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Original article

Changes in the quality of meat from roe deer (*Capreolus capreolus* L.) bucks during cold storage under vacuum and modified atmosphere

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Abstract

This paper analyses changes in the quality of meat (*M. longissimus dorsi*) of roe deer bucks during 21 days of cold storage (2°C) under vacuum and modified atmosphere (MA) conditions (40% CO_2/60% N_2 and 60% CO_2/40% N_2). After 21 days of storage, meat packaged in a MA with 40% CO_2 had higher ($P \leq 0.05$) L^*, a^*, b^* and C^* values in comparison with meat stored under vacuum and MA with 60% CO_2. The mean pH and TBARS values of meat packaged under vacuum and a MA with 40% CO_2 were increasing for the first 7 days of storage, and then they decreased ($P \leq 0.05$). Following storage, the colour of meat became lighter (L^*) and more yellow (b^*). The meat stored under vacuum was characterised by increased ($P \leq 0.05$) cooking loss. During meat storage, a significant increase ($P \leq 0.05$) in total microbial counts and psychrotrophic bacteria was observed.

Key words: roe deer, bucks, modified atmosphere, ageing, meat quality

Introduction

Packaging technology which modifies the atmospheric conditions of the package is popularly applied to extend the shelf-life of meat. This method regulates the process of microbial growth, changes in meat colour and lipid oxidation (Jo et al. 1999, Labadie 1999). The food processing industry relies on two methods of modifying the atmosphere in the packaging process: vacuum packaging and modified atmosphere packaging (Jeremiah 2001).

Vacuum packaging is a popular method of extending the shelf-life of meat intended for distribution (John et al. 2005). The disadvantage of vacuum packaging of meat is that the absence of oxygen increases the share of reduced myoglobin in fresh red meat (beef, mutton, pork), thus producing a dark purple colour on the surface of the meat which is unattractive from the consumer's point of view (Mancini and Hunt 2005). Similarly to vacuum packaging, modified atmosphere packaging (MAP) extends the shelf-life of meat and preserves its attractive colour. MAP can deliver optimal results subject to the gas mixture composition applied in the packaging process (Jeremiah 2001). From among the gases which may come into contact with food products under EU legislation (European Parliament and Council Directive 1995), carbon dioxide, nitrogen and oxygen are most

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popularly applied in meat packaging (Soørheim et al. 1999).

The issue of modified atmosphere packaging of meat from slaughter animals and poultry meat has been discussed in numerous scientific papers. The effects of MAP on the quality of venison from farmed animals have also been investigated (Seman et al. 1989, Wiklund et al. 2001, Vergara et al. 2003, Wiklund et al. 2006), yet very few publications (Buys et al. 1997, Paulsen et al. 2005) address wild game meat from free-living animals.

The objective of this study was to determine the effect of modified atmosphere (MA) type (vacuum, 40% CO_2/60% N_2 and 60% CO_2/40% N_2) and storage time (7 and 21 days at 2°C) on changes in the physicochemical properties and microbiological quality of meat from hunter-harvested roe deer (*Capreolus capreolus* L.) bucks.

Materials and Methods

Animals

The experimental materials consisted of carcasses of roe deer (*Capreolus capreolus* L.) bucks shot in forests of north-eastern Poland during the hunting season 2006/2007. Among the carcasses supplied to the meat processing plant, 15 carcasses of bucks were selected for analysis, based on the following criteria: age of animals at harvest – 3 to 5 years; time that passed from the harvest of animals to carcass cutting (approximately 54 h); no bullet damage to *M. longissimus dorsi*; correct carcass evisceration procedure; no shot damage or contamination due to bullet; carcass temperature (measured at the geometric centre of the thickest portion of the leg) – not higher than 7°C; pH_u (ultimate pH) value of *M. longissimus dorsi* – 5.4 to 5.8 (to eliminate DFD meat).

