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CHANGES IN THE SENSORY PROPERTIES OF BEEF STORED UNDER DIFFERENT MODIFIED ATMOSPHERES

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ABSTRACT

The aim of this study was to evaluate the sensory properties of *musculus longissimus lumborum* (LL) collected from Holstein-Friesian Black-and-White (HF BW) bulls and stored for 7, 14 and 21 days under different modified atmospheres (MA): vacuum, 80% O_2 + 20% CO_2, 60% O_2 + 30% CO_2 + 10% N_2, 40% CO_2 + 60% N_2, 30% CO_2 + 70% Ar. Meat stored for 21 days in MA containing 80% O_2 was more susceptible to undesirable changes in colour. The aroma of raw meat, evaluated immediately after the package was opened, changed throughout storage. Beef stored in MA containing O_2 scored lower for taste evaluated after thermal treatment. The juiciness and tenderness of beef improved during storage, and the highest scores for those attributes were assigned after 21 days of vacuum storage. A decrease in Warner-Bratzler shear force (WBSF) values and a corresponding increase in tenderness, point to the tenderization of beef regardless of storage conditions.

Key words: beef quality, storage period, colour, taste, juiciness, tenderness

INTRODUCTION

The quality of meat used for culinary purposes is determined by various pre-slaughter and post-slaughter factors. A thorough knowledge of the effects exerted by the above factors on meat quality is important for the selection of appropriate conditions and time of storage. Post-slaughter factors affecting meat quality include carcass processing and cold storage under proper conditions over a specified period of time. Cold storage is the simplest preservation technique developed to maintain the freshness of meat products [Brewer and Novakofski 2008]. This is an important consideration in beef which, compared with other kinds of meat, requires a long aging process during which certain quality attributes can be improved.

The key sensory properties of beef such as colour, general appearance, tenderness and palatability, are considerably influenced by the biochemical processes that occur in muscle tissue *post mortem*. Therefore, proper storage can contribute to producing high-quality beef [Hocquette et al. 2014]. The extent and rate of *post mortem* changes in the sensory quality of meat are determined by meat handling before packaging, gas composition in MA packaging, and storage time [Brewer and Novakofski 2008, Resconi et al. 2012]. The sensory attributes of meat, in particular tenderness, are also affected by pre-slaughter factors such as the animal's breed, sex, age and diet, muscle type as well as physiological changes observed in muscles directly before slaughter.

The sensory properties of meat are modified during cold storage, even under optimal conditions, mostly due to lipid oxidation [Zakrys et al. 2008] and protein transformations [Lund et al. 2007, Pospiech et al. 2007, Kim et al. 2010]. The rate and extent of changes are determined by the time and conditions of storage (gas composition in the package). It should also be noted that not only the products of lipid oxidation exert a direct effect on meat flavour because muscle tissue contains also numerous aroma compounds found in feed and ingested by animals or absorbed by meat during storage (odour of refrigerated beef, mouldy odour, putrefactive odour, etc.) [Kołczak 2008].

Changes in the quality of meat during modified atmosphere (MA) storage have been widely discussed in the literature. However, only a few studies have com-

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pared different kinds of MA packaging, and the present study attempts to fill in this knowledge gap. Modified atmosphere systems tested under laboratory conditions and applied in the food industry for preserving beef, and a gas mixture containing argon (Ar), were analysed in this experiment. The effect of Ar-based MA packaging on meat products remains insufficiently investigated, although Pérez-Rodríguez et al. [2014] observed a beneficial influence of Ar on the sensory quality of meat. Further research is needed to confirm this observation, especially that previous studies have focused exclusively on poultry meat [Fraqueza and Barreto 2009, Tománková et al. 2012].

The objective of this study was to analyse changes in the sensory properties of *musculus longissimus lumborum* (LL) collected from young Holstein-Friesian Black-and-White (HF BW) bulls and stored for 7, 14 and 21 days under different MA conditions (vacuum, 80% O_2 + 20% CO_2, 60% O_2 + 30% CO_2 + 10% N_2, 40% CO_2 + 60% N_2, 30% CO_2 + 70% Ar). The following research hypothesis was tested: storage time and gas composition in MA packaging can affect the eating quality and sensory attributes of beef.

MATERIAL AND METHODS

The experimental material comprised the carcasses of 10 young HF BW bulls. All animals were raised indoor on the same farm, and were fed farm-made feed, i.e. hay (*ad libitum*), maize silage and ground cereal grain (approx. 2 kg) in fall and winter, and green fodder (*ad libitum*), ground cereal grain and hay in summer. At around 19 months of age, the bulls were transported to a meat processing plant over a distance of approximately 90 km, and slaughtered. All slaughter and post slaughter processes were carried out in accordance with the current meat industry regulations (EC 2009). Upon arrival, their average body weight was 630 ±33 kg. Before slaughter, the animals were kept in lairage, in individual pens, for approximately 18 h. The slaughter of bulls was carried out after stunning with a Radical needle apparatus. Average hot carcass weight was 330 ±13 kg. After carcass processing (i.e. approx. 45 min *post mortem*) and chilling (at ±2°C for 48 h), pH_{45} and pH_{48} were measured in LL muscles between the 1st and 2nd lumbar vertebrae to avoid quality defects. The carcasses were divided into primal cuts, and lumbar segments of the right and left *musculus longissimus dorsi* (LD) were collected (between the last but one and the last thoracic vertebrae, and the last lumbar vertebra – LL). The muscles were weighed, vacuum-packaged and transported to the laboratory in isothermal containers. Upon arrival at the laboratory, LL muscles were divided into samples of similar weight (approx. 250 g) which were assigned to 5 groups: A, B, C, D, E (Fig. 1):

- A (30 samples) – vacuum-packaged,
- B (30 samples) – packaged under MA composed of 80% O_2 + 20% CO_2,
- C (30 samples) – packaged under MA composed of 60% O_2 + 30% CO_2 + 10% N_2,
- D (30 samples) – packaged under MA composed of 40% CO_2 + 60% N_2,
- E (30 samples) – packaged under MA composed of 30% CO_2 + 70% Ar.

