 2008). The optimal intramuscular fat content of 3–5 % was achieved in the present study, which could be due to the fact that beef was obtained from females. Research has shown that meat from young bulls usually contains lower levels of intramuscular fat. Litwińczuk et al. (2006) evaluated the physicochemical quality of meat from PHF BW heifers and bulls and commercial crosses sired by beef bulls. The cited authors demonstrated that genotype had a significant effect on the chemical composition of meat, in particular the intramuscular fat content of *m. longissimus lumborum* which was higher in BW bulls than in crosses sired by Limousin and Charolaise bulls. In a study by Śmiecińska and Wajda (2005), the percentage of intramuscular fat was lower in meat from Limousin crosses than in meat from BW heifers. In the current study, meat from PHF BW heifers had a higher fat content than meat from crossbred heifers, but the noted difference was statistically not significant.

Table 1. **Hot carcass weight and proximate chemical composition of meat from heifers**

Specification	Statistical measures	Heifers	
		PHF BW	PHF BW x LIM
Hot carcass weight (kg)	LSM	237.43	247.02
	SD	16.23	16.41
Dry matter (%)	LSM	26.55	26.31
	SD	0.58	0.79
Total protein (%)	LSM	22.54	22.78
	SD	0.32	0.51
Fat (%)	LSM	3.97	3.42
	SD	0.83	0.94
Ash (%)	LSM	1.02	1.04
	SD	0.01	0.02

Beef is used mostly for culinary purposes and therefore it has to meet functional quality standards. The physicochemical properties of beef affect its appearance, shelf-life and sensory attributes. Meat quality is also determined by the ultimate pH value measured after post-mortem glycolysis, which influences sensory properties (tenderness, juiciness), technological properties (color, water-holding capacity) and microbiological stability (Pastsart et al., 2013).

No significant differences were noted between PHF BW and PHF BW x LIM heifers in respect of other meat quality parameters (physicochemical and sensory properties) evaluated at 0, 7 and 14 days of cold storage (Tables 2 and 3).

In order to determine changes in the quality of cold-stored meat, we compared samples of the *longissimus lumborum* muscle before storage (approx. 72 hours post mortem) with vacuum-packaged samples stored for 7 and 14 days.

Weight loss observed in meat during cold storage is a consequence of natural processes related to the drying of the surface layer of meat due to evaporation and drip losses. Loss in meat weight during storage is important for assessing the cost-effectiveness of the process, but it also affects the chemical composition of meat, its parameters related to water content and the consumer acceptance of the packaged product (Stenstr□m et al., 2014). In this study, significantly greater weight loss was noted after 14 days of storage in meat from both PHF BW and PHF BW x LIM heifers (Table 2). Stetzer et al., (2007) and Zakrys-Waliwander et al., (2012) also reported increased weight losses in vacuum-packaged meat during prolonged storage periods. The above could result from the mechanical effect of reduced pressure on the texture of vacuum-packaged meat, leading to increased drip loss. According to some authors (Lund et al., 2007; Zakrys-Waliwander et al., 2012), weight loss is lower in vacuum-packaged meat than in meat stored in a modified atmosphere, and is affected by the composition of the internal atmosphere of a package (high oxygen concentrations).

The pH of muscle tissue has a significant effect on post mortem changes that determine the processing characteristics and eating quality of meat. A normal pH range for high-quality beef is 5.4–5.8. In all analyzed groups, average pH values were similar and indicative of high quality of raw material, a normal post-mortem aging process and adequate cold storage conditions. The absence of significant differences in the pH of heifer meat during cold storage is consistent with the findings of other authors (Stenström et al., 2014).

The content and distribution of water and the ability of meat to retain its own water are determined by numerous factors, including the spatial arrangement (structure) of muscles, with myofibrillar/cytoskeletal proteins as the essential constituents. In living muscles, the amount of water in the capillary spaces of muscle cells remains unchanged. Water-holding capacity varies during rigor mortis formation and after its dissipation, reaching the highest value at slaughter and at the end of meat aging. Following rigor mortis, proteolytic breakdown of cytoskeletal proteins occurs in cold-stored meat. The spatial arrangement and the electrostatic charge of myofibrils change, thus altering the functional properties of meat. Transformations of myofibrillar proteins and their content have a considerable effect on the water-holding capacity of meat (Huf-Lonergan and Lonergan, 2005; Pospiech et al., 2007). Rapid and extensive proteolysis enhances water binding and retention by meat and reduces drip loss (Poulanne and Haanen, 2010). In addition to the factors described above, the water-holding