Preparation of meat samples

M. longissimus dorsi was cut out on the left and the right side of each carcass and transported to the laboratory. In the laboratory the muscles from each carcass were divided into 7 parts which were allocated to four groups: O, A, B, C. Samples O were subjected to laboratory analysis immediately, samples A were vacuum-packaged, while samples B and C were packaged in a modified atmosphere with the following gas mixture composition: B – 40% CO_2/60% N_2, C – 60% CO_2/40 % N_2. Meat samples were packaged approximately 58 h after the harvest of animals. Packaging was carried out with a packaging machine (Model PP-5MG (015), TEPRO S.A., Koszalin, Poland), using barrier bags made of AMILEN-UX 90 laminate with gas permeability: O_2 = 1 cm^{-3} m^{-2} 24 h^{-1} bar^{-1} at 23°C; N_2 < 0.1 cm^{-3} m^{-2} 24 h^{-1} bar^{-1} at 23°C; CO_2 = 1.6 cm^{-3} m^{-2} 24 h^{-1} bar^{-1} at 23°C; and with water vapour transmission 3 g m^{-2} 24 h^{-1} at 23°C. The samples were stored at 2°C for 7 and 21 days. The low muscle weight of *M. longissimus dorsi* of roe deer rendered it impossible to obtain a larger number of samples and to store them for different periods of time.

Research methods

Meat samples, non-stored and stored under MA, were analyzed at a laboratory to determine their quality attributes, including pH value, colour, water-holding capacity, TBARS values and microbiological quality.

The pH values were measured using a combination Double Pore electrode (Hamilton) inserted into muscular tissue, and a pH 340i pH-meter equipped with a TFK 150/E temperature sensor (WTW). The measurements were performed prior to carcass cutting at the meat processing plant, at the moment of selecting buck carcasses for the study (in *M. longissimus dorsi* at the last rib, approximately 54 h post mortem), prior to sample packaging, after 7 and 21 days of vacuum and MA storage (immediately after taking the sample out of the package).

Meat colour was determined based on the values of CIELAB coordinates, L^* (lightness), a^* (redness), b^* (yellowness), C^* (chroma), h^o (hue angle) (CIE 1978). The colour space parameters L^*, a^* and b^* were measured three times by the reflectance method with a HunterLab MiniScan XE Plus spectrocolorimeter (Hunter Associates Laboratory Inc., Reston, VA, USA), at different points over the muscle cross-section area (prior to sample packaging and after 7 and 21 days of vacuum and MA storage). Prior to measurements, samples wrapped in oxygen-permeable and water-impermeable foil were stored for 0.5 h at 4°C.

The evaluation of the water-holding capacity of meat included the determination of natural drip loss, cooking loss (Honikel 1998), and water-holding capacity – by the Grau and Hamm method (Van Oeckel 1999).

TBARS values were determined as described by Pikul et al. (1989), and expressed as mg of malondialdehyde per kg of meat.

Samples for microbiological examinations were removed aseptically by excising a 3-4 mm thick layer with a scalpel from each sample of *M. longissimus dorsi*. Ten grams of each sample were mixed with 90 ml sterile 0.1% peptone water (w/v) and homogenised with a Stomacher-mixer for 60 s. The homogenate was diluted for cultivations. The media and incubation

conditions were as follows: for total viable counts – Standard Plate Count Agar (Oxoid), 30°C, 3 days; for aerobic psychrotrophic bacteria – Standard Plate Count Agar (Oxoid), 8°C, 7 days. All microbial counts were expressed as base-10 logarithms of colony forming units (cfu) per g of meat.

The data were processed by one-way analysis of variance in order to determine the effect of MA type and storage time on each variable. Duncan's test was carried out to determine differences between groups. The level of statistical significance was $P \leq 0.05$. Statistical analyses were performed using STATISTICA software (Data Analysis Software System), version 9.0 (2009).

Results

No significant differences ($P > 0.05$) were found between the mean values of colour parameters L^*, a^*, b^*, C^* and h^o of roebuck meat after 7 days of storage under vacuum and MA (Table 1). After 21 days of cold storage, meat samples packaged in a MA composed of 40% CO_2/60% N_2 were marked by higher ($P \leq 0.05$) L^*, a^*, b^*, C^* values in comparison with the samples stored in MA conditions of 60% CO_2/40% N_2, and demonstrated higher ($P \leq 0.05$) a^*, b^*, C^* values in comparison with vacuum-packaged meat.