Beef samples were packaged in bags made of ethylene-vinyl alcohol (EVOH) copolymer with enhanced gas barrier performance, using the PP15 (MGO) Tepro Vacu Tronic 2000 vacuum packaging machine (Tepro S.A.). Packaged samples were stored in a refrig-

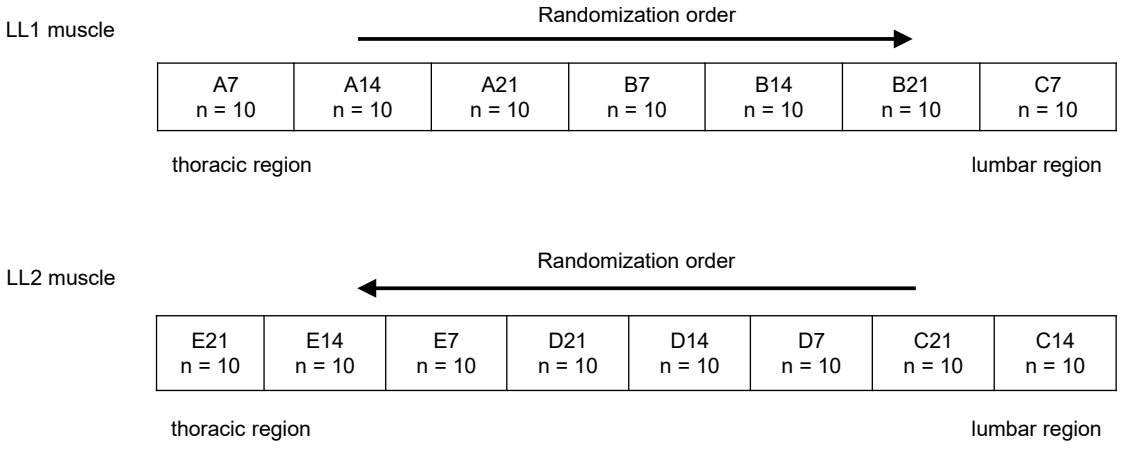

Fig. 1. Division of *musculus longissimus lumborum* (right – LL1 and left – LL2) into samples, including packaging method (A, B, C, D, E) and storage time (7, 14, 21 days)

erating chamber at a temperature of 2°C for 7, 14 and 21 days. Relative air humidity in the chamber was 50%.

The sensory properties and Warner-Bratzler shear force (WBSF) values of beef were analysed after the respective cold storage periods (7, 14, 21 days). The aroma of raw meat was evaluated immediately after opening the package, on a 9-point hedonic scale [Bingol and Ergun 2011]: 1 – extremely unacceptable, 2 – very much unacceptable, 3 – moderately unacceptable, 4 – slightly unacceptable, 5 – between acceptable and unacceptable, 6 – slightly acceptable, 7 – moderately acceptable, 8 – very much acceptable, 9 – extremely acceptable.

The colour of raw meat was evaluated on an 8-point scale [Montgomery et al. 2003]: 1 – dark brownish-greenish grey, 2 – light brownish-greenish grey, 3 – light grey, 4 – moderately dark red, 5 – slightly dark red, 6 – cherry red, 7 – moderately light cherry red, 8 – very light cherry red. Beef colour was assessed before and after the respective cold storage periods, immediately after the evaluation of beef aroma, i.e. around 30 min after opening the package.

The sensory properties of raw meat and thermally processed meat were evaluated by 6 trained panellists selected for their sensory sensitivity [ISO 2012]. The panellists assessed samples in individual compartments. Fluorescent white lights (500 lx) that simulated daylight, installed at a height of approximately 1 m, were used to evenly illuminate the table. Relative air humidity of minimum 60% and temperature of 21°C were maintained in the panel room.

The sensory attributes of thermally processed beef were evaluated after removing external fat and epimysium. Meat was cut into 2 cm cubes. Prior to the analysis, the samples were heated in 0.6% NaCl solution at 96°C (±2°C) until internal temperature reached 75°C. The serving temperature of beef samples was around 40°C.

Shear force was measured after thermal treatment, in the INSTRON 5542 universal testing machine fitted with a Warner-Bratzler head (500 N, speed 100 mm · min^{-1}). Meat samples were heated in a water bath at a temperature of 75°C for 50 min., they were cooled in a water bath at a constant temperature of 1–5°C for approximately 40 min., wrapped in aluminium foil and stored at 4 °C for 24 h. The maximum WBSF required to cut cylinder-shaped samples (1.27 cm in diameter, 2 cm in height) across the grain was measured. Knife blade used with a triangular notch.