capacity of meat is also affected by the age, breed and sex of animals, and the type of muscle (Florek et al., 2007; Stetzer et al., 2007). Water-holding capacity is a key indicator of the processing suitability of meat (Huff-Lonergan and Lonergan, 2005). It also affects the nutritional value of meat as drip loss includes the loss of nutritious components such as proteins, non-protein nitrogenous compounds, carbohydrates, minerals and vitamins. In our study, average drip loss determined by the Grau and Hamm method was significantly ($P \leq 0.01$) higher in meat stored for 14 days, compared with fresh meat and meat stored for 7 days. The average value of forced drip loss was comparable in the analyzed genetic groups. In a study by Daszkiewicz et al., (2009), forced drip loss (determined by the same method) was greater than in our experiment in meat from purebred BW bulls ($7.05 cm^2$) and crossbred PHF BW x Limousin bulls ($7.30 cm^2$). The effect of storage time on the water-holding capacity of meat was noted in our study as well as in experiments conducted by Stetzer et al., (2007) and Zakrys-Waliwander et al., (2012). However, it should be stressed that drip loss is also determined by water loss during meat storage. According to the "leaking out" hypothesis, water is lost as dripping at early stages of cold storage which explains most of the reduction in drip loss when sampling at a later time post mortem (Moeseke van and Smet de, 1999).

Color is the most important attribute of beef, and an indicator of its technological quality, which greatly influences consumer purchasing decisions. Meat color is determined by the amount, composition and transformations of pigments. The color of meat surface and subsurface changes during storage, and the observed changes are affected by temperature, time and conditions of storage. Therefore, meat color stability can be achieved by optimizing storage parameters, taking into account the kind of meat and the type of muscle (Lindahl, 2011). Prolonged storage contributed to a significant ($P \leq 0.05$) increase in the color lightness (L^*) of meat from crossbred heifers and a decrease in the redness (a^*) of meat from PHF BW heifers. Meat from both PHF BW and PHF BW x LIM heifers, stored for 7 days, was characterized by lower yellowness (b^*), compared with meat evaluated 72 hours post mortem and meat stored for 14 days. A similar trend was reported by Lagerstedt et al., (2011).

Differences in the mean values of parameters a^* and b^* were reflected in differences in color saturation (C^*) and hue (h^*), which decreased in meat stored for 7 days and increased in meat stored for 14 days. Statistically significant differences were noted only for color saturation. The average value of total color change ΔE, calculated relative to fresh meat, was higher in meat stored for 14 days than in meat stored for 7 days, but the difference was statistically non-significant. Changes in the color of beef observed in our study were a natural consequence of transformations of meat pigments. During cold storage, changes in meat color result mostly from alterations in the chemical composition of myoglobin (Mancini and Hunt, 2005). The rate of those changes and, consequently, meat color, are affected by: the concentrations of hydrogen ions (pH), oxygen availability, temperature, access to light, tissue structure, the activity of reducing enzymes, the presence of substrates and cofactors, and lipid oxidation (Ramanathan et al., 2013). Our results and the findings of other authors (Mancini and Ramanathan, 2014; Martin et al., 2013; Vitale et al., 2014) show that meat color is also influenced by the time of cold storage which should be adjusted to the kind of meat, the type of muscle, temperature during storage, the type and method of packaging.

The compounds that are formed during lipid oxidation contribute to undesirable quality changes in cold stored meat, including changes in color (parameters $L^*a^*b^*$) and sensory properties (Gök, 2008). One of the most common method used to determine oxidative changes in meat and meat products, based on 2-thiobarbituric acid (TBA) as a reagent, is known as the TBA assay (Pikul et al., 1989). This colorimetric technique allows measuring the absorbance of the red pigment – the product of a reaction between 2-thiobarbituric acid and malondialdehyde (MDA) – the secondary product of autooxidation of polyunsaturated fatty acids. This method is non-specific, because apart from MDA, also other secondary products of lipid oxidation can react with 2-thiobarbituric acid. Therefore, the term "TBARS assay" (TBA-reactive substances) is also used in literature (Diaz et al., 2014). Cold storage had no significant influence on TBARS values, which indicates that storage conditions were appropriate and lipid oxidation led to only minor changes. Protection offered by vacuum packaging is another important consideration due to the pro-oxidative effect of oxygen present in the package, which has been demonstrated in many studies (Gök, 2008). The TBARS values determined in our study were not high when compared with those reported by other authors (Vitale et al., 2014), but our results cannot be directly compared with other findings due to methodological differences (Diaz et al., 2014).