The colour of meat samples after storage was lighter and more yellow (higher L^* and b^* values, respectively), compared with meat which was not stored (Table 1). A significant ($P \leq 0.05$) increase in L^* and b^* values in meat packaged under vacuum and a MA with 60% CO_2 was determined after 7 days of storage, and in a MA with 40% CO_2 – after 21 days of storage. The period of storage had a minor effect on a^* value, but after 21 days of storage of vacuum-packaged meat it was significantly ($P \leq 0.05$) lower than that reported before storage (Table 1). A steady increase in h^o value was observed throughout the entire period of cold storage of meat packaged under vacuum and MA (Table 1).

The conducted experiment did not indicate significant differences ($P > 0.05$) between the mean pH values of meat packaged under vacuum and a MA with a varied CO_2 content (Table 2). An increase in the pH of meat packaged under vacuum ($P \leq 0.05$) and a MA with 40% CO_2 ($P > 0.05$) was observed after 7 days of sample storage (Table 2). No changes in the mean pH values of meat packaged in a MA with 60% CO_2 were noted over the same period. The average pH values of meat were lower ($P \leq 0.05$) after 21 days of cold storage than after 7 days (irrespective of the packaging method).

Meat packaged under vacuum and in MA was characterised by similar ($P > 0.05$) natural drip loss (Table 2). The meat ageing period had no significant ($P > 0.05$) effect on natural drip loss.

Water-holding capacity determined by the Grau and Hamm method in meat packaged under vacuum and a MA with 60% CO_2 was determined at a similar level ($P > 0.05$) (Table 2). Meat samples stored in a MA with 40% CO_2 were marked by a significantly higher ($P \leq 0.05$) water-holding capacity after 21 days of storage, in comparison with meat packaged under a MA with 60% CO_2. An analysis of changes in

Table 1. Means (± S.D.) for the colour parameters (L^*, a^*, b^*, C^*, h^o) of meat stored at 2°C for 7 and 21 days under vacuum and modified atmosphere.

Parameter	Storage time	Modified atmosphere*		
		A	B	C
L^*	0	$32.05^{ab} \pm 1.36$	$32.98^{ax} \pm 1.48$	$31.57^{abx} \pm 1.11$
	7	$34.26^{a} \pm 1.12$	$33.98^{b} \pm 1.80$	$34.89^{a} \pm 1.26$
	21	$34.70^{b} \pm 1.78$	$35.31^{abx} \pm 0.88$	$33.49^{bx} \pm 3.35$
a^*	0	$14.79^{a} \pm 1.49$	15.07 ± 1.28	14.33 ± 1.07
	7	14.48 ± 1.30	14.31 ± 1.11	14.29 ± 1.20
	21	$13.81^{ax} \pm 0.93$	$14.89^{xy} \pm 1.64$	$13.53^{y} \pm 1.31$
b^*	0	$9.80^{abx} \pm 0.98$	$10.82^{axy} \pm 1.22$	$9.71^{aby} \pm 0.58$
	7	$11.37^{a} \pm 1.36$	$11.57^{b} \pm 1.24$	$11.50^{a} \pm 1.21$
	21	$11.42^{bx} \pm 1.32$	$13.02^{abxy} \pm 1.26$	$11.46^{by} \pm 1.90$
C^*	0	18.17 ± 1.15	$19.11^{x} \pm 1.35$	$18.07^{x} \pm 1.39$
	7	18.41 ± 1.83	$18.41^{a} \pm 1.54$	18.35 ± 1.60
	21	$17.94^{x} \pm 1.44$	$19.80^{axy} \pm 1.95$	$17.78^{y} \pm 1.79$
h^o	0	$33.62^{ab} \pm 3.54$	$35.67^{ab} \pm 3.27$	$34.19^{ab} \pm 1.84$
	7	$38.06^{a} \pm 1.44$	$38.88^{ac} \pm 2.07$	$38.78^{a} \pm 1.85$
	21	$39.47^{b} \pm 2.37$	$41.21^{bc} \pm 1.96$	$40.05^{b} \pm 4.71$

* Modified atmosphere: Type A: vacuum; Type B: 40% CO_2 + 60% N_2; Type C: 60% CO_2 + 40% N_2
Values in the same row with the same letters are significantly different, ^{xy} – $P \leq 0.05$
Values in the same column with the same letters are significantly different, ^{abc} – $P \leq 0.05$

Table 2. Means (± S.D.) for the pH values, water-holding capacity and TBARS values of meat stored at 2°C for 7 and 21 days under vacuum and modified atmosphere.