The results were processed statistically using STATISTICA data analysis software, ver. 13.3. Arithmetic means ($\bar{x}$) and standard deviations (s) were calculated for the analysed traits and parameters. The effects of storage time and different MA packaging systems on the quality of LL muscles were evaluated by one-way analysis of variance (ANOVA). The statistical significance of differences between group means was determined by Duncan's multiple range test with a significance level of $P \leq 0.01$.

RESULTS AND DISCUSSION

Colour of meat. The greatest differences in this attribute were observed after 21 days of storage, in particular in samples stored in MA composed of 80% O_2 + 20% CO_2, where a brownish-greenish grey cast was noted (Table 2). An analysis of colour scores of individual samples did not reveal any undesirable changes after 7 or 14 days of storage. Discoloration was first noted after 21 days of storage in MA containing 80% O_2. Beef samples stored for 21 days in MA composed of 30% CO_2 + 70% Ar, 60% O_2 + 30% CO_2 + 10% N_2 and in vacuum packages were characterized by the most desirable colour.

Meat colour is determined by the quantity and composition of muscle pigments, and by their transformations. The changes in beef colour observed in our study were a natural consequence of transformations of muscle pigments. During cold storage, changes in meat colour result mostly from alterations in the chemical composition of myoglobin [Mancini et al. 2008]. In cattle, the myoglobin content of skeletal muscles is affected by the breed and age of animals, the type of muscle and physical activity in the pre-slaughter period [Liu et al. 2014]. When the partial pressure of oxygen increases, myoglobin is converted into bright red oxymyoglobin. Under low oxygen concentrations, oxymyoglobin is oxidized to grey-brown metmyoglobin which can undergo reduction. The rate of those changes and, consequently, meat colour, 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 [Nassu et al. 2012]. Many authors [Esmer et al. 2011, Lindahl 2011, Resconi et al. 2012] have demonstrated that oxygen-based MA has an adverse effect on meat colour, which is consistent with our findings.

Odour of raw meat. In the present study, the aroma of raw meat changed during storage (Table 3), which corroborates the findings of Lavieri and Williams [2014]. The aroma of beef samples evaluated on day 21 of storage (in all MAP systems), immediately after the package was opened, was less desirable than the aroma of samples assessed after 7 and 14 days of storage. It should be stressed, however, that despite a significant deterioration in aroma, beef stored for 21 days received high scores for this attribute. An analysis of the effect of MA composition on the aroma of raw meat did not reveal radical adverse changes in this attribute, but the noted differences were statistically significant. Vacuum-packaged samples stored for 7 and 14 days received higher scores for aroma than the remaining samples. After 21 days of cold stor-

Table 1. The sensory properties of beef were evaluated on a 5-point hedonic scale

Specification	Scale				
	5	4	3	2	1
aroma – intensity aroma – desirability	very distinct very desirable	distinct desirable	weakly distinct neutral	perceptible slightly undesirable	imperceptible very undesirable
juiciness	juicy	slightly juicy	weakly juicy	slightly dry	clearly dry
tenderness	very tender	tender	slightly tough	tough	very tough
taste – intensity taste – desirability	very distinct very desirable	distinct desirable	weakly distinct neutral	perceptible slightly undesirable	imperceptible very undesirable

age, meat samples packaged under MA composed of 40% CO_2 + 60% N_2 scored lowest for this attribute.

Aroma and taste of meat after thermal treatment. An evaluation of the effect of storage time on aroma intensity (Table 4) in thermally-processed beef revealed significant changes only in the samples packaged under high-oxygen MA (80% O_2 + 20% CO_2). An analysis of the effect of MA on aroma intensity indicated that the samples stored for 7 days in MA composed of 80% O_2 + 20% CO_2 scored higher for this attribute than those stored in vacuum packages and in MA composed of 60% O_2 + 30% CO_2 + 10% N_2. After 14-day storage, beef samples packaged under MA composed of 80% O_2 + 20% CO_2 were assigned the lowest scores for aroma intensity, significantly lower compared with vacuum-packaged samples and those packaged under MA composed of 30% CO_2 + 70% Ar. After 21-day storage, no significant changes in aroma intensity were noted in the analysed samples.

An analysis of the effect of storage time on aroma desirability (Table 3) demonstrated that beef samples packaged under MA composed of 80% O_2 + 20% CO_2 and 60% O_2 + 30% CO_2 + 10% N_2 received the lowest scores for this attribute after 14 days of storage. No significant changes were found in the aroma desirability of samples packaged under different MA systems and stored for 7 and 21 days. A significant effect of the gas composition of MA on this attribute was observed only after 14 days of storage. Meat samples stored in MA composed of 80% O_2 + 20% CO_2 received the lowest scores for aroma desirability, and the noted differences were significant relative to the samples stored in vacuum packages and in MA composed of 40% CO_2 + 60% N_2 and 30% CO_2 + 70% Ar.

The aroma of raw meat resembles that of industrially-produced lactic acid, and is not highly attractive to consumers. The development of undesirable aroma in meat may be associated with the rapid growth of microorganisms, mostly bacteria of the genus *Pseudomonas* [Lavieri and Williams 2014]. Adverse changes in aroma can also result from the growth of *Bronchothrix thermosphacta* contributing to the formation of cheese-like and dairy-like off-odours, and psychrotrophic Enterobacteriaceae imparting a sulphur off-odour [Mills et al. 2014]. When the above microorganisms have a high share of the microflora, the accumulation of their metabolites contributes to the development of an unpleasant aroma [Gribble et al. 2014]. The oxidation of fatty acids is yet another reason for deterioration in the aroma and taste of meat. The resulting compounds are responsible for undesirable, rancid off-flavours. The group of these compounds includes low-molecular-weight volatile substances, mainly aldehydes that are oxidized to carboxylic acids [Hęś et al. 2009]. It should also be noted that meat flavour is directly affected not only by the products of lipid oxidation but also by the content and quality of intramuscular fat.