Adequate storage time (Gök, 2008) and method are crucial to maintaining high sensory quality of meat (Li et al., 2013). In our experiment, aroma intensity increased in meat from both PHF BW and PHF BW x LIM heifers during extended cold storage ($P \leq 0.01$). Taste intensity improved significantly in meat stored for 7 days, compared with meat evaluated before storage (Table 3).

The desirability of aroma and taste increased with storage time. Vacuum-packaged beef stored for 14 days received the highest scores for taste desirability, and the differences between means were statistically significant in the group of PHF BW heifers.

Meat juiciness was higher after 14 days of cold storage than before storage ($P \leq 0.05$). High average scores for juiciness, noted in both groups of heifers, resulted from a high intramuscular fat content of beef.

Meat tenderness is one of the most important eating quality traits. It is affected by the structure of proteins of intramuscular connective tissue and myofibrillar proteins, and the activity of proteolytic enzymes present in muscles. Beef tenderness is also influenced by the age and

breed of animals, the type of muscle, post mortem handling of carcasses, and heat treatment method (Pospiech et al., 2007; Stetzer et al., 2007). Table 3 data shows that tenderness improved during cold storage, and a significant difference between average tenderness values was noted in meat from PHF BW heifers analyzed before storage and after 14 days of storage (P≤0.01).

Table 2. **Meat weight losses after cold storage, physicochemical properties and the TBARS values of meat from heifers**

Specification		Cold storage time (days)					
		0 (n = 11)		7 (n = 11)		14 (n = 11)	
		LSM	SD	LSM	SD	LSM	SD
Weight losses (%)	PHF BW	-	-	1.85^{b}	0.57	2.59^{a}	0.69
	PHF BW x LIM	-	-	2.13^{b}	0.87	2.56^{a}	0.86
pH_u (pH ultimate)	PHF BW	5.58	0.07	5.57	0.06	5.56	0.06
	PHF BW x LIM	5.55	0.02	5.56	0.06	5.54	0.04
Water-holding capacity (cm^2) - Grau and Hamm method	PHF BW	5.60^{B}	0.63	5.57^{B}	0.64	6.50^{A}	0.59
	PHF BW x LIM	5.98	0.89	5.29^{B}	0.42	6.52^{A}	0.60
L^* (lightness)	PHF BW	37.67	1.15	37.68	1.94	39.59	1.01
	PHF BW x LIM	37.36^{b}	1.16	37.46^{b}	1.28	39.55^{a}	1.31
a^* (redness)	PHF BW	18.07^{Aa}	1.19	16.51^{B}	0.67	16.88^{b}	1.16
	PHF BW x LIM	17.37	1.33	16.34	0.75	17.45	1.31
b^* (yellowness)	PHF BW	15.03^{A}	1.12	13.42^{Bb}	1.02	14.68^{a}	1.22
	PHF BW x LIM	14.34^{a}	0.59	13.40^{b}	0.29	14.73^{a}	0.89
C^* (chroma)	PHF BW	23.51^{A}	1.41	21.29^{B}	0.95	22.39	1.33
	PHF BW x LIM	22.53	1.38	21.14^{b}	0.53	22.85^{a}	1.50
$h°$ (hue angle)	PHF BW	39.74	1.03	39.07	1.80	41.00	1.54
	PHF BW x LIM	39.60	1.10	39.39	1.66	40.19	1.35
ΔE	PHF BW	-	-	2.99	1.00	3.74	0.99
	PHF BW x LIM	-	-	2.17	1.12	2.49	0.58
TBARS value (mg malondialdehyde/kg meat)	PHF BW	0.27	0.12	0.37	0.19	0.72	0.25
	PHF BW x LIM	0.24	0.15	0.39	0.11	0.69	0.22
Values in the same row followed by different letters are significantly different: a, b - P ≤ 0.05; A, B - P ≤ 0.01							