Parameter	Storage time	Modified atmosphere*		
		A	B	C
pH	0	$5.48^{a} \pm 0.05$	5.50 ± 0.06	5.48 ± 0.06
	7	$5.53^{ab} \pm 0.05$	$5.54^{a} \pm 0.06$	$5.49^{a} \pm 0.05$
	21	$5.47^{b} \pm 0.08$	$5.47^{a} \pm 0.07$	$5.43^{a} \pm 0.11$
Drip loss (%)	0	2.13 ± 0.58	2.13 ± 0.58	2.13 ± 0.58
	7	1.99 ± 0.56	2.04 ± 0.49	2.09 ± 0.32
	21	2.06 ± 0.57	2.16 ± 0.44	1.99 ± 0.44
Water-holding capacity – Grau and Hamm method (cm^2)	0	4.49 ± 1.19	$4.49^{ab} \pm 1.19$	4.49 ± 1.19
	7	3.67 ± 1.04	$3.29^{a} \pm 1.07$	3.59 ± 1.10
	21	4.32 ± 1.09	$3.38^{bx} \pm 1.19$	$4.49^{x} \pm 1.56$
Cooking loss (%)	0	$31.80^{a} \pm 0.98$	31.80 ± 0.98	31.80 ± 0.98
	7	32.20 ± 1.56	31.29 ± 1.76	32.04 ± 1.75
	21	$33.02^{a} \pm 1.63$	32.17 ± 1.81	32.23 ± 2.38
TBARS values (mg malondialdehyde/ /kg meat)	0	$0.89^{a} \pm 0.11$	$0.89^{a} \pm 0.11$	$0.89^{a} \pm 0.11$
	7	$1.05^{ab} \pm 0.19$	$1.12^{ab} \pm 0.22$	$1.14^{ab} \pm 0.18$
	21	$0.80^{a} \pm 0.12$	$0.91^{b} \pm 0.21$	$0.77^{a} \pm 0.20$

* Modified atmosphere: Type A: vacuum; Type B: 40% CO_2 + 60% N_2; Type C: 60% CO_2 + 40% N_2
Values in the same row with the same letters are significantly different, ^{xy} – $P \leq 0.05$
Values in the same column with the same letters are significantly different, ^{abc} – $P \leq 0.05$

Table 3. Microbial counts (log_{10} cfu/g) (means ± S.D.) of meat stored at 2°C for 7 and 21 days under vacuum and modified atmosphere.

Parameter	Storage time	Modified atmosphere*		
		A	B	C
Total viable counts	0	$5.10^{a} \pm 0.59$	$5.10^{a} \pm 0.59$	$5.10^{a} \pm 0.59$
	7	$6.10^{a} \pm 0.60$	$6.13^{a} \pm 0.42$	$6.20^{a} \pm 0.37$
	21	$7.65^{a} \pm 0.48$	$7.71^{a} \pm 0.52$	$7.62^{a} \pm 0.57$
Psychrotrophic bacteria	0	$3.80^{a} \pm 0.63$	$3.80^{a} \pm 0.63$	$3.80^{a} \pm 0.63$
	7	$5.24^{a} \pm 0.71$	$5.35^{a} \pm 0.63$	$5.67^{a} \pm 0.37$
	21	$5.92^{a} \pm 0.42$	$5.94^{a} \pm 0.29$	$6.19^{a} \pm 0.32$

* Modified atmosphere: Type A: vacuum; Type B: 40% CO_2 + 60% N_2; Type C: 60% CO_2 + 40% N_2
Values in the same column with the same letters are significantly different, ^{a} – $P \leq 0.05$

water-holding capacity determined by the Grau and Hamm method over time has shown a increase in water- holding capacity after the first 7 days of cold storage of samples packaged under vacuum ($P > 0.05$) and a MA with 40% CO_2 ($P \leq 0.05$) and 60% CO_2 ($P > 0.05$) (Table 2). After 21 days of storage under vacuum and a MA with 60% CO_2, water- holding capacity decreased ($P > 0.05$) in comparison with meat stored for 7 days. The average water-holding capacity of meat after 21-day storage under a MA with 40% CO_2 stabilised at the level indicated by the analyses conducted after 7 days of meat ageing.