The time of cold storage exerted a significant effect on taste intensity only in beef samples stored in MA composed of 80% O_2 + 20% CO_2 (Table 4). The lowest scores for taste intensity, similarly to aroma intensity and desirability, were assigned to the samples stored for 14 days in MA composed of 80% O_2 + 20% CO_2. An analysis of the influence of MA composition on taste intensity revealed no significant differences in this attribute after 7 days of storage. Beef samples stored for 14 days in high-oxygen MA were characterized by lower intensity of taste compared with the samples stored in vacuum packages and in MA composed of 30% CO_2 + 70% Ar. After 21 days of storage, the taste of vacuum-packaged samples was more intense than that of samples stored in MA composed of 40% CO_2 + 60% N_2.

An analysis of the effect of storage time on taste desirability demonstrated that meat samples packaged under MA composed of 80% O_2 + 20% CO_2 scored lower for this attribute after 14 days of storage than after 7 days of storage (Table 4). An evaluation of the effect of MA composition on taste desirability indicated that vacuum-packaged samples stored for 7 days received higher scores for this attribute than those packaged under MA composed of 30% CO_2 + 70% Ar. After 14-day storage, beef samples stored in vacuum packages had a more desirable taste than those stored in MA composed of 60% O_2 + 30% CO_2 + 10% N_2 and 80% O_2 + 20% CO_2. The gas composition of MA had no significant effect on taste desirability in meat samples stored for 21 days.

In this study, the high-oxygen MA packaging system had a negative impact on beef flavour, in particular after

Table 2. Colour of meat (points) after modified atmosphere storage (mean ± standard deviation)

Parameter	Modified atmosphere	Storage time of meat, days		
		7 n = 50	14 n = 50	21 n = 50
Meat colour evaluated on a grading scale	vacuum	5.20 ± 1.01	5.30 ± 0.79	6.05^{X} ± 0.83
	80% O_2 + 20% CO_2	5.65^{A} ± 1.13	5.45^{A} ± 0.76	4.10^{BY} ± 1.17
	60% O_2 + 30% CO_2 + 10% N_2	5.70 ± 1.03	5.05 ± 1.96	6.05^{X} ± 1.65
	40% CO_2 + 60% N_2	5.30 ± 1.01	5.20 ± 0.79	4.75 ± 1.48
	30% CO_2 + 70% Ar	4.80^{B} ± 0.63	5.55 ± 1.21	6.25^{AX} ± 1.21

A, B – Values within a row followed by the different superscript letters are significantly different at $P < 0.05$.
X, Y – Values within a column followed by the different superscript letters are significantly different at $P < 0.01$.

Table 3. Aroma of raw meat (points) after modified atmosphere storage (mean ± standard deviation)

Parameter	Modified atmosphere	Storage time of meat, days		
		7 n = 50	14 n = 50	21 n = 50
Aroma of raw meat after storage	vacuum	8.65^{AX} ± 0.34	8.50^{AX} ± 0.28	7.55^{BY} ± 0.28
	80% O_2 + 20% CO_2	8.10^{AY} ± 0.21	7.90^{AY} ± 0.32	7.45^{BY} ± 0.16
	60% O_2 + 30% CO_2 + 10% N_2	8.05^{AY} ± 0.28	8.00^{AY} ± 0.24	7.65^{BY} ± 0.24
	40% CO_2 + 60% N_2	7.80^{AY} ± 0.54	7.65^{AY} ± 0.24	6.70^{BX} ± 0.59
	30% CO_2 + 70% Ar	7.85^{AY} ± 0.34	7.95^{AY} ± 0.28	7.15^{B} ± 0.41

Explanation as in Table 2.

Table 4. Aroma and taste (points) of meat after modified atmosphere storage (arithmetic mean ± standard deviation)