Table 3. **Sensory properties (points) and shear force of meat from heifers**

Specification		Cold storage time (days)					
		0 (n = 11)		7 (n = 11)		14 (n = 11)	
		LSM	SD	LSM	SD	LSM	SD
Aroma (intensity)	PHF BW	4.11^{B}	0.78	4.78^{A}	0.12	4.82^{A}	0.13
	PHF BW x LIM	4.20^{B}	0.44	4.89^{A}	0.21	4.91^{A}	0.18
Aroma (desirability)	PHF BW	4.77	0.36	4.83	0.15	4.81	0.13
	PHF BW x LIM	4.80	0.45	4.82	0.11	4.89	0.13
Taste (intensity)	PHF BW	4.00^{B}	0.43	4.72^{A}	0.26	4.77^{A}	0.26
	PHF BW x LIM	4.10^{b}	0.42	4.70^{a}	0.28	4.70^{a}	0.27
Taste (desirability)	PHF BW	4.72	0.36	4.66^{b}	0.25	4.94^{a}	0.16
	PHF BW x LIM	4.60	0.42	4.80	0.28	4.85	0.27
Juiciness	PHF BW	4.00^{b}	0.25	4.22	0.56	4.61^{a}	0.33
	PHF BW x LIM	3.80^{b}	0.45	4.30	0.57	4.50^{a}	0.35
Tenderness	PHF BW	3.72^{B}	0.36	4.11	0.74	4.55^{A}	0.46
	PHF BW x LIM	4.10	0.65	4.20	0.91	4.50	0.50
Shear force (N)	PHF BW	46.25^{Aa}	13.89	30.70^{ab}	9.95	22.45^{Bb}	4.47
	PHF BW x LIM	35.83^{a}	10.18	25.39	6.68	22.79^{b}	6.91
Values in the same row followed by different letters are significantly different: a, b - P ≤ 0.05; A, B - P ≤ 0.01.							

Shear force values decreased with storage time in meat from both PHF BW and PHF BW x LIM heifers, which points to beef tenderization during cold storage. A trend towards higher tenderness and lower shear force in beef samples, observed over storage time in the present study, has also been reported by other authors (White et al., 2006; Florek et al., 2007).

Conclusions

1. Muscle samples from PHF BW heifers and LIM crosses did not differ significantly with respect to chemical composition, physicochemical properties and sensory properties at successive stages of cold storage (no significant differences were found in the mean values of the analyzed parameters). However in the current study, meat from PHF BW heifers had a higher fat content than meat from crossbred heifers, but the noted difference was statistically not significant. Moreover average hot carcass weight was by approximately 10 kg higher in crossbred heifers, compared with PHF BW heifers (237.43 kg), but the noted difference was not statistically significant.

2. Prolonged storage contributed to increased weight loss ($P \leq 0.05$) and water-holding capacity (shear force) ($P \leq 0.01$), an increase in color lightness (L^*) ($P \leq 0.05$) and a decrease in redness (a^*) ($P \leq 0.01$). Meat stored for 7 days was characterized by lower yellowness (b^*), compared with meat evaluated 72 hours post mortem and meat stored for 14 days ($P \leq 0.01$). Differences in the mean values of parameters a^* and b^* were reflected in differences in color saturation (C^*). However, differences in total color change (ΔE) between the analyzed cold storage periods were statistically not significant.

3. In all analyzed groups, average pH values were similar (no significant differences) and indicative of high quality of raw material, a normal post-mortem aging process and adequate cold storage conditions. Cold storage had no significant influence on TBARS values, which indicates that storage conditions were appropriate and lipid oxidation led to only minor changes. Protection offered by vacuum packaging is another important consideration due to the pro-oxidative effect of oxygen present in the package.

4. Aroma and taste intensity and desirability increased in meat from both PHF BW and PHF BW x LIM heifers during extended cold storage ($P \leq 0.01$). Meat juiciness was higher after 14 days of cold storage than before storage ($P \leq 0.05$). Tenderness improved during cold storage, and a significant difference between average tenderness values was noted in meat from PHF BW heifers analyzed before storage and after 14 days of storage ($P \leq 0.01$). Shear force values decreased with storage time in meat from both PHF BW ($P \leq 0.01$) and PHF BW x LIM heifers ($P \leq 0.05$).

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