No statistically significant differences ($P > 0.05$) were reported in the cooking loss of meat packaged under vacuum and MA (Table 2). A clearly pronounced increase ($P \leq 0.05$) in cooking loss was observed in vacuum-packaged meat samples as the time of sample storage was prolonged.

The results of the present study did not point to significant variations ($P > 0.05$) in TBARS values in vacuum-packaged meat and meat stored in MA (Table 2). TBARS values were significantly ($P \leq 0.05$) higher after 7 days of cold storage, compared with the data obtained prior to storage. An analysis performed after 21 days of meat ageing demonstrated a drop ($P \leq 0.05$) in TBARS values in comparison with the values determined after 7 days of sample storage.

During the cold storage of meat, a significant ($P \leq 0.05$) increase in total microbial counts and psychrotrophic bacteria was observed (Table 3). The applied packaging methods (vacuum, MAP) did not significantly ($P > 0.05$) affect the microbiological quality of meat.

Discussion

In the present study, the average pH_u of roebuck meat ranged from 5.48 to 5.50 (Table 1). For comparison, in experiments performed by Trziszka (1975), the mean pH_u value determined in the *M. longissimus dorsi* of roe deer was 5.50. Paulsen and Winkelmayer (2004) reported that the ultimate pH (24 – 48 h post mortem) of *M. semimembranosus* was 5.4 – 5.6. In a study by Bittner and Beutling (2001), the pH values measured in the *M. semimembranosus* (5.66) and *M. longus colli* (5.95) of roe deer shot during the mating season were higher compared with those determined in animals shot outside the rutting period (5.77 vs. 5.47).

CO_2 is highly soluble in water and it is partially transformed to H_2CO_3 in meat, which could lead to a drop in pH values (Jacobsen and Bertelsen 2002). In the present study, there were no significant differences between the mean pH values of meat packaged under vacuum and a MA with a varied CO_2 content. It could be explained by the fact that meat offers a relatively strong buffering system and that the vast majority of "added" CO_2 is present in meat in dissolved form (Sørheim et al. 2004). In the light of the above, the effect of CO_2 on the pH value of meat may be observed when MA applied for packaging purposes contains high concentrations of this gas (Sørheim et al. 2004).

The changes in the pH of roebuck meat packaged under vacuum and a MA with 40% CO_2, aged for 7 days, resulted from the process of meat autolysis (Moore and Gill 1987). In meat samples stored in a MA containing 60% CO_2, the effect of autolytic changes on meat acidity was probably neutralised by high CO_2 concentrations. The decrease in the pH values of meat aged for 21 days was probably caused by the growth of lactic acid bacteria and increased lactic acid concentrations (Fernández-López et al. 2008).

The changes in the pH of roebuck meat during cold storage were similar to those observed by Seman et al. (1989) during the storage (6, 12 and 18 weeks, -1 ± 3°C) of *M. longissimus dorsi* from farm-raised red deer stags. In the cited study, the pH values of meat were increasing until 12 weeks of storage and then decreased in vacuum-packaged meat and in meat packaged in a MA (100% CO_2) using a dual aluminized polyethylene outer barrier film. Wiklund et al. (2001) reported that the pH values of vacuum-packaged meat (*M. longissimus dorsi*) from red deer hinds, stored for 12 weeks at -1.5°C, dropped ($P < 0.001$) between weeks 1 and 3, and by week 6 they returned ($P < 0.001$) to the level recorded in week 1. Vergara et al. (2003) and Wiklund et al. (2006) observed an increase in the pH of *M. longissimus dorsi* from red deer stored (2°C) in a MA (40% CO_2/60% N_2; 80% CO_2/20% O_2; 80% CO_2/20% N_2) for 23 days and under vacuum (-1.5°C) for 12 weeks. In an experiment performed by Pollard et al. (2002), the pH value of vacuum-packaged *M. longissimus dorsi* from red deer stags showed a steady increase over the entire storage period (5 weeks at 1°C), while the pH of *M. semimbranosus* was found to increase only for the first 3 weeks.