Parameter	Modified atmosphere	Storage time of meat, days		
		7 n = 50	14 n = 50	21 n = 50
Aroma – intensity	vacuum	4.65^{Y} ± 0.24	4.75^{X} ± 0.26	4.85 ± 0.24
	80% O_2 + 20% CO_2	4.90^{AX} ± 0.21	4.40^{BY} ± 0.32	4.70 ± 0.26
	60% O_2 + 30% CO_2 + 10% N_2	4.65^{Y} ± 0.24	4.50 ± 0.33	4.65 ± 0.24
	40% CO_2 + 60% N_2	4.85 ± 0.24	4.60 ± 0.32	4.65 ± 0.24
	30% CO_2 + 70% Ar	4.85 ± 0.24	4.70^{X} ± 0.26	4.65 ± 0.24
Aroma – desirability	vacuum	4.90 ± 0.21	4.80^{X} ± 0.26	4.85 ± 0.24
	80% O_2 + 20% CO_2	4.95^{A} ± 0.16	4.25^{BY} ± 0.26	4.60 ± 0.46
	60% O_2 + 30% CO_2 + 10% N_2	4.80^{A} ± 0.26	4.35^{B} ± 0.41	4.70 ± 0.35
	40% CO_2 + 60% N_2	4.80 ± 0.26	4.70^{X} ± 0.35	4.55 ± 0.37
	30% CO_2 + 70% Ar	4.85 ± 0.24	4.80^{X} ± 0.26	4.65 ± 0.24
Taste – intensity	vacuum	4.80 ± 0.26	4.90^{X} ± 0.21	4.90^{X} ± 0.21
	80% O_2 + 20% CO_2	4.80^{A} ± 0.26	4.25^{BY} ± 0.49	4.65 ± 0.41
	60% O_2 + 30% CO_2 + 10% N_2	4.65 ± 0.24	4.55 ± 0.28	4.70 ± 0.26
	40% CO_2 + 60% N_2	4.80 ± 0.26	4.55 ± 0.37	4.55^{Y} ± 0.16
	30% CO_2 + 70% Ar	4.70 ± 0.26	4.75^{X} ± 0.35	4.70 ± 0.26
Taste – desirability	vacuum	4.95^{X} ± 0.16	4.85^{X} ± 0.24	4.85 ± 0.24
	80% O_2 + 20% CO_2	4.85^{A} ± 0.24	4.30^{BY} ± 0.35	4.60 ± 0.46
	60% O_2 + 30% CO_2 + 10% N_2	4.70 ± 0.35	4.45^{Y} ± 0.37	4.75 ± 0.42
	40% CO_2 + 60% N_2	4.80 ± 0.26	4.65 ± 0.41	4.55 ± 0.28
	30% CO_2 + 70% Ar	4.60^{Y} ± 0.32	4.65 ± 0.47	4.70 ± 0.42

Explanation as in Table 2.

Table 5. Juiciness, tenderness (points) and Warner-Bratzler shear force (N) values of meat after modified atmosphere storage (arithmetic mean ± standard deviation)

Parameter	Modified atmosphere	Storage time of meat, days		
		7 n = 50	14 n = 50	21 n = 50
Juiciness	vacuum	$4.60^{B} \pm 0.46$	4.85 ± 0.24	$4.95^{AX} \pm 0.16$
	80% O_2 + 20% CO_2	$4.50^{B} \pm 0.41$	4.65 ± 0.41	$4.85^{A} \pm 0.24$
	60% O_2 + 30% CO_2 + 10% N_2	4.35 ± 0.58	4.60 ± 0.39	4.70 ± 0.42
	40% CO_2 + 60% N_2	4.65 ± 0.47	4.70 ± 0.42	$4.50^{Y} \pm 0.33$
	30% CO_2 + 70% Ar	$4.30^{B} \pm 0.54$	$4.75^{A} \pm 0.26$	$4.80^{A} \pm 0.26$
Tenderness	vacuum	4.55 ± 0.50	4.60 ± 0.57	$4.85^{X} \pm 0.24$
	80% O_2 + 20% CO_2	$4.25^{B} \pm 0.63$	$4.80^{A} \pm 0.26$	$4.70^{A} \pm 0.26$
	60% O_2 + 30% CO_2 + 10% N_2	3.85 ± 0.85	4.45 ± 0.60	4.50 ± 0.58
	40% CO_2 + 60% N_2	4.40 ± 0.74	4.45± 0.50	$4.30^{Y} \pm 0.42$
	30% CO_2 + 70% Ar	$3.95^{B} \pm 0.80$	4.50 ± 0.62	$4.80^{AX} \pm 0.26$
Warner-Bratzler shear force	vacuum	$34.00^{Y} \pm 7.05$	27.67 ± 8.67	24.98 ± 5.07
	80% O_2 + 20% CO_2	$42.42^{AX} \pm 6.50$	$23.99^{AY} \pm 6.62$	$30.49^{B} \pm 5.46$
	60% O_2 + 30% CO_2 + 10% N_2	$40.83^{AX} \pm 10.94$	$27.22^{B} \pm 8.38$	$27.25^{B} \pm 3.43$
	40% CO_2 + 60% N_2	$42.65^{AX} \pm 6.27$	$28.96^{B} \pm 7.83$	$25.41^{B} \pm 5.00$
	30% CO_2 + 70% Ar	$33.54^{Y} \pm 6.77$	$35.58^{X} \pm 5.71$	30.27 ± 5.64

Explanation as in Table 2.

14 days of cold storage, which is consistent with the findings of Kim et al. [2010]. The cited authors reported that beef steaks packaged in MA composed of 80% O_2 + 20% CO_2 received higher ($P \leq 0.05$) off-flavour scores than vacuum-packaged steaks. Clausen et al. [2009] found that warmed-over flavour (WOF) developed more frequently ($P \leq 0.001$) in samples of beef LD packaged in high-oxygen MA systems than in those stored in vacuum and atmospheric air. According to Calkins and Hodgen [2007], WOF may also appear in thermally-processed meat. Brewer and Novakofski [2008], who evaluated the quality of beef steaks aged in vacuum bags for 14 days, found that the time of cold storage had no significant effect on meat palatability. In the present study, storage time also had a minor influence on the flavour of cooked meat, and a significant effect of this factor was noted in beef samples stored under aerobic conditions. Resconi et al. [2012] reported significant ($P \leq 0.05$) deterioration in the aroma and taste of cooked beef steaks stored under MA with 60% and 80% of oxygen for 4 and 8 days.