Venison is generally regarded to have a darker colour than the meat of domesticated animals. This was confirmed by the present study. The analysed roebuck meat was dark (low L^* values), with high proportions of the red (a^*) and yellow (b^*) components. The darker colouring of venison is a natural phenomenon resulting from, among others, elevated myoglobin levels in the muscles of wild animals due to increased locomotor activity.

The changes in the colour of roebuck meat, noted in the current experiment, were determined by the chemical transformations of myoglobin (Mancini and Hunt 2005). The increase in h^o values of the colour of meat was indicative of progressive formation of metmyoglobin during meat storage. This confirms the well-known tendency for the colour of venison on display to deteriorate (Purchas et al. 2010). The rate of oxidation of oxymyoglobin to metmyoglobin is accelerated at low oxygen pressure (George and Stratmann 1952). According to Smiddy et al. (2002), vacuum packaging and packaging in a MA do not guarantee the complete removal of oxygen from the package. Mancini and Hunt (2005) reported that the levels of O_2 in ultra-low-oxygen atmospheres used in MAP should be less than 1% for pork and less than 0.05% for beef. In the present study, the residual oxygen content of the package was not determined.

The amount of metmyoglobin formed on meat surface is closely related to the pH of the tissue. In meat with a lower pH, myoglobin becomes more susceptible to oxidation and its content increases (Mancini and Hunt 2005). Those observations are of paramount importance for the interpretation of the obtained results. The investigated roebuck meat has a naturally low pH, which was additionally affected by CO_2 applied in the MA experiment.

Huff-Lonergan and Lonergan (2005), and Kristensen and Purslow (2001) reported that the water-holding capacity of meat increases in *post-rigor*, reaching its second peak (the first is observed directly after slaughter) in ripened meat. The above mentioned findings are supported by the results of this study (after 7 days of roebuck meat ageing). The discussed phenomenon is caused by autolytic changes in cytoskeletal proteins during meat ageing, mainly under the influence of the calpain system, and it enhances the water-holding capacity of meat. The results reported in respect of the water-holding capacity of roebuck meat (natural drip, water-holding capacity

determined by the Grau and Hamm method) were, to a certain degree, affected by the meat's water loss due to drip during cold storage. The above phenomenon is referred to as the "drip hypothesis" in scientific literature (Moeseke and Smet 1999). According to this hypothesis, the water lost initially by post-mortem meat cannot be lost as drip in successive periods. In some situations, this could create the impression of an apparent increase in the meat's water-holding capacity.

Changes in the water-holding capacity of venison stored in a MA are scarcely documented. Paulsen et al. (2005) found that tenderloins of the roe deer, cut out and deboned 24 h post mortem and stored under vacuum at 3.5°C for up to 132 h post mortem, were characterised by greater cooking loss in comparison with tenderloins which were cut out and deboned 12 h post mortem as well as tenderloins cut out and deboned 132 h post mortem. Vergara et al. (2003) reported an increase in the cooking loss of red deer meat during cold storage in a MA. According to the above authors, the MA composition had no significant effect on cooking loss.

In the present study, the average malondialdehyde (MDA) content of meat from roebucks was comparable to that determined in an experiment performed by Daszkiewicz et al. (2009) on meat from red deer (0.80 – 0.89 μg g^{-1}). Wiklund et al. (2006) reported that deer meat had MDA levels of 0.22 μg g^{-1}. High TBA values (up to 6 μg of MDA per g of meat) in meat from farm-raised sika deer (*Cervus nippon*) were recorded by Okabe et al. (2002).

The increase in TBARS values observed in meat in the first phase of cold storage in the present experiment was probably due to the presence of residual oxygen in the package. The drop in TBARS values between 7 and 21 days of cold storage of roebuck meat could be due to the low stability of MDA and other short-carbon-chain compounds which are the products of fat oxidation (Fernández et al. 1997). This is in agreement with the findings of Wilklund et al. (2006) who reported that the storage (12 weeks at -1.5°C) of red deer meat led to a significant increase in the content of lipid oxidation products over the first 6 weeks, and then the oxidation process seemed to slow down.