Juiciness, tenderness and shear force of meat. The juiciness of meat samples stored in vacuum packages and in MA composed of 80% O_2 + 20% CO_2 was higher after 21 days than after 7 days of storage (Table 5). The juiciness of samples packaged in MA composed of 30% CO_2 + 70% Ar also increased over storage – it was lower after 7 days than after 14 and 21 days. No significant changes in juiciness were observed in beef samples packaged under different MA systems and stored for 7 and 14 days. However, after 21 days of storage, significant differences were found between the average juiciness scores of samples packaged in vacuum and MA composed of 40% CO_2 + 60% N_2. According to Lund et al. [2007] and Kim et al. [2010], a high-oxygen MA packaging system, compared with anaerobic conditions, may lead to a decrease in meat juiciness by inducing structural changes in myosin. Clausen et al. [2009] also demonstrated that high-oxygen MAP systems, compared with vacuum, resulted in a decrease in the juiciness of beef steaks.

An analysis of the effect of storage time on beef tenderness revealed that samples stored in MA composed of 80% O_2 + 20% CO_2 were more tender after 14 days and 21 days than after 7 days of cold storage (Table 5). The samples stored for 21 days under 30% CO_2 + 70% Ar received higher scores for tenderness than those stored for 7 days. Different MAP systems had no significant ($P > 0.05$) effect on the tenderness of beef samples stored for 7 and 14 days. After 21-day storage, meat packaged under MA composed of 40% CO_2 + 60% N_2 was less tender than the samples packaged in vacuum and MA containing Ar.

During cold storage, WBSF values decreased in beef packaged in the following MA systems: 80% O_2 + 20% CO_2, 60% O_2 + 30% CO_2 + 10% N_2 and 40% CO_2 + 60% N_2 (Table 5). After 7 days of storage, meat samples packaged in vacuum and MA composed of 30% CO_2 + 70% Ar were characterized by the lowest WBSF. After 14 days of storage, the samples stored under 30% CO_2 + 70% Ar had higher WBSF values than those stored in MA composed of 80% O_2 + 20% CO_2. The

gas composition of MA had no significant effect on shear force in meat samples stored for 21 days.

According to many researchers, a decrease in WBSF can be attributed to an increase in the concentration of Ca^{2+} ions, which activate proteolytic enzymes affecting the degradation of myofibrillar proteins [Goll et al. 2008, Kemp et al. 2010]. Protein degradation contributes to the loosening of muscle fibre structure, thus increasing meat tenderness [Pospiech et al. 2007]. Zakrys-Waliwander et al. [2012] found that average WBSF values were lower ($P \leq 0.05$) in bovine LD muscles packaged under vacuum than in high-oxygen MA (80% O_2 + 20% CO_2), and the observed differences were significant after 8 and 14 days of storage. The cited authors also noted that in vacuum-packaged steaks, WBSF values were higher ($P \leq 0.05$) after 8 days than after 1, 4 and 14 days of storage, whereas in high-oxygen MAP (80% O_2 + 20% CO_2) steaks, WBSF values were higher ($P \leq 0.05$) after 8 and 14 days than after 1 and 4 days of storage. Kim et al. [2010] found that the LL muscle stored for 9 days at a temperature of 1–3°C in vacuum had significantly higher tenderness scores than the samples packaged in MA composed of 80% O_2 + 20% CO_2. In a study by Brewer and Novakofski [2008], tenderness increased ($P \leq 0.05$) and WBSF decreased ($P \leq 0.05$) in beef steaks aged in vacuum bags for 14 days. Wu et al. [2014], who investigated WBSF values in the bovine LD muscle after 1, 2, 7, 14, 21 and 28 days of storage at a temperature of –1.5°C and structural protein changes during beef aging, demonstrated that the degradation of these proteins, in particular myosin, was the key factor in the improvement of meat tenderness. It appears that meat packaged in high-oxygen MA tends to have lower tenderness and higher WBSF values due to the post-mortem oxidation of myofibrillar proteins, mostly myosin, and the activity of enzymes involved in protein proteolysis [Goll et al. 2008]. Their activity is affected by environmental factors and reactions occurring in muscles immediately before and after slaughter [Kemp et al. 2010]. Proteolysis is also determined by muscle fibre metabolism. Protein oxidation, which can be related to lipid oxidation, is another important consideration. Therefore, storage under aerobic conditions can be a limiting factor for proteolysis in meat [Lund et al. 2011].

CONCLUSIONS

It can be concluded that meat stored for 21 days in MA containing 80% O_2 was more susceptible to undesirable changes in colour, which were observed after 21 days of storage. Beef samples stored for 21 days in MA composed of 30% CO_2 + 70% Ar, 60% O_2 + 30% CO_2 + 10% N_2 and in vacuum packages were characterized by the most desirable colour. The aroma of raw meat, determined immediately after the package was opened, changed throughout storage. It should be stressed, however, that despite the observed changes, beef stored for 21 days under all MAP systems received high scores for aroma in the sensory evaluation. Beef stored in MA containing O_2 scored lower for taste and aroma evaluated after thermal treatment, in particular after 14 days of storage, most probably due to lipid oxidation under aerobic conditions. The juiciness and tenderness of beef improved during storage, and the highest scores for those attributes were assigned after 21 days of vacuum storage. Meat samples stored for 21 days in MA composed of 40% CO_2 + 60% N_2 were characterized by significantly lower juiciness and tenderness, compared with the samples stored in vacuum packages and in MA composed of 80% O_2 + 20% CO_2 and 30% CO_2 + 70% Ar. A decrease in WBSF values, observed during storage, and a corresponding increase in tenderness, point to the tenderization of beef regardless of storage conditions.