It is widely believed that lipid oxidation in meat is initiated in highly unsaturated phospholipids of subcellular membranes (Buckley et al. 1989). Williams et al. (1983) demonstrated that 100 g muscle tissue of antelope (960.9 mg), deer (967.4 mg) and elk (707.5 mg) had much higher phospholipid concentrations than beef (502.3 mg). The ferric haem ion acts as a catalyst of lipid oxidation. The muscle pigment content varies between animal species, reaching 1 – 5 μg Fe g^{-1} in chicken meat, 16 – 20 μg Fe g^{-1} in beef, 19 – 29 μg Fe g^{-1} in emu meat and 22 – 30 μg Fe g^{-1} in ostrich meat (Berge et al. 1997). In a study by Wilklund et al. (2006) the pigment content of deer meat was equivalent to 24 μg Fe g^{-1}. The above data suggest that wild game meat may be more susceptible to oxidation than meat from farm animals.

Microbial contamination is a factor which can remarkably affect the safety and quality of wild game meat. Gill (2007) reported that the initial microbiological condition of the carcasses of wild animals is affected by several highly variable factors. Thus, the microbiological condition of wild deer carcasses and meat can be expected to vary greatly. This is consistent with the results of the present experiment and other studies. As noted by Paulsen et al. (2003), Paulsen and Winkelmayer (2004), Smith et al. (1974) and Sumner et al. (1977), the maximum counts of aerobic bacteria recovered from wild deer carcasses were > 10^8 cfu/cm^2 or g. In a study performed by Atanassova et al. (2008) on samples of freshly shot game in Germany, the mesophillic aerobic counts showed mean $\log_{10}$ 2.6 cfu/cm^2 for roe deer, 2.9 cfu/cm^2 for red deer and 3.2 cfu/cm^2 for wild boars. Paulsen and Winkelmayer (2004) reported that the microbial contamination (total aerobic counts – bacterial surface counts) of game carcasses in October – December were significantly lower (4.12 $\log_{10}$ cfu/cm^2) than in June – August (5.65 $\log_{10}$ cfu/cm^2).

It has been assumed that the symptoms of microbial spoilage of meat (undesirable aroma and colour) may be observed when total microbial counts reach 7 – 8 log cfu/cm^2 or g meat (Jeremiah 2001). In the present study, the above level was attained after 21 days of cold storage of meat samples under vacuum and MA, but without the undesirable aroma or colour of the investigated meat.

In a study conducted by Paulsen et al. (2005), total microbial counts in roe deer meat after 132 h of vacuum storage at 3.5°C ranged from 5.73 to 5.98 $\log_{10}$ cfu/g. Seman et al. (1989) found that the total counts of aerobic bacteria in the meat of farm-raised red deer stags, stored at -1°C for 6, 12 and 18 weeks under vacuum, increased from $\log_{10}$ 2.70 cfu/g after 6 weeks to $\log_{10}$ 5.53 cfu/g after 18 weeks. Much lower average values of the investigated bacterial populations were noted by the cited authors in meat stored in a MA composed of 100% CO_2. In experiments by Buys et al. (1997) involving wholesale cuts of the Springbok gazelle (*Antidorcas marsupialis masupialis*), stored for 19 days under vacuum at 0°C, the average values of the total population size ($\log_{10}$ cfu/cm^3) of aerobic bacteria and lactic acid bacteria reached 5.90 and 6.48 or 6.15 and 5.49, respectively (the first value is indicative of deboned cuts, the second value corresponds to bone-in cuts).

Conclusions

The results of this study did not indicate a significant influence of the applied modified atmosphere (MA) type (vacuum, 40% CO_2/60% N_2 and 60% CO_2/40% N_2) on changes in the pH values, TBARS values, water-holding capacity and microbiological quality of roe deer meat. TBARS values increased already after 7 days of storage of meat samples packaged both in vacuum and MA conditions. This indicates that roebuck meat lipids are susceptible to oxidation, which implies that residual O_2 has to be maximally limited in meat packaging. As regards the evaluation of colour attributes, carried out after 21 days of meat storage, it was found that samples packaged in a MA with 40% CO_2 were characterized by the highest L^*, a^*, b^* and C^* values. The increase in b^* values (yellowness), observed during meat storage, could be associated with metmyoglobin formation. Those changes were more rapid in meat stored under vacuum and a MA with 60% CO_2. This may suggest that a MA with 40% CO_2 is the most suitable method of storing meat from hunter-harvested roe deer bucks.

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