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REFERENCES

Bingol, E.B., Ergun, O. (2011). Effects of modified atmosphere packaging (MAP) on the microbiological quality and shelf life of ostrich meat. Meat Sci., 88, 774–785. DOI: 10.1016/j.meatsci.2011.03.013.

Brewer, M.S., Novakofski, J.E. (2008). Consumer sensory evaluations of aging effects on beef quality. J. Food Sci., 73, 78–82. DOI: 10.1111/j.1750-3841.2007.00575.x.

Calkins, C.R., Hodgen, J.M. (2007). A fresh look at meat flavor. Meat Sci., 77, 63–90. DOI: 10.1016/j.meatsci.2007.04.016.

Clausen, I., Jacobsen, M., Ertbjerg, P., Madsen, T.N. (2009). Modified atmosphere packaging affects lipid oxidation, myofibrillar fragmentation index and eating quality of beef. Packag. Technol. Sci., 22, 85–96. DOI: 10.1002/pts.828.

EC (2009). Council Regulation (EC) No 1099/2009 of 24 September 2009 on the protection of animals at the time of killing. Official J. Eur. Union L 303, 1–30.

Esmer, O.K., Irkin, R., Degirmencioglu, N., Degirmencioglu, A. (2011). The effects of modified atmosphere gas composition on microbiological criteria, color and oxidation values of minced beef meat. Meat Sci., 88, 221–226. DOI: 10.1016/j.meatsci.2010.12.021.

Fraqueza, M.J., Barreto, A.S. (2009). The effect on turkey meat shelf life of modified-atmosphere packaging with an argon mixture. Poultry Sci., 88, 1991–1998. DOI: 10.3382/ps.2008-00239.

Goll, D.E., Neti, G., Mares, S.W., Thompson, V.F. (2008). Myofibrillar protein turnover: The proteasome and the calpains. J. Anim. Sci., 86, 19–35. DOI: 10.2527/jas.2007-0395.

Gribble, A., Mills, J., Brightwell, G. (2014). The spoilage characteristics of Brochothrix thermosphacta and two psychrotolerant Enterobacteriaceae in vacuum packed lamb and the comparison between high and low pH cuts. Meat Sci., 97, 83–92. DOI: 10.1016/j.meatsci.2014.01.006.

Hęś, M., Gramza-Michałowska, A., Szymandera-Buszka, K. (2009). Effect of cooking methods and frozen storage on lipid oxidation in meat products with antioxidants. Bromat. Chem. Toksykol., 42 (3), 455–459. (in Polish).

Hocquette, J.F., Wezemael, Van L.V., Chriki, S., Legrand, I., Verbeke, W., Farmer, L., Scollan, N.D., Polkinghorne, R., Rødbotten, R., Allen, P., Pethick, D.W. (2014). Modelling of beef sensory quality for a better prediction of palatability. Meat Sci., 97, 316–322. DOI: 10.1016/j.meatsci.2013.07.031.

ISO (2012). Sensory Analysis – General guidelines for the selection, training and monitoring of selected assessors and expert sensory assessors. ISO 8586: 2012. International Organization for Standardization, Geneva, Switzerland.

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

Kim, Y.H., Huff-Lonergan, E., Sebranek, J.G., Lonergan, S.M. (2010). High-oxygen modified atmosphere packaging system induces lipid and myoglobin oxidation and protein polymerization. Meat Sci., 85, 759–767. DOI: 10.1016/j.meatsci.2010.04.001.

Kołczak, T. (2008). Jakość wołowiny [Beef quality]. Żywność Nauka Technologia Jakość, 1(56), 5–22 [in Polish].

Lavieri, N., Williams, S.K. (2014). Effects of packaging systems and fat concentrations on microbiology, sensory and physical properties of ground beef stored at 4 ± 1°C. Meat Sci., 97, 534–541. DOI: 10.1016/j.meatsci.2014.02.014.

Lindahl, G. (2011). Colour stability of steaks from large beef cuts aged under vacuum or high oxygen modified atmosphere. Meat Sci., 87, 428–435. DOI: 10.1016/j.meatsci.2010.10.023.

Liu, Ch., Zhang, Y., Yang, X., Liang, R., Mao, Y., Hou, X., Lu, X., Luo, X. (2014). Potential mechanism of carbon monoxide and high oxygen packaging in maintaining color stability of different bovine muscles. Meat Sci., 97, 189–96. DOI: 10.1016/j.meatsci.2014.01.027.

Lund, M.N., Heinonen, M., Baron, C.P. (2011). Protein oxidation in muscle foods: a review. Mol. Nutr. Food Res., 55, 83–95. DOI: 10.1002/mnfr.201000453.

Lund, M.N., Lametsch, R., Hviid, M.S., Jensen, O.N., Skibsted, L.H. (2007). High-oxygen packaging atmosphere influences protein oxidation and tenderness of porcine longissimus dorsi during chill storage. Meat Sci., 77, 295–303. DOI: 10.1016/j.meatsci.2007.03.016.

Mancini, R.A., Seyfert, M., Hunt, M.C. (2008). Effects of data expression, sample location and oxygen partial pressure on initial nitric oxide metmyoglobin formation and metmyoglobin-reducing-activity measurement in beef muscle. Meat Sci., 79, 244–251. DOI: 10.1016/j.meatsci.2007.09.008.

Mills, J., Donnison, A., Brightwell G. (2014). Factors affecting microbial spoilage and shelf-life of chilled vacuum-packed lamb transported to distant markets: A review. Meat Sci., 98, 71–80. DOI: 10.1016/j.meatsci.2014.05.002.

Montgomery, J.L., Parrish, F.C. jr., Olson, D.G., Dickson, J.S., Niebuhr S. (2003). Storage and packaging effects on sensory and color characteristics of ground beef. Meat Sci., 64, 357–363. DOI: 10.1016/S0309-1740(02)00171-7.

Nassu, R.T., Uttaro, B., Aalhus, J.L., Zawadski, S., Juarez, M., Dugan, M.E.R. (2012). Type of packaging affects the colour stability of vitamin E enriched beef. Food Chem., 135, 1868–1872. DOI: 10.1016/j.foodchem.2012.06.055.

Pérez-Rodríguez, F., Zamorano, A.R., Posada-Izquierdo, G.D., García-Gimeno, R.M. (2014). Study of the effect of post-packaging pasteurization and argon modified atmosphere packaging on the sensory quality and growth of endogenous microflora of a sliced cooked meat product. Food Sci. Technol. Int., 20(1), 3–12. DOI: 10.1177/1082013212469613.

Pospiech, E., Grześ, B., Mikołajczak, B., Iwańska, E., Łyczyński, A. (2007). Proteins of meat as a potential indicator of its quality – a review. Pol. J. Food Nutr. Sci., 57 (1), 11–16.

Resconi, V.C., Escudero, A., Beltrán, J.A., Olleta, J.L., Sañudo, C., Del Mar Campo M.D. (2012). Color, lipid oxidation, sensory quality, and aroma compounds of beef steaks displayed under different levels of oxygen in a modified atmosphere package. J. Food Sci., 71, 10–18. DOI: 10.1111/j.1750-3841.2011.02506.x.

Tománková, J., Bořilová, G., Steinhauserová, I., Gallas, L. (2012). Volatile organic compounds as biomarkers of the freshness of poultry meat packaged in modified atmosphere. Czech J. Food Sci, 30(5), 395–403. DOI: 10.17221/408/2011-CJFS.

Wu, G., Farouk, M.M., Clerens, S., Rosenvold, K. (2014). Effect of beef ultimate pH and large structural protein changes with aging on meat tenderness. Meat Sci., 98, 637–645. DOI: 10.1016/j.meatsci.2014.06.010.

Zakrys, P.I., Hogan, S.A., O'Sullivan, M.G, Allen, P., Kerry, J.P. (2008). Effects of oxygen concentration on the sensory evaluation and quality indicators of beef muscle packed under modified atmosphere. Meat Sci., 79, 648–655. DOI: 10.1016/j.meatsci.2007.10.030.

Zakrys-Waliwander, P.I., O'Sullivan, M.G., O'Neill, E.E., Kerry, J.P. (2012). The effects of high oxygen modified atmosphere packaging on protein oxidation of bovine m. longissimus dorsi muscle during chilled storage. Food Chem., 131, 527–532. DOI: 10.1016/j.foodchem.2011.09.017.

Śmiecińska, K. (2021). Changes in the sensory properties of beef stored under different modified atmospheres. Acta Sci. Pol. Zootechnica, 20(4), 15–24. DOI: 10.21005/asp.2021.20.4.03

ZMIANY WŁAŚCIWOŚCI SENSORYCZNYCH MIĘSA WOŁOWEGO W CZASIE PRZECHOWYWANIA W RÓŻNYCH WARUNKACH MODYFIKOWANEJ ATMOSFERY

STRESZCZENIE

Celem podjętych badań była ocena właściwości sensorycznych mięśnia *longissimus lumborum* (LL) buhajków rasy holsztyńsko-fryzyjskiej odmiany czarno-białej (hf cb) w czasie 7, 14 i 21 dni przechowywania w różnych warunkach modyfikowanej atmosfery (MA) (próżnia, 80% O_2 + 20% CO_2, 60% O_2 + 30% CO_2 + 10% N_2, 40% CO_2 + 60% N_2, 30% CO_2 + 70 % Ar). Na podstawie uzyskanych wyników zaobserwowano, że mięso przechowywane w mieszance z 80% udziałem O_2 było bardziej podatne na niekorzystne zmiany barwy po 21 dniach przechowywania. W miarę upływu czasu przechowywania następowały zmiany zapachu mięsa surowego, ocenianego bezpośrednio po otwarciu opakowania. Przechowywanie mięsa wołowego w MA zawierających O_2 prowadziło do pogorszenia smakowitości ocenianej po obróbce termicznej. Wraz z upływem czasu przechowywania obserwowano poprawę soczystości i kruchości badanego mięsa, które najkorzystniej zostały ocenione po 21 dniach przechowywania w próżni. Stwierdzony, postępujący w czasie spadek wartości siły cięcia koresponduje z wynikami oceny kruchości i świadczy o postępującym procesie kruszenia badanego mięsa, niezależnie od sposobu jego przechowywania.

Słowa kluczowe: jakość wołowiny, czas przechowywania, barwa, smakowitość, soczystość, kruchość